Exhibits to Written Statement of Steven Klafka

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Prevention of Significant Deterioration

The Art and Science of the PSD
Air Quality Analysis
The Modeling Perspective

INTRODUCTION

The purpose of this outline is to provide a checklist for environmental consultants or Modeling Unit staff that perform or review air quality analyses included in a PSD permit application. This outline is not an official guidance document and is not meant as a substitute for USEPA's ***The New Source Review Workshop Manual*** **(Draft, October 1990)**, the ***Guideline on Air Quality Models*** **(Appendix W of 40 CFR Part 51)**, model user guides or implementation documents. Guidance for performing air quality studies from these sources should be carefully read. This checklist prompts the reader to consider addressing certain topics that may be "under emphasized" in the federal manuals that are applicable to submitting a successful air quality analysis. Also, included below are other topics in modeling for PSD that have recently been implemented through federal memorandums but not formally introduced in federal guidance documents.

I. DETERMINING PSD PERMITTING APPLICABILITY

A. Definition - PSD: A process of regulating increases in emissions of industrial air pollution sources. Where an area or locale has attainment of the NAAQS (National Ambient Air Quality Standards) for pollutants in question, PSD permitting and air quality analysis procedures prevail.

B. Goals of PSD
   1. To ensure that economic growth will occur in harmony with the preservation of existing clean air resources.
   2. To protect the public health and welfare from adverse ambient air quality.
   3. To preserve, protect, and enhance the air quality in areas of special natural recreational, scenic, or historic value, such as national parks and wilderness areas.

C. Qualification - Determining PSD Applicability
   1. Is the source a "major stationary source" emitting 250 tons per year or more for a given pollutant? …or 100 tons per year or more for a pollutant from a certain specific industries.

   2. Is the source's incremental change in emission "a major modification" over the Significant Impact Emission Rate threshold?

II. MODEL SELECTION

A. For the pollutants NOx (nitrogen oxides), SO_2 (sulfur dioxides), PM10 (particulate matter 10 microns or less in size), $PM_{2.5}$ (particulate matter $_{2.5}$ microns or less in size), CO (carbon monoxide), and Pb (lead).

1. For both simple and complex terrain two models can be used:
   a. Use AERSCREEN Version 11126 for initial evaluation of the source. AERSCREEN is a screening version of AERMOD.

   b. For a full study, use AERMOD Version 12345

B. For Ozone and VOC.

1. If emissions for VOC exceed 40 tons per year, some evaluation of ozone air quality will have to be made. Consult with the reviewing air quality analyst from Illinois EPA for the appropriate response to ozone and VOC air quality, before submitting your air quality analysis for review.

C. For $PM_{2.5}$

1. Model "primary" $PM_{2.5}$ as a separate pollutant. AERMOD should be used, and emissions should include condensables.

2. Illinois EPA now requires that "secondary" $PM_{2.5}$ be addressed as well. The permit applicant should contact Illinois EPA for further guidance. Currently, the USEPA draft guidance memorandum of March 4, 2013 is being used as a broad guideline for developing approaches to address both primary and secondary $PM_{2.5}$. The permit applicant should contact Illinois EPA for further guidance. Appendix B is offered as a possible approach to assessing $PM_{2.5}$ impacts, thought consultations with Illinois EPA are needed before an approach is decided.

The URL for this memorandum:

http://www.epa.gov/ttn/scram/guidance/guide/Draft_Guidance_for_PM25_Permit_Modeling.pdf

D. Whenever possible, a formal modeling protocol should be submitted to the reviewing authority. Following this outline and the federal guidance will help in preparing such a document. A protocol is especially helpful to the reviewer when unique situations occur, not normally covered by federal guidance. Alerting the reviewer to these situations early through the modeling protocol avoids needless delays in the PSD permitting process.

III. PRELIMINARY IMPACT ANALYSIS - Assessing the Significant Impact Area

A. Model for each averaging time of the pollutant emissions concerning the PSD permitting source(s) only.

1. This includes permitted and traditional sources that have increased emissions as a result of emission increases with the PSD permitted source(s)

B. If the stack height is determined to be below GEP stack height, determine downwash of PSD permitting source(s) using BPIP downwash analysis.

C. Reduced load analysis.

1. Should be applied as follows:

a. Run PSD sources at default loads of 100, 75, 50 percent reducing flow rate, stack temperature, and emissions by these percentages...

b. or run PSD sources by process specific operations, representing full, average, and nominal loads.

c. Reduced load analysis may be bypassed if the proposed source operates solely at 100% load. This should be identified as a condition of the permit.

d. Special load and other downwash considerations could be applicable.

2. Start-up mode modeling should be included as a separate modeling scenario, separate from the standard reduced load analysis. This would be for lower loads briefly occurring during start-up. Modeling should be done for pollutants with short averaging times of 1 to 3 hours like CO, NO_2, and SO_2.

3. If the source will be permitted to operate under a malfunction or breakdown scenario, then modeling should be performed under the permitted emissions and parameters that reflect the projected circumstances.

D. Grid selection.

1. Cartesian grids are preferable to polar grids in reviewing modeling analyses. Polar grids are acceptable for Significant Impact Analysis, however, they should be refrained from for the NAAQS and PSD Increment analyses.

E. Using a polar grid:

1. Radius of 50 kilometers or less, to the extent that the impact area can be properly defined.

2. Fenceline receptors approximately 50 meters apart.

3. Radials 10° apart.

4. Rings 1/2 km apart for the first 5 km. Rings 1 km apart for the next 5 km, 2 km apart for the next 10 km, 3 km for the next 15 km, and 5 km apart for the last 15 km.

5. Identifying elevated receptor for complex terrain.

6. Define peaks using 1 x 1 kilometer with 100 meter resolution surrounding highest "course grid" receptors.

7. Using a Cartesian grid to determine the impact area is acceptable (see Article V - The Compliance Demonstration for its use).

F. Five years of local NWS meteorology.

1. Use anemometer heights associated with the station the time data was collected, not the default height of 10 meters. Many NWS sites use a standard anemometer height of 10 meters after 1995, when these sites became ASOS stations.

2. Approaches to met data development should be explicitly discussed in the modeling protocol. Selections for values pertaining to surface roughness, Bowen ratio, and albedo surrounding NWS surface met data sites for stage 3 development in AERMET will be provided by Illinois EPA. Met data selections are subject to approval by Illinois EPA before processing with the AERMET meteorological processor can proceed.

3. The latest available years of met data should be used. These years would be the last five years preceding the current calendar year. Years going back further could be used subject to approval by Illinois EPA.

4. Use AERMET version 12345 and associated preprocessor AERMINUTE version 11325 to process your met data.

G. Using other standard modeling protocol:

1. Urban or Rural classifications (perform Auer’s Analysis).

    a. Auer's Analysis should be performed using the latest aerial photos of the area the proposed source will occupy.

    b. Zoning maps should be excluded from use since lands under urban classifications may be undeveloped and actually rural.

2. Regulatory default options.

3. Such commands and options involving variable emission rates, urban modeling, exponential decay, and dispersion options, need to be approved by Illinois EPA before executing.

H. No background concentrations need to be considered.

I. A significant impact, is based on levels established for each pollutant, in accordance with PSD guidance.

1. Define the impact area radius as the distance from the source site to the furthest point where a receptor yields a significant impact concentration increase.

J. Determine if Monitor De Minimus Concentration Levels are exceeded for the evaluation of pre or post-construction monitoring.

K. If the proposed source does not cause a significant impact then a full impact analysis is not necessary, and one should proceed to conduct an additional impact analysis under VI (roman numeral 6).

IV. FULL IMPACT ANALYSIS

A. PSD Facility Sources.

1. All sources at the facility (PSD and non-PSD) are to be modeled for the NAAQS.
2. This includes not only permitted sources but traditional sources as well. These traditional sources include:

   a. Fugitive sources such as:
      - all roads, paved and unpaved
      - stockpiles
      - material handling processes
      - dumping and loading operations
      - uncaptured emissions not venting through control equipment and/or a stack

   b. Road should be modeled under the guidance from USEPA. See Appendix A.

   c. Cooling towers (considered a non-fugitive source)

   d. Any other traditional sources that are not permitted.

3. Special Issues

   a. Horizontal Vents and Rain Caps – Consult with Illinois EPA.

   b. Flares - USEPA Guidance...see AERSCREEN User's Guide, p. 13.

B. NAAQS Inventory (from the reviewing authority).

1. An inventory of background sources defined by:

   a. Pollutant

   b. Radius of significant impact plus 50 kilometers

   c. Origin of impact area, PSD source UTMs

2. Fugitive sources to be included.

3. Where the background source screening area may cross UTM zones, inventories will be constructed county by county. UTM values will be marked different from one zone to the other. Determinations of distance of background sources to the proposed PSD Source should be carefully done considering the transition between zones.

4. Special attention needs to be given to the North American Datum (NAD) used to locate the proposed source. The Illinois EPA's Emission Inventory System now uses NAD 1983. Newer topographic maps also used NAD 1983. Using different datums for source locations can dislocated sources by approximately 200 meters. All source locations in the modeling should conform to "one" datum, preferably to NAD 1983.

C. PSD Increment Inventory (from the reviewing authority).

1. Considered a subset of the NAAQS Inventory.

2. Applies to all counties that have had PSD baselines set within the impact area.

3. Not only past PSD sources should be modeled but any source that increased their emissions, just not the PSD permitted sources only.

4. Growth for area and mobile source should be considered (mobile source data available from state Department of Transportation).

D. Screening Technique

1. Due to limitations with past screening techniques, no automated screening processes will be performed on any emission inventories. Illinois EPA will consider screening of sources that are obviously not imposing an impact in the permit applicant's significant impact area on a case-by-case basis. The applicant may also propose to drop sources if it can be proven that the sources will not impact the air quality in the significant impact area as well.

2. Screening can be applied to both the NAAQS and PSD inventories.

E. Monitored Background Concentration (from Illinois EPA).

V. THE COMPLIANCE DEMONSTRATION - THE FULL IMPACT ANALYSIS

A. NAAQS Analysis

1. Determining downwash of PSD permitting source(s) using BPIP downwash analysis.

2. Using a Cartesian grid:

   a. Covering the complete impact area.

   b. Resolution of 1 km by 1km.

   c. Fenceline receptors.

   d. 100 meter resolution for 1 X 1 km portions of the grid that have concentration peaks over 2/3 of the primary standard.

   e. Identifying elevated receptors for complex terrain.

   f. Using a Cartesian grid is preferable to a polar grid since the adequacy of a polar grid is compromised with the use of multiple sources. Hence peaks are more difficult to resolve since other sources are off center from the grid.

3. Five years of local NWS meteorology.

   a. In running AERMET to produce meteorology for an AERMOD modeling run, estimate surface roughness around the NWS surface data collection site, not the site of the PSD source. Regional values for Bowen ratio and albedo can be used.

   b. Auer's land use analysis should be performed to determine surface roughness around NWS surface met data sites, when running AERMET.

   c. See the ***AERMOD Implementation Guide*** for further guidance on the SCRAM web site when utilizing the AERMOD suite of processors and software.

4. Using other standard modeling protocol including:

   a. Regulatory default options.

   b. Other guidance offered in the ***AERMOD Implementation Guide*** on the SCRAM web site.

5. Background concentration needs to be added to the concentration values.

6. All NAAQS concentrations rates are to be determined.

   a. For 3 and 24 hour averaging times for SO2 and the 1 and 8 hour averaging times for CO:

      1.) The highest yearly second high concentration over five years that were modeled for a given receptor, is considered the highest value for regulatory evaluation.

      2.) IMPORTANT NOTE: The 3 and 24 hour averaging times for SO_2 will be in effect until the one hour SO_2 non-attainment areas in

Illinois are designated. That may not take place until sometime after June 2013.

b. For the 1 hour averaging time for SO_2 (After August 23, 2010):
   1.) The highest of the average of the fourth highest concentrations per receptor over five years of modeling, derived from the maximum hourly concentration for each day of the year.

c. For averaging times less than annual for PM-10:
   1.) The cumulative sixth highest concentration over five years that were modeled for a given receptor, is considered the highest value for regulatory evaluation.

d. For $PM_{2.5}$:
   1.) The highest of the average of the eighth highest concentrations per receptor, over five years of modeling. See the March 4, 2013 USEPA Draft Guidance Memo for further clarification.

e. For the 1 hour averaging time for NO_2 (After April 11, 2010):
   1.) The highest of the average of the eight highest concentrations per receptor over five years of modeling, derived from the maximum hourly concentration for each day of the year.

f. For Lead:
   1.) The highest quarterly concentration, as a three month rolling average, in the five years that were modeled.

g. For VOC:
   1.) Screening tables apply. One hour standard in effect.

   2.) Monitored background concentration must be added to calculated concentration.

h. For annual concentration rates for all pollutants:
   1.) For PM10, no annual average needs to be modeled.

   2.) For $PM_{2.5}$, the highest average high per receptor of the five years that were modeled.

   3.) For NO_2 and SO_2, the highest concentration over the five years that were modeled.

i. Specific options with one hour and annual NO_2:

   1.) NOx speciation.
      a.) Initially assume 100% NOx to NO_2.

b.) Use state agency monitored values of NOx and NO_2 to determine a NO_2/NOx ratio. Use the higher of two values; the monitored NO_2/NOx ratio or the default value of 0.80.

c.) The PVMRM or OLM option in AERMOD. See the March 1, 2011 USEPA memorandum for complete details for implementing these two options.

d.) IMPORTANT: For the one hour averaging time, use of PVMRM and OLM are subject to approval of USEPA Region V. Proposals for their use should be in the form of a modeling protocol.

B. PSD Increment Analysis

1. Determining downwash of PSD permitting source(s) using BPIP PRIME downwash analysis.

2. Using a Cartesian grid:
   a. Covering the complete impact area.

   b. Resolution of 1 km by 1km.

   c. Fenceline receptors.

   d. 100 meter resolution for 1 X 1 km portions of the grid that have concentration peaks over 2/3 of the primary standard.

   e. Identifying elevated receptors for complex terrain.

3. Five years of local NWS meteorology as advised under NAAQS Analysis.

4. Using other standard modeling protocol:

   a. Dispersion Mode, Urban or Rural (default to rural or perform Auer's analysis).

   b. Regulatory default options.

5. No background concentrations need to be considered.

6. All PSD increment concentrations are to be determined.

   a. For SO_2 and PM10:
      1.) The highest yearly second highest concentration over five years that was modeled for a given receptor, is considered the highest value for regulatory evaluation. Please note that SO_2 increments for the 3 and 24 hour averaging times as well as the annual averaging time are still in effect even though the 24 hour and annual NAAQS will be phased out in the near future.

b. $PM_{2.5}$ increments go into effect on October 20, 2011, and are not in effect with present permit application submittals.

c. For annual concentration rate for NO_2, PM10, and SO_2:

1.) Highest high in the five years that was modeled.

2.) PM10 annual increments still apply even though the PM10 NAAQS annual standard has been vacated.

c. For VOC, CO, and Pb there are no PSD increments.

VI. ADDITIONAL IMPACT ANALYSIS

A. An additional impact analysis should be performed as a part of the air quality analysis for the proposed or modified source that has any increase in emissions of any regulated pollutant.

B. Growth

1. Growth of the source.

2. Associated Growth
   a. Residential growth.
   b. Commercial and Industrial Growth.

C. Ambient air quality impact analysis.

D. Soils and vegetation impacts.

1. This analysis shall include an evaluation of both regulated criteria and non-criteria PSD pollutants. The scope of the analysis shall further extend to include trace elements and organic HAPs of potential significance.

2. Emissions from the PSD applicant's source should be modeled and evaluated against the concentration and depositional levels that could have a harmful impact on soils and vegetation.

3. For the soils and vegetation analysis, an inventory of soil types and flora of significant commercial and recreational value must be provided for an area corresponding to the maximum significant impact area obtained from the air quality analysis. A characterization of the physical and chemical properties of the soils, with particular attention to soil texture, drainage, pH, cation exchange capacity, and base saturation must be provided for the identified soil types.

a. This information can be obtained from local and county-level agencies responsible for soil conservation, habitat protection, and agronomic issues.

b. Contacting the Land Grant University cooperative extension office for a specific county might be a good place to start in obtaining such data.

4. An evaluation of potential adverse impacts to soils and vegetation should rely upon ambient air and deposition modeling of the PSD applicant's sources in combination with the results of literature/information searches. This approach will provide up-to-date information and results based upon currently accepted methods that go beyond simply applying the data and methodology contained in the USEPA screening analysis document A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils and Animals (EPA 450/2-81-078). The USEPA screening procedure can be pursued as part of the analysis, however, it should include an investigation to determine the validity of thresholds for potential pollutant impacts as currently contained in the screening document, as well as identifying threshold effect levels for those pollutants not originally covered. In general, the soils and vegetation analysis should include an evaluation of all applicable regulated NSR pollutants, and a complete analysis will include, as appropriate, an evaluation of the potential impact posed by volatile organic compound (VOC) emissions as a precursor pollutant and the potential impact of the constituents of particulate matter emissions.

5. Four major areas should be covered in your analysis.

a. Nitrogen deposition or "nutrient enrichment" and its effect on plant community composition and the local ecology.

b. Possible adverse affects from soil acidification when considering deposition of nitrogen and sulfur species.

c. An overall evaluation of direct foliar damage and potential phytotoxic effects from ambient air concentrations.

d. An evaluation of the soils accumulation of regulated NSR pollutants, particular attention to possible plant uptake and potential adverse effects (reduced plant growth and crop yields, impaired photosynthesis, interference with biochemical pathways, etc.).

6. The point of this analysis is to determine if specific soils or sensitive vegetation could be affected by both short and long-term exposure to low ambient concentrations and deposition from regulated PSD pollutants.

7. Adverse impacts to particular soils and vegetation species can occur below the secondary standard for the NAAQS or where no NAAQS exists for a regulated pollutant.

   a. Guidance on exposure thresholds can be found through literature searches. Some suggested sources are listed below, however, this is not an exhaustive or all inclusive list.

   "A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils, and Animals" (USEPA)
   "Air Quality Criteria Documents" (USEPA)
   "Impacts of Coal-Fired Plants of Fish, Wildlife, and Their Habitats" (US Department of the Interior) "A Screening Procedure to Evaluate Air Pollution Effects on Class I Wilderness Area" (US Forest Service) "Air Quality in the National Parks" (National Park Service)

   b. The concentration and depositional data in "A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils, and Animals" is no longer adequate for a soil and vegetation analysis, since the relevant science in regard to soil and vegetation impacts has evolved in the thirty years since this document was published. The overall approach from the EPA screening procedure can still be implemented with newer data from your literature searches while also giving attention to the four main areas identified above.

   c. Other potential sources for further assistance in finding information concerning impact thresholds for soils and vegetation types in the impact area include USEPA Region 5 ecologist, Chuck Maurice maurice.charles@epa.gov 312/866-6635, and the US Fish and Wildlife Service Field Chicago District Office at this web site:

      http://www.fws.gov/midwest/Chicago/

E. Visibility.

   1. Visibility for Class I areas should be incorporated into the Class I impacts analysis under F.

   2. Visibility for Class II areas should be performed as prescribed in the NSR Workshop Manual, in Chapter D, Additional Impact Analysis.

F. Class I impacts.

   1. Depending on the size, scope and location of a PSD project, the Federal Land Manager may want a detailed analysis of air quality affects upon nearby Class I areas. The PSD applicant is advised to contact the FLM for further guidance. Below is an outline of the steps involved in a typical Class I analysis.

2. The proposed or modified source is reviewed for impact under the FLAG (Federal Land Managers' Air Quality Related Values Workgroup) guidance.

3. Significant Impact Analysis for PM10, SO_2, and NO_2.

   a. Generally, a proposed or modified source would have to reside within 200 to 300 km of a Class I area.

   b. CALPUFF would be the preferred model in screening mode.

   c. Significant impact thresholds would be those set up by FLAG.

4. Significant Impact Analysis for all other criteria pollutants.

   a. A proposed or modified source would have to reside within 100 km of a Class I area.

   b. AERMOD maybe used for distances up to 50 km.

   c. A significant impact equal to or greater than 1 ug/m3, 24-hour average, would have to be incurred at the site of the Class I.

   d. This standard is for 24-hour averaging times for all pollutants that have caused significant impacts.

5. PSD Increment Analysis

   a. Refined impact analysis is advised from the FLAG guidance applying Class I Increment standards.
   b. CALPUFF is used for the refined modeling.
   c. Non increment pollutants are modeled against the NAAQS.

G. Biological Assessment

1. Depending on the size, scope and location of a PSD project, a biological assessment of the impact of the PSD source on threatened or endangered species may have to be performed. Oversight and guidance of this assessment would originate from USEPA and the US Fish and Wildlife Service. Illinois EPA can provide assistance through sharing materials of previous assessments.

2. Also the applicant has the responsibility for providing documentation of consultations over threatened and endangered species issues with Illinois Department of Natural Resources. This action should be undertaken to address regulations separately promulgated under the Illinois Endangered Species Protection Act.

APPENDIX A - Modeling Roads

Modeling techniques involving roads should follow the guidance offered by USEPA and its Haul Road work group. Presentations explaining the guidance from this work group can be downloaded from the internet at:

http://www.epa.gov/ttn/scram/10thmodconf/presentations/1-13-Haul_Road_10th.pdf

and,

http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2012/presentations/Tues/4-8_Haul%20Road_HQ.pdf

Volume sources as roads should be modeled:

- Top of Plume Height = 1.7 X (vehicle height)
- Release Height = 0.5 x (top of plume height)
- Plume Width = (vehicle width) + (6 meters for single lane)
- σ_{yo} = (width of plume)/2.15
- σ_{zo} = (top of plume height)/2.15
- Locations = Series of volume sources centered on the road centerline, spaced adjacent or side-by-side.

Roads may be modeled as area sources where ambient receptors are located within source dimensions or where other mechanical sources are emitting in the general vicinity of the road. As area sources alone, roads should be modeled:

- Length = length of roadway
- Adjusted road width = (vehicle width) + (6 meters for a single lane) or (road width + 6 meters for two-lane)
- Top of Plume Height = 1.7 x (vehicle height)
- Release Height = 0.5 x (top of plume height)
- σ_{zo} = (top of plume height)/2.15

Locations = Area source centered on coordinates of the road

Please consult Illinois EPA if further guidance is needed.

APPENDIX B - Addressing "Secondary" $PM_{2.5}$

Secondary $PM_{2.5}$ must be addressed in a PSD air quality analysis. For the most part, NO_x and SO_2, can lead to formation of $PM_{2.5}$ further downwind. The photochemical reactions that transform these pollutants into nitrates and sulfates, which become the major species of $PM_{2.5}$, take place over many hours or days. Below, preliminary guidance provided by Illinois EPA is gathered from technical documents supported by USEPA and NACCA, as well as direct guidance development from Illinois EPA. The basic idea is to implement a proportionality analysis using modeling results in development of the recently finalized the Cross State Air Pollution Rule (CSAPR).

For an assessment of the need for a PSD air quality analysis of $PM_{2.5}$ with the consideration of "secondary" $PM_{2.5}$, a direction can be taken based on one of four conditions.

Condition 1: If $PM_{2.5}$ emissions are below 10 tpy and NOx and SO_2 emissions are below 40 tpy, then $PM_{2.5}$ need not be considered in the air quality analysis.

Condition 2: If $PM_{2.5}$ emissions are greater than 10 tpy and NOx and SO_2 are below 40 tpy, then direct or primary $PM_{2.5}$ should be evaluated for compliance with PSD standards through modeling, but $PM_{2.5}$ precursors or secondary $PM_{2.5}$ doesn't not need to be included in the analysis.

Condition 3: If $PM_{2.5}$ emissions are greater than 10 tpy and NOx and/or SO_2 are above 40 tpy, then direct or primary $PM_{2.5}$ should be evaluated for compliance with PSD standards through modeling, with consideration of $PM_{2.5}$ precursors or secondary $PM_{2.5}$ emissions in the analysis.

Condition 4: If $PM_{2.5}$ emissions are below 10 tpy and NOx and/or SO_2 are above 40 tpy, then $PM_{2.5}$ needs to be considered in the air quality analysis as in condition 3.

The purpose of a secondary $PM_{2.5}$ analysis is to assess possibilities of transformation of SO_2 and NOx into nitrates and sulfates from a source that may occur and be transported downwind. These impacts would not occur in the near-field, where primary pollutant peak impacts would be found. No peer-reviewed regulatory model presently exists to examine the impacts of an individual source of SO_2 or NO_x upon secondary formation of $PM_{2.5}$. All photochemical models are regional in scale and depending on its size, the PSD permit applicant's source may not show any measurable impact. However, other available information from emissions inventories, meteorological analyses, and other modeling projects can be used to estimate the impact from this source.

Because of the well established relationship between NO_x and SO_2, regional transport, and the formation of $PM_{2.5}$, to assist states to meet the $PM_{2.5}$ NAAQS, USEPA recently finalized the Cross State Air Pollution Rule (CSAPR). This rule included extensive modeling to support the emissions reductions necessary in each state to achieve the $PM_{2.5}$ NAAQS in the eastern U.S. Electric Generating Units (EGUs) are the source category responsible for these reductions.

USEPA used a regional model, CAMx, and the Air Quality Assessment Tool (AQAT) to determine levels of reduction from EGUs necessary to achieve the NAAQS at every site. The documentation includes extensive tables showing impacts at all $PM_{2.5}$ monitoring sites in the eastern U.S. and emission reduction levels necessary to achieve those results.

To examine the possible impact of this project, modeling USEPA used to establish the final 2014 budgets in CSAPR is used for this analysis. The CSAPR website is located at http://www.epa.gov/airtransport/.

Information regarding SO_2 emission reductions necessary to achieve the future year modeled design values can be found in the "Significant Contribution Assessment TSD" associated with the CSAPR rulemaking. One can use the "base case" and the "remedy control scenario" annual SO_2 emissions for Illinois for 2014 to draw comparisons. Surrounding states have made significantly larger reductions, however, to be conservative, one should assume that only the Illinois reductions will affect the Illinois monitor being used to draw a finding for a peak concentration of $PM_{2.5}$.

From the maximum annual modeled design value concentrations for a given location for the 2014 base case and for the 2014 control scenario, an improvement in $PM_{2.5}$ air quality can be derived. Therefore, Illinois EGU annual emission reductions in SO_2 and NOx produced lowered impacts. The combined estimated SO_2 and NOx emissions for a PSD permitted source divided be the reduction of the sum of SO_2 and NOx emissions in the CSPAR modeling produces a ratio where the impact of PSD permitting source can be determined, based on the reduced impact of the Illinois EGUs from the reduction of emissions.

The calculation to estimate annual secondary formation is as follows:

PSD project emissions for SO_2 & NO_x (TPY)/CSPAR reduction emissions SO_2 & NO_x (TPY) = (PSD project $PM_{2.5}$ impact)

(PSD project $PM_{2.5}$ impact) * (Reduced impact from IL EGU's in $\mu g/m^3$ of $PM_{2.5}$ (annual averaging time)) = PSD project impact in $\mu g/m^3$ of $PM_{2.5}$.

The calculation to estimate 24-hour secondary formation is as follows:

PSD project emissions for SO_2 & NO_x (TPY)/CSPAR reduction emissions SO_2 & NO_x (TPY) = (PSD project $PM_{2.5}$ impact)

(PSD project $PM_{2.5}$ impact) * (Reduced impact from IL EGU's in $\mu g/m^3$ of $PM_{2.5}$ (24 hour averaging time)) = PSD project impact in $\mu g/m^3$ of $PM_{2.5}$.

The calculated secondary impact concentration should be added to the modeled primary impact concentration to determine if overall, $PM_{2.5}$ is making a significant impact based on the significant impact standards that have been set, 1.2 $\mu g/m^3$ for the 24 hour averaging time and 0.3 $\mu g/m^3$ for the annual averaging time.

The NAAQS, PSD Increment, and Background for $PM_{2.5}$

If it has been determined that the PSD source has produced a significant impact to the air quality for $PM_{2.5}$ then NAAQS and PSD increment modeling will be performed. Primary $PM_{2.5}$ can be modeled using AERMOD. The PSD

source's calculated secondary $PM_{2.5}$ concentration should be added to the concentration to be used at a comparison to the NAAQS for $PM_{2.5}$. Initially, for background $PM_{2.5}$ the current design value from a nearby Illinois EPA monitor, should be added to the modeled concentration. Illinois EPA produces a reference sheet as a guide for defining a conservative estimate based on Illinois EPA monitoring data. Less conservative but more realistic approaches are offered in this guide to provide justifiable background values. For example, for $PM_{2.5}$, other approaches have been proposed in the modeling community, based on temporal or timed pairings. Consultations with Illinois EPA are needed before these approaches are decided on. Likewise, PSD increment modeling would follow a similar approach for comparison of the standards without the need for adding a background.

Photochemical Modeling

In certain cases, photochemical modeling may be required depending on the size and type of the PSD source submitting an application. It is imperative that the applicant discuss the proposed project with the Illinois EPA through a written modeling protocol document and/or through teleconferences or face-to-face meetings, in order to avoid potential delays to advancing the permit application process to a timely completion.

Original DRAFT - January 26, 2000
Revision dated - March 1, 2000
Revision dated - May 16, 2000
Revision dated – November 2, 2005
Revision dated - November 29, 2005
Revision dated – August 21, 2007
Revision dated – August 15, 2008
Revision dated – August 25, 2008
Revision dated – October 10, 2008
Revision dated – March 12, 2009
Revision dated - December 10, 2009
Revision dated - January 8, 2010
Revision dated - February 19, 2010
Revision dated - April 15, 2010
Revision dated - January 26, 2011
Revision dated - April 5, 2011
Revision dated - April 12, 2011
Revision dated - April 15, 2011
Revision dated - May 5, 2011
Revision dated - May 26, 2011
Revision dated - March 6, 2012
Revision dated - October 22, 2012
Revision dated - November 8, 2012
Revision dated - December 10, 2012
Revision dated – April 19, 2013

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

AUG 2 3 2010

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

MEMORANDUM

SUBJECT: Applicability of Appendix W Modeling Guidance for the 1-hour SO_2 National Ambient Air Quality Standard

FROM: Tyler Fox, Leader
Air Quality Modeling Group, C439-01

TO: Regional Air Division Directors

INTRODUCTION

On June 2, 2010, EPA announced a new 1-hour sulfur dioxide (SO_2) National Ambient Air Quality Standard (1-hour SO_2 NAAQS or 1-hour SO_2 standard) which is attained when the 3-year average of the 99th-percentile of the annual distribution of daily maximum 1-hour concentrations does not exceed 75 ppb at each monitor within an area. The final rule for the new 1-hour SO_2 NAAQS was published in the Federal Register on June 22, 2010 (75 FR 35520-35603), and the standard becomes effective on August 23, 2010 (EPA, 2010a). This memorandum clarifies the applicability of current guidance in the *Guideline on Air Quality Models* (40 CFR Part 51, Appendix W) for modeling SO_2 impacts in accordance with the Prevention of Significant Deterioration (PSD) permit requirements to demonstrate compliance with the new 1-hour SO_2 standard.

SUMMARY OF CURRENT GUIDANCE

Current modeling guidance for estimating ambient impacts of SO_2 for comparison with applicable NAAQS is presented in Section 4 of Appendix W under the general heading of "Traditional Stationary Source Models." This guidance acknowledges the fact that ambient SO_2 impacts are largely a result of emissions from stationary sources. Section 4.2.2 provides specific recommendations regarding "Refined Analytical Techniques," stating that "For a wide range of regulatory applications in all types of terrain, the recommended model is AERMOD" (see Section 4.2.2.b). As described in Section 4.1.d, the AERMOD dispersion model "employs best state-of-practice parameterizations for characterizing the meteorological influences and dispersion" (Cimorelli, *et al.*, 2004; EPA, 2004; EPA, 2009).

Section 7.2.6 of Appendix W addresses the issue of chemical transformation for modeling SO_2 emissions, stating that:

> The chemical transformation of SO_2 emitted from point sources or single industrial plants in rural areas is generally assumed to be relatively unimportant to the estimation of maximum concentrations when travel time is limited to a few hours. However, in urban areas, where synergistic effects among pollutants are of considerable consequence, chemical transformation rates may be of concern. In urban area applications, a half-life of 4 hours may be applied to the analysis of SO_2 emissions. Calculations of transformation coefficients from site specific studies can be used to define a ''half-life'' to be used in a steady-state Gaussian plume model with any travel time, or in any application, if appropriate documentation is provided. Such conversion factors for pollutant half-life should not be used with screening analyses.

The AERMOD model incorporates the 4 hour half-life for modeling ambient SO_2 concentrations in urban areas under the regulatory default option.

General guidance regarding source emission input data requirements for modeling ambient SO_2 impacts is provided in Section 8.1 of Appendix W and guidance regarding determination of background concentrations for purposes of a cumulative ambient air quality impact analysis is provided in Section 8.2.

APPLICABILITY OF CURRENT GUIDANCE TO 1-HOUR SO_2 NAAQS

The current guidance in Appendix W regarding SO_2 modeling in the context of the previous 24-hour and annual primary SO_2 NAAQS and the 3-hour secondary SO_2 NAAQS is generally applicable to the new 1-hour SO_2 standard. Since short-term SO_2 standards (≤ 24 hours) have been in existence for decades, existing SO_2 emission inventories used to support modeling for compliance with the 3-hour and 24-hour SO_2 standards should serve as a useful starting point, and may be adequate in many cases for use in assessing compliance with the new 1-hour SO_2 standard, since issues identified in Table 8-2 of Appendix W related to short-term vs. long-term emission estimates may have already been addressed. However, the PSD applicant and reviewing authority may need to reassess emission estimates for very short-term emission scenarios, such as start-up and shut-down operations, for purposes of estimating source impacts on the 1-hour SO_2 standard. This is especially true if existing emission estimates for 3-hour or 24-hour periods are based on averages that include zero (0) or reduced emissions for some of the hours.

Given the form of the new 1-hour SO_2 standard, we are providing clarification regarding the appropriate data periods for modeling demonstrations of compliance with the NAAQS vs. demonstrations of attainment of the NAAQS through ambient monitoring. While monitored design values for the 1-hour SO_2 standard are based on a 3-year average (in accordance with Section 1(c) of Appendix T to 40 CFR Part 50), Section 8.3.1.2 of Appendix W addresses the length of the meteorological data record for dispersion modeling, stating that "[T]he use of 5 years of NWS [National Weather Service] meteorological data or at least l year of site specific data is required." Section 8.3.1.2.b further states that "one year or more (including partial years), up to five years, of site specific data . . . are preferred for use in air quality analyses." Although the monitored design value for the 1-hour SO_2 standard is defined in terms of the 3-year average, this definition does not preempt or alter the Appendix W requirement for use of 5 years of NWS meteorological data or at least 1 year of site specific data. The 5-year average based on use of NWS data, or an average across one or more years of available site specific data, serves as an unbiased estimate of the 3-year average for purposes of modeling demonstrations of compliance with the NAAQS. Modeling of "rolling 3-year averages," using years 1 through 3, years 2 through 4, and years 3 through 5, is not required. Furthermore, since modeled results for SO_2 are averaged across the number of years modeled for comparison to the new 1-hour SO_2 standard, the meteorological data period should include complete years of data to avoid introducing a seasonal bias to the averaged impacts. In order to comply with Appendix W recommendations in cases where partial years of site specific meteorological data are available, while avoiding any seasonal bias in the averaged impacts, an approach that utilizes the most conservative modeling result based on the first complete-year period of the available data record vs. results based on the last complete-year period of available data may be appropriate, subject to approval by the appropriate reviewing authority. Such an approach would ensure that all available site specific data are accounted for in the modeling analysis without imposing an undue burden on the applicant and avoiding arbitrary choices in the selection of a single complete-year data period.

The form of the new 1-hour SO_2 standard also has implications regarding appropriate methods for combining modeled ambient concentrations with monitored background concentrations for comparison to the NAAQS in a cumulative modeling analysis. As noted in the March 23, 2010 memorandum regarding "Modeling Procedures for Demonstrating Compliance with $PM_{2.5}$ NAAQS" (EPA, 2010b), combining the 98^{th} percentile monitored value with the 98^{th} percentile modeled concentrations for a cumulative impact assessment could result in a value that is below the 98^{th} percentile of the combined cumulative distribution and would, therefore, not be protective of the NAAQS. However, unlike the recommendations presented for $PM_{2.5}$, the modeled contribution to the cumulative ambient impact assessment for the 1-hour SO_2 standard should follow the form of the standard based on the 99^{th} percentile of the annual distribution of daily maximum 1-hour concentrations averaged across the number of years modeled. A "first tier" assumption that may be applied without further justification is to add the overall highest hourly background SO_2 concentration from a representative monitor to the modeled design value, based on the form of the standard, for comparison to the NAAQS. Additional refinements to this "first tier" approach based on some level of temporal pairing of modeled and monitored values may be considered on a case-by-case basis, subject to approval by the reviewing authority, with adequate justification and documentation.

Section 8.2.3 of Appendix W provides recommendations regarding the determination of background concentrations for multi-source areas. That section emphasizes the importance of professional judgment by the reviewing authority in the identification of nearby and other sources to be included in the modeled emission inventory, and establishes "a significant concentration gradient in the vicinity of the source" under consideration as the main criterion for this selection. Appendix W also indicates that "the number of such [nearby] sources is expected to be small except in unusual situations." See Section 8.2.3.b.

The representativeness of available ambient air quality data also plays an important role in determining which nearby sources should be included in the modeled emission inventory. Key issues to consider in this regard are the extent to which ambient air impacts of emissions from nearby sources are reflected in the available ambient measurements, and the degree to which emissions from those background sources during the monitoring period are representative of allowable emission levels under the existing permits. The professional judgments that are required in developing an appropriate inventory of background sources should strive toward the proper balance between adequately characterizing the potential for cumulative impacts of emission sources within the study area to cause or contribute to violations of the NAAQS, while minimizing the potential to overestimate impacts by double counting modeled source impacts that are also reflected in the ambient monitoring data.

We would also caution against the literal and uncritical application of very prescriptive procedures for identifying which background sources should be included in the modeled emission inventory for NAAQS compliance demonstrations, including those described in Chapter C, Section IV.C.1 of the draft *New Source Review Workshop Manual* (EPA, 1990), noting again that Appendix W emphasizes the importance of professional judgment in this process. While the draft workshop manual serves as a useful general reference that provides potential approaches for meeting the requirements of New Source Review (NSR) and PSD programs, it is not the only source of EPA modeling guidance. The procedures described in the manual may be appropriate in some circumstances for defining the spatial extent of sources whose emissions may need to be considered, but not in others. While the procedures described in the NSR Workshop Manual may appear very prescriptive, it should be recognized that "[i]t is not intended to be an official statement of policy and standards and does not establish binding regulatory requirements." See, Preface.

Given the range of issues involved in the determination of an appropriate inventory of emissions to include in a cumulative impact assessment, the PSD applicant should consult with the appropriate reviewing authority early in the process regarding the selection and proper application of appropriate monitored background concentrations and the selection and appropriate characterization of modeled background source emission inventories for use in demonstrating compliance with the new 1-hour SO_2 standard.

SUMMARY

To summarize, we emphasize the following points:

1. Current guidance in Appendix W for modeling to demonstrate compliance with the previous 24-hour and annual primary SO_2 standards, and 3-hour secondary SO_2 standard, is generally applicable for the new 1-hour SO_2 NAAQS.
2. While the 1-hour NAAQS for SO_2 is defined in terms of the 3-year average for monitored design values to determine attainment of the NAAQS, this definition does not preempt or alter the Appendix W requirement for use of 5 years of NWS meteorological data or at least l year of site specific data.

REFERENCES

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine, R. B. Wilson, R. F. Lee, W. D. Peters, R. W. Brode, and J. O. Paumier, 2004. AERMOD: Description of Model Formulation with Addendum, EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1990. New Source Review Workshop Manual: Prevention of Significant Deterioration and Nonattainment Area Permitting – DRAFT. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 2004. User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 2009. Addendum – User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 2010a. Applicability of the Federal Prevention of Significant Deterioration Permit Requirements to New and Revised National Ambient Air Quality Standards. Stephen D. Page Memorandum, dated April 1, 2010. U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 2010b. Modeling Procedures for Demonstrating Compliance with $PM_{2.5}$ NAAQS. Stephen D. Page Memorandum, dated March 23, 2010. U.S. Environmental Protection Agency, Research Triangle Park, NC.

cc: Richard Wayland, C304-02
Anna Wood, C504-01
Raj Rao, C504-01
Roger Brode, C439-01
James Thurman, C439-01
Dan deRoeck, C504-03
Elliott Zenick, OGC
Brian Doster, OGC
EPA Regional Modeling Contacts

Federal Register

Wednesday,

November 9, 2005

Part III

Environmental Protection Agency

40 CFR Part 51

Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 51

[AH–FRL–7990–9]

RIN 2060–AK60

Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: EPA's *Guideline on Air Quality Models* (''*Guideline*'') addresses the regulatory application of air quality models for assessing criteria pollutants under the Clean Air Act. In today's action we promulgate several additions and changes to the *Guideline.* We recommend a new dispersion model—AERMOD—for adoption in appendix A of the *Guideline.* AERMOD replaces the Industrial Source Complex (ISC3) model, applies to complex terrain, and incorporates a new downwash algorithm—PRIME. We remove an existing model—the Emissions Dispersion Modeling System (EDMS)—from appendix A. We also make various editorial changes to update and reorganize information.

DATES: This rule is effective December 9, 2005. As proposed, beginning November 9, 2006, the new model—AERMOD—*should be* used for appropriate application as replacement for ISC3. During the one-year period following this promulgation, protocols for modeling analyses based on ISC3 which are submitted in a timely manner *may be* approved at the discretion of the appropriate Reviewing Authority. Applicants are therefore encouraged to consult with the Reviewing Authority as soon as possible to assure acceptance during this period.

ADDRESSES: All documents relevant to this rule have been placed in Docket No. A–99–05 at the following address: Air Docket in the EPA Docket Center, (EPA/DC) EPA West (MC 6102T), 1301 Constitution Ave., NW., Washington, DC 20004. This docket is available for public inspection and copying between 8 a.m. and 5:30 p.m., Monday through Friday, at the address above.

FOR FURTHER INFORMATION CONTACT: Tyler J. Fox, Air Quality Modeling Group (MD–D243–01), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; telephone (919) 541–5562. (*Fox.Tyler@epa.gov*).

SUPPLEMENTARY INFORMATION:

Outline

I. General Information

A. How Can I Get Copies of Related Information?

EPA established an official public docket for this action under Docket No. A–99–05. The official public docket is the collection of materials that is available for public viewing at the Air Docket in the EPA Docket Center, (EPA/DC) EPA West (MC 6102T), 1301 Constitution Ave., NW., Washington, DC 20004. The EPA Docket Center Public Reading Room (B102) is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Reading Room is (202) 566–1744, and the telephone number for the Air Docket is (202) 566–1742. An electronic image of this docket may be accessed via Internet at *www.epa.gov/eDocket,* where Docket No. A–99–05 is indexed as OAR–2003–0201. Materials related to our Notice of Data Availability (published September 8, 2003) and public comments received pursuant to the notice were placed in eDocket OAR–2003–0201.[1]

Our Air Quality Modeling Group maintain an Internet website (Support Center for Regulatory Air Models—SCRAM) at: *www.epa.gov/scram001.* You may find codes and documentation for models referenced in today's action on the SCRAM Web site. We have also uploaded various support documents (*e.g.,* evaluation reports).

II. Background

The *Guideline* is used by EPA, States, and industry to prepare and review new source permits and State Implementation Plan revisions. The *Guideline* is intended to ensure consistent air quality analyses for activities regulated at 40 CFR 51.112, 51.117, 51.150, 51.160, 51.166, and 52.21. We originally published the *Guideline* in April 1978 and it was incorporated by reference in the regulations for the Prevention of Significant Deterioration (PSD) of Air Quality in June 1978. We revised the *Guideline* in 1986, and updated it with supplement A in 1987, supplement B in July 1993, and supplement C in August 1995. We published the *Guideline* as appendix W to 40 CFR part 51 when we issued supplement B. We republished the *Guideline* in August 1996 (61 FR 41838) to adopt the CFR system for labeling paragraphs. On April 21, 2000 we issued a Notice of Proposed Rulemaking (NPR) in the **Federal Register** (65 FR 21506), which was the original proposal for today's promulgation.

III. Public Hearing on the April 2000 Proposal

We held the 7th Conference on Air Quality Modeling (7th conference) in Washington, DC on June 28–29, 2000. As required by Section 320 of the Clean Air Act, these conferences take place approximately every three years to standardize modeling procedures, with special attention given to appropriate modeling practices for carrying out programs PSD (42 U.S.C. 7620). This conference served as the forum for receiving public comments on the *Guideline* revisions proposed in April 2000. The 7th conference featured presentations in several key modeling areas that support the revisions promulgated today. A presentation by the American Meteorological Society (AMS)/EPA Regulatory Model Improvement Committee (AERMIC) covered the enhanced Gaussian dispersion model with boundary layer parameterization: AERMOD.[2] Also at the 7th conference, the Electric Power Research Institute (EPRI) presented evaluation results from the recent research efforts to better define and characterize dispersion around

[1] *http://cascade.epa.gov/RightSite/dk_public_collection_detail.htm?ObjectType=dk_docket_collection&cid=OAR-2003-0201&ShowList=items&Action=view.*

[2] *AMS/EPA Regulatory MODel.*

buildings (downwash effects). These efforts were part of a program called the Plume RIse Model Enhancements (PRIME). At the time, PRIME was integrated within ISC3ST (*ISC–PRIME*) and the results presented were within the ISC3 context. As discussed in today's rule, the PRIME algorithm has now been fully integrated into AERMOD.

We proposed an update to the Emissions and Dispersion Modeling System (EDMS 3.1), which is used for assessing air quality impacts from airports. A representative of the Federal Aviation Administration (FAA) presented a further upgrade to EDMS 4.0 that would include AERMOD and forthcoming performance evaluations for two airports.

The presentations were followed by a critical review/discussion of AERMOD and available performance evaluations, facilitated jointly by the Air & Waste Management Association's AB–3 Committee and the American Meteorological Society's Committee of Meteorological Aspects of Air Pollution.

For the new models and modeling techniques proposed in April 2000, we asked the public to address the following questions:

- Has the scientific merit of the models presented been established?
- Are the models' accuracy sufficiently documented?
- Are the proposed regulatory uses of individual models for specific applications appropriate and reasonable?
- Do significant implementation issues remain or is additional guidance needed?
- Are there serious resource constraints imposed by modeling systems presented?
- What additional analyses or information are needed?

We placed a transcript of the 7th conference proceedings and a copy of all written comments, many of which address the above questions, in Docket No. A–99–05. The comments on AERMOD were reviewed and nearly every commenter urged us to integrate aerodynamic downwash into AERMOD (i.e., not to require two models for some analyses). The only comments calling for further actions were associated with the need for documentation, evaluation and review of the suggested downwash enhancement to AERMOD.

As a result of American Meteorological Society (AMS)/EPA Regulatory Model Improvement Committee's (AERMIC) efforts to revise AERMOD, incorporating the PRIME algorithm and making certain other incidental modifications and to respond to public concerns, we believed that the revised AERMOD merited another public examination of performance results. Also, since the April 2000 NPR, the Federal Aviation Administration (FAA) decided to configure EDMS 3.1 to incorporate the AERMOD dispersion model. FAA presented this strategy at the 7th conference and performance evaluations at two airports were to be available before final promulgation. This was in response to public concern over lack of EDMS evaluation.

On April 15, 2003 we published a Notice of Final Rulemaking (NFR; 68 FR 18440) that adopted CALPUFF in appendix A of the *Guideline.* We also made various editorial changes to update and reorganize information, and removed obsolete models. We announced that action on AERMOD and the Emissions and Dispersion Model (EDMS) for assessing airport impacts was being deferred, and would be reconsidered in a separate action when new information became available for these models.

This deferred action took the form of a Notice of Data Availability (NDA), which was published on September 8, 2003 (68 FR 52934). In this notice, we made clear that the purpose of the NDA was to furnish pertinent technical details related to model changes since the April 2000 NPR. New performance data and evaluation of design concentration using the revised AERMOD are contained in reports cited later in this *preamble* (see section V). In our April 2003 NFR, we stated that results of EDMS 4.0 performance (with AERMOD) had recently become available. In the NDA we clarified that these results would not be provided because of FAA's decision to withdraw EDMS from the *Guideline's* appendix A, and we affirmed our support for this removal. We solicited public comments on the new data and information related to AERMOD.

IV. Discussion of Public Comments and Issues From Our April 21, 2000 Proposal

All comments submitted to Docket No. A–99–05 are filed in Category IV–D.[3] We summarized these comments, developed detailed responses, and documented conclusions on appropriate actions in a Response-to-Comments document.[4] In this document, we considered and discussed all significant comments. Whenever the comments revealed any new information or suggested any alternative solutions, we considered this prior to taking final action.

The remainder of this preamble section discusses the primary issues encountered by the Agency during the public comment period associated with the April 2000 proposal. This overview also serves in part to explain the changes to the *Guideline* in today's action, and the main technical and policy concerns addressed by the Agency.

A. AERMOD and PRIME

AERMOD is a best state-of-the-practice Gaussian plume dispersion model whose formulation is based on planetary boundary layer principles. AERMOD provides better characterization of plume dispersion than does ISC3. At the 7th conference, AERMIC members presented developmental and evaluation results of AERMOD. Comprehensive comments were submitted on the AERMOD code and formulation document and on the AERMET draft User's Guide (AERMET is the meteorological preprocessor for AERMOD).

As identified in the April 2000 **Federal Register** proposal, applications for which AERMOD was suited include assessment of plume impacts from stationary sources in simple, intermediate, and complex terrain, for *other than* downwash and deposition applications. We invited comments on whether technical concerns had been reasonably addressed and whether AERMOD is appropriate for its intended applications. Since AERMOD lacks a general (all-terrain) screening tool, we invited comment on the practicality of using SCREEN3 as an interim tool for AERMOD. We also sought comments on minor changes to the list of acceptable screening techniques for complex terrain.

PRIME was designed to incorporate the latest scientific algorithms for evaluating building downwash. At the time of the proposal, the PRIME algorithm for simulating aerodynamic downwash was not incorporated into AERMOD. For testing purposes, PRIME was implemented within ISC3ST (short-term average version of the Industrial Source Complex), which AERMOD was proposed to replace. This special model, called *ISC–PRIME,* was proposed for

[3] Additional comments received since we published the final rule on April 15, 2003 (discussed in the previous section) are filed in category IV–E. This category includes comments received pursuant to the Notice of Data Availability we published in September 2003.

[4] Summary of Public Comments and EPA Responses: AERMOD; 7th Conference on Air Quality Modeling; Washington, DC, June 28–29, 2000 AND Notice of Data Availability—September 8, 2003 (Air Docket A–99–05, Item V–C–2). This document may also be examined from EPA's SCRAM Web site at *www.epa.gov/scram001.*

aerodynamic downwash and dry deposition. We sought comment on the technical viability of AERMOD and ISC–PRIME for its intended applications.

Scientific merit and accuracy. Regarding the scientific merits of AERMOD, substantial support was expressed in public comments that AERMOD represents sound and significant advances over ISC3ST. The scientific merits of this approach have been documented both through scientific peer review and performance evaluations. The formulation of AERMOD has been subjected to an extensive, independent peer review.[5] Findings of the peer review panel suggest that AERMOD's scientific basis is ''state-of-the-science.'' Additionally, the model formulations used in AERMOD and the performance evaluations have been accepted for publication in two refereed journals.[6 7] Finally, the adequacy of AERMOD's complex terrain approach for regulatory applications is seen most directly in its performance. AERMOD's complex terrain component has been evaluated extensively by comparing model-estimated regulatory design values and concentration frequency distributions with observations. These comparisons have demonstrated AERMOD's superiority to ISC3ST and CTDMPLUS (Complex Terrain Dispersion Model PLUS unstable algorithms) in estimating those flat and complex terrain impacts of greatest regulatory importance.[8] For incidental and unique situations involving a well-defined hill or ridge and where a detailed dispersion analysis of the spatial pattern of plume impacts is of interest, CTDMPLUS in the *Guideline*'s appendix A remains available.

Public comments also supported our conclusion about the scientific merits of PRIME. A detailed article in a peer-reviewed journal has been published which contains all the basic equations with clear definitions of the variables, and the reasoning and references for the model assumptions.[9]

Although some comments asked for more detailed documentation and review, there were no comments which questioned the technical credibility of the PRIME model. In fact, almost every commenter asked for PRIME to be incorporated into AERMOD. As summarized above, we believe that the scientific merit of PRIME has been established via (1) model evaluation and documentation, (2) peer review within the submittal process to a technical journal, and (3) via the public review process.

Based on the external peer review of the evaluation report and the public review comments, we have concluded that: (1) AERMOD's accuracy is adequately documented; (2) AERMOD's accuracy is an improvement over ISC3ST's ability to predict measured concentrations; and (3) AERMOD is an acceptable regulatory air dispersion model replacement for ISC3ST.

Some commenters have identified what they perceived to be weaknesses in the evaluation and performance of ISC–PRIME,[10] and some concerns were raised about the scope of the PRIME evaluation. However, as shown by the overwhelming number of requests for the incorporation of PRIME into AERMOD, commenters were convinced that the accuracy of PRIME, as implemented within the ISC3ST framework, was reasonably documented and found acceptable for regulatory applications. Although some commenters requested more evaluations, practical limitations on the number of valid, available data sets prevented the inclusion of every source type and setting in the evaluation. All the data bases that were reasonably available were used in the development and evaluation of the model, and those data bases were sufficient to establish the basis for the evaluation. Based on our review of the documentation and the public comments, we conclude that the accuracy of PRIME is sufficiently documented and find it acceptable for use in a dispersion model recommended in the *Guideline.*

B. Appropriate for Proposed Use

Responding to a question posed in our April 2000 proposal, the majority of commenters questioned the reasonableness of requiring simultaneous use of two models (ISC–PRIME and AERMOD) for those sources with potential downwash concerns. Commenters urged the Agency to eliminate the need to use two models for evaluating the same source. In response to this request, AERMIC developed a version of AERMOD that incorporates PRIME: AERMOD (02222) and initiated an analysis to insure that concentration estimates by AERMOD (02222) are equivalent to ISC–PRIME predictions in areas affected by downwash before it replaces ISC–PRIME. Careful thought was given to the way that PRIME was incorporated into AERMOD, with the goal of making the merge seamless. While discontinuities from the concatenation of these two sets of algorithms were of concern, we mitigated this situation wherever possible (see part D of this preamble, and the Response to Comments document[4]). With regard to testing the performance of AERMOD (02222), we have carefully confirmed that the AERMOD (02222)'s air quality concentration predictions in the wake region reasonably compare to those predictions from ISC–PRIME. In fact, the results indicate that AERMOD (02222)'s performance matches the performance of ISC–PRIME, and are presented in an updated evaluation report[11] and analysis of regulatory design concentrations.[12] We discuss AERMOD (02222) performance in detail in part D.

Because the technical basis for the PRIME algorithms and the AERMOD formulations have been independently peer-reviewed, we believe that further peer review of the new model (AERMOD 02222) is not necessary. The scientific formulation of the PRIME algorithms has not been changed. However, the coding for the interface between PRIME and the accompanying dispersion model had to be modified somewhat to accommodate the different ways that ISC3ST and AERMOD simulate the atmosphere. The main public concern was the interaction between the two models and whether the behavior would be appropriate for all reasonable source settings. This concern was addressed through the extensive testing conducted within the performance evaluation[11] and analysis of design concentrations.[12] Both sets of

[5] U.S. Environmental Protection Agency, 2002. Compendium of Reports from the Peer Review Process for AERMOD. February 2002. Available at *www.epa.gov/scram001/.*

[6] Cimorelli, A. *et al.,* 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization. *Journal of Applied Meteorology,* 44(5): 682–693.

[7] Perry, S. *et al.,* 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part II: Model Performance against 17 Field Study Databases. *Journal of Applied Meteorology,* 44(5): 694–708.

[8] Paine R. J. *et al.,* 1998. Evaluation Results for AERMOD, Draft Report. Docket No. A–99–05; II–A–05. Available at *www.epa.gov./scram001/.*

[9] Schulman, L.L. *et al.,* 2000. Development and Evaluation of the PRIME Plum Rise and Building Downwash Model. JAWMA 50: 378–390.

[10] Electric Power Research Institute, 1997. Results of the Independent Evaluation of ISCST3 and ISC–PRIME. Final Report, TR–2460026, November 1997. Available at *www.epa.gov/scram001/.*

[11] Environmental Protection Agency, 2003. AERMOD: Latest Features and Evaluation Results. Publication No. EPA–454/R–03–003. Available at *www.epa.gov/scram001/.*

[12] Environmental Protection Agency, 2003. Comparison of Regulatory Design Concentrations: AERMOD versus ISC3ST, CTDMPLUS, and ISC–PRIME. Final Report. Publication No. EPA–454/R–03–002. Available at *www.epa.gov/scram001/.*

analyses indicate that the new model is performing acceptably well and the results are similar to those obtained from the earlier performance evaluation [8] [10] and analysis of regulatory design concentrations (*i.e.*, for AERMOD (99351)).[13]

While dry deposition is treated in ISC3ST, time and resources did not allow its incorporation in AERMOD (99351). Since no recommendation for deposition is made for regulatory applications, we did not consider that the absence of this capability compromises the suitability of AERMOD for its intended purposes. Nevertheless, a number of commenters requested that deposition algorithms be added to AERMOD, and we developed an update to AERMOD (02222) that offers dry and wet deposition for both gases and particles as an option.

The version of AERMOD under review at the 7th Conference was AERMOD (99351) and, as mentioned above, AERMIC has made a number of changes to AERMOD (99351) following this conference. These changes were initiated in response to public comments and, after the release of a new draft version of the model, in response to the recommendations from the *beta* testers. Changes made to AERMOD include the following:

• Adding the PRIME algorithms to the model (response to public comments);

• Modifying the complex terrain algorithms to make AERMOD less sensitive to the selection of the domain of the study area (response to public comments);

• Modifying the urban dispersion for low-level emission sources, such as area sources, to produce a more realistic urban dispersion and, as a part of this change, changing the minimum layer depth used to calculate the effective dispersion parameters for all dispersion settings (scientific formulation correction which was requested by beta testers); and

• Upgrading AERMOD to include all the newest features that exist in the latest version of ISC3ST such as Fortran90 compliance and allocatable arrays, EVENTS processing and the TOXICS option (response to public comments).

In the follow-up quality control checking of the model and the source code, additional changes were identified as necessary and the following revisions were made:

• Adding meander treatment to: (1) Stable and unstable urban cases, and (2) the rural unstable dispersion settings (only the rural, stable dispersion setting considered meander in AERMOD (99351)—this change created a consistent treatment of air dispersion in all dispersion settings);

• Making some changes to the basic meander algorithms (improved scientific formulation); and

• Repairing miscellaneous coding errors.

As we mentioned earlier, the version of AERMOD that is being promulgated today—AERMOD (02222)—has been subjected to further performance evaluation [11] and analysis of design concentrations.[12]

C. Implementation Issues/Additional Guidance

Other than miscellaneous suggestions for certain enhancements for AERMOD (99351) such as a Fortran90 compilation of the source code, creation of allocatable arrays, and development of a Windows® graphical user interface, no significant implementation obstacles were identified in public comments.

For AERMET (meteorological preprocessor for AERMOD), we have implemented some enhancements that commenters suggested. For site-specific applications, several commenters cited AERMOD's requirements for NWS cloud cover data. In response, we revised the AERMET to incorporate the bulk Richardson number methodology. This approach uses temperature differences near the surface of the earth, which can be routinely monitored, and eliminates the need for the cloud cover data at night. We made a number of other revisions in response to public comments, enabling AERMET to: (1) Use the old and the new Forecasting Systems Laboratory formats, (2) use the Hourly U.S. Weather Observations/Automated Surface Observing Stations (HUSWO/ASOS) data, (3) use site-specific solar radiation and temperature gradient data to eliminate the need for cloud cover data, (4) appropriately handle meteorological data from above the arctic circle, and (5) accept a wider range of reasonable friction velocities and reduce the number of warning messages. As mentioned earlier, we added a meander component to the treatment of stable and unstable urban conditions to consistently treat meander phenomena for all cases.

AERMAP (the terrain preprocessor for AERMOD) has been upgraded in response to public comments calling for it to: (1) Treat complex terrain receptors without a dependance on the selected domain, (2) accommodate the Spatial Data Transfer Standard (SDTS) data available from the U.S. Geological Survey (USGS), (3) appropriately use Digital Elevation Model (DEM) data with 2 different datums (NAD27 and NAD83); (4) accept all 7 digits of the North UTM coordinate, and (5) do more error-checking in the raw data (mostly checking for missing values, but not for harsh terrain changes in adjacent points). All of these recommendations have been implemented.

In response to comments about the selection of the domain affecting the results of the maximum concentrations in complex terrain and the way AERMAP estimates the effective hill height scale (h_C), the algorithms within AERMAP and AERMOD have been adjusted so that the hill height is less sensitive to the arbitrary selection of the domain. This adjustment has been evaluated against the entire set of evaluation data. The correction was found to substantially reduce the effect of the domain size upon the computation of controlling hill heights for each receptor. Application of this change to the evaluation databases did not materially affect the evaluation results.

In general, public comments that requested additional guidance were either obviated by revisions to AERMOD (99351) and its related preprocessors or deemed unnecessary. In the latter case, the reasons were explained in the Response-to-Comments document.[4]

Some public comments suggested additional testing of AERMOD (99351). In fact, after the model revisions that were described earlier were completed, AERMOD (02222) was subjected to additional testing.[11] [12] These new analyses will be discussed in part D.

With respect to a screening version of AERMOD, a tool called AERSCREEN is being developed with a beta version expected to be publicly available in Fall 2005. SCREEN3 is the current screening model in the *Guideline,* and since SCREEN3 has been successfully applied for a number of years, we believe that SCREEN3 produces an acceptable degree of conservatism for regulatory applications and may be used until AERSCREEN or a similar technique becomes available and tested for general application.

D. AERMOD Revision and Reanalyses Published In 2003

1. Performance Analysis for AERMOD (02222)

We have tested the performance of AERMOD (02222) by applying all of the original data sets used to support the version proposed in April, 2000: AERMOD (99351) [8] and ISC–PRIME.[10] These data sets include: 5 complex

[13] Peters, W.D. *et al.,* 1999. Comparison of Regulatory Design Concentrations: AERMOD vs. ISCST3 and CTDMPLUS, Draft Report. Docket No. A–99–05; II–A–15.

terrain data sets, 7 building downwash data sets, and 5 simple terrain data sets (see appendix A of the Response-to-Comments document [4]). This performance analysis, which is a check of the model's maximum concentration predictions against observed data, includes a comparison of the current version of the new model (AERMOD 02222) with ISC3ST or ISC–PRIME for downwash conditions. The results and conclusions of the performance analyses are presented in 2 sections: Non-downwash and downwash source scenarios.

a. Non-Downwash Cases

For the user community to obtain a full understanding of the impacts of today's proposal for the non-downwash source scenarios (flat and complex terrain), our performance evaluation of AERMOD (02222) must be discussed with respect to the old model, ISC3ST, and with respect to AERMOD (99351). Based on the evaluation, we have concluded that AERMOD (02222) significantly outperforms ISC3ST and that AERMOD (02222)'s performance is even better than that of AERMOD (99351).

Evaluation of AERMOD (99351)

Comparative performance statistics were calculated for both ISC3ST and AERMOD (99351) using data sets in non-downwash conditions. This analysis looked at combinations of test sites (flat and complex terrain), pollutants, and concentration averaging times. Comparisons indicated very significant improvements in performance when applying AERMOD (99351). In all but 1 of the total of 20 cases in which AERMOD (99351) could be compared to ISC3ST, AERMOD performed as well as (but generally better than) ISC3ST, that is, AERMOD predicted maximum concentrations that were closer to the measured maximum concentrations. In the most dramatic case (*i.e.*, Lovett; 24-hr) in which AERMOD performed better than ISC3ST, AERMOD's maximum concentration predictions were about the same as the measured concentrations while the ISC3ST's predicted maximum concentrations were about 9 times higher than the measured concentrations. In the one case (*i.e.*, Clifty Creek; 3-hr) where ISC3ST performed better than AERMOD (99351), ISC3ST's concentration predictions matched the observed data and the AERMOD concentration predictions were about 25% higher than the observed data. These results were reported in the supporting documentation for AERMOD (99351).

Evaluation of AERMOD (02222)

With the changes to AERMOD (99351) as outlined above, how has the performance of the AERMOD been affected? The performance of the current version of AERMOD is about the same or slightly better than the April 2000 version when a comparison is made over all the available data sets. There were examples of AERMOD (02222) showing better and poorer performance when compared to the performance results of AERMOD (99351). However, for those cases where AERMOD (02222)'s performance was degraded, the degradation was small. On the other side, there were more examples where AERMOD (02222) more closely predicted measured concentrations. The performance improvements were also rather small but, in general, were somewhat larger than the size of the performance degradations. There also were a number of cases where the performance remained unchanged between the 2 models. Thus, overall, there was a slight improvement in AERMOD's performance and, consequently, we believe that AERMOD (02222) significantly outperforms ISC3ST for non-downwash source scenarios.

For AERMOD (02222) with the 5 data bases examined for simple terrain, the ratios of modeled/observed Robust High Concentration ranged from 0.77 to 1.11 (1-hr average), 0.98 to 1.24 (3-hr average), 0.94 to 0.97 (24-hr average) and 0.30 to 0.97 (annual average). These ratios reflect better performance than ISC3ST for all cases.

For AERMOD (02222) with the 5 data bases examined for complex terrain, these ratios ranged from 1.03 to 1.12 (3-hr average), 0.67 to 1.78 (24-hr average) and 0.54 to 1.59 (annual average). At Tracy—the only site for which there are 1-hr data—AERMOD performed considerably better (ratio = 1.04) than either ISC3ST or CTDMPLUS. At three of the other four sites, AERMOD generally performed much better than either ISC3ST or (where applicable) alternative models for the 3-hr and 24-hr averaging times; results were comparable for Clifty Creek (for the 3-hr averaging times, AERMOD (02222) predictions were only about 5% higher than ISC3ST's—down from 25% for AERMOD (99351) as described earlier). At the two sites where annual peak comparisons are available, AERMOD performed much better than either ISC3ST or alternative models.

b. Downwash Cases

For the downwash data sets, there were combinations of test sites, pollutants, stack heights and averaging times where the proposed (ISC–PRIME) model performance could be compared to the performance of AERMOD (02222) with PRIME incorporated. There was an equal number of non-downwash cases where AERMOD performed better than ISC–PRIME and where ISC–PRIME performed better than AERMOD. There was only one case where there was a significant difference between the two models' performance, and AERMOD clearly performed better than ISC–PRIME in this case. In all other cases, the difference in the performance, whether an improvement or a degradation, was small. This comparison indicated that AERMOD (02222) performs very similarly, if not somewhat better, when compared to ISC–PRIME for downwash cases.

2. Analysis of Regulatory Design Concentrations for AERMOD (02222)

Although not a performance tool, the analysis of design concentrations (''consequence'' analysis) is designed to test model stability and continuity, and to help the user community understand the differences to be expected between air dispersion models. The consequences, or changes in the regulatory concentrations predicted when using the new model (AERMOD 02222) versus ISC3ST, cover 96 source scenarios and at least 3 averaging periods per source scenario, and are evaluated and summarized here. The purpose is to provide the user community with a sense of potential changes in their air dispersion analyses when applying the new model over a broad range of source types and settings. The *consequence analysis*, in which AERMOD was run for hundreds of source scenarios, also provides a check for model stability (abnormal halting of model executions when using valid control files and input data) and for spurious results (unusually high or low concentration predictions which are unexplained). The results are placed into 3 categories: non-downwash source scenarios in flat, simple terrain; downwash source scenarios in flat terrain; and, complex terrain source settings. The focus of this discussion is on how design concentrations change from those predicted by ISC3ST when applying the latest version of AERMOD versus applying the earlier version of AERMOD (99351).

a. Non-Downwash Cases

For the non-downwash situations, there were 48 cases covering a variety of source types (point, area, and volume sources), stack heights, terrain types (flat and simple), and dispersion settings (urban and rural). For each case in the consequence analysis, we calculated the ratio between AERMOD's regulatory concentration predictions and ISC3ST's regulatory concentration predictions. The average ratio of AERMOD to ISC3ST-predicted concentrations changed from 1.14 when applying AERMOD (99351) to 0.96 when applying AERMOD (02222).[14] Thus, in general, AERMOD (02222) tends to predict concentrations closer to ISC3ST than does version 99351 proposed in April 2000. Also, the variation of the differences between ISC3ST and AERMOD has decreased with AERMOD (02222). Comparing the earlier consequence analysis to the latest study with AERMOD (02222), we saw a 25% reduction in the number of cases where the AERMOD-predicted concentrations differed by over a factor of two from ISC3ST's predictions.

b. Downwash Cases

For the downwash analysis, there were 20 cases covering a range of stack heights, locations of stacks relative to the building, dispersion settings, and building shapes. As before, we calculated the ratio regulatory concentration predictions from AERMOD (02222 with PRIME) and compared them as ratios to those from ISC3ST for each case. For additional information, we also included ratios with ISC–PRIME that was also proposed in April 2000.

Calculated over all the 20 cases, and for all averaging times considered, the average ISC–PRIME to ISC3ST concentration ratio is about 0.86, whereas for AERMOD (PRIME) to ISC3ST, it is 0.82. The maximum value of the concentration ratios range from 2.24 for ISC–PRIME/ISC3ST to 3.67 for AERMOD (PRIME)/ISC3ST. Similarly, the minimum value of the concentration ratio range from 0.04 for ISC–PRIME/ ISC3ST to 0.08 for AERMOD (PRIME)/ ISC3ST. (See Table 4–5 in reference 12.)

Although results above for the two models that use PRIME—AERMOD (02222) and ISC–PRIME—show differences, we find that building downwash is not a significant factor in determining the maximum concentrations in some of the cases, *i.e.*, the PRIME algorithms do not predict a building cavity concentration. Of those cases where downwash was important, the average concentration ratios of ISC–PRIME/ISC3ST and AERMOD (02222)/ ISC3ST are about 1. The maximum value of the concentration ratios range from 2.24 for ISC–PRIME/ISC3ST to 1.87 for AERMOD (02222)/ISC3ST and the minimum value of the concentration ratios range from 0.34 for ISC–PRIME/ ISC3ST to 0.38 for AERMOD (02222)/ ISC3ST. These results show relatively close agreement between the two PRIME models. (*See* Table 4–6 in reference 12.)

ISC3ST does not predict cavity concentrations but comparisons can be made between AERMOD and ISC–PRIME. The average AERMOD (02222) predicted 1-hour cavity concentration is about the same (112%) as the average ISC–PRIME 1-hour cavity concentration. In the extremes, the AERMOD (02222)-predicted cavity concentrations ranged from about 40% higher to 15% lower than the corresponding ISC–PRIME cavity concentration predictions. Thus, in general, where downwash is a significant factor, AERMOD (02222) and ISC–PRIME predict similar maximum concentrations. (*See* Table 4–8 in reference 12.)

Although the same downwash algorithms are used in both models, there are differences in the melding of PRIME with the core model, and differences in the way that these models simulate the atmosphere.[15] The downwash algorithm implementation therefore could not be exactly the same.

c. Complex Terrain

During the testing of AERMOD after modifications were made to the complex terrain algorithm (*see* discussion of hill height scale (h_C) in B. Appropriate for Proposed Use in this preamble), a small error was found in the original complex terrain code while conducting the consequence analysis. This error was subsequently repaired. Final testing indicated that the revised complex terrain code produced reasonable results for the consequence analysis, as described below.

The analysis of predicted design concentrations included a suite of complex terrain settings. There were 28 cases covering a variety of stack heights, stack gas buoyancy values, types of hills, and distances between source and terrain. The ratios between the AERMOD (02222 & 99351)—predicted maximum concentrations and the ISC3ST maximum concentrations were calculated for all cases for a series of averaging times. When comparing AERMOD (99351) to ISC3ST and then AERMOD (02222) to ISC3ST, the average maximum concentration ratio, the highest ratios and the lowest ratios were almost unchanged. There were no cases in either consequence analysis where AERMOD (02222 & 99351) predicted higher concentrations than those predicted by ISC3ST. Thus, in general, the consequences of moving from ISC3ST to AERMOD (02222) rather than to AERMOD (99351) in complex terrain were essentially the same. (*See* Table 4–9 in reference 12.)

E. Emission and Dispersion Modeling System (EDMS)

The Emissions and Dispersion Modeling System (EDMS) was developed jointly by the Federal Aviation Administration (FAA) and the U.S. Air Force in the late 1970s and first released in 1985 to assess the air quality of proposed airport development projects. EDMS has an emissions preprocessor and its dispersion module estimates concentrations for various averaging times for the following pollutants: CO, HC, NO_X, SO_X, and suspended particles (*e.g.*, PM–10). The first published application of EDMS was in December 1986 for Stapleton International Airport (FAA–EE–11–A/ REV2).

In 1988, version 4a4 revised the dispersion module to include an integral dispersion submodel: GIMM (Graphical Input Microcomputer Model). This version was proposed for adoption in the *Guideline*'s appendix A in February 1991 (56 FR 5900). This version was included in appendix A in July 1993 (58 FR 38816) and recommended for limited applications for assessments of localized airport impacts on air quality. FAA later updated EDMS to Version 3.0.

In response to the growing needs of air quality analysts and changes in regulations (*e.g.*, conformity requirements from the Clean Air Act Amendment of 1990), FAA updated EDMS to version 3.1, which is based on the CALINE3 [16] and PAL2 dispersion kernels. In our April 2000 NPR we proposed to adopt the version 3.1 update to EDMS. However, this update had not been subjected to performance evaluation and no studies of EDMS' performance have been cited in appendix A of the *Guideline*. Comment was invited on whether this compromises the viability of EDMS 3.1 as a recommended or preferred model and how this deficiency can be corrected.

Several commenters expressed concern about EDMS 3.1 as a recommended model in appendix A. Indeed, there were concerns that EDMS

[14] A ratio of 1.00 indicates that the two models are predicting the same concentrations. See Table 4.1 in reference 12.

[15] AERMOD uses more complex techniques to estimate temperature profiles which, in turn, affect the calculation of the plume rise. Plume rise may affect the cavity and downwash concentrations.

[16] Currently listed in appendix A of the *Guideline*.

3.1 had not been as well validated as other models, nor subjected to peer review, as required by the *Guideline*'s subsection 3.1.1. One of these commenters suggested that EDMS 3.1 should be presented only as one of several alternative models.

At the 7th Conference, FAA proposed for appendix A adoption an even newer, enhanced version of EDMS—version 4.0, which incorporates the AERMOD dispersion kernel (without alteration). In this system, the latest version of AERMOD would be employed as a standalone component of EDMS. This dispersion kernel was to replace PAL2 and CALINE3 currently in EDMS 3.1. There were no public comments specific to FAA's proposed AERMOD-based enhancements to EDMS announced after our April 2000 NPR.

In response to written comments on our April 2000 NPR, at the 7th Conference (transcript) FAA promised a complete evaluation process that would include sensitivity testing, intermodel comparison, and analysis of EDMS predictions against field observations. The intermodel comparisons were proposed for the UK's Atmospheric Dispersion Modeling System (ADMS).[17]

As we explained in our September 8, 2003 Notice of Data Availability, FAA has decided to withdraw EDMS from the *Guideline*'s appendix A. We stated that no new information was therefore provided in that notice, and we affirmed support for EDMS' removal from appendix A. This removal, which we promulgate today, obviates the need for EDMS' documentation and evaluation at this time.

V. Discussion of Public Comments on Our September 8, 2003 Notice of Data Availability

As mentioned in section III, after AERMOD was revised pursuant to comments received on the April 21, 2000 proposal, a Notice of Data Availability (NDA) was issued on September 8, 2003 to explain the modifications and to reveal AERMOD's new evaluation data. Public comments were solicited for 30 days and posted electronically in eDocket OAR–2003–0201.[1] (As mentioned in section IV, additional comments received since we published the final rule on April 15, 2003 are filed in Docket A–99–05; category IV–E.) We summarized these comments and developed detailed responses; these appear as appendix C to the Response-to-Comments document.[4] In appendix C, we considered and discussed all significant comments, developed responses, and documented conclusions on appropriate actions for today's notice. Whenever the comments revealed any new information or suggested any alternative solutions, we considered them in our final action and made corrections or enhancements where appropriate.

In the remainder of this preamble section we highlight the main issues raised by the commenters who reviewed the NDA, and summarize our responses. These comments broadly fall into two categories: technical/operational, and administrative.

The technical/operational comments were varied. One commenter thought EPA's sensitivity studies for simulating area sources were too limited, and noted that AERMOD, when used to simulate an area source adjacent to gently sloping terrain, produced ground-level concentrations not unlike those from ISC3ST. In response we explained qualitatively how AERMOD interprets this situation and cautioned that reviewing authorities should be consulted in such scenarios for guidance on switch settings. Other commenters believed that AERMOD exhibited unrealistic treatment of complex terrain elements and offered supporting data. In response, AERMIC concluded that AERMOD does exhibit terrain amplification factors on the windward side of isolated hills, where impacts are expected to be greatest. Commenters also presented evidence that the PRIME algorithm in AERMOD misbehaves in its treatment of building wake and wind incidence. Another model was cited as having better skill in this regard. In response, we acknowledged this but established that AERMOD's capability was acceptable for handling the majority of building geometries encountered (see Response-to-Comments document[4] for more details).

A number of commenters addressed administrative or procedural matters. Some believed that the transition period for implementation—one year—is too short. We explained in response that one year is consistent with past practice and is adequate for most users and reviewing authorities given our previous experience with new models and the fact that AERMOD has been in the public domain for several years. Some were disappointed that the review period (30 days) for the NDA was too short. We believe that the period was adequate to review the two reports that presented updated information on the performance and practical consequences of the model as revised. Regarding the evaluation/comparison regime used for AERMOD, others objected to the methodology used to evaluate AERMOD (one that emphasizes Robust High Concentration), claiming it is ill-suited to the way dispersion models estimate ambient concentrations. We acknowledged that other methods are available that are designed to reflect the underlying physics and formulations of dispersion models, and may be more robust in their mechanisms to account for the stochastic nature of the atmosphere. In fact, we cited several recent cases from the literature in which such methods were applied in evaluations that included AERMOD. We also explained that the approach taken by AERMIC was based on existing guidance in section 9 of Appendix W, and expressed a commitment to explore other methods in the future, including an update to section 9. We believe however that the evaluation methodology used was reasonable for its intended purpose—examining a large array of concentrations for a wide variety of source types—and confers a measure of consistency given its past use. Other commenters expressed disappointment that AERMOD wasn't compared to state-of-the-science models as advised in its peer review report. In response, we cited a substantial list of studies in which AERMOD has, in fact, been compared to some of these models, *e.g.*, HPDM and ADMS (in various combinations). On the whole, as we noted in our response, AERMOD typically performed as well as HPDM and ADMS, and all of them generally performed better than ISC3ST. Still others expressed disappointment that the evaluation input data weren't posted on our Web site until January 22, 2004—three months after the close of the comment period. We acknowledge that the input data were not posted when the NDA was published. However, the actual evaluation input data for AERMOD had not been requested previously, and we did not believe they were required as a basis for reviewing the reports we released. Moreover, since the posting, we are unaware of any belated adverse comments from anyone attempting to access and use the data.

We believe we have carefully considered and responded to public comments and concerns regarding AERMOD. We have also made efforts to update appendix W to better reflect current practice in model solicitation, evaluation and selection. We also have made other technical revisions so the guidance conforms with the latest form of the PM–10 National Ambient Air Quality Standard.

[17] Cambridge Environmental Research Consultants; *http://www.cerc.co.uk/*.

VI. Final Action

In this section we explain the changes to the *Guideline* in today's action in terms of the main technical and policy concerns addressed by the Agency in its response to public comments (sections IV & V). Air quality modeling involves estimating ambient concentrations using scientific methodologies selected from a range of possible methods, and should utilize the most advanced practical technology that is available at a reasonable cost to users, keeping in mind the intended uses of the modeling and ensuring transparency to the public. With these changes, we believe that the *Guideline* continues to reflect recent advances in the field and balance these important considerations. Today's action amends Appendix W of 40 CFR part 51 as detailed below:

AERMOD

Based on the supporting information contained in the docket, and reflected in peer review and public comments, we find that the AERMOD modeling system and PRIME are based on sound scientific principles and provide significant improvements over the current regulatory model, ISC3ST. AERMOD characterizes plume dispersion better than ISC3ST. The accuracy of the AERMOD system is generally well-documented and superior to that of ISC3ST. We are adopting the model based on its performance and other factors.

Public comments on the April 2000 proposal expressed significant concern about the need to use two models (AERMOD and ISC–PRIME) to simulate just one source when downwash posed a potential impact. In response to this concern we incorporated PRIME into AERMOD and documented satisfactory tests of the algorithm. AERMOD, with the inclusion of PRIME, is now appropriate and practical for regulatory applications.

The state-of-the-science for modeling atmospheric deposition continues to evolve, the best techniques are currently being assessed, and their results are being compared with observations. Consequently, as we now say in *Guideline* paragraph 4.2.2(c), the approach taken for any regulatory purpose should be coordinated with the appropriate reviewing authority. We agreed with the public comments calling for the addition of state-of-the-science deposition algorithms, and developed a modification to AERMOD (02222) for *beta* testing. This model, AERMOD (04079) was posted on our Web site *http://www.epa.gov/scram001/tt25.htm#aermoddep* on March 19, 2004. The latest version of AERMOD may now be used for deposition analysis in special situations.

Since AERMOD treats dispersion in complex terrain, we have merged sections 4 and 5 of appendix W, as proposed in the April 2000 NPR. And while AERMOD produces acceptable regulatory design concentrations in complex terrain, it does not replace CTDMPLUS for detailed or receptor-oriented complex terrain analysis, as we have made clear in *Guideline* section 4.2.2. CTDMPLUS remains available for use in complex terrain.

We have implemented the majority of suggestions to improve the AERMET, AERMAP, and AERMOD source code to reflect all the latest features that have been available in ISC3ST and that are available in the latest versions of Fortran compilers. Also, the latest formats for meteorological and terrain input data are now accepted by the new versions of AERMET and AERMAP. Our guidance, documentation and users' guides have been modified in response to a number of detailed comments.

With respect to AERMOD (02222)'s performance, we have concluded that:

(1) AERMOD (99351), the version proposed in April 2000, performs significantly better than ISC3ST, and AERMOD (02222) performs slightly better than AERMOD (99351) in non-downwash settings in both simple and complex terrain;

(2) The performance evaluation indicates that AERMOD (02222) performs slightly better than ISC–PRIME for downwash cases.

With respect to changes in AERMOD's regulatory design concentrations compared to those for ISC3ST, we have concluded that:

- For non-downwash settings, AERMOD (02222), on average, tends to predict concentrations closer to ISC3ST, and with somewhat smaller variations, than the April 2000 proposal of AERMOD;
- Where downwash is a significant factor in the air dispersion analysis, AERMOD (02222) predicts maximum concentrations that are very similar to ISC–PRIME's predictions;
- For those source scenarios where maximum 1-hour cavity concentrations are calculated, the average AERMOD (02222)-predicted cavity concentration tends to be about the same as the average ISC–PRIME cavity concentrations; and
- In complex terrain, the consequences of using AERMOD (02222) instead of ISC3ST remained essentially unchanged in general, although they varied based on individual circumstances.

Since AERMOD (02222) was released, an updated version was posted on our Web site on March 22, 2004: AERMOD (04079). The version we are releasing pursuant to today's promulgation, however, is AERMOD (04300). This version, consonant with AERMOD (02222) in its formulations, addresses the following minor code issues:

- The area source algorithm in simple and complex terrain required a correction to the way the dividing streamline height is calculated.
- In PRIME, incorrect turbulence parameters were being passed to one of the numerical plume rise routines, and this has been corrected.
- A limit has been placed on plume cooling within PRIME to avoid supercooling, which had been causing runtime instability.
- A correction has been made to avoid AERMOD's termination under certain situations with capped stacks (i.e., where the routine was attempting to take a square root of a negative number). Our testing has demonstrated only very minor impacts from these corrections on the evaluation results or the consequence analysis.

AERMOD (04300) has other draft portions of code that represent options not required for regulatory applications. These include:

- Dry and wet deposition for both gases and particles;
- The ozone limiting method (OLM), referenced in section 5.2.4 (Models for Nitrogen Dioxide—Annual Average) of the *Guideline* for treating NO_X conversion; and
- The Plume Volume Molar Ratio Method (PVMRM) for treating NO_X conversion.
- The bulk Richardson number approach (discussed earlier) for using near-surface temperature difference has been corrected in AERMOD (04300).

Based on the technical information contained in the docket for this rule, and with consideration of the performance analysis in combination with the analysis of design concentrations, we believe that AERMOD is appropriate for regulatory use and we are revising the *Guideline* to adopt it as a refined model today.

In implementing the changes to the *Guideline*, we recognize that there may arise occasions in which the application of a new model can result in the discovery by a permit applicant of previously unknown violations of NAAQS or PSD increments due to emissions from existing nearby sources. This potential has been acknowledged previously and is addressed in existing EPA guidance (''Air Quality Analysis for Prevention of Significant Deterioration

(PSD),'' Gerald A. Emison, July 5, 1988). To summarize briefly, the guidance identifies three possible outcomes of modeling by a permit applicant and details actions that should be taken in response to each:

1. Where dispersion modeling shows no violation of a NAAQS or PSD increment in the impact area of the proposed source, a permit may be issued and no further action is required.

2. Where dispersion modeling predicts a violation of a NAAQS or PSD increment within the impact area but it is determined that the proposed source will not have a significant impact (i.e., will not be above de minimis levels) at the point and time of the modeled violation, then the permit may be issued immediately, but the State must take appropriate actions to remedy the violations within a timely manner.

3. Where dispersion modeling predicts a violation of a NAAQS or PSD increment within the impact area and it is determined that the proposed source will have a significant impact at the point and time of the modeled violation, then the permit may not be issued until the source owner or operator eliminates or reduces that impact below significance levels through additional controls or emissions offsets. Once it does so, then the permit may be issued even if the violation persists after the source owner or operator eliminates its contribution, but the State must take further appropriate actions at nearby sources to eliminate the violations within a timely manner.

In previous promulgations, we have traditionally allowed a one-year transition (''grandfather'') period for new refined techniques. Accordingly, for appropriate applications, AERMOD *may be* substituted for ISC3 during the one-year period following the promulgation of today's notice. Beginning one year after promulgation of today's notice, (1) applications of ISC3 with approved protocols may be accepted (see **DATES** section) and (2) AERMOD *should be* used for appropriate applications as a replacement for ISC3.

We separately issue guidance for use of modeling for facility-specific and community-scale air toxics risk assessments through the Air Toxics Risk Assessment Reference Library.[18] We recognize that the tools and approaches recommended therein will eventually reflect the improved formulations of the AERMOD modeling system and we expect to appropriately incorporate them as expeditiously as practicable. In the interim, as appropriate, we will consider the use of either ISC3 or AERMOD in air toxic risk assessment applications.

EDMS

FAA has completed development of the new EDMS4.0 to incorporate AERMOD. The result is a conforming enhancement that offers a stronger scientific basis for air quality modeling. FAA has made this model available on its Web site, which we cite in an updated *Guideline* paragraph 7.2.4(c). As described earlier in this preamble, the summary description for EDMS will be removed from appendix A.

VII. Final Editorial Changes to Appendix W

Today's update of the *Guideline* takes the form of many revisions, and some of the text is unaltered. Therefore, as a purely practical matter, we have chosen to publish the new version of the entire text of appendix W and its appendix A. Guidance and editorial changes associated with the resolution of the issues discussed in the previous section are adopted in the appropriate sections of the *Guideline*, as follows:

Preface

You will note some minor revisions of appendix W to reflect current EPA practice.

Section 4

As mentioned earlier, we revised section 4 to present AERMOD as a refined regulatory modeling technique for particular applications.

Section 5

As mentioned above, we merged pertinent guidance in section 5 (Modeling in Complex Terrain) with that in section 4. With the anticipated widespread use of AERMOD for all terrain types, there is no longer any utility in the previous differentiation between simple and complex terrain for model selection. To further simplify, the list of acceptable, yet equivalent, screening techniques for complex terrain was removed. CTSCREEN and guidance for its use are retained; CTSCREEN remains acceptable for all terrain above stack top. The screening techniques whose descriptions we removed, i.e., Valley (as implemented in SCREEN3), COMPLEX I (as implemented in ISC3ST), and RTDM remain available for use in applicable cases where established/accepted procedures are used. Consultation with the appropriate reviewing authority is still advised for application of these screening models.

Section 6

As proposed, we renumbered this to become section 5. In subsection 5.1, we reference the Plume Volume Molar Ratio Method (PVMRM) for point sources of NO_X, and mention that it is currently being tested to determine suitability as a refined method.

Section 7

As proposed, we renumbered this to become section 6. We updated the reference to the Emissions and Dispersion Modeling System (EDMS).

Section 8

As proposed, we revised section 8 (renumbered to section 7) to provide guidance for using AERMET (AERMOD's meteorological preprocessor).

- In subsection 7.2.4, we introduce the atmospheric stability characterization for AERMOD.
- In subsection 7.2.5, we describe the plume rise approaches used by AERMOD.

Section 9

As proposed, we renumbered section 9 to become section 8. We added paragraphs 8.3.1.2(e) and 8.3.1.2(f) to clarify use of site specific meteorological data for driving CALMET in the separate circumstances of long range transport and for complex terrain applications.

Section 10

As proposed, we revised section 10 (renumbered section 9) to include AERMOD. In May 1999, the D.C. Court of Appeals vacated the PM–10 standard we promulgated in 1997, and this standard has since been removed from the CFR (69 FR 45592; July 30, 2004). Paragraph 10.2.3.2(a) has been corrected to be consistent with the current (original) PM–10 standard, which is based on expected exceedances.

Section 11

As proposed, we renumbered section 11 to become section 10.

Sections 12 & 13

We renumbered section 12 to become section 11, and section 13 (References) to become section 12. We revised renumbered section 12 by adding some references, deleting obsolete/superseded ones, and resequencing. You will note that the peer scientific review for AERMOD and latest evaluation references have been included.

Appendix A

We added AERMOD (with the PRIME downwash algorithm integrated) to

[18] *http://www.epa.gov/ttn/fera/risk_atra_main.html.*

appendix A. We removed EDMS from appendix A. We also updated the description for CALPUFF, and made minor updates to some of the other model descriptions.

Availability of Related Information

Our Air Quality Modeling Group maintains an Internet Web site (Support Center for Regulatory Air Models—SCRAM) at: *http://www.epa.gov/scram001.* You may find codes and documentation for models referenced in today's action on the SCRAM Web site. In addition, we have uploaded various support documents (e.g., evaluation reports).

VIII. Statutory and Executive Order Reviews

A. Executive Order 12866: Regulatory Planning and Review

Under Executive Order 12866 [58 FR 51735 (October 4, 1993)], the Agency must determine whether the regulatory action is ''significant'' and therefore subject to review by the Office of Management and Budget (OMB) and the requirements of the Executive Order. The Order defines ''significant regulatory action'' as one that is likely to result in a rule that may:

(1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs of the rights and obligations of recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

It has been determined that this rule is not a ''significant regulatory action'' under the terms of Executive Order 12866 and is therefore not subject to EO 12866 review.

B. Paperwork Reduction Act

This final rule does not contain any information collection requirements subject to review by OMB under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.*

Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

An agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

C. Regulatory Flexibility Act (RFA)

The RFA generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impact of today's rule on small entities, small entities are defined as: (1) A small business that meets the RFA default definitions for small business (based on Small Business Administration size standards), as described in 13 CFR 121.201; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

After considering the economic impacts of today's final rule on small entities, I certify that this action will not have a significant economic impact on a substantial number of small entities. As this rule merely updates existing technical requirements for air quality modeling analyses mandated by various CAA programs (e.g., prevention of significant deterioration, new source review, State Implementation Plan revisions) and imposes no new regulatory burdens, there will be no additional impact on small entities regarding reporting, recordkeeping, and compliance requirements.

D. Unfunded Mandates Reform Act of 1995

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), Public Law 104–4, establishes requirements for Federal agencies to assess the effects of their regulatory actions on State, local, and tribal governments and the private sector. Under section 202 of the UMRA, EPA generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with ''Federal mandates'' that may result in expenditures to State, local, and tribal governments, in the aggregate, or to the private sector, of $100 million or more in any one year. Before promulgating an EPA rule for which a written statement is needed, section 205 of the UMRA generally requires EPA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows EPA to adopt an alternative other than the least costly, most cost-effective or least burdensome alternative if the Administrator publishes with the final rule an explanation why that alternative was not adopted. Before EPA establishes any regulatory requirements that may significantly or uniquely affect small governments, including tribal governments, it must have developed under section 203 of the UMRA a small government agency plan.

The plan must provide for notifying potentially affected small governments, enabling officials of affected small governments to have meaningful and timely input in the development of EPA regulatory proposals with significant Federal intergovernmental mandates, and informing, educating, and advising small governments on compliance with the regulatory requirements.

Today's rule recommends a new modeling system, AERMOD, to replace ISC3ST as an analytical tool for use in SIP revisions and for calculating PSD increment consumption. AERMOD has been used for these purposes on a case-by-case basis (per *Guideline* subsection 3.2.2) for several years. Since the two modeling systems are comparable in scope and purpose, use of AERMOD itself does not involve any significant increase in costs. Moreover, modeling costs (which include those for input data acquisition) are typically among the implementation costs that are considered as part of the programs (*i.e.*, PSD) that establish and periodically revise requirements for compliance.

Any incremental modeling costs attributable to today's rule do not approach the $100 million threshold prescribed by UMRA. EPA has determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments. This rule therefore contains no Federal mandates (under the regulatory provisions of Title II of the UMRA) for State, local, or tribal governments or the private sector.

E. Executive Order 13132: Federalism

Executive Order 13132, entitled ''Federalism'' (64 FR 43255, August 10, 1999), requires EPA to develop an accountable process to ensure ''meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications.'' ''Policies that have federalism implications'' is defined in the Executive Order to include regulations that have ''substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government.''

This final rule does not have federalism implications. It will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. This rule does not create a mandate on State, local or tribal governments. The rule does not impose any enforceable duties on these entities (*see* D. Unfunded Mandates Reform Act of 1995, above). The rule would add better, more accurate techniques for air dispersion modeling analyses and does not impose any additional requirements for any of the affected parties covered under Executive Order 13132. Thus, Executive Order 13132 does not apply to this rule.

F. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

Executive Order 13175, entitled ''Consultation and Coordination with Indian Tribal Governments'' (65 FR 67249, November 9, 2000), requires EPA to develop an accountable process to ensure ''meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications.'' This final rule does not have tribal implications, as specified in Executive Order 13175. As stated above (*see* D. Unfunded Mandates Reform Act of 1995, above), the rule does not impose any new requirements for calculating PSD increment consumption, and does not impose any additional requirements for the regulated community, including Indian Tribal Governments. Thus, Executive Order 13175 does not apply to this rule.

Today's final rule does not significantly or uniquely affect the communities of Indian tribal governments. Accordingly, the requirements of section 3(b) of Executive Order 13175 do not apply to this rule.

G. Executive Order 13045: Protection of Children From Environmental Health and Safety Risks

Executive Order 13045 applies to any rule that EPA determines (1) to be ''economically significant'' as defined under Executive Order 12866, and (2) the environmental health or safety risk addressed by the rule has a disproportionate effect on children. If the regulatory action meets both the criteria, the Agency must evaluate the environmental health or safety effects of the planned rule on children; and explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the Agency.

This final rule is not subject to Executive Order 13045, entitled ''Protection of Children from Environmental Health Risks and Safety Risks'' (62 FR 19885, April 23, 1997) because it does not impose an economically significant regulatory action as defined by Executive Order 12866 and the action does not involve decisions on environmental health or safety risks that may disproportionately affect children.

H. Executive Order 13211: Actions That Significantly Affect Energy Supply, Distribution, or Use

This rule is not subject to Executive Order 13211, ''Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use'' (66 FR 28355 (May 22, 2001)) because it is not a significant regulatory action under Executive Order 12866.

I. National Technology Transfer and Advancement Act of 1995

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (''NTTAA''), Public Law 104–113, section 12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.*, materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

This action does not involve technical standards. Therefore, EPA did not consider the use of any voluntary consensus standards.

J. Congressional Review Act of 1998

The Congressional Review Act, 5 U.S.C. 801 *et seq.*, as added by the Small Business Regulatory Enforcement Fairness Act of 1996, generally provides that before a rule may take effect, the agency promulgating the rule must submit a rule report, which includes a copy of the rule, to each House of the Congress and to the Comptroller General of the United States. EPA will submit a report containing this rule and other required information to the U.S. Senate, the U.S. House of Representatives, and the Comptroller General of the United States prior to publication of the rule in the **Federal Register**. A Major rule cannot take effect until 60 days after it is published in the **Federal Register**. This action is not a ''major rule'' as defined by 5 U.S.C. 804(2), and will be effective 30 days from the publication date of this notice.

List of Subjects in 40 CFR Part 51

Environmental protection, Administrative practice and procedure, Air pollution control, Carbon monoxide, Intergovernmental relations, Nitrogen oxides, Ozone, Particulate Matter, Reporting and recordkeeping requirements, Sulfur oxides.

Dated: October 21, 2005.

Stephen L. Johnson,

Administrator.

■ Part 51, chapter I, title 40 of the Code of Federal Regulations is amended as follows:

PART 51—REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMITTAL OF IMPLEMENTATION PLANS

■ 1. The authority citation for part 51 continues to read as follows:

Authority: 23 U.S.C. 100; 42 U.S.C. 7401–7671q.

■ 2. Appendix W to Part 51 revised to read as follows:

Appendix W to Part 51—Guideline on Air Quality Models

Preface

a. Industry and control agencies have long expressed a need for consistency in the application of air quality models for regulatory purposes. In the 1977 Clean Air Act, Congress mandated such consistency and encouraged the standardization of model applications. The *Guideline on Air Quality Models* (hereafter, *Guideline*) was first published in April 1978 to satisfy these requirements by specifying models and providing guidance for their use. The *Guideline* provides a common basis for estimating the air quality concentrations of criteria pollutants used in assessing control strategies and developing emission limits.

b. The continuing development of new air quality models in response to regulatory requirements and the expanded requirements for models to cover even more complex problems have emphasized the need for periodic review and update of guidance on these techniques. Historically, three primary activities have provided direct input to revisions of the *Guideline*. The first is a series of annual EPA workshops conducted for the purpose of ensuring consistency and providing clarification in the application of models. The second activity was the solicitation and review of new models from the technical and user community. In the March 27, 1980 **Federal Register**, a procedure was outlined for the submittal to EPA of privately developed models. After extensive evaluation and scientific review, these models, as well as those made available by EPA, have been considered for recognition in the *Guideline*. The third activity is the extensive on-going research efforts by EPA and others in air quality and meteorological modeling.

c. Based primarily on these three activities, new sections and topics have been included as needed. EPA does not make changes to the guidance on a predetermined schedule, but rather on an as-needed basis. EPA believes that revisions of the *Guideline* should be timely and responsive to user needs and should involve public participation to the greatest possible extent. All future changes to the guidance will be proposed and finalized in the **Federal Register**. Information on the current status of modeling guidance can always be obtained from EPA's Regional Offices.

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List of Tables

1.0 Introduction

a. The *Guideline* recommends air quality modeling techniques that should be applied to State Implementation Plan (SIP) revisions for existing sources and to new source reviews (NSR), including prevention of significant deterioration (PSD).[1 2 3] Applicable only to criteria air pollutants, it is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, State and local agencies and by industry. The guidance is appropriate for use by other Federal agencies and by State agencies with air quality and land management responsibilities. The *Guideline* serves to identify, for all interested parties, those techniques and data bases EPA considers acceptable. The *Guideline* is not intended to be a compendium of modeling techniques. Rather, it should serve as a common measure of acceptable technical analysis when supported by sound scientific judgment.

b. Due to limitations in the spatial and temporal coverage of air quality measurements, monitoring data normally are not sufficient as the sole basis for demonstrating the adequacy of emission limits for existing sources. Also, the impacts of new sources that do not yet exist can only be determined through modeling. Thus, models, while uniquely filling one program need, have become a primary analytical tool in most air quality assessments. Air quality measurements can be used in a complementary manner to dispersion models, with due regard for the strengths and weaknesses of both analysis techniques. Measurements are particularly useful in assessing the accuracy of model estimates. The use of air quality measurements alone however could be preferable, as detailed in a later section of this document, when models are found to be unacceptable and monitoring data with sufficient spatial and temporal coverage are available.

c. It would be advantageous to categorize the various regulatory programs and to apply a designated model to each proposed source needing analysis under a given program. However, the diversity of the nation's topography and climate, and variations in source configurations and operating characteristics dictate against a strict modeling ''cookbook''. There is no one model capable of properly addressing all conceivable situations even within a broad category such as point sources. Meteorological phenomena associated with threats to air quality standards are rarely amenable to a single mathematical treatment; thus, case-by-case analysis and judgment are frequently required. As modeling efforts become more complex, it is increasingly important that they be directed by highly competent individuals with a broad range of experience and knowledge in air quality meteorology. Further, they should be coordinated closely with specialists in emissions characteristics, air monitoring and data processing. The judgment of experienced meteorologists and analysts is essential.

d. The model that most accurately estimates concentrations in the area of interest is always sought. However, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations, and also by the deliberations of Congress, that consistency in the selection and application of models and data bases should also be sought, even in case-by-case analyses. Consistency ensures that air quality control agencies and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. Such consistency is not, however, promoted at the expense of model and data base accuracy. The *Guideline* provides a consistent basis for selection of the most accurate models and data bases for use in air quality assessments.

e. Recommendations are made in the *Guideline* concerning air quality models, data bases, requirements for concentration estimates, the use of measured data in lieu of model estimates, and model evaluation procedures. Models are identified for some specific applications. The guidance provided here should be followed in air quality analyses relative to State Implementation Plans and in supporting analyses required by EPA, State and local agency air programs. EPA may approve the use of another technique that can be demonstrated to be more appropriate than those recommended in this guide. This is discussed at greater length in Section 3. In all cases, the model applied to a given situation should be the one that provides the most accurate representation of atmospheric transport, dispersion, and chemical transformations in the area of interest. However, to ensure consistency, deviations from this guide should be carefully documented and fully supported.

f. From time to time situations arise requiring clarification of the intent of the guidance on a specific topic. Periodic workshops are held with the headquarters, Regional Office, State, and local agency modeling representatives to ensure consistency in modeling guidance and to promote the use of more accurate air quality models and data bases. The workshops serve to provide further explanations of *Guideline* requirements to the Regional Offices and workshop reports are issued with this clarifying information. In addition, findings from ongoing research programs, new model development, or results from model evaluations and applications are continuously evaluated. Based on this information changes in the guidance may be indicated.

g. All changes to the *Guideline* must follow rulemaking requirements since the *Guideline* is codified in Appendix W of Part 51. EPA will promulgate proposed and final rules in the **Federal Register** to amend this Appendix. Ample opportunity for public comment will be provided for each proposed change and public hearings scheduled if requested.

h. A wide range of topics on modeling and data bases are discussed in the *Guideline*. Section 2 gives an overview of models and their appropriate use. Section 3 provides specific guidance on the use of ''preferred'' air quality models and on the selection of alternative techniques. Sections 4 through 7 provide recommendations on modeling techniques for application to simple-terrain stationary source problems, complex terrain problems, and mobile source problems. Specific modeling requirements for selected regulatory issues are also addressed. Section 8 discusses issues common to many modeling analyses, including acceptable model components. Section 9 makes recommendations for data inputs to models including source, meteorological and background air quality data. Section 10 covers the uncertainty in model estimates and how that information can be useful to the regulatory decision-maker. The last chapter summarizes how estimates and measurements of air quality are used in assessing source impact and in evaluating control strategies.

i. Appendix W to 40 CFR Part 51 itself contains an appendix: Appendix A. Thus, when reference is made to ''Appendix A'' in this document, it refers to Appendix A to Appendix W to 40 CFR Part 51. Appendix A contains summaries of refined air quality models that are ''preferred'' for specific applications; both EPA models and models developed by others are included.

2.0 Overview of Model Use

a. Before attempting to implement the guidance contained in this document, the reader should be aware of certain general information concerning air quality models and their use. Such information is provided in this section.

2.1 Suitability of Models

a. The extent to which a specific air quality model is suitable for the evaluation of source impact depends upon several factors. These include: (1) The meteorological and topographic complexities of the area; (2) the level of detail and accuracy needed for the analysis; (3) the technical competence of those undertaking such simulation modeling; (4) the resources available; and (5) the detail and accuracy of the data base, *i.e.*, emissions inventory, meteorological data, and air quality data. Appropriate data should be available before any attempt is made to apply a model. A model that requires detailed, precise, input data should not be used when such data are unavailable. However, assuming the data are adequate, the greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distinguish the effects of various control strategies.

b. Air quality models have been applied with the most accuracy, or the least degree of uncertainty, to simulations of long term averages in areas with relatively simple topography. Areas subject to major topographic influences experience meteorological complexities that are extremely difficult to simulate. Although models are available for such circumstances, they are frequently site specific and resource intensive. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time as better models and data bases become available.

c. Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. The need for specialists is critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly, or with inappropriate data, can lead to serious misjudgements regarding the source impact or the effectiveness of a control strategy.

d. The resource demands generated by use of air quality models vary widely depending on the specific application. The resources required depend on the nature of the model and its complexity, the detail of the data base, the difficulty of the application, and the amount and level of expertise required. The costs of manpower and computational facilities may also be important factors in the selection and use of a model for a specific analysis. However, it should be recognized that under some sets of physical circumstances and accuracy requirements, no present model may be appropriate. Thus, consideration of these factors should lead to selection of an appropriate model.

2.2 Levels of Sophistication of Models

a. There are two levels of sophistication of models. The first level consists of relatively simple estimation techniques that generally use preset, worst-case meteorological conditions to provide conservative estimates of the air quality impact of a specific source, or source category. These are called screening techniques or screening models. The purpose of such techniques is to eliminate the need of more detailed modeling for those sources that clearly will not cause or contribute to ambient concentrations in excess of either the National Ambient Air Quality Standards (NAAQS)[4] or the allowable prevention of significant deterioration (PSD) concentration increments.[2 3] If a screening technique indicates that the concentration contributed by the source exceeds the PSD increment or the increment remaining to just meet the NAAQS, then the second level of more sophisticated models should be applied.

b. The second level consists of those analytical techniques that provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies. These are referred to as refined models.

c. The use of screening techniques followed, as appropriate, by a more refined analysis is always desirable. However there are situations where the screening techniques are practically and technically the only viable option for estimating source impact. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

2.3 Availability of Models

a. For most of the screening and refined models discussed in the *Guideline*, codes, associated documentation and other useful information are available for download from EPA's Support Center for Regulatory Air Modeling (SCRAM) Internet Web site at *http://www.epa.gov/scram001*. A list of alternate models that can be used with case-by-case justification (subsection 3.2) and an example air quality analysis checklist are also posted on this Web site. This is a site with which modelers should become familiar.

3.0 Recommended Air Quality Models

a. This section recommends the approach to be taken in determining refined modeling techniques for use in regulatory air quality programs. The status of models developed by EPA, as well as those submitted to EPA for review and possible inclusion in this guidance, is discussed. The section also addresses the selection of models for individual cases and provides recommendations for situations where the preferred models are not applicable. Two additional sources of modeling guidance are the Model Clearinghouse [5] and periodic Regional/State/Local Modelers workshops.

b. In this guidance, when approval is required for a particular modeling technique or analytical procedure, we often refer to the *''appropriate reviewing authority''*. In some EPA regions, authority for NSR and PSD permitting and related activities has been delegated to State and even local agencies. In these cases, such agencies are *''representatives''* of the respective regions. Even in these circumstances, the Regional Office retains the ultimate authority in decisions and approvals. Therefore, as discussed above and depending on the circumstances, the appropriate reviewing authority may be the Regional Office, Federal Land Manager(s), State agency(ies), or perhaps local agency(ies). In cases where review and approval comes solely from the Regional Office (sometimes stated as *''Regional Administrator''*), this will be stipulated. If there is any question as to the appropriate reviewing authority, you should contact the Regional modeling contact (*http://www.epa.gov/scram001/tt28.htm#regionalmodelingcontacts*) in the appropriate EPA Regional Office, whose jurisdiction generally includes the physical location of the source in question and its expected impacts.

c. In all regulatory analyses, especially if other-than-preferred models are selected for use, early discussions among Regional Office staff, State and local control agencies, industry representatives, and where appropriate, the Federal Land Manager, are invaluable and are encouraged. Agreement on the data base(s) to be used, modeling techniques to be applied and the overall technical approach, prior to the actual analyses, helps avoid misunderstandings concerning the final results and may reduce the later need for additional analyses. The use of an air quality analysis checklist, such as is posted on EPA's Internet SCRAM Web site (subsection 2.3), and the preparation of a written protocol help to keep misunderstandings at a minimum.

d. It should not be construed that the preferred models identified here are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality. The model that most accurately estimates concentrations in the area of interest is always sought. However, designation of specific models is needed to promote consistency in model selection and application.

e. The 1980 solicitation of new or different models from the technical community [6] and the program whereby these models were evaluated, established a means by which new models are identified, reviewed and made available in the *Guideline*. There is a pressing need for the development of models for a wide range of regulatory applications. Refined models that more realistically simulate the physical and chemical process in the atmosphere and that more reliably estimate pollutant concentrations are needed.

3.1 Preferred Modeling Techniques

3.1.1 Discussion

a. EPA has developed models suitable for regulatory application. Other models have been submitted by private developers for possible inclusion in the *Guideline*. Refined models which are preferred and recommended by EPA have undergone evaluation exercises [7 8 9 10] that include statistical measures of model performance in comparison with measured air quality data as suggested by the American Meteorological Society [11] and, where possible, peer scientific reviews.[12 13 14]

b. When a single model is found to perform better than others, it is recommended for application as a preferred model and listed in Appendix A. If no one model is found to clearly perform better through the evaluation exercise, then the preferred model listed in Appendix A may be selected on the basis of other factors such as past use, public familiarity, cost or resource requirements, and availability. Accordingly, dispersion models listed in Appendix A meet these conditions:

i. The model must be written in a common programming language, and the executable(s) must run on a common computer platform.

ii. The model must be documented in a user's guide which identifies the mathematics of the model, data requirements and program operating characteristics at a level of detail comparable to that available for other recommended models in Appendix A.

iii. The model must be accompanied by a complete test data set including input parameters and output results. The test data must be packaged with the model in computer-readable form.

iv. The model must be useful to typical users, e.g., State air pollution control agencies, for specific air quality control problems. Such users should be able to operate the computer program(s) from available documentation.

v. The model documentation must include a comparison with air quality data (and/or tracer measurements) or with other well-established analytical techniques.

vi. The developer must be willing to make the model and source code available to users at reasonable cost or make them available for public access through the Internet or National Technical Information Service: The model and its code cannot be proprietary.

c. The evaluation process includes a determination of technical merit, in accordance with the above six items including the practicality of the model for use in ongoing regulatory programs. Each model will also be subjected to a performance evaluation for an appropriate data base and to a peer scientific review. Models for wide use (not just an isolated case) that are found to perform better will be proposed for inclusion as preferred models in future *Guideline* revisions.

d. No further evaluation of a preferred model is required for a particular application if the EPA recommendations for regulatory use specified for the model in the *Guideline* are followed. Alternative models to those listed in Appendix A should generally be compared with measured air quality data when they are used for regulatory applications consistent with recommendations in subsection 3.2.

3.1.2 Recommendations

a. Appendix A identifies refined models that are preferred for use in regulatory applications. If a model is required for a particular application, the user should select a model from that appendix. These models may be used without a formal demonstration of applicability as long as they are used as indicated in each model summary of Appendix A. Further recommendations for the application of these models to specific source problems are found in subsequent sections of the *Guideline*.

b. If changes are made to a preferred model without affecting the concentration estimates, the preferred status of the model is unchanged. Examples of modifications that do not affect concentrations are those made to enable use of a different computer platform or those that affect only the format or averaging time of the model results. However, when any changes are made, the Regional Administrator should require a test case example to demonstrate that the concentration estimates are not affected.

c. A preferred model should be operated with the options listed in Appendix A as ''Recommendations for Regulatory Use.'' If other options are exercised, the model is no longer ''preferred.'' Any other modification to a preferred model that would result in a change in the concentration estimates likewise alters its status as a preferred model. Use of the model must then be justified on a case-by-case basis.

3.2 Use of Alternative Models

3.2.1 Discussion

a. Selection of the best techniques for each individual air quality analysis is always encouraged, but the selection should be done in a consistent manner. A simple listing of models in this *Guideline* cannot alone achieve that consistency nor can it necessarily provide the best model for all possible situations. An EPA reference [15] provides a statistical technique for evaluating model performance for predicting peak concentration values, as might be observed at individual monitoring locations. This protocol is available to assist in developing a consistent approach when justifying the use of other-than-preferred modeling techniques recommended in the *Guideline*. The procedures in this protocol provide a general framework for objective decision-making on the acceptability of an alternative model for a given regulatory application. These objective procedures may be used for conducting both the technical evaluation of the model and the field test or performance evaluation. An ASTM reference [16] provides a general philosophy for developing and implementing advanced statistical evaluations of atmospheric dispersion models, and provides an example statistical technique to illustrate the application of this philosophy.

b. This section discusses the use of alternate modeling techniques and defines three situations when alternative models may be used.

3.2.2 Recommendations

a. Determination of acceptability of a model is a Regional Office responsibility. Where the Regional Administrator finds that an alternative model is more appropriate than a preferred model, that model may be used subject to the recommendations of this subsection. This finding will normally result from a determination that (1) a preferred air quality model is not appropriate for the particular application; or (2) a more appropriate model or analytical procedure is available and applicable.

b. An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. There are three separate conditions under which such a model may normally be approved for use: (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A; or (3) if the preferred model is less appropriate for the specific application, or there is no preferred model. Any one of these three separate conditions may make use of an alternative model acceptable. Some known alternative models that are applicable for selected situations are listed on EPA's SCRAM Internet Web site (subsection 2.3). However, inclusion there does not confer any unique status relative to other alternative models that are being or will be developed in the future.

c. Equivalency, condition (1) in paragraph (b) of this subsection, is established by demonstrating that the maximum or highest, second highest concentrations are within 2 percent of the estimates obtained from the preferred model. The option to show equivalency is intended as a simple demonstration of acceptability for an alternative model that is so nearly identical (or contains options that can make it identical) to a preferred model that it can be treated for practical purposes as the preferred model. Two percent was selected as the basis for equivalency since it is a rough approximation of the fraction that PSD Class I increments are of the NAAQS for SO_2, i.e., the difference in concentrations that is judged to be significant. However, notwithstanding this demonstration, models that are not equivalent may be used when one of the two other conditions described in paragraphs (d) and (e) of this subsection are satisfied.

d. For condition (2) in paragraph (b) of this subsection, established procedures and techniques [15 16] for determining the acceptability of a model for an individual case based on superior performance should be followed, as appropriate. Preparation and implementation of an evaluation protocol which is acceptable to both control agencies and regulated industry is an important element in such an evaluation.

e. Finally, for condition (3) in paragraph (b) of this subsection, an alternative refined model may be used provided that:

i. The model has received a scientific peer review;

ii. The model can be demonstrated to be applicable to the problem on a theoretical basis;

iii. The data bases which are necessary to perform the analysis are available and adequate;

iv. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates; and

v. A protocol on methods and procedures to be followed has been established.

3.3 Availability of Supplementary Modeling Guidance

a. The Regional Administrator has the authority to select models that are appropriate for use in a given situation. However, there is a need for assistance and guidance in the selection process so that fairness and consistency in modeling decisions is fostered among the various Regional Offices and the States. To satisfy that need, EPA established the Model Clearinghouse [5] and also holds periodic workshops with headquarters, Regional Office, State, and local agency modeling representatives.

b. The Regional Office should always be consulted for information and guidance concerning modeling methods and interpretations of modeling guidance, and to ensure that the air quality model user has available the latest most up-to-date policy and procedures. As appropriate, the Regional Office may request assistance from the Model Clearinghouse after an initial evaluation and decision has been reached concerning the application of a model, analytical technique or data base in a particular regulatory action.

4.0 Traditional Stationary Source Models

4.1 Discussion

a. Guidance in this section applies to modeling analyses for which the predominant meteorological conditions that control the design concentration are steady state and for which the transport distances are nominally 50km or less. The models recommended in this section are generally used in the air quality impact analysis of stationary sources for most criteria pollutants. The averaging time of the concentration estimates produced by these models ranges from 1 hour to an annual average.

b. Simple terrain, as used here, is considered to be an area where terrain features are all lower in elevation than the top of the stack of the source(s) in question. Complex terrain is defined as terrain exceeding the height of the stack being modeled.

c. In the early 1980s, model evaluation exercises were conducted to determine the ''best, most appropriate point source model'' for use in simple terrain.[12] No one model was found to be clearly superior and, based on past use, public familiarity, and availability, ISC (predecessor to ISC3 [17]) became the recommended model for a wide range of regulatory applications. Other refined models which also employed the same basic Gaussian kernel as in ISC, i.e., BLP, CALINE3 and OCD, were developed for specialized applications (Appendix A). Performance evaluations were also made for these models, which are identified below.

d. Encouraged by the development of pragmatic methods for better characterization of plume dispersion [18 19 20 21] the AMS/EPA Regulatory Model Improvement Committee (AERMIC) developed AERMOD.[22] AERMOD employs best state-of-practice parameterizations for characterizing the meteorological influences and dispersion. The model utilizes a probability density function (pdf) and the superposition of several Gaussian plumes to characterize the distinctly non-Gaussian nature of the vertical pollutant distribution for elevated plumes during convective conditions; otherwise the distribution is Gaussian. Also, nighttime urban boundary layers (and plumes within them) have the turbulence enhanced by AERMOD to simulate the influence of the urban heat island. AERMOD has been evaluated using a variety of data sets and has been found to perform better than ISC3 for many applications, and as well or better than CTDMPLUS for several complex terrain data sets (Section A.1; subsection n). The current version of AERMOD has been modified to include an algorithm for dry and wet deposition for both gases and particles. Note that when deposition is invoked, mass in the plume is depleted. Availability of this version is described in Section A.1, and is subject to applicable guidance published in the *Guideline*.

e. A new building downwash algorithm [23] was developed and tested within AERMOD. The PRIME algorithm has been evaluated using a variety of data sets and has been found to perform better than the downwash algorithm that is in ISC3, and has been shown to perform acceptably in tests within AERMOD (Section A.1; subsection n).

4.2 Recommendations

4.2.1 Screening Techniques

4.2.1.1 Simple Terrain

a. Where a preliminary or conservative estimate is desired, point source screening techniques are an acceptable approach to air quality analyses. EPA has published guidance for screening procedures.[24 25]

b. All screening procedures should be adjusted to the site and problem at hand. Close attention should be paid to whether the area should be classified urban or rural in accordance with Section 7.2.3. The climatology of the area should be studied to help define the worst-case meteorological conditions. Agreement should be reached between the model user and the appropriate reviewing authority on the choice of the screening model for each analysis, and on the input data as well as the ultimate use of the results.

4.2.1.2 Complex Terrain

a. CTSCREEN [26] can be used to obtain conservative, yet realistic, worst-case estimates for receptors located on terrain above stack height. CTSCREEN accounts for the three-dimensional nature of plume and terrain interaction and requires detailed terrain data representative of the modeling domain. The model description and user's instructions are contained in the user's guide.[26] The terrain data must be digitized in the same manner as for CTDMPLUS and a terrain processor is available.[27] A discussion of the model's performance characteristics is provided in a technical paper.[28] CTSCREEN is designed to execute a fixed matrix of meteorological values for wind speed (u), standard deviation of horizontal and vertical wind speeds (σ_v, σ_w), vertical potential temperature gradient (dθ/dz), friction velocity (u_*), Monin-Obukhov length (L), mixing height (z_i) as a function of terrain height, and wind directions for both neutral/stable conditions and unstable convective conditions. Table 4–1 contains the matrix of meteorological variables that is used for each CTSCREEN analysis. There are 96 combinations, including exceptions, for each wind direction for the neutral/stable case, and 108 combinations for the unstable case. The specification of wind direction, however, is handled internally, based on the source and terrain geometry. Although CTSCREEN is designed to address a single source scenario, there are a number of options that can be selected on a case-by-case basis to address multi-source situations. However, the appropriate reviewing authority should be consulted, and concurrence obtained, on the protocol for modeling multiple sources with CTSCREEN to ensure that the worst case is identified and assessed. The maximum concentration output from CTSCREEN represents a worst-case 1-hour concentration. Time-scaling factors of 0.7 for 3-hour, 0.15 for 24-hour and 0.03 for annual concentration averages are applied internally by CTSCREEN to the highest 1-hour concentration calculated by the model.

b. Placement of receptors requires very careful attention when modeling in complex terrain. Often the highest concentrations are predicted to occur under very stable conditions, when the plume is near, or impinges on, the terrain. The plume under such conditions may be quite narrow in the vertical, so that even relatively small changes in a receptor's location may substantially affect the predicted concentration. Receptors within about a kilometer of the source may be even more sensitive to location. Thus, a dense array of receptors may be required in some cases. In order to avoid excessively large computer runs due to such a large array of receptors, it is often desirable to model the area twice. The first model run would use a moderate number of receptors carefully located over the area of interest. The second model run would use a more dense array of receptors in areas showing potential for high concentrations, as indicated by the results of the first model run.

c. As mentioned above, digitized contour data must be preprocessed [27] to provide hill shape parameters in suitable input format. The user then supplies receptors either through an interactive program that is part of the model or directly, by using a text editor; using both methods to select receptors will generally be necessary to assure that the maximum concentrations are estimated by either model. In cases where a terrain feature may ''appear to the plume'' as smaller, multiple hills, it may be necessary to model the terrain both as a single feature and as multiple hills to determine design concentrations.

d. Other screening techniques [17 25 29] may be acceptable for complex terrain cases where established procedures are used. The user is encouraged to confer with the appropriate reviewing authority if any unresolvable problems are encountered, *e.g.*, applicability, meteorological data, receptor siting, or terrain contour processing issues.

4.2.2 Refined Analytical Techniques

a. A brief description of each preferred model for refined applications is found in Appendix A. Also listed in that appendix are availability, the model input requirements, the standard options that should be selected when running the program, and output options.

b. For a wide range of regulatory applications in all types of terrain, the recommended model is AERMOD. This recommendation is based on extensive developmental and performance evaluation (Section A.1; subsection n). Differentiation of simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the well-known dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions.

c. If aerodynamic building downwash is important for the modeling analysis, *e.g.*, paragraph 6.2.2(b), then the recommended model is AERMOD. The state-of-the-science for modeling atmospheric deposition is evolving and the best techniques are currently being assessed and their results are being compared with observations. Consequently, while deposition treatment is available in AERMOD, the approach taken for any purpose should be coordinated with the appropriate reviewing authority. Line sources can be simulated with AERMOD if point or volume sources are appropriately combined. If buoyant plume rise from line sources is important for the modeling analysis, the recommended model is BLP. For other special modeling applications, CALINE3 (or CAL3QHCR on a case-by-case basis), OCD, and EDMS are available as described in Sections 5 and 6.

d. If the modeling application involves a well defined hill or ridge and a detailed dispersion analysis of the spatial pattern of plume impacts is of interest, CTDMPLUS, listed in Appendix A, is available. CDTMPLUS provides greater resolution of concentrations about the contour of the hill feature than does AERMOD through a different plume-terrain interaction algorithm.

TABLE 4–1A.—NEUTRAL/STABLE METEOROLOGICAL MATRIX FOR CTSCREEN

Variable	Specific values				
U (m/s)	1.0	2.0	3.0	4.0	5.0
σ_v (m/s)	0.3	0.75			
σ_w (m/s)	0.08	0.15	0.30	0.75	
Δθ/Δz (K/m)	0.01	0.02	0.035		
WD	(Wind direction is optimized internally for each meteorological combination.)				

Exceptions:

(1) If U ≤ 2 m/s and $\sigma_v \leq 0.3$ m/s, then include $\sigma_w = 0.04$ m/s.

(2) If $\sigma_w = 0.75$ m/s and U ≥ 3.0 m/s, then $\Delta\theta/\Delta z$ is limited to ≤ 0.01 K/m.

(3) If U ≥ 4 m/s, then $\sigma_w \geq 0.15$ m/s.

(4) $\sigma_w \leq \sigma_v$

TABLE 4–1B.—UNSTABLE/CONVECTIVE METEOROLOGICAL MATRIX FOR CTSCREEN

Variable	Specific values				
U (m/s)	1.0	2.0	3.0	4.0	5.0
U_* (m/s)	0.1	0.3	0.5		
L (m)	−10	−50	−90		
$\Delta\theta/\Delta z$ (K/m)	0.030	(potential temperature gradient above Z_i)			
Z_i (m)	0.5h	1.0h	1.5h	(h = terrain height)	

5.0 Models for Ozone, Particulate Matter, Carbon Monoxide, Nitrogen Dioxide, and Lead

5.1 Discussion

a. This section identifies modeling approaches or models appropriate for addressing ozone (O_3)[a], carbon monoxide (CO), nitrogen dioxide (NO_2), particulates (PM–2.5[a] and PM–10), and lead. These pollutants are often associated with emissions from numerous sources. Generally, mobile sources contribute significantly to emissions of these pollutants or their precursors. For cases where it is of interest to estimate concentrations of CO or NO_2 near a single or small group of stationary sources, refer to Section 4. (Modeling approaches for SO_2 are discussed in Section 4.)

b. Several of the pollutants mentioned in the preceding paragraph are closely related to each other in that they share common sources of emissions and/or are subject to chemical transformations of similar precursors.[30] [31] For example, strategies designed to reduce ozone could have an effect on the secondary component of PM–2.5 and vice versa. Thus, it makes sense to use models which take into account the chemical coupling between O_3 and PM–2.5, when feasible. This should promote consistency among methods used to evaluate strategies for reducing different pollutants as well as consistency among the strategies themselves. Regulatory requirements for the different pollutants are likely to be due at different times. Thus, the following paragraphs identify appropriate modeling approaches for pollutants individually.

c. The NAAQS for ozone was revised on July 18, 1997 and is now based on an 8-hour averaging period. Models for ozone are needed primarily to guide choice of strategies to correct an observed ozone problem in an area not attaining the NAAQS for ozone. Use of photochemical grid models is the recommended means for identifying strategies needed to correct high ozone concentrations in such areas. Such models need to consider emissions of volatile organic compounds (VOC), nitrogen oxides (NO_X) and carbon monoxide (CO), as well as means for generating meteorological data governing transport and dispersion of ozone and its precursors. Other approaches, such as Lagrangian or observational models may be used to guide choice of appropriate strategies to consider with a photochemical grid model. These other approaches may be sufficient to address ozone in an area where observed concentrations are near the NAAQS or only slightly above it. Such a decision needs to be made on a case-by-case basis in concert with the Regional Office.

d. A control agency with jurisdiction over one or more areas with significant ozone problems should review available ambient air quality data to assess whether the problem is likely to be significantly impacted by regional transport.[32] Choice of a modeling approach depends on the outcome of this review. In cases where transport is considered significant, use of a nested regional model may be the preferred approach. If the observed problem is believed to be primarily of local origin, use of a model with a single horizontal grid resolution and geographical coverage that is less than that of a regional model may suffice.

e. The fine particulate matter NAAQS, promulgated on July 18, 1997, includes particles with an aerodynamic diameter nominally less than or equal to 2.5 micrometers (PM–2.5). Models for PM–2.5 are needed to assess adequacy of a proposed strategy for meeting annual and/or 24-hour NAAQS for PM–2.5. PM–2.5 is a mixture consisting of several diverse components. Because chemical/physical properties and origins of each component differ, it may be appropriate to use either a single model capable of addressing several of the important components or to model primary and secondary components using different models. Effects of a control strategy on PM–2.5 is estimated from the sum of the effects on the components composing PM–2.5. Model users may refer to guidance[33] for further details concerning appropriate modeling approaches.

f. A control agency with jurisdiction over one or more areas with PM–2.5 problems should review available ambient air quality data to assess which components of PM–2.5 are likely to be major contributors to the problem. If it is determined that regional transport of secondary particulates, such as sulfates or nitrates, is likely to contribute significantly to the problem, use of a regional model may be the preferred approach. Otherwise, coverage may be limited to a domain that is urban scale or less. Special care should be taken to select appropriate geographical coverage for a modeling application.[33]

g. The NAAQS for PM–10 was promulgated in July 1987 (40 CFR 50.6). A SIP development guide[34] is available to assist in PM–10 analyses and control strategy development. EPA promulgated regulations for PSD increments measured as PM–10 in a notice published on June 3, 1993 (40 CFR 51.166(c)). As an aid to assessing the impact on ambient air quality of particulate matter generated from prescribed burning activities, a reference[35] is available.

h. Models for assessing the impacts of particulate matter may involve dispersion models or receptor models, or a combination (depending on the circumstances). Receptor models focus on the behavior of the ambient environment at the point of impact as opposed to source-oriented dispersion models, which focus on the transport, diffusion, and transformation that begin at the source and continue to the receptor site. Receptor models attempt to identify and apportion sources by relating known sample compositions at receptors to measured or inferred compositions of source emissions. When complete and accurate emission inventories or meteorological characterization are unavailable, or unknown pollutant sources exist, receptor modeling may be necessary.

i. Models for assessing the impact of CO emissions are needed for a number of different purposes. Examples include evaluating effects of point sources, congested intersections and highways, as well as the cumulative effect of numerous sources of CO in an urban area.

j. Models for assessing the impact of sources on ambient NO_2 concentrations are primarily needed to meet new source review requirements, such as addressing the effect of a proposed source on PSD increments for annual concentrations of NO_2. Impact of an individual source on ambient NO_2 depends, in part, on the chemical environment into which the source's plume is to be emitted. There are several approaches for estimating effects of an individual source on ambient NO_2. One approach is through use of a plume-in-grid algorithm imbedded within a photochemical grid model. However, because of the rigor and complexity involved, and because this approach may not be capable of defining sub-grid concentration gradients, the plume-in-grid approach may be impractical for estimating effects on an annual PSD increment. A second approach which does not have this limitation and accommodates

[a] Modeling for attainment demonstrations for O_3 and PM–2.5 should be conducted in time to meet required SIP submission dates as provided for in the respective implementation rules. Information on implementation of the 8-hr O_3 and PM–2.5 standards is available at: *http://www.epa.gov/ttn/naags/.*

distance-dependent conversion ratios—the Plume Volume Molar Ratio Method (PVMRM) [36]—is currently being tested to determine suitability as a refined method. A third (screening) approach is to develop site specific (domain-wide) conversion factors based on measurements. If it is not possible to develop site specific conversion factors and use of the plume-in-grid algorithm is also not feasible, other screening procedures may be considered.

k. In January 1999 (40 CFR Part 58, Appendix D), EPA gave notice that concern about ambient lead impacts was being shifted away from roadways and toward a focus on stationary point sources. EPA has also issued guidance on siting ambient monitors in the vicinity of such sources.[37] For lead, the SIP should contain an air quality analysis to determine the maximum quarterly lead concentration resulting from major lead point sources, such as smelters, gasoline additive plants, etc. General guidance for lead SIP development is also available.[38]

5.2 Recommendations

5.2.1 Models for Ozone

a. *Choice of Models for Multi-source Applications*. Simulation of ozone formation and transport is a highly complex and resource intensive exercise. Control agencies with jurisdiction over areas with ozone problems are encouraged to use photochemical grid models, such as the Models-3/Community Multi-scale Air Quality (CMAQ) modeling system,[39] to evaluate the relationship between precursor species and ozone. Judgement on the suitability of a model for a given application should consider factors that include use of the model in an attainment test, development of emissions and meteorological inputs to the model and choice of episodes to model.[32] Similar models for the 8-hour NAAQS and for the 1-hour NAAQS are appropriate.

b. *Choice of Models to Complement Photochemical Grid Models.* As previously noted, observational models, Lagrangian models, or the refined version of the Ozone Isopleth Plotting Program (OZIPR) [40] may be used to help guide choice of strategies to simulate with a photochemical grid model and to corroborate results obtained with a grid model. Receptor models have also been used to apportion sources of ozone precursors (*e.g.*, VOC) in urban domains. EPA has issued guidance [32] in selecting appropriate techniques.

c. *Estimating the Impact of Individual Sources*. Choice of methods used to assess the impact of an individual source depends on the nature of the source and its emissions. Thus, model users should consult with the Regional Office to determine the most suitable approach on a case-by-case basis (subsection 3.2.2).

5.2.2 Models for Particulate Matter

5.2.2.1 PM–2.5

a. *Choice of Models for Multi-source Applications*. Simulation of phenomena resulting in high ambient PM–2.5 can be a multi-faceted and complex problem resulting from PM–2.5's existence as an aerosol mixture. Treating secondary components of PM–2.5, such as sulfates and nitrates, can be a highly complex and resource-intensive exercise. Control agencies with jurisdiction over areas with secondary PM–2.5 problems are encouraged to use models which integrate chemical and physical processes important in the formation, decay and transport of these species (*e.g.*, Models-3/CMAQ [38] or REMSAD [41]). Primary components can be simulated using less resource-intensive techniques. Suitability of a modeling approach or mix of modeling approaches for a given application requires technical judgement,[33] as well as professional experience in choice of models, use of the model(s) in an attainment test, development of emissions and meteorological inputs to the model and selection of days to model.

b. *Choice of Analysis Techniques to Complement Air Quality Simulation Models*. Receptor models may be used to corroborate predictions obtained with one or more air quality simulation models. They may also be potentially useful in helping to define specific source categories contributing to major components of PM–2.5.[33]

c. *Estimating the Impact of Individual Sources*. Choice of methods used to assess the impact of an individual source depends on the nature of the source and its emissions. Thus, model users should consult with the Regional Office to determine the most suitable approach on a case-by-case basis (subsection 3.2.2).

5.2.2.2 PM–10

a. Screening techniques like those identified in subsection 4.2.1 are applicable to PM–10. Conservative assumptions which do not allow removal or transformation are suggested for screening. Thus, it is recommended that subjectively determined values for ''half-life'' or pollutant decay not be used as a surrogate for particle removal. Proportional models (rollback/forward) may not be applied for screening analysis, unless such techniques are used in conjunction with receptor modeling.[34]

b. Refined models such as those discussed in subsection 4.2.2 are recommended for PM–10. However, where possible, particle size, gas-to-particle formation, and their effect on ambient concentrations may be considered. For point sources of small particles and for source-specific analyses of complicated sources, use the appropriate recommended steady-state plume dispersion model (subsection 4.2.2).

c. Receptor models have proven useful for helping validate emission inventories and for corroborating source-specific impacts estimated by dispersion models. The Chemical Mass Balance (CMB) model is useful for apportioning impacts from localized sources.[42 43 44] Other receptor models, *e.g.*, the Positive Matrix Factorization (PMF) model [45] and Unmix,[46] which don't share some of CMB's constraints, have also been applied. In regulatory applications, dispersion models have been used in conjunction with receptor models to attribute source (or source category) contributions. Guidance is available for PM–10 sampling and analysis applicable to receptor modeling.[47]

d. Under certain conditions, recommended dispersion models may not be reliable. In such circumstances, the modeling approach should be approved by the Regional Office on a case-by-case basis. Analyses involving model calculations for stagnation conditions should also be justified on a case-by-case basis (subsection 7.2.8).

e. Fugitive dust usually refers to dust put into the atmosphere by the wind blowing over plowed fields, dirt roads or desert or sandy areas with little or no vegetation. Reentrained dust is that which is put into the air by reason of vehicles driving over dirt roads (or dirty roads) and dusty areas. Such sources can be characterized as line, area or volume sources. Emission rates may be based on site specific data or values from the general literature. Fugitive emissions include the emissions resulting from the industrial process that are not captured and vented through a stack but may be released from various locations within the complex. In some unique cases a model developed specifically for the situation may be needed. Due to the difficult nature of characterizing and modeling fugitive dust and fugitive emissions, it is recommended that the proposed procedure be cleared by the Regional Office for each specific situation before the modeling exercise is begun.

5.2.3 Models for Carbon Monoxide

a. Guidance is available for analyzing CO impacts at roadway intersections.[48] The recommended screening model for such analyses is CAL3QHC.[49 50] This model combines CALINE3 (listed in Appendix A) with a traffic model to calculate delays and queues that occur at signalized intersections. The screening approach is described in reference 48; a refined approach may be considered on a case-by-case basis with CAL3QHCR.[51] The latest version of the MOBILE (mobile source emission factor) model should be used for emissions input to intersection models.

b. For analyses of highways characterized by uninterrupted traffic flows, CALINE3 is recommended, with emissions input from the latest version of the MOBILE model. A scientific review article for line source models is available.[52]

c. For urban area wide analyses of CO, an Eulerian grid model should be used. Information on SIP development and requirements for using such models can be found in several references.[48 53 54 55]

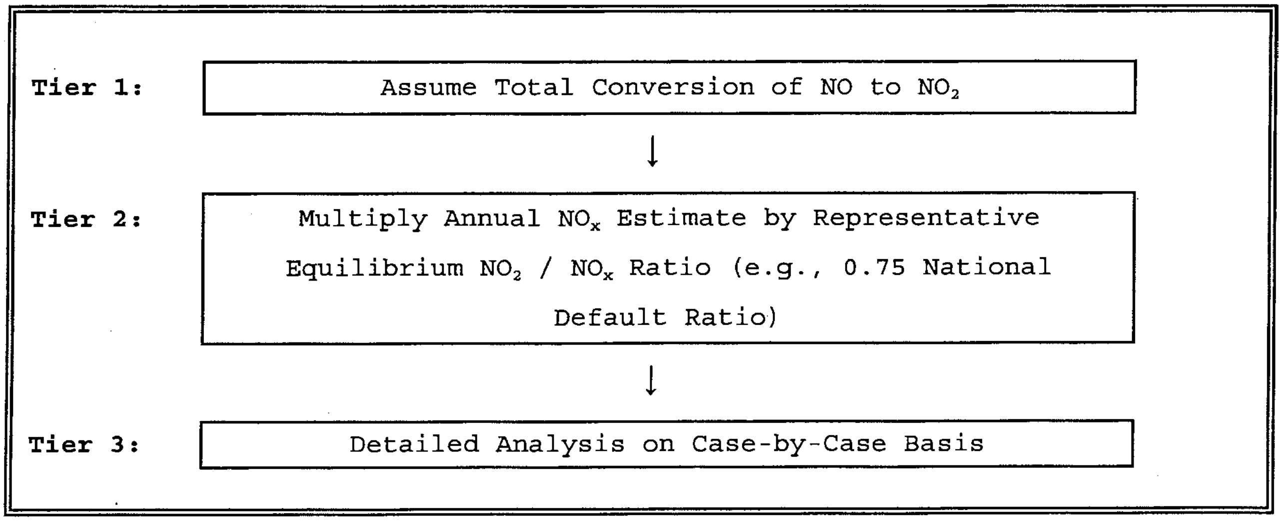
d. Where point sources of CO are of concern, they should be treated using the screening and refined techniques described in Section 4.

5.2.4 Models for Nitrogen Dioxide (Annual Average)

a. A tiered screening approach is recommended to obtain annual average estimates of NO_2 from point sources for New Source Review analysis, including PSD, and for SIP planning purposes. This multi-tiered approach is conceptually shown in Figure 5–1 and described in paragraphs b through d of this subsection:

Figure 5–1

Multi-tiered screening approach for Estimating Annual NO_2 Concentrations from Point Sources



b. For Tier 1 (the initial screen), use an appropriate model in subsection 4.2.2 to estimate the maximum annual average concentration and assume a total conversion of NO to NO_2. If the concentration exceeds the NAAQS and/or PSD increments for NO_2, proceed to the 2nd level screen.

c. For Tier 2 (2nd level) screening analysis, multiply the Tier 1 estimate(s) by an empirically derived NO_2/NO_X value of 0.75 (annual national default).[56] The reviewing agency may establish an alternative default NO_2/NO_X ratio based on ambient annual average NO_2 and annual average NO_X data representative of area wide quasi-equilibrium conditions. Alternative default NO_2/NO_X ratios should be based on data satisfying quality assurance procedures that ensure data accuracy for both NO_2 and NO_X within the typical range of measured values. In areas with relatively low NO_X concentrations, the quality assurance procedures used to determine compliance with the NO_2 national ambient air quality standard may not be adequate. In addition, default NO_2/NO_X ratios, including the 0.75 national default value, can underestimate long range NO_2 impacts and should be used with caution in long range transport scenarios.

d. For Tier 3 (3rd level) analysis, a detailed screening method may be selected on a case-by-case basis. For point source modeling, detailed screening techniques such as the Ozone Limiting Method [57] may also be considered. Also, a site specific NO_2/NO_X ratio may be used as a detailed screening method if it meets the same restrictions as described for alternative default NO_2/NO_X ratios. Ambient NO_X monitors used to develop a site specific ratio should be sited to obtain the NO_2 and NO_X concentrations under quasi-equilibrium conditions. Data obtained from monitors sited at the maximum NO_X impact site, as may be required in a PSD pre-construction monitoring program, likely reflect transitional NO_X conditions. Therefore, NO_X data from maximum impact sites may not be suitable for determining a site specific NO_2/NO_X ratio that is applicable for the entire modeling analysis. A site specific ratio derived from maximum impact data can only be used to estimate NO_2 impacts at receptors located within the same distance of the source as the source-to-monitor distance.

e. In urban areas (subsection 7.2.3), a proportional model may be used as a preliminary assessment to evaluate control strategies to meet the NAAQS for multiple minor sources, *i.e.*, minor point, area and mobile sources of NO_X; concentrations resulting from major point sources should be estimated separately as discussed above, then added to the impact of the minor sources. An acceptable screening technique for urban complexes is to assume that all NO_X is emitted in the form of NO_2 and to use a model from Appendix A for nonreactive pollutants to estimate NO_2 concentrations. A more accurate estimate can be obtained by: (1) Calculating the annual average concentrations of NO_X with an urban model, and (2) converting these estimates to NO_2 concentrations using an empirically derived annual NO_2/NO_X ratio. A value of 0.75 is recommended for this ratio. However, a spatially averaged alternative default annual NO_2/NO_X ratio may be determined from an existing air quality monitoring network and used in lieu of the 0.75 value if it is determined to be representative of prevailing ratios in the urban area by the reviewing agency. To ensure use of appropriate locally derived annual average NO_2/NO_X ratios, monitoring data under consideration should be limited to those collected at monitors meeting siting criteria defined in 40 CFR Part 58, Appendix D as representative of ''neighborhood'', ''urban'', or ''regional'' scales. Furthermore, the highest annual spatially averaged NO_2/NO_X ratio from the most recent 3 years of complete data should be used to foster conservatism in estimated impacts.

f. To demonstrate compliance with NO_2 PSD increments in urban areas, emissions from major and minor sources should be included in the modeling analysis. Point and area source emissions should be modeled as discussed above. If mobile source emissions do not contribute to localized areas of high ambient NO_2 concentrations, they should be modeled as area sources. When modeled as area sources, mobile source emissions should be assumed uniform over the entire highway link and allocated to each area source grid square based on the portion of highway link within each grid square. If localized areas of high concentrations are likely, then mobile sources should be modeled as line sources using an appropriate steady-state plume dispersion model (*e.g.*, CAL3QHCR; subsection 5.2.3).

g. More refined techniques to handle special circumstances may be considered on a case-by-case basis and agreement with the appropriate reviewing authority (paragraph 3.0(b)) should be obtained. Such techniques should consider individual quantities of NO and NO_2 emissions, atmospheric transport and dispersion, and atmospheric transformation of NO to NO_2. Where they are available, site specific data on the conversion of NO to NO_2 may be used. Photochemical dispersion models, if used for other pollutants in the area, may also be applied to the NO_X problem.

5.2.5 Models for Lead

a. For major lead point sources, such as smelters, which contribute fugitive emissions and for which deposition is important, professional judgement should be used, and there should be coordination with the appropriate reviewing authority (paragraph 3.0(b)). To model an entire major urban area or to model areas without significant sources of lead emissions, as a minimum a proportional (rollback) model may be used for air quality analysis. The rollback philosophy assumes that measured pollutant concentrations are proportional to emissions. However, urban or other dispersion models are encouraged in these circumstances where the use of such models is feasible.

b. In modeling the effect of traditional line sources (such as a specific roadway or highway) on lead air quality, dispersion models applied for other pollutants can be used. Dispersion models such as CALINE3 and CAL3QHCR have been used for modeling carbon monoxide emissions from highways and intersections (subsection 5.2.3). Where there is a point source in the middle of a substantial road network, the lead concentrations that result from the road network should be treated as background (subsection 8.2); the point source and any nearby major roadways should be modeled separately using the appropriate recommended steady-state plume dispersion model (subsection 4.2.2).

6.0 Other Model Requirements

6.1 Discussion

a. This section covers those cases where specific techniques have been developed for special regulatory programs. Most of the programs have, or will have when fully developed, separate guidance documents that cover the program and a discussion of the tools that are needed. The following paragraphs reference those guidance documents, when they are available. No attempt has been made to provide a comprehensive discussion of each topic since the reference documents were designed to do that. This section will undergo periodic revision as new programs are added and new techniques are developed.

b. Other Federal agencies have also developed specific modeling approaches for their own regulatory or other requirements.[58] Although such regulatory requirements and manuals may have come about because of EPA rules or standards, the implementation of such regulations and the use of the modeling techniques is under the jurisdiction of the agency issuing the manual or directive.

c. The need to estimate impacts at distances greater than 50km (the nominal distance to which EPA considers most steady-state Gaussian plume models are applicable) is an important one especially when considering the effects from secondary pollutants. Unfortunately, models originally available to EPA had not undergone sufficient field evaluation to be recommended for general use. Data bases from field studies at mesoscale and long range transport distances were limited in detail. This limitation was a result of the expense to perform the field studies required to verify and improve mesoscale and long range transport models. Meteorological data adequate for generating three-dimensional wind fields were particularly sparse. Application of models to complicated terrain compounds the difficulty of making good assessments of long range transport impacts. EPA completed limited evaluation of several long range transport (LRT) models against two sets of field data and evaluated results.[59] Based on the results, EPA concluded that long range and mesoscale transport models were limited for regulatory use to a case-by-case basis. However a more recent series of comparisons has been completed for a new model, CALPUFF (Section A.3). Several of these field studies involved three-to-four hour releases of tracer gas sampled along arcs of receptors at distances greater than 50km downwind. In some cases, short-term concentration sampling was available, such that the transport of the tracer puff as it passed the arc could be monitored. Differences on the order of 10 to 20 degrees were found between the location of the simulated and observed center of mass of the tracer puff. Most of the simulated centerline concentration maxima along each arc were within a factor of two of those observed. It was concluded from these case studies that the CALPUFF dispersion model had performed in a reasonable manner, and had no apparent bias toward over or under prediction, so long as the transport distance was limited to less than 300km.[60]

6.2 Recommendations

6.2.1 Visibility

a. Visibility in important natural areas (e.g., Federal Class I areas) is protected under a number of provisions of the Clean Air Act, including Sections 169A and 169B (addressing impacts primarily from existing sources) and Section 165 (new source review). Visibility impairment is caused by light scattering and light absorption associated with particles and gases in the atmosphere. In most areas of the country, light scattering by PM–2.5 is the most significant component of visibility impairment. The key components of PM–2.5 contributing to visibility impairment include sulfates, nitrates, organic carbon, elemental carbon, and crustal material.

b. The visibility regulations as promulgated in December 1980 (40 CFR 51.300–307) require States to mitigate visibility impairment, in any of the 156 mandatory Federal Class I areas, that is found to be ''reasonably attributable'' to a single source or a small group of sources. In 1985, EPA promulgated Federal Implementation Plans (FIPs) for several States without approved visibility provisions in their SIPs. The IMPROVE (Interagency Monitoring for Protected Visual Environments) monitoring network, a cooperative effort between EPA, the States, and Federal land management agencies, was established to implement the monitoring requirements in these FIPs. Data has been collected by the IMPROVE network since 1988.

c. In 1999, EPA issued revisions to the 1980 regulations to address visibility impairment in the form of regional haze, which is caused by numerous, diverse sources (e.g., stationary, mobile, and area sources) located across a broad region (40 CFR 51.308–309). The state of relevant scientific knowledge has expanded significantly since the Clean Air Act Amendments of 1977. A number of studies and reports [61 62] have concluded that long range transport (e.g., up to hundreds of kilometers) of fine particulate matter plays a significant role in visibility impairment across the country. Section 169A of the Act requires states to develop SIPs containing long-term strategies for remedying existing and preventing future visibility impairment in 156 mandatory Class I federal areas. In order to develop long-term strategies to address regional haze, many States will need to conduct regional-scale modeling of fine particulate concentrations and associated visibility impairment (e.g., light extinction and deciview metrics).

d. To calculate the potential impact of a plume of specified emissions for specific transport and dispersion conditions (''plume blight''), a screening model, VISCREEN, and guidance are available.[63] If a more comprehensive analysis is required, a refined model should be selected . The model selection (VISCREEN vs. PLUVUE II or some other refined model), procedures, and analyses should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected Federal Land Manager (FLM). FLMs are responsible for determining whether there is an adverse effect by a plume on a Class I area.

e. CALPUFF (Section A.3) may be applied when assessment is needed of reasonably attributable haze impairment or atmospheric deposition due to one or a small group of sources. This situation may involve more sources and larger modeling domains than that to which VISCREEN ideally may be applied. The procedures and analyses should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s).

f. Regional scale models are used by EPA to develop and evaluate national policy and assist State and local control agencies. Two such models which can be used to assess visibility impacts from source emissions are Models-3/CMAQ [38] and REMSAD.[41] Model users should consult with the appropriate reviewing authority (paragraph 3.0(b)), which in this instance would include FLMs.

6.2.2 Good Engineering Practice Stack Height

a. The use of stack height credit in excess of Good Engineering Practice (GEP) stack height or credit resulting from any other dispersion technique is prohibited in the development of emission limitations by 40 CFR 51.118 and 40 CFR 51.164. The definitions of GEP stack height and dispersion technique are contained in 40 CFR 51.100. Methods and procedures for making the appropriate stack height calculations, determining stack height credits and an example of applying those techniques are found in several references [64 65 66 67], which provide a great deal of additional information for evaluating and describing building cavity and wake effects.

b. If stacks for new or existing major sources are found to be less than the height defined by EPA's refined formula for determining GEP height, then air quality impacts associated with cavity or wake effects due to the nearby building structures should be determined. The EPA refined formula height is defined as H + 1.5L (*see* reference 66). Detailed downwash screening procedures [24] for both the cavity and wake regions should be followed. If more refined concentration estimates are required, the recommended steady-state plume dispersion model in subsection 4.2.2 contains algorithms for building wake calculations and should be used.

6.2.3 Long Range Transport (LRT) (*i.e.,* Beyond 50km)

a. Section 165(d) of the Clean Air Act requires that suspected adverse impacts on PSD Class I areas be determined. However, 50km is the useful distance to which most steady-state Gaussian plume models are considered accurate for setting emission limits. Since in many cases PSD analyses show that Class I areas may be threatened at distances greater than 50km from new sources, some procedure is needed to (1) determine if an adverse impact will occur, and (2) identify the model to be used in setting an emission limit if the Class I increments are threatened. In addition to the situations just described, there are certain applications containing a mixture of both long range and short range source-receptor relationships in a large modeled domain (*e.g.,* several industrialized areas located along a river or valley). Historically, these applications have presented considerable difficulty to an analyst if impacts from sources having transport distances greater than 50km significantly contributed to the design concentrations. To properly analyze applications of this type, a modeling approach is needed which has the capability of combining, in a consistent manner, impacts involving both short and long range transport. The CALPUFF modeling system, listed in Appendix A, has been designed to accommodate both the Class I area LRT situation and the large modeling domain situation. Given the judgement and refinement involved, conducting a LRT modeling assessment will require significant consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s). The FLM has an affirmative responsibility to protect air quality related values (AQRVs) that may be affected, and to provide the appropriate procedures and analysis techniques. Where there is no increment violation, the ultimate decision on whether a Class I area is adversely affected is the responsibility of the appropriate reviewing authority (Section 165(d)(2)(C)(ii) of the Clean Air Act), taking into consideration any information on the impacts on AQRVs provided by the FLM. According to Section 165(d)(2)(C)(iii) of the Clean Air Act, if there is a Class I increment violation, the *source* must demonstrate to the satisfaction of the FLM that the emissions from the source will have no adverse impact on the AQRVs.

b. If LRT is determined to be important, then refined estimates utilizing the CALPUFF modeling system should be obtained. A screening approach [60 68] is also available for use on a case-by-case basis that generally provides concentrations that are higher than those obtained using refined characterizations of the meteorological conditions. The meteorological input data requirements for developing the time and space varying three-dimensional winds and dispersion meteorology for refined analyses are discussed in paragraph 8.3.1.2(d). Additional information on applying this model is contained in Appendix A. To facilitate use of complex air quality and meteorological modeling systems, a written protocol approved by the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s) may be considered for developing consensus in the methods and procedures to be followed.

6.2.4 Modeling Guidance for Other Governmental Programs

a. When using the models recommended or discussed in the *Guideline* in support of programmatic requirements not specifically covered by EPA regulations, the model user should consult the appropriate Federal or State agency to ensure the proper application and use of the models. For modeling associated with PSD permit applications that involve a Class I area, the appropriate Federal Land Manager should be consulted on all modeling questions.

b. The Offshore and Coastal Dispersion (OCD) model, described in Appendix A, was developed by the Minerals Management Service and is recommended for estimating air quality impact from offshore sources on onshore, flat terrain areas. The OCD model is not recommended for use in air quality impact assessments for onshore sources. Sources located on or just inland of a shoreline where fumigation is expected should be treated in accordance with subsection 7.2.8.

c. The latest version of the Emissions and Dispersion Modeling System (EDMS), was developed and is supported by the Federal Aviation Administration (FAA), and is appropriate for air quality assessment of primary pollutant impacts at airports or air bases. EDMS has adopted AERMOD for treating dispersion. Application of EDMS is intended for estimating the collective impact of changes in aircraft operations, point source, and mobile source emissions on pollutant concentrations. It is not intended for PSD, SIP, or other regulatory air quality analyses of point or mobile sources at or peripheral to airport property that are unrelated to airport operations. If changes in other than aircraft operations are associated with analyses, a model recommended in Chapter 4 or 5 should be used. The latest version of EDMS may be obtained from FAA at its Web site: *http://www.aee.faa.gov/emissions/edms/edmshome.htm.*

7.0 General Modeling Considerations

7.1 Discussion

a. This section contains recommendations concerning a number of different issues not explicitly covered in other sections of this guide. The topics covered here are not specific to any one program or modeling area but are common to nearly all modeling analyses for criteria pollutants.

7.2 Recommendations

7.2.1 Design Concentrations (*See Also* Subsection 10.2.3.1)

7.2.1.1 Design Concentrations for SO_2, PM–10, CO, Pb, and NO_2

a. An air quality analysis for SO_2, PM–10, CO, Pb, and NO_2 is required to determine if the source will (1) cause a violation of the NAAQS, or (2) cause or contribute to air quality deterioration greater than the specified allowable PSD increment. For the former, background concentration (subsection 8.2) should be added to the estimated impact of the source to determine the design concentration. For the latter, the design concentration includes impact from all increment consuming sources.

b. If the air quality analyses are conducted using the period of meteorological input data recommended in subsection 8.3.1.2 (*e.g.,* 5 years of National Weather Service (NWS) data or at least 1 year of site specific data; subsection 8.3.3), then the design concentration based on the highest, second-highest short term concentration over the entire receptor network for each year modeled or the highest long term average (whichever is controlling) should be used to determine emission limitations to assess compliance with the NAAQS and PSD increments. For the 24-hour PM–10 NAAQS (which is a probabilistic standard)—when multiple years are modeled, they collectively represent a single period. Thus, if 5 years of NWS data are modeled, then the highest sixth highest concentration for the whole period becomes the design value. And in general, when n years are modeled, the (n+1)th highest concentration over the n-year period is the design value, since this represents an average or expected exceedance rate of one per year.

c. When sufficient and representative data exist for less than a 5-year period from a nearby NWS site, or when site specific data have been collected for less than a full continuous year, or when it has been determined that the site specific data may not be temporally representative (subsection 8.3.3), then the highest concentration estimate should be considered the design value. This is because the length of the data record may be too short to assure that the conditions producing worst-case estimates have been adequately sampled. The highest value is then a surrogate for the concentration that is not to be exceeded more than once per year (the wording of the deterministic standards). Also, the highest concentration should be used whenever selected worst-case conditions are input to a screening technique, as described in EPA guidance.[24]

d. If the controlling concentration is an annual average value and multiple years of data (site specific or NWS) are used, then the design value is the highest of the annual averages calculated for the individual years. If the controlling concentration is a quarterly average and multiple years are used, then the highest individual quarterly average should be considered the design value.

e. As long a period of record as possible should be used in making estimates to determine design values and PSD increments. If more than 1 year of site specific data is available, it should be used.

7.2.1.2 Design Concentrations for O_3 and PM–2.5

a. Guidance and specific instructions for the determination of the 1-hr and 8-hr design concentrations for ozone are provided in Appendix H and I (respectively) of reference 4. Appendix H explains how to determine when the expected number of days per calendar year with maximum hourly concentrations above the NAAQS is equal to or less than 1. Appendix I explains the data handling conventions and computations necessary for determining whether the 8-hour primary and secondary NAAQS are met at an ambient monitoring site. For PM–2.5, Appendix N of reference 4, and supplementary guidance,[69] explain the data handling conventions and computations necessary for determining when the annual and 24-hour primary and secondary NAAQS are met. For all SIP revisions the user should check with the Regional Office to obtain the most recent guidance documents and policy memoranda concerning the pollutant in question. There are currently no PSD increments for O_3 and PM–2.5.

7.2.2 Critical Receptor Sites

a. Receptor sites for refined modeling should be utilized in sufficient detail to estimate the highest concentrations and possible violations of a NAAQS or a PSD increment. In designing a receptor network, the emphasis should be placed on receptor resolution and location, not total number of receptors. The selection of receptor sites should be a case-by-case determination taking into consideration the topography, the climatology, monitor sites, and the results of the initial screening procedure.

7.2.3 Dispersion Coefficients

a. Steady-state Gaussian plume models used in most applications should employ dispersion coefficients consistent with those contained in the preferred models in Appendix A. Factors such as averaging time, urban/rural surroundings (*see* paragraphs (b)—(f) of this subsection), and type of source (point vs. line) may dictate the selection of specific coefficients. Coefficients used in some Appendix A models are identical to, or at least based on, Pasquill-Gifford coefficients [70] in rural areas and McElroy-Pooler [71] coefficients in urban areas. A key feature of AERMOD's formulation is the use of directly observed variables of the boundary layer to parameterize dispersion.[22]

b. The selection of either rural or urban dispersion coefficients in a specific application should follow one of the procedures suggested by Irwin [72] and briefly described in paragraphs (c)—(f) of this subsection. These include a land use classification procedure or a population based procedure to determine whether the character of an area is primarily urban or rural.

c. Land Use Procedure: (1) Classify the land use within the total area, A_o, circumscribed by a 3km radius circle about the source using the meteorological land use typing scheme proposed by Auer [73]; (2) if land use types I1, I2, C1, R2, and R3 account for 50 percent or more of A_o, use urban dispersion coefficients; otherwise, use appropriate rural dispersion coefficients.

d. Population Density Procedure: (1) Compute the average population density, $\bar{p}$ per square kilometer with A_o as defined above; (2) If $\bar{p}$ is greater than 750 people/km_2, use urban dispersion coefficients; otherwise use appropriate rural dispersion coefficients.

e. Of the two methods, the land use procedure is considered more definitive. Population density should be used with caution and should not be applied to highly industrialized areas where the population density may be low and thus a rural classification would be indicated, but the area is sufficiently built-up so that the urban land use criteria would be satisfied. In this case, the classification should already be ''urban'' and urban dispersion parameters should be used.

f. Sources located in an area defined as urban should be modeled using urban dispersion parameters. Sources located in areas defined as rural should be modeled using the rural dispersion parameters. For analyses of whole urban complexes, the entire area should be modeled as an urban region if most of the sources are located in areas classified as urban.

g. Buoyancy-induced dispersion (BID), as identified by Pasquill [74], is included in the preferred models and should be used where buoyant sources, *e.g.*, those involving fuel combustion, are involved.

7.2.4 Stability Categories

a. The Pasquill approach to classifying stability is commonly used in preferred models (Appendix A). The Pasquill method, as modified by Turner [75], was developed for use with commonly observed meteorological data from the National Weather Service and is based on cloud cover, insolation and wind speed.

b. Procedures to determine Pasquill stability categories from other than NWS data are found in subsection 8.3. Any other method to determine Pasquill stability categories must be justified on a case-by-case basis.

c. For a given model application where stability categories are the basis for selecting dispersion coefficients, both σ_y and σ_z should be determined from the same stability category. ''Split sigmas'' in that instance are not recommended. Sector averaging, which eliminates the σ_y term, is commonly acceptable in complex terrain screening methods.

d. AERMOD, also a preferred model in Appendix A, uses a planetary boundary layer scaling parameter to characterize stability.[22] This approach represents a departure from the discrete, hourly stability categories estimated under the Pasquill-Gifford-Turner scheme.

7.2.5 Plume Rise

a. The plume rise methods of Briggs [76 77] are incorporated in many of the preferred models and are recommended for use in many modeling applications. In AERMOD,[22] for the stable boundary layer, plume rise is estimated using an iterative approach, similar to that in the CTDMPLUS model. In the convective boundary layer, plume rise is superposed on the displacements by random convective velocities.[78] In AERMOD, plume rise is computed using the methods of Briggs excepting cases involving building downwash, in which a numerical solution of the mass, energy, and momentum conservation laws is performed.[23] No explicit provisions in these models are made for multistack plume rise enhancement or the handling of such special plumes as flares; these problems should be considered on a case-by-case basis.

b. Gradual plume rise is generally recommended where its use is appropriate: (1) In AERMOD; (2) in complex terrain screening procedures to determine close-in impacts and (3) when calculating the effects of building wakes. The building wake algorithm in AERMOD incorporates and exercises the thermodynamically based gradual plume rise calculations as described in (a) above. If the building wake is calculated to affect the plume for any hour, gradual plume rise is also used in downwind dispersion calculations to the distance of final plume rise, after which final plume rise is used. Plumes captured by the near wake are re-emitted to the far wake as a ground-level volume source.

c. Stack tip downwash generally occurs with poorly constructed stacks and when the ratio of the stack exit velocity to wind speed is small. An algorithm developed by Briggs [77] is the recommended technique for this situation and is used in preferred models for point sources.

7.2.6 Chemical Transformation

a. The chemical transformation of SO_2 emitted from point sources or single industrial plants in rural areas is generally assumed to be relatively unimportant to the estimation of maximum concentrations when travel time is limited to a few hours. However, in urban areas, where synergistic effects among pollutants are of considerable consequence, chemical transformation rates may be of concern. In urban area applications, a half-life of 4 hours [75] may be applied to the analysis of SO_2 emissions. Calculations of transformation coefficients from site specific studies can be used to define a ''half-life'' to be used in a steady-state Gaussian plume model with any travel time, or in any application, if appropriate documentation is provided. Such conversion factors for pollutant half-life should not be used with screening analyses.

b. Use of models incorporating complex chemical mechanisms should be considered only on a case-by-case basis with proper demonstration of applicability. These are generally regional models not designed for the evaluation of individual sources but used primarily for region-wide evaluations. Visibility models also incorporate chemical transformation mechanisms which are an integral part of the visibility model itself and should be used in visibility assessments.

7.2.7 Gravitational Settling and Deposition

a. An ''infinite half-life'' should be used for estimates of particle concentrations when steady-state Gaussian plume models containing only exponential decay terms for treating settling and deposition are used.

b. Gravitational settling and deposition may be directly included in a model if either is a significant factor. When particulate matter sources can be quantified and settling and dry deposition are problems, professional judgement should be used, and there should be coordination with the appropriate reviewing authority (paragraph 3.0(b)).

7.2.8 Complex Winds

a. *Inhomogeneous Local Winds.* In many parts of the United States, the ground is neither flat nor is the ground cover (or land use) uniform. These geographical variations can generate local winds and circulations, and modify the prevailing ambient winds and circulations. Geographic effects are most apparent when the ambient winds are light or calm.[79] In general these geographically induced wind circulation effects are named after the source location of the winds, *e.g.*, lake and sea breezes, and mountain and valley winds. In very rugged hilly or mountainous terrain, along coastlines, or near large land use variations, the characterization of the winds is a balance of various forces, such that the assumptions of steady-state straight-line transport both in time and space are inappropriate. In the special cases described, the CALPUFF modeling system (described in Appendix A) may be applied on a case-by-case basis for air quality estimates in such complex non-steady-state meteorological conditions. The purpose of choosing a modeling system like CALPUFF is to fully treat the time and space variations of meteorology effects on transport and dispersion. The setup and application of the model should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) consistent with limitations of paragraph 3.2.2(e). The meteorological input data requirements for developing the time and space varying three-dimensional winds and dispersion meteorology for these situations are discussed in paragraphs 8.3.1.2(d) and 8.3.1.2(f). Examples of inhomogeneous winds include, but aren't limited to, situations described in the following paragraphs (i)—(iii):

i. *Inversion Breakup Fumigation.* Inversion breakup fumigation occurs when a plume (or multiple plumes) is emitted into a stable layer of air and that layer is subsequently mixed to the ground through convective transfer of heat from the surface or because of advection to less stable surroundings. Fumigation may cause excessively high concentrations but is usually rather short-lived at a given receptor. There are no recommended refined techniques to model this phenomenon. There are, however, screening procedures [24] that may be used to approximate the concentrations. Considerable care should be exercised in using the results obtained from the screening techniques.

ii. *Shoreline Fumigation.* Fumigation can be an important phenomenon on and near the shoreline of bodies of water. This can affect both individual plumes and area-wide emissions. When fumigation conditions are expected to occur from a source or sources with tall stacks located on or just inland of a shoreline, this should be addressed in the air quality modeling analysis. The Shoreline Dispersion Model (SDM) listed on EPA's Internet SCRAM Web site (subsection 2.3) may be applied on a case-by-case basis when air quality estimates under shoreline fumigation conditions are needed.[80] Information on the results of EPA's evaluation of this model together with other coastal fumigation models is available.[81] Selection of the appropriate model for applications where shoreline fumigation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

iii. *Stagnation.* Stagnation conditions are characterized by calm or very low wind speeds, and variable wind directions. These stagnant meteorological conditions may persist for several hours to several days. During stagnation conditions, the dispersion of air pollutants, especially those from low-level emissions sources, tends to be minimized, potentially leading to relatively high ground-level concentrations. If point sources are of interest, users should note the guidance provided for CALPUFF in paragraph (a) of this subsection. Selection of the appropriate model for applications where stagnation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

7.2.9 Calibration of Models

a. Calibration of models is not common practice and is subject to much error and misunderstanding. There have been attempts by some to compare model estimates and measurements on an event-by-event basis and then to calibrate a model with results of that comparison. This approach is severely limited by uncertainties in both source and meteorological data and therefore it is difficult to precisely estimate the concentration at an exact location for a specific increment of time. Such uncertainties make calibration of models of questionable benefit. Therefore, model calibration is unacceptable.

8.0 Model Input Data

a. Data bases and related procedures for estimating input parameters are an integral part of the modeling procedure. The most appropriate data available should always be selected for use in modeling analyses. Concentrations can vary widely depending on the source data or meteorological data used. Input data are a major source of uncertainties in any modeling analysis. This section attempts to minimize the uncertainty associated with data base selection and use by identifying requirements for data used in modeling. A checklist of input data requirements for modeling analyses is posted on EPA's Internet SCRAM Web site (subsection 2.3). More specific data requirements and the format required for the individual models are described in detail in the users' guide for each model.

8.1 Source Data

8.1.1 Discussion

a. Sources of pollutants can be classified as point, line and area/volume sources. Point sources are defined in terms of size and may vary between regulatory programs. The line sources most frequently considered are roadways and streets along which there are well-defined movements of motor vehicles, but they may be lines of roof vents or stacks such as in aluminum refineries. Area and volume sources are often collections of a multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Large area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square.

b. Emission factors are compiled in an EPA publication commonly known as AP–42 [82]; an indication of the quality and amount of data on which many of the factors are based is also provided. Other information concerning emissions is available in EPA publications relating to specific source categories. The appropriate reviewing authority (paragraph 3.0(b)) should be consulted to determine appropriate source definitions and for guidance concerning the determination of emissions from and techniques for modeling the various source types.

8.1.2 Recommendations

a. For point source applications the load or operating condition that causes maximum ground-level concentrations should be established. As a minimum, the source should be modeled using the design capacity (100 percent load). If a source operates at greater than design capacity for periods that could result in violations of the standards or PSD increments, this load) [a] should be modeled. Where the source operates at substantially less than design capacity, and the changes in the stack parameters associated with the operating conditions could lead to higher ground level concentrations, loads such as 50 percent and 75 percent of capacity should also be modeled. A range of operating conditions should be considered in screening analyses; the load causing the highest concentration, in addition to the design load, should be included in refined modeling. For a steam power plant, the following (b–h) is typical of the kind of data on source characteristics and operating conditions that may be needed. Generally, input data requirements for air quality models necessitate the use of metric units; where English units are common for engineering usage, a conversion to metric is required.

b. *Plant layout.* The connection scheme between boilers and stacks, and the distance and direction between stacks, building parameters (length, width, height, location and orientation relative to stacks) for plant structures which house boilers, control equipment, and surrounding buildings within a distance of approximately five stack heights.

c. *Stack parameters.* For all stacks, the stack height and inside diameter (meters), and the temperature (K) and volume flow rate (actual cubic meters per second) or exit gas velocity (meters per second) for operation at 100 percent, 75 percent and 50 percent load.

d. *Boiler size.* For all boilers, the associated megawatts, 10^6 BTU/hr, and pounds of steam per hour, and the design and/or actual fuel consumption rate for 100 percent load for coal (tons/hour), oil (barrels/hour), and natural gas (thousand cubic feet/hour).

e. *Boiler parameters.* For all boilers, the percent excess air used, the boiler type (e.g., wet bottom, cyclone, etc.), and the type of firing (e.g., pulverized coal, front firing, etc.).

f. *Operating conditions.* For all boilers, the type, amount and pollutant contents of fuel, the total hours of boiler operation and the boiler capacity factor during the year, and the percent load for peak conditions.

g. *Pollution control equipment parameters.* For each boiler served and each pollutant affected, the type of emission control equipment, the year of its installation, its design efficiency and mass emission rate, the date of the last test and the tested efficiency, the number of hours of operation during the latest year, and the best engineering estimate of its projected efficiency if used in conjunction with coal combustion; data for any anticipated modifications or additions.

h. *Data for new boilers or stacks.* For all new boilers and stacks under construction

[a] Malfunctions which may result in excess emissions are not considered to be a normal operating condition. They generally should not be considered in determining allowable emissions. However, if the excess emissions are the result of poor maintenance, careless operation, or other preventable conditions, it may be necessary to consider them in determining source impact.

and for all planned modifications to existing boilers or stacks, the scheduled date of completion, and the data or best estimates available for items (b) through (g) of this subsection following completion of construction or modification.

i. In stationary point source applications for compliance with short term ambient standards, SIP control strategies should be tested using the emission input shown on Table 8–1. When using a refined model, sources should be modeled sequentially with these loads for every hour of the year. To evaluate SIPs for compliance with quarterly and annual standards, emission input data shown in Table 8–1 should again be used. Emissions from area sources should generally be based on annual average conditions. The source input information in each model user's guide should be carefully consulted and the checklist (paragraph 8.0(a)) should also be consulted for other possible emission data that could be helpful. NAAQS compliance demonstrations in a PSD analysis should follow the emission input data shown in Table 8–2. For purposes of emissions trading, new source review and demonstrations, refer to current EPA policy and guidance to establish input data.

j. Line source modeling of streets and highways requires data on the width of the roadway and the median strip, the types and amounts of pollutant emissions, the number of lanes, the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments should be specified by appropriate grid coordinates. Detailed information and data requirements for modeling mobile sources of pollution are provided in the user's manuals for each of the models applicable to mobile sources.

k. The impact of growth on emissions should be considered in all modeling analyses covering existing sources. Increases in emissions due to planned expansion or planned fuel switches should be identified. Increases in emissions at individual sources that may be associated with a general industrial/commercial/residential expansion in multi-source urban areas should also be treated. For new sources the impact of growth on emissions should generally be considered for the period prior to the start-up date for the source. Such changes in emissions should treat increased area source emissions, changes in existing point source emissions which were not subject to preconstruction review, and emissions due to sources with permits to construct that have not yet started operation.

TABLE 8–1.—MODEL EMISSION INPUT DATA FOR POINT SOURCES [1]

Averaging time	Emission limit (#/MMBtu) [2]	×	Operating level (MMBtu/hr) [2]	×	Operating factor (e.g., hr/yr, hr/day)
Stationary Point Source(s) Subject to SIP Emission Limit(s) Evaluation for Compliance with Ambient Standards (Including Areawide Demonstrations)					
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.		Actual or design capacity (whichever is greater), or federally enforceable permit condition.		Actual operating factor averaged over most recent 2 years.[3]
Short term	Maximum allowable emission limit or federally enforceable permit limit.		Actual or design capacity (whichever is greater), or federally enforceable permit condition.[4]		Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base).[5]
Nearby Source(s) [6 7]					
Same input requirements as for stationary point source(s) above.					
Other Source(s) [7]					
If modeled (subsection 8.2.3), input data requirements are defined below.					
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.[6]		Annual level when actually operating, averaged over the most recent 2 years.[3]		Actual operating factor averaged over the most recent 2 years.[3]
Short term	Maximum allowable emission limit or federally enforceable permit limit.[6]		Annual level when actually operating, averaged over the most recent 2 years.[3]		Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base).[5]

[1] The model input data requirements shown on this table apply to stationary source control strategies for STATE IMPLEMENTATION PLANS. For purposes of emissions trading, new source review, or prevention of significant deterioration, other model input criteria may apply. Refer to the policy and guidance for these programs to establish the input data.

[2] Terminology applicable to fuel burning sources; analogous terminology (e.g., #/throughput) may be used for other types of sources.

[3] Unless it is determined that this period is not representative.

[4] Operating levels such as 50 percent and 75 percent of capacity should also be modeled to determine the load causing the highest concentration.

[5] If operation does not occur for all hours of the time period of consideration (e.g., 3 or 24 hours) and the source operation is constrained by a federally enforceable permit condition, an appropriate adjustment to the modeled emission rate may be made (e.g., if operation is only 8 a.m. to 4 p.m. each day, only these hours will be modeled with emissions from the source. Modeled emissions should not be averaged across non-operating time periods.)

[6] See paragraph 8.2.3(c).

[7] See paragraph 8.2.3(d).

TABLE 8–2.—POINT SOURCE MODEL EMISSION INPUT DATA FOR NAAQS COMPLIANCE IN PSD DEMONSTRATIONS

Averaging time	Emission limit (#/MMBtu)[1]	×	Operating level (MMBtu/hr)[1]	×	Operating factor (e.g., hr/yr, hr/day)
Proposed Major New or Modified Source					
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.		Design capacity or federally enforceable permit condition.		Continuous operation (i.e., 8760 hours).[2]
Short term (≤ 24 hours)	Maximum allowable emission limit or federally enforceable permit limit.		Design capacity or federally enforceable permit condition.[3]		Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base).[2]
Nearby Source(s)[4,6]					
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.[5]		Actual or design capacity (whichever is greater), or federally enforceable permit condition.		Actual operating factor averaged over the most recent 2 years.[7,8]
Short term (≤ 24 hours)	Maximum allowable emission limit or federally enforceable permit limit.[5]		Actual or design capacity (whichever is greater), or federally enforceable permit condition.[3]		Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base).[2]
Other Source(s)[6,9]					
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.[5]		Annual level when actually operating, averaged over the most recent 2 years.[7]		Actual operating factor averaged over the most recent 2 years.[7,8]
Short term (≤ 24 hours)	Maximum allowable emission limit or federally enforceable permit limit.[5]		Annual level when actually operating, averaged over the most recent 2 years.[7]		Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base).[2]

[1] Terminology applicable to fuel burning sources; analogous terminology (e.g., #/throughput) may be used for other types of sources.

[2] If operation does not occur for all hours of the time period of consideration (e.g., 3 or 24 hours) and the source operation is constrained by a federally enforceable permit condition, an appropriate adjustment to the modeled emission rate may be made (e.g., if operation is only 8 a.m. to 4 p.m. each day, only these hours will be modeled with emissions from the source. Modeled emissions should not be averaged across non-operating time periods.

[3] Operating levels such as 50 percent and 75 percent of capacity should also be modeled to determine the load causing the highest concentration.

[4] Includes existing facility to which modification is proposed if the emissions from the existing facility will not be affected by the modification. Otherwise use the same parameters as for major modification.

[5] See paragraph 8.2.3(c).

[6] See paragraph 8.2.3(d).

[7] Unless it is determined that this period is not representative.

[8] For those permitted sources not in operation or that have not established an appropriate factor, continuous operation (i.e., 8760) should be used.

[9] Generally, the ambient impacts from non-nearby (background) sources can be represented by air quality data unless adequate data do not exist.

8.2 Background Concentrations

8.2.1 Discussion

a. Background concentrations are an essential part of the total air quality concentration to be considered in determining source impacts. Background air quality includes pollutant concentrations due to: (1) Natural sources; (2) nearby sources other than the one(s) currently under consideration; and (3) unidentified sources.

b. Typically, air quality data should be used to establish background concentrations in the vicinity of the source(s) under consideration. The monitoring network used for background determinations should conform to the same quality assurance and other requirements as those networks established for PSD purposes.[83] An appropriate data validation procedure should be applied to the data prior to use.

c. If the source is not isolated, it may be necessary to use a multi-source model to establish the impact of nearby sources. Since sources don't typically operate at their maximum allowable capacity (which may include the use of ''dirtier'' fuels), modeling is necessary to express the potential contribution of background sources, and this impact would not be captured via monitoring. Background concentrations should be determined for each critical (concentration) averaging time.

8.2.2 Recommendations (Isolated Single Source)

a. Two options (paragraph (b) or (c) of this section) are available to determine the background concentration near isolated sources.

b. Use air quality data collected in the vicinity of the source to determine the background concentration for the averaging times of concern. Determine the mean background concentration at each monitor by excluding values when the source in question is impacting the monitor. The mean annual background is the average of the annual concentrations so determined at each monitor. For shorter averaging periods, the meteorological conditions accompanying the concentrations of concern should be identified. Concentrations for meteorological conditions of concern, at monitors not impacted by the source in question, should be averaged for each separate averaging time to determine the average background value. Monitoring sites inside a 90° sector downwind of the source may be used to determine the area of impact. One hour concentrations may be added and averaged to determine longer averaging periods.

c. If there are no monitors located in the vicinity of the source, a ''regional site'' may be used to determine background. A ''regional site'' is one that is located away from the area of interest but is impacted by similar natural and distant man-made sources.

8.2.3 Recommendations (Multi-Source Areas)

a. In multi-source areas, two components of background should be determined: contributions from nearby sources and contributions from other sources.

b. *Nearby Sources:* All sources expected to cause a significant concentration gradient in the vicinity of the source or sources under consideration for emission limit(s) should be explicitly modeled. The number of such sources is expected to be small except in unusual situations. Owing to both the uniqueness of each modeling situation and the large number of variables involved in identifying nearby sources, no attempt is made here to comprehensively define this term. Rather, identification of nearby sources calls for the exercise of professional judgement by the appropriate reviewing authority (paragraph 3.0(b)). This guidance is not intended to alter the exercise of that judgement or to comprehensively define which sources are nearby sources.

c. For compliance with the short-term and annual ambient standards, the nearby sources as well as the primary source(s) should be evaluated using an appropriate Appendix A model with the emission input data shown in Table 8–1 or 8–2. When modeling a nearby source that does not have a permit and the emission limit contained in the SIP for a particular source category is greater than the emissions possible given the source's maximum physical capacity to emit, the ''maximum allowable emission limit'' for such a nearby source may be calculated as the emission rate representative of the nearby source's maximum physical capacity to emit, considering its design specifications and allowable fuels and process materials. However, the burden is on the permit applicant to sufficiently document what the maximum physical capacity to emit is for such a nearby source.

d. It is appropriate to model nearby sources only during those times when they, by their nature, operate at the same time as the primary source(s) being modeled. Where a primary source believes that a nearby source does not, by its nature, operate at the same time as the primary source being modeled, the burden is on the primary source to demonstrate to the satisfaction of the appropriate reviewing authority (paragraph 3.0(b)) that this is, in fact, the case. Whether or not the primary source has adequately demonstrated that fact is a matter of professional judgement left to the discretion of the appropriate reviewing authority. The following examples illustrate two cases in which a nearby source may be shown not to operate at the same time as the primary source(s) being modeled. Some sources are only used during certain seasons of the year. Those sources would not be modeled as nearby sources during times in which they do not operate. Similarly, emergency backup generators that never operate simultaneously with the sources that they back up would not be modeled as nearby sources. To reiterate, in these examples and other appropriate cases, the burden is on the primary source being modeled to make the appropriate demonstration to the satisfaction of the appropriate reviewing authority.

e. The impact of the nearby sources should be examined at locations where interactions between the plume of the point source under consideration and those of nearby sources (plus natural background) can occur. Significant locations include: (1) the area of maximum impact of the point source; (2) the area of maximum impact of nearby sources; and (3) the area where all sources combine to cause maximum impact. These locations may be identified through trial and error analyses.

f. *Other Sources:* That portion of the background attributable to all other sources (*e.g.*, natural sources, minor sources and distant major sources) should be determined by the procedures found in subsection 89.2.2 or by application of a model using Table 8–1 or 8–2.

8.3 Meteorological Input Data

a. The meteorological data used as input to a dispersion model should be selected on the basis of spatial and climatological (temporal) representativeness as well as the ability of the individual parameters selected to characterize the transport and dispersion conditions in the area of concern. The representativeness of the data is dependent on: (1) The proximity of the meteorological monitoring site to the area under consideration; (2) the complexity of the terrain; (3) the exposure of the meteorological monitoring site; and (4) the period of time during which data are collected. The spatial representativeness of the data can be adversely affected by large distances between the source and receptors of interest and the complex topographic characteristics of the area. Temporal representativeness is a function of the year-to-year variations in weather conditions. Where appropriate, data representativeness should be viewed in terms of the appropriateness of the data for constructing realistic boundary layer profiles and three dimensional meteorological fields, as described in paragraphs (c) and (d) below.

b. Model input data are normally obtained either from the National Weather Service or as part of a site specific measurement program. Local universities, Federal Aviation Administration (FAA), military stations, industry and pollution control agencies may also be sources of such data. Some recommendations for the use of each type of data are included in this subsection.

c. Regulatory application of AERMOD requires careful consideration of minimum data for input to AERMET. Data representativeness, in the case of AERMOD, means utilizing data of an appropriate type for constructing realistic boundary layer profiles. Of paramount importance is the requirement that all meteorological data used as input to AERMOD must be both laterally and vertically representative of the transport and dispersion within the analysis domain. Where surface conditions vary significantly over the analysis domain, the emphasis in assessing representativeness should be given to adequate characterization of transport and dispersion between the source(s) of concern and areas where maximum design concentrations are anticipated to occur. The representativeness of data that were collected off-site should be judged, in part, by comparing the surface characteristics in the vicinity of the meteorological monitoring site with the surface characteristics that generally describe the analysis domain. The surface characteristics input to AERMET should be based on the topographic conditions in the vicinity of the meteorological tower. Furthermore, since the spatial scope of each variable could be different, representativeness should be judged for each variable separately. For example, for a variable such as wind direction, the data may need to be collected very near plume height to be adequately representative, whereas, for a variable such as temperature, data from a station several kilometers away from the source may in some cases be considered to be adequately representative.

d. For long range transport modeling assessments (subsection 6.2.3) or for assessments where the transport winds are complex and the application involves a non-steady-state dispersion model (subsection 7.2.8), use of output from prognostic mesoscale meteorological models is encouraged.[84 85 86] Some diagnostic meteorological processors are designed to appropriately blend available NWS comparable meteorological observations, local site specific meteorological observations, and prognostic mesoscale meteorological data, using empirical relationships, to diagnostically adjust the wind field for mesoscale and local-scale effects. These diagnostic adjustments can sometimes be improved through the use of strategically placed site specific meteorological observations. The placement of these special meteorological observations (often more than one location is needed) involves expert judgement, and is specific to the terrain and land use of the modeling domain. Acceptance for use of output from prognostic mesoscale meteorological models is contingent on concurrence by the appropriate reviewing authorities (paragraph 3.0(b)) that the data are of acceptable quality, which can be demonstrated through statistical comparisons with observations of winds aloft and at the surface at several appropriate locations.

8.3.1 Length of Record of Meteorological Data

8.3.1.1 Discussion

a. The model user should acquire enough meteorological data to ensure that worst-case meteorological conditions are adequately represented in the model results. The trend toward statistically based standards suggests a need for all meteorological conditions to be adequately represented in the data set selected for model input. The number of years of record needed to obtain a stable distribution of conditions depends on the variable being measured and has been estimated by Landsberg and Jacobs [87] for various parameters. Although that study indicates in excess of 10 years may be required to achieve stability in the frequency distributions of some meteorological variables, such long periods are not reasonable for model input data. This is due in part to the fact that hourly data in model input format are frequently not available for such periods and that hourly calculations of concentration for long periods may be prohibitively expensive. Another study [88] compared various periods from a 17-year data set to determine the minimum number of years of data needed to approximate the concentrations modeled with a 17-year period of meteorological data from one station. This study indicated that the variability of model estimates due to the meteorological data input was adequately reduced if a 5-year period of record of meteorological input was used.

8.3.1.2 Recommendations

a. Five years of representative meteorological data should be used when estimating concentrations with an air quality model. Consecutive years from the most recent, readily available 5-year period are preferred. The meteorological data should be *adequately representative*, and may be site specific or from a nearby NWS station. Where professional judgment indicates NWS-collected ASOS (automated surface observing stations) data are inadequate {for cloud cover observations}, the most recent 5 years of NWS data that are observer-based may be considered for use.

b. The use of 5 years of NWS meteorological data or at least l year of site specific data is required. If one year or more (including partial years), up to five years, of site specific data is available, these data are preferred for use in air quality analyses. Such data should have been subjected to quality assurance procedures as described in subsection 8.3.3.2.

c. For permitted sources whose emission limitations are based on a specific year of meteorological data, that year should be added to any longer period being used (*e.g.*, 5 years of NWS data) when modeling the facility at a later time.

d. For LRT situations (subsection 6.2.3) and for complex wind situations (paragraph 7.2.8(a)), if only NWS or comparable standard meteorological observations are employed, five years of meteorological data (within and near the modeling domain) should be used. Consecutive years from the most recent, readily available 5-year period are preferred. Less than five, but at least three, years of meteorological data (need not be consecutive) may be used if mesoscale meteorological fields are available, as discussed in paragraph 8.3(d). These mesoscale meteorological fields should be used in conjunction with available standard NWS or comparable meteorological observations within and near the modeling domain.

e. For solely LRT applications (subsection 6.2.3), if site specific meteorological data are available, these data may be helpful when used in conjunction with available standard NWS or comparable observations and mesoscale meteorological fields as described in paragraph 8.3.1.2(d).

f. For complex wind situations (paragraph 7.2.8(a)) where site specific meteorological data are being relied upon as the basis for characterizing the meteorological conditions, a data base of at least 1 full-year of meteorological data is required. If more data are available, they should be used. Site specific meteorological data may have to be collected at multiple locations. Such data should have been subjected to quality assurance procedures as described in paragraph 8.3.3.2(a), and should be reviewed for spatial and temporal representativeness.

8.3.2 National Weather Service Data

8.3.2.1 Discussion

a. The NWS meteorological data are routinely available and familiar to most model users. Although the NWS does not provide direct measurements of all the needed dispersion model input variables, methods have been developed and successfully used to translate the basic NWS data to the needed model input. Site specific measurements of model input parameters have been made for many modeling studies, and those methods and techniques are becoming more widely applied, especially in situations such as complex terrain applications, where available NWS data are not adequately representative. However, there are many model applications where NWS data are adequately representative, and the applications still rely heavily on the NWS data.

b. Many models use the standard hourly weather observations available from the National Climatic Data Center (NCDC). These observations are then preprocessed before they can be used in the models.

8.3.2.2 Recommendations

a. The preferred models listed in Appendix A all accept as input the NWS meteorological data preprocessed into model compatible form. If NWS data are judged to be adequately representative for a particular modeling application, they may be used. NCDC makes available surface [89 90] and upper air [91] meteorological data in CD–ROM format.

b. Although most NWS measurements are made at a standard height of 10 meters, the actual anemometer height should be used as input to the preferred model. Note that AERMOD at a minimum requires wind observations at a height above ground between seven times the local surface roughness height and 100 meters.

c. Wind directions observed by the National Weather Service are reported to the nearest 10 degrees. A specific set of randomly generated numbers has been developed for use with the preferred EPA models and should be used with NWS data to ensure a lack of bias in wind direction assignments within the models.

d. Data from universities, FAA, military stations, industry and pollution control agencies may be used if such data are equivalent in accuracy and detail to the NWS data, and they are judged to be adequately representative for the particular application.

8.3.3 Site Specific Data

8.3.3.1 Discussion

a. Spatial or geographical representativeness is best achieved by collection of all of the needed model input data in close proximity to the actual site of the source(s). Site specific measured data are therefore preferred as model input, provided that appropriate instrumentation and quality assurance procedures are followed and that the data collected are adequately representative (free from inappropriate local or microscale influences) and compatible with the input requirements of the model to be used. It should be noted that, while site specific measurements are frequently made ''on-property'' (*i.e.*, on the source's premises), acquisition of adequately representative site specific data does not preclude collection of data from a location off property. Conversely, collection of meteorological data on a source's property does not of itself guarantee adequate representativeness. For help in determining representativeness of site specific measurements, technical guidance [92] is available. Site specific data should always be reviewed for representativeness and consistency by a qualified meteorologist.

8.3.3.2 Recommendations

a. EPA guidance [92] provides recommendations on the collection and use of site specific meteorological data. Recommendations on characteristics, siting, and exposure of meteorological instruments and on data recording, processing, completeness requirements, reporting, and archiving are also included. This publication should be used as a supplement to other limited guidance on these subjects.[83 93 94] Detailed information on quality assurance is also available.[95] As a minimum, site specific measurements of ambient air temperature, transport wind speed and direction, and the variables necessary to estimate atmospheric dispersion should be available in meteorological data sets to be used in modeling. Care should be taken to ensure that meteorological instruments are located to provide representative characterization of pollutant transport between sources and receptors of interest. The appropriate reviewing authority (paragraph 3.0(b)) is available to help determine the appropriateness of the measurement locations.

b. All site specific data should be reduced to hourly averages. Table 8–3 lists the wind related parameters and the averaging time requirements.

c. *Missing Data Substitution.* After valid data retrieval requirements have been met [92], hours in the record having missing data should be treated according to an established data substitution protocol provided that data from an adequately representative alternative site are available. Such protocols are usually part of the approved monitoring program plan. Data substitution guidance is provided in Section 5.3 of reference 92. If no representative alternative data are available for substitution, the absent data should be coded as missing using missing data codes appropriate to the applicable meteorological pre-processor. Appropriate model options for treating missing data, if available in the model, should be employed.

d. *Solar Radiation Measurements.* Total solar radiation or net radiation should be measured with a reliable pyranometer or net radiometer, sited and operated in accordance with established site specific meteorological guidance.[92] [95]

e. *Temperature Measurements.* Temperature measurements should be made at standard shelter height (2m) in accordance with established site specific meteorological guidance.[92]

f. *Temperature Difference Measurements.* Temperature difference (ΔT) measurements should be obtained using matched thermometers or a reliable thermocouple system to achieve adequate accuracy. Siting, probe placement, and operation of ΔT systems should be based on guidance found in Chapter 3 of reference 92, and such guidance should be followed when obtaining vertical temperature gradient data. AERMET employs the Bulk Richardson scheme which requires measurements of temperature difference. To ensure correct application and acceptance, AERMOD users should consult with the appropriate Reviewing Authority before using the Bulk Richardson scheme for their analysis.

g. *Winds Aloft.* For simulation of plume rise and dispersion of a plume emitted from a stack, characterization of the wind profile up through the layer in which the plume disperses is required. This is especially important in complex terrain and/or complex wind situations where wind measurements at heights up to hundreds of meters above stack base may be required in some circumstances. For tall stacks when site specific data are needed, these winds have been obtained traditionally using meteorological sensors mounted on tall towers. A feasible alternative to tall towers is the use of meteorological remote sensing instruments (e.g., acoustic sounders or radar wind profilers) to provide winds aloft, coupled with 10-meter towers to provide the near-surface winds. (For specific requirements for AERMOD and CTDMPLUS, *see* Appendix A.) Specifications for wind measuring instruments and systems are contained in reference 92.

h. *Turbulence.* There are several dispersion models that are capable of using direct measurements of turbulence (wind fluctuations) in the characterization of the vertical and lateral dispersion (e.g., CTDMPLUS, AERMOD, and CALPUFF). For specific requirements for CTDMPLUS, AERMOD, and CALPUFF, see Appendix A. For technical guidance on measurement and processing of turbulence parameters, see reference 92. When turbulence data are used in this manner to directly characterize the vertical and lateral dispersion, the averaging time for the turbulence measurements should be one hour (Table 8–3). There are other dispersion models (e.g., BLP, and CALINE3) that employ P–G stability categories for the characterization of the vertical and lateral dispersion. Methods for using site specific turbulence data for the characterization of P–G stability categories are discussed in reference 92. When turbulence data are used in this manner to determine the P–G stability category, the averaging time for the turbulence measurements should be 15 minutes.

i. *Stability Categories.* For dispersion models that employ P–G stability categories for the characterization of the vertical and lateral dispersion, the P–G stability categories, as originally defined, couple near-surface measurements of wind speed with subjectively determined insolation assessments based on hourly cloud cover and ceiling height observations. The wind speed measurements are made at or near 10m. The insolation rate is typically assessed using observations of cloud cover and ceiling height based on criteria outlined by Turner.[70] It is recommended that the P–G stability category be estimated using the Turner method with site specific wind speed measured at or near 10m and representative cloud cover and ceiling height. Implementation of the Turner method, as well as considerations in determining representativeness of cloud cover and ceiling height in cases for which site specific cloud observations are unavailable, may be found in Section 6 of reference 92. In the absence of requisite data to implement the Turner method, the SRDT method or wind fluctuation statistics (i.e., the σ_E and σ_A methods) may be used.

j. The SRDT method, described in Section 6.4.4.2 of reference 92, is modified slightly from that published from earlier work [96] and has been evaluated with three site specific data bases.[97] The two methods of stability classification which use wind fluctuation statistics, the σ_E and σ_A methods, are also described in detail in Section 6.4.4 of reference 92 (note applicable tables in Section 6). For additional information on the wind fluctuation methods, several references are available.[98] [99] [100] [101]

k. *Meteorological Data Preprocessors.* The following meteorological preprocessors are recommended by EPA: AERMET,[102] PCRAMMET,[103] MPRM,[104] METPRO,[105] and CALMET [106] AERMET, which is patterned after MPRM, should be used to preprocess all data for use with AERMOD. Except for applications that employ AERMOD, PCRAMMET is the recommended meteorological preprocessor for use in applications employing hourly NWS data. MPRM is a general purpose meteorological data preprocessor which supports regulatory models requiring PCRAMMET formatted (NWS) data. MPRM is available for use in applications employing site specific meteorological data. The latest version (MPRM 1.3) has been configured to implement the SRDT method for estimating P–G stability categories. METPRO is the required meteorological data preprocessor for use with CTDMPLUS. CALMET is available for use with applications of CALPUFF. All of the above mentioned data preprocessors are available for downloading from EPA's Internet SCRAM Web site (subsection 2.3).

TABLE 8–3.—AVERAGING TIMES FOR SITE SPECIFIC WIND AND TURBULENCE MEASUREMENTS

Parameter	Averaging time (hour)
Surface wind speed (for use in stability determinations)	1
Transport direction	1
Dilution wind speed	1
Turbulence measurements (σ_E and σ_A) for use in stability determinations	1[1]
Turbulence measurements for direct input to dispersion models	1

[1] To minimize meander effects in σ_A when wind conditions are light and/or variable, determine the hourly average σ value from four sequential 15-minute σ's according to the following formula:

$$\sigma_{1-hr} = \sqrt{\frac{\sigma_{15}^2 + \sigma_{15}^2 + \sigma_{15}^2 + \sigma_{15}^2}{4}}$$

8.3.4 Treatment of Near-Calms and Calms

8.3.4.1 Discussion

a. Treatment of calm or light and variable wind poses a special problem in model applications since steady-state Gaussian plume models assume that concentration is inversely proportional to wind speed. Furthermore, concentrations may become unrealistically large when wind speeds less than 1 m/s are input to the model. Procedures have been developed to prevent the occurrence of overly conservative concentration estimates during periods of calms. These procedures acknowledge that a steady-state Gaussian plume model does not apply during calm conditions, and that our knowledge of wind patterns and plume behavior during these conditions does not, at present, permit the development of a better technique. Therefore, the procedures disregard hours which are identified as calm. The hour is treated as missing and a convention for handling missing hours is recommended.

b. AERMOD, while fundamentally a steady-state Gaussian plume model, contains algorithms for dealing with low wind speed (near calm) conditions. As a result, AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s, but still greater than the instrument threshold. Required input to AERMET, the meteorological processor for AERMOD, includes a threshold wind speed and a reference wind speed. The threshold wind speed is typically the threshold of the instrument used to collect the wind speed data. The reference wind speed is selected by the model as the lowest level of non-missing wind speed and direction data where the speed is greater than the wind speed threshold, and the height of the measurement is between seven times the local surface roughness and 100 meters. If the only valid observation of the reference wind speed between these heights is less than the threshold, the hour is considered calm, and no concentration is calculated. None of the observed wind speeds in a measured wind profile that are less than the threshold speed are used in construction of the modeled wind speed profile in AERMOD.

8.3.4.2 Recommendations

a. Hourly concentrations calculated with steady-state Gaussian plume models using calms should not be considered valid; the wind and concentration estimates for these hours should be disregarded and considered to be missing. Critical concentrations for 3-, 8-, and 24-hour averages should be calculated by dividing the sum of the hourly concentrations for the period by the number of valid or non-missing hours. If the total number of valid hours is less than 18 for 24-hour averages, less than 6 for 8-hour averages or less than 3 for 3-hour averages, the total concentration should be divided by 18 for the 24-hour average, 6 for the 8-hour average and 3 for the 3-hour average. For annual averages, the sum of all valid hourly concentrations is divided by the number of non-calm hours during the year. AERMOD has been coded to implement these instructions. For models listed in Appendix A, a post-processor computer program, CALMPRO [107] has been prepared, is available on the SCRAM Internet Web site (subsection 2.3), and should be used.

b. Stagnant conditions that include extended periods of calms often produce high concentrations over wide areas for relatively long averaging periods. The standard steady-state Gaussian plume models are often not applicable to such situations. When stagnation conditions are of concern, other modeling techniques should be considered on a case-by-case basis (see also subsection 7.2.8).

c. When used in steady-state Gaussian plume models, measured site specific wind speeds of less than 1 m/s but higher than the response threshold of the instrument should be input as 1 m/s; the corresponding wind direction should also be input. Wind observations below the response threshold of the instrument should be set to zero, with the input file in ASCII format. For input to AERMOD, no adjustment should be made to the site specific wind data. In all cases involving steady-state Gaussian plume models, calm hours should be treated as missing, and concentrations should be calculated as in paragraph (a) of this subsection.

9.0 Accuracy and Uncertainty of Models

9.1 Discussion

a. Increasing reliance has been placed on concentration estimates from models as the primary basis for regulatory decisions concerning source permits and emission control requirements. In many situations, such as review of a proposed source, no practical alternative exists. Therefore, there is an obvious need to know how accurate models really are and how any uncertainty in the estimates affects regulatory decisions. During the 1980's, attempts were made to encourage development of standardized evaluation methods.[11 108] EPA recognized the need for incorporating such information and has sponsored workshops [109] on model accuracy, the possible ways to quantify accuracy, and on considerations in the incorporation of model accuracy and uncertainty in the regulatory process. The Second (EPA) Conference on Air Quality Modeling, August 1982 [110], was devoted to that subject.

b. To better deduce the statistical significance of differences seen in model performance in the face of unaccounted for uncertainties and variations, investigators have more recently explored the use of bootstrap techniques.[111 112] Work is underway to develop a new generation of evaluation metrics [16] that takes into account the statistical differences (in error distributions) between model predictions and observations.[113] Even though the procedures and measures are still evolving to describe performance of models that characterize atmospheric fate, transport and diffusion [114 115 116], there has been general acceptance of a need to address the uncertainties inherent in atmospheric processes.

9.1.1 Overview of Model Uncertainty

a. Dispersion models generally attempt to estimate concentrations at specific sites that really represent an ensemble average of numerous repetitions of the same event.[16] The event is characterized by measured or ''known'' conditions that are input to the models, *e.g.,* wind speed, mixed layer height, surface heat flux, emission characteristics, etc. However, in addition to the known conditions, there are unmeasured or unknown variations in the conditions of this event, *e.g.,* unresolved details of the atmospheric flow such as the turbulent velocity field. These unknown conditions, may vary among repetitions of the event. As a result, deviations in observed concentrations from their ensemble average, and from the concentrations estimated by the model, are likely to occur even though the known conditions are fixed. Even with a *perfect model* that predicts the correct ensemble average, there are likely to be deviations from the observed concentrations in individual repetitions of the event, due to variations in the unknown conditions. The statistics of these concentration residuals are termed ''inherent'' uncertainty. Available evidence suggests that this source of uncertainty alone may be responsible for a typical range of variation in concentrations of as much as ±50 percent.[117]

b. Moreover, there is ''reducible'' uncertainty [108] associated with the model and its input conditions; neither models nor data bases are perfect. Reducible uncertainties are caused by: (1) Uncertainties in the input values of the known conditions (*i.e.,* emission characteristics and meteorological data); (2) errors in the measured concentrations which are used to compute the concentration residuals; and (3) inadequate model physics and formulation. The ''reducible'' uncertainties can be minimized through better (more accurate and more representative) measurements and better model physics.

c. To use the terminology correctly, reference to model accuracy should be limited to that portion of reducible uncertainty which deals with the physics and the formulation of the model. The accuracy of the model is normally determined by an evaluation procedure which involves the comparison of model concentration estimates with measured air quality data.[118] The statement of accuracy is based on statistical tests or performance measures such as bias, noise, correlation, etc.[11] However, information that allows a distinction between contributions of the various elements of inherent and reducible uncertainty is only now beginning to emerge.[16] As a result most discussions of the accuracy of models make no quantitative distinction between (1) limitations of the model versus (2) limitations of the data base and of knowledge concerning atmospheric variability. The reader should be aware that statements on model accuracy and uncertainty may imply the need for improvements in model performance that even the ''perfect'' model could not satisfy.

9.1.2 Studies of Model Accuracy

a. A number of studies [119 120] have been conducted to examine model accuracy, particularly with respect to the reliability of short-term concentrations required for ambient standard and increment evaluations. The results of these studies are not surprising. Basically, they confirm what expert atmospheric scientists have said for some time: (1) Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations; and (2) the models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area. For example, errors in highest estimated concentrations of ± 10 to 40 percent are found to be typical [121 122], *i.e.,* certainly well within the often quoted factor-of-two accuracy that has long been recognized for these models. However, estimates of concentrations that occur at a specific time and site, are poorly correlated with actually observed concentrations and are much less reliable.

b. As noted above, poor correlations between paired concentrations at fixed stations may be due to ''reducible'' uncertainties in knowledge of the precise plume location and to unquantified inherent uncertainties. For example, Pasquill [123] estimates that, apart from data input errors, maximum ground-level concentrations at a given hour for a point source in flat terrain could be in error by 50 percent due to these uncertainties. Uncertainty of five to 10 degrees in the measured wind direction, which transports the plume, can result in concentration errors of 20 to 70 percent for a particular time and location, depending on stability and station location. Such uncertainties do not indicate that an estimated concentration does not occur, only that the precise time and locations are in doubt.

9.1.3 Use of Uncertainty in Decision-Making

a. The accuracy of model estimates varies with the model used, the type of application, and site specific characteristics. Thus, it is desirable to quantify the accuracy or uncertainty associated with concentration estimates used in decision-making. Communications between modelers and decision-makers must be fostered and further developed. Communications concerning concentration estimates currently exist in most cases, but the communications dealing with the accuracy of models and its meaning to the decision-maker are limited by the lack of a technical basis for quantifying and directly including uncertainty in decisions. Procedures for quantifying and interpreting uncertainty in the practical application of such concepts are only beginning to evolve; much study is still required.[108 109 110 124 125]

b. In all applications of models an effort is encouraged to identify the reliability of the model estimates for that particular area and to determine the magnitude and sources of error associated with the use of the model. The analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the procedure. Information that might be useful to the decision-maker in recognizing the seriousness of potential air quality violations includes such model accuracy estimates as accuracy of peak predictions, bias, noise, correlation, frequency distribution, spatial extent of high concentration, etc. Both space/time pairing of estimates and measurements and unpaired comparisons are recommended. Emphasis should be on the highest concentrations and the averaging times of the standards or increments of concern. Where possible, confidence intervals about the statistical values should be provided. However, while such information can be provided by the modeler to the decision-maker, it is unclear how this information should be used to make an air pollution control decision. Given a range of possible outcomes, it is easiest and tends to ensure consistency if the decision-maker confines his judgement to use of the ''best estimate'' provided by the modeler (*i.e.,* the design concentration estimated by a model recommended in the *Guideline* or an alternate model of known accuracy). This is an indication of the practical limitations imposed by current abilities of the technical community.

c. To improve the basis for decision-making, EPA has developed and is continuing to study procedures for determining the accuracy of models, quantifying the uncertainty, and expressing confidence levels in decisions that are made concerning emissions controls.[126 127] However, work in this area involves ''breaking new ground'' with slow and sporadic progress likely. As a result, it may be necessary to continue using the ''best estimate'' until sufficient technical progress has been made to meaningfully implement such concepts dealing with uncertainty.

9.1.4 Evaluation of Models

a. A number of actions have been taken to ensure that the best model is used correctly for each regulatory application and that a model is not arbitrarily imposed. First, the *Guideline* clearly recommends the most appropriate model be used in each case. Preferred models, based on a number of factors, are identified for many uses. General guidance on using alternatives to the preferred models is also provided. Second, the models have been subjected to a systematic performance evaluation and a peer scientific review. Statistical performance measures, including measures of difference (or residuals) such as bias, variance of difference and gross variability of the difference, and measures of correlation such as time, space, and time and space combined as recommended by the AMS Woods Hole Workshop [11], were generally followed. Third, more specific information has been provided for justifying the site specific use of alternative models in previously cited EPA guidance [15], and new models are under consideration and review.[16] Together these documents provide methods that allow a judgement to be made as to what models are most appropriate for a specific application. For the present, performance and the theoretical evaluation of models are being used as an indirect means to quantify one element of uncertainty in air pollution regulatory decisions.

b. EPA has participated in a series of conferences entitled, ''Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.'' [128] for the purpose of promoting the development of improved methods for the characterization of model performance. There is a consensus developing on what should be considered in the evaluation of air quality models [129], namely quality assurance planning, documentation and scrutiny should be consistent with the intended use, and should include:

- Scientific peer review;
- Supportive analyses (diagnostic evaluations, code verification, sensitivity and uncertainty analyses);
- Diagnostic and performance evaluations with data obtained in trial locations, and
- Statistical performance evaluations in the circumstances of the intended applications.

Performance evaluations and diagnostic evaluations assess different qualities of how well a model is performing, and both are needed to establish credibility within the client and scientific community. Performance evaluations allow us to decide how well the model simulates the average temporal and spatial patterns seen in the observations, and employ large spatial/temporal scale data sets (*e.g.,* national data sets). Performance evaluations also allow determination of relative performance of a model in comparison with alternative modeling systems. Diagnostic evaluations allow determination of a model capability to simulate individual processes that affect the results, and usually employ smaller spatial/temporal scale date sets (*e.g.,* field studies). Diagnostic evaluations allow us to decide if we get the right answer for the right reason. The objective comparison of modeled concentrations with observed field data provides only a partial means for assessing model performance. Due to the limited supply of evaluation data sets, there are severe practical limits in assessing model performance. For this reason, the conclusions reached in the science peer reviews and the supportive analyses have particular relevance in deciding whether a model will be useful for its intended purposes.

c. To extend information from diagnostic and performance evaluations, sensitivity and uncertainty analyses are encouraged since they can provide additional information on the effect of inaccuracies in the data bases and on the uncertainty in model estimates. Sensitivity analyses can aid in determining the effect of inaccuracies of variations or uncertainties in the data bases on the range of likely concentrations. Uncertainty analyses can aid in determining the range of likely concentration values, resulting from uncertainties in the model inputs, the model formulations, and parameterizations. Such information may be used to determine source impact and to evaluate control strategies. Where possible, information from such sensitivity analyses should be made available to the decision-maker with an appropriate interpretation of the effect on the critical concentrations.

9.2 Recommendations

a. No specific guidance on the quantification of model uncertainty for use in decision-making is being given at this time. As procedures for considering uncertainty develop and become implementable, this guidance will be changed and expanded. For the present, continued use of the ''best estimate'' is acceptable; however, in specific circumstances for O_3, PM–2.5 and regional haze, additional information and/or procedures may be appropriate.[32 33]

10.0 Regulatory Application of Models

10.1 Discussion

a. Procedures with respect to the review and analysis of air quality modeling and data analyses in support of SIP revisions, PSD permitting or other regulatory requirements need a certain amount of standardization to ensure consistency in the depth and comprehensiveness of both the review and the analysis itself. This section recommends procedures that permit some degree of standardization while at the same time allowing the flexibility needed to assure the technically best analysis for each regulatory application.

b. Dispersion model estimates, especially with the support of measured air quality data, are the preferred basis for air quality demonstrations. Nevertheless, there are instances where the performance of recommended dispersion modeling techniques, by comparison with observed air quality data, may be shown to be less than acceptable. Also, there may be no recommended modeling procedure suitable for the situation. In these instances, emission limitations may be established solely on the basis of observed air quality data as would be applied to a modeling analysis. The same care should be given to the analyses of the air quality data as would be applied to a modeling analysis.

c. The current NAAQS for SO_2 and CO are both stated in terms of a concentration not to be exceeded more than once a year. There is only an annual standard for NO_2 and a quarterly standard for Pb. Standards for fine particulate matter (PM–2.5) are expressed in terms of both long-term (annual) and short-term (daily) averages. The long-term standard is calculated using the three year average of the annual averages while the short-term standard is calculated using the three year average of the 98th percentile of the daily average concentration. For PM–10, the convention is to compare the arithmetic mean, averaged over 3 consecutive years, with the concentration specified in the NAAQS (50 μg/m^3). The 24-hour NAAQS (150 μg/m^3) is met if, over a 3-year period, there is (on average) no more than one exceedance per year. As noted in subsection 7.2.1.1, the modeled compliance for this NAAQS is based on the highest 6th highest concentration over 5 years. For ozone the short term 1-hour standard is expressed in terms of an expected exceedance limit while the short term 8-hour standard is expressed in terms of a three year average of the annual fourth highest daily maximum 8-hour value. The NAAQS are subjected to extensive review and possible revision every 5 years.

d. This section discusses general requirements for concentration estimates and identifies the relationship to emission limits. The following recommendations apply to: (1) Revisions of State Implementation Plans and (2) the review of new sources and the prevention of significant deterioration (PSD).

10.2 Recommendations

10.2.1 Analysis Requirements

a. Every effort should be made by the Regional Office to meet with all parties involved in either a SIP revision or a PSD permit application prior to the start of any work on such a project. During this meeting, a protocol should be established between the preparing and reviewing parties to define the procedures to be followed, the data to be collected, the model to be used, and the analysis of the source and concentration data. An example of requirements for such an effort is contained in the Air Quality Analysis Checklist posted on EPA's Internet SCRAM Web site (subsection 2.3). This checklist suggests the level of detail required to assess the air quality resulting from the proposed action. Special cases may require additional data collection or analysis and this should be determined and agreed upon at this preapplication meeting. The protocol should be written and agreed upon by the parties concerned, although a formal legal document is not intended. Changes in such a protocol are often required as the data collection and analysis progresses. However, the protocol establishes a common understanding of the requirements.

b. An air quality analysis should begin with a screening model to determine the potential of the proposed source or control strategy to violate the PSD increment or NAAQS. For traditional stationary sources, EPA guidance [24] should be followed. Guidance is also available for mobile sources.[48]

c. If the concentration estimates from screening techniques indicate a significant impact or that the PSD increment or NAAQS may be approached or exceeded, then a more refined modeling analysis is appropriate and the model user should select a model according to recommendations in Sections 4–8. In some instances, no refined technique may be specified in this guide for the situation. The model user is then encouraged to submit a model developed specifically for the case at hand. If that is not possible, a screening technique may supply the needed results.

d. Regional Offices should require permit applicants to incorporate the pollutant contributions of all sources into their analysis. Where necessary this may include emissions associated with growth in the area of impact of the new or modified source. PSD air quality assessments should consider the amount of the allowable air quality increment that has already been consumed by other sources. Therefore, the most recent source applicant should model the existing or permitted sources in addition to the one currently under consideration. This would permit the use of newly acquired data or improved modeling techniques if such have become available since the last source was permitted. When remodeling, the worst case used in the previous modeling analysis should be one set of conditions modeled in the new analysis. All sources should be modeled for each set of meteorological conditions selected.

10.2.2 Use of Measured Data in Lieu of Model Estimates

a. Modeling is the preferred method for determining emission limitations for both new and existing sources. When a preferred model is available, model results alone (including background) are sufficient. Monitoring will normally not be accepted as the sole basis for emission limitation. In some instances when the modeling technique available is only a screening technique, the addition of air quality data to the analysis may lend credence to model results.

b. There are circumstances where there is no applicable model, and measured data may need to be used. However, only in the case of a NAAQS assessment for an existing source should monitoring data alone be a basis for emission limits. In addition, the following items (i–vi) should be considered prior to the acceptance of the measured data:

i. Does a monitoring network exist for the pollutants and averaging times of concern?

ii. Has the monitoring network been designed to locate points of maximum concentration?

iii. Do the monitoring network and the data reduction and storage procedures meet EPA monitoring and quality assurance requirements?

iv. Do the data set and the analysis allow impact of the most important individual sources to be identified if more than one source or emission point is involved?

v. Is at least one full year of valid ambient data available?

vi. Can it be demonstrated through the comparison of monitored data with model results that available models are not applicable?

c. The number of monitors required is a function of the problem being considered. The source configuration, terrain configuration, and meteorological variations all have an impact on number and placement of monitors. Decisions can only be made on a case-by-case basis. Guidance is available for establishing criteria for demonstrating that a model is not applicable?

d. Sources should obtain approval from the appropriate reviewing authority (paragraph 3.0(b)) for the monitoring network prior to the start of monitoring. A monitoring protocol agreed to by all concerned parties is highly desirable. The design of the network, the number, type and location of the monitors, the sampling period, averaging time as well as the need for meteorological monitoring or the use of mobile sampling or plume tracking techniques, should all be specified in the protocol and agreed upon prior to start-up of the network.

10.2.3 Emission Limits

10.2.3.1 Design Concentrations

a. Emission limits should be based on concentration estimates for the averaging time that results in the most stringent control requirements. The concentration used in specifying emission limits is called the design value or design concentration and is a sum of the concentration contributed by the primary source, other applicable sources, and—for NAAQS assessments—the background concentration.

b. To determine the averaging time for the design value, the most restrictive NAAQS or PSD increment, as applicable, should be identified. For a NAAQS assessment, the averaging time for the design value is determined by calculating, for each averaging time, the ratio of the difference between the applicable NAAQS (S) and the background concentration (B) to the (model) predicted concentration (P) (*i.e.*, (S–B)/P). For a PSD increment assessment, the averaging time for the design value is determined by calculating, for each averaging time, the ratio of the applicable PSD increment (I) and the model-predicted concentration (P) (*i.e.*, I/P). The averaging time with the lowest ratio identifies the most restrictive standard or increment. If the annual average is the most restrictive, the highest estimated annual average concentration from one or a number of years of data is the design value. When short term standards are most restrictive, it may be necessary to consider a broader range of concentrations than the highest value. For example, for pollutants such as SO_2, the highest, second-highest concentration is the design value. For pollutants with statistically based NAAQS, the design value is found by determining the more restrictive of: (1) The short-term concentration over the period specified in the standard, or (2) the long-term concentration that is not expected to exceed the long-term NAAQS. Determination of design values for PM–10 is presented in more detail in EPA guidance.[34]

10.2.3.2 NAAQS Analyses for New or Modified Sources

a. For new or modified sources predicted to have a significant ambient impact [83] and to be located in areas designated attainment or unclassifiable for the SO_2, Pb, NO_2, or CO NAAQS, the demonstration as to whether the source will cause or contribute to an air quality violation should be based on: (1) The highest estimated annual average concentration determined from annual averages of individual years; or (2) the highest, second-highest estimated concentration for averaging times of 24-hours or less; and (3) the significance of the spatial and temporal contribution to any modeled violation. For Pb, the highest estimated concentration based on an individual calendar quarter averaging period should be used. Background concentrations should be added to the estimated impact of the source. The most restrictive standard should be used in all cases to assess the threat of an air quality violation. For new or modified sources predicted to have a significant ambient impact [83] in areas designated attainment or unclassifiable for the PM–10 NAAQS, the demonstration of whether or not the source will cause or contribute to an air quality violation should be based on sufficient data to show whether: (1) The projected 24-hour average concentrations will exceed the 24-hour NAAQS more than once per year, on average; (2) the expected (i.e., average) annual mean concentration will exceed the annual NAAQS; and (3) the source contributes significantly, in a temporal and spatial sense, to any modeled violation.

10.2.3.3 PSD Air Quality Increments and Impacts

a. The allowable PSD increments for criteria pollutants are established by regulation and cited in 40 CFR 51.166. These maximum allowable increases in pollutant concentrations may be exceeded once per year at each site, except for the annual increment that may not be exceeded. The highest, second-highest increase in estimated concentrations for the short term averages as determined by a model should be less than or equal to the permitted increment. The modeled annual averages should not exceed the increment.

b. Screening techniques defined in subsection 4.2.1 can sometimes be used to estimate short term incremental concentrations for the first new source that triggers the baseline in a given area. However, when multiple increment-consuming sources are involved in the calculation, the use of a refined model with at least 1 year of site specific or 5 years of (off-site) NWS data is normally required (subsection 8.3.1.2). In such cases, sequential modeling must demonstrate that the allowable increments are not exceeded temporally and spatially, *i.e.*, for all receptors for each time period throughout the year(s) (time period means the appropriate PSD averaging time, *e.g.*, 3-hour, 24-hour, *etc.*).

c. The PSD regulations require an estimation of the SO_2, particulate matter (PM–10), and NO_2 impact on any Class I area. Normally, steady-state Gaussian plume models should not be applied at distances greater than can be accommodated by the steady state assumptions inherent in such models. The maximum distance for refined steady-state Gaussian plume model application for regulatory purposes is generally considered to be 50km. Beyond the 50km range, screening techniques may be used to determine if more refined modeling is needed. If refined models are needed, long range transport models should be considered in accordance with subsection 6.2.3. As previously noted in Sections 3 and 7, the need to involve the Federal Land Manager in decisions on potential air quality impacts, particularly in relation to PSD Class I areas, cannot be overemphasized.

11.0 Bibliography [a]

American Meteorological Society. Symposia on Turbulence, Diffusion, and Air Pollution (1st–10th); 1971–1992. Symposia on Boundary Layers & Turb. 11th–12th; 1995–1997. Boston, MA.

American Meteorological Society, 1977–1998. Joint Conferences on Applications of Air Pollution Meteorology (1st–10th). Sponsored by the American Meteorological Society and the Air & Waste Management Association. Boston, MA.

American Meteorological Society, 1978. Accuracy of Dispersion Models. *Bulletin of the American Meteorological Society*, 59(8): 1025–1026.

American Meteorological Society, 1981. Air Quality Modeling and the Clean Air Act: Recommendations to EPA on Dispersion Modeling for Regulatory Applications. Boston, MA.

Briggs, G.A., 1969. Plume Rise. U.S. Atomic Energy Commission Critical Review Series, Oak Ridge National Laboratory, Oak Ridge, TN.

Drake, R.L. and S.M. Barrager, 1979. Mathematical Models for Atmospheric Pollutants. EPRI EA–1131. Electric Power Research Institute, Palo Alto, CA.

Environmental Protection Agency, 1978. Workbook for Comparison of Air Quality Models. Publication No. EPA–450/2–78–028a and b. Office of Air Quality Planning & Standards, Research Triangle Park, NC.

Erisman J.W., Van Pul A. and Wyers P. (1994) Parameterization of surface resistance for the quantification of atmospheric deposition of acidifying pollutants and ozone. *Atmos. Environ.*, 28: 2595–2607.

Fox, D.G., and J.E. Fairobent, 1981. NCAQ Panel Examines Uses and Limitations of Air Quality Models. *Bulletin of the American Meteorological Society*, 62(2): 218–221.

Gifford, F.A., 1976. Turbulent Diffusion Typing Schemes: A Review. *Nuclear Safety*, 17(1): 68–86.

Gudiksen, P.H., and M.H. Dickerson, Eds., Executive Summary: Atmospheric Studies in Complex Terrain Technical Progress Report FY–1979 Through FY–1983. Lawrence Livermore National Laboratory, Livermore, CA. (Docket Reference No. II–I–103).

Hanna, S.R., G.A. Briggs, J. Deardorff, B.A. Egan, G.A. Gifford and F. Pasquill, 1977. AMS Workshop on Stability Classification Schemes And Sigma Curves—Summary of Recommendations. *Bulletin of the American Meteorological Society*, 58(12): 1305–1309.

Hanna, S.R., G.A. Briggs and R.P. Hosker, Jr., 1982. Handbook on Atmospheric Diffusion. Technical Information Center, U.S. Department of Energy, Washington, D.C.

Haugen, D.A., Workshop Coordinator, 1975. Lectures on Air Pollution and Environmental Impact Analyses. Sponsored by the American Meteorological Society, Boston, MA.

Hoffnagle, G.F., M.E. Smith, T.V. Crawford and T.J. Lockhart, 1981. On-site Meteorological Instrumentation Requirements to Characterize Diffusion from Point Sources—A Workshop, 15–17 January 1980, Raleigh, NC. *Bulletin of the American Meteorological Society*, 62(2): 255–261.

Hunt, J.C.R., R.G. Holroyd, D.J. Carruthers, A.G. Robins, D.D. Apsley, F.B. Smith and D.J. Thompson, 1990. Developments in Modeling Air Pollution for Regulatory Uses. *In* Proceedings of the 18th NATO/CCMS International Technical Meeting on Air Pollution Modeling and its Application, Vancouver, Canada. Also *In* Air Pollution Modeling and its Application VIII (1991). H. van Dop and D.G. Steyn, eds. Plenum Press, New York, NY. pp. 17–59

Pasquill, F. and F.B. Smith, 1983. Atmospheric Diffusion, 3rd Edition. Ellis Horwood Limited, Chichester, West Sussex, England, 438pp.

Randerson, D., Ed., 1984. Atmospheric Science and Power Production. DOE/TIC 2760l. Office of Scientific and Technical Information, U.S. Department of Energy, Oak Ridge, TN.

Scire, J.S. and L.L. Schulman, 1980: Modeling plume rise from low-level buoyant line and point sources. AMS/APCA Second Joint Conference on Applications of Air Pollution Meteorology, March 24–27, New Orleans, LA.

Smith, M.E., Ed., 1973. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. The American Society of Mechanical Engineers, New York, NY.

Stern, A.C., Ed., 1976. *Air Pollution, Third Edition, Volume I: Air Pollutants, Their Transformation and Transport.* Academic Press, New York, NY.

Turner, D.B., 1979. Atmospheric Dispersion Modeling: A Critical Review. *Journal of the Air Pollution Control Association*, 29(5): 502–519.

Venkatram, A. and J.C. Wyngaard, Editors, 1988. *Lectures on Air Pollution Modeling.* American Meteorological Society, Boston, MA. 390pp.

12.0 References

1. Code of Federal Regulations; Title 40 (Protection of Environment). Sections 51.112, 51.117, 51.150, 51.160.

2. Environmental Protection Agency, 1990. New Source Review Workshop Manual: Prevention of Significant Deterioration and Nonattainment Area Permitting (Draft). Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Available at: *http://www.epa.gov/ttn/nsr/*)

3. Code of Federal Regulations; Title 40 (Protection of Environment). Sections 51.166 and 52.21.

4. Code of Federal Regulations (Title 40, Part 50): Protection of the Environment; National Primary and Secondary Ambient Air Quality Standards.

5. Environmental Protection Agency, 1988. Model Clearinghouse: Operational Plan (Revised). Staff Report. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Docket No. A–88–04, II–J–1)

6. Environmental Protection Agency, 1980. Guidelines on Air Quality Models. **Federal Register**, 45(61): 20157–20158.

7. Scire, J.S. and L.L. Schulman, 1981. Evaluation of the BLP and ISC Models with SF6 Tracer Data and SO_2 Measurements at Aluminum Reduction Plants. APCA Specialty Conference on Dispersion

[a] The documents listed here are major sources of supplemental information on the theory and application of mathematical air quality models.

Modeling for Complex Sources, St. Louis, MO.

8. Environmental Protection Agency, 1986. Evaluation of Mobile Source Air Quality Simulation Models. Publication No. EPA–450/4–86–002. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 86–167293)

9. Strimaitis, D.G., J.S. Scire and J.C. Chang. 1998. Evaluation of the CALPUFF Dispersion Model with Two Power Plant Data Sets. Tenth Joint Conference on the Application of Air Pollution Meteorology, Phoenix, Arizona. American Meteorological Society, Boston, MA. January 11–16, 1998.

10. Environmental Protection Agency, 2003. AERMOD: Latest Features and Evaluation Results. Publication No. EPA–454/R–03–003. U.S. Environmental Protection Agency, Research Triangle Park, NC. (Available at *http://www.epa.gov/scram001/*)

11. Fox, D.G., 1981. Judging Air Quality Model Performance. *Bulletin of the American Meteorological Society*, 62(5): 599–609.

12. American Meteorological Society, 1983. Synthesis of the Rural Model Reviews. Publication No. EPA–600/3–83–108. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB 84–121037)

13. Allwine, K.J., W.F. Dabberdt and L.L. Simmons. 1998. Peer Review of the CALMET/CALPUFF Modeling System. Prepared by the KEVRIC Company, Inc. under EPA Contract No. 68–D–98–092 for Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A–99–05, II–A–8)

14. Hanna, S., M. Garrison and B. Turner, 1998. AERMOD Peer Review report. Prepared by SAI, Inc. under EPA Contract No. 68–D6–0064/1–14 for Environmental Protection Agency, Research Triangle Park, NC. 12pp. & appendices (Docket No. A–99–05, II–A–6)

15. Environmental Protection Agency, 1992. Protocol for Determining the Best Performing Model. Publication No. EPA–454/R–92–025. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93–226082)

16. ASTM D6589: Standard Guide for Statistical Evaluation of Atmospheric Dispersion Model Performance. (2000)

17. Environmental Protection Agency, 1995. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volumes 1 and 2. Publication Nos. EPA–454/B–95–003a & b. U.S. Environmental Protection Agency, Research Triangle Park, NC. (NTIS Nos. PB 95–222741 and PB 95–222758, respectively)

18. Hanna, S.R. and R.J. Paine, 1989. Hybrid Plume Dispersion Model (HPDM) Development and Evaluation. *J. Appl. Meteorol.*, 28: 206–224.

19. Hanna, S.R. and J.C. Chang, 1992. Boundary layer parameterizations for applied dispersion modeling over urban areas. Bound. Lay. Meteorol., 58, 229–259.

20. Hanna, S.R. and J.C. Chang, 1993. Hybrid Plume Dispersion Model (HPDM) Improvements and Testing at Three Field Sites. Atmos. Environ., 27A: 1491–1508.

21. American Meteorological Society, 1984. Workshop on Updating Applied Diffusion Models. 24–27 January 1984. Clearwater, Florida. J. Climate and Appl. Met., 24(11): 1111—1207.

22. Environmental Protection Agency, 2002. AERMOD: Description of Model Formulation. Research Triangle Park, NC. EPA Report No. EPA–454/R–02–002d; April 2002; AND Cimorelli, A. *et al.*, 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization. *Journal of Applied Meteorology*, 44(5): 682–693.

23. L.L. Schulman, D.G. Strimaitis and J.S. Scire, 2002. Development and evaluation of the PRIME plume rise and building downwash model. *Journal of the Air & Waste Management Association*, 50: 378–390.

24. Environmental Protection Agency, 1992. Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised. Publication No. EPA–454/R–92–019. U.S. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 93–219095)

25. Environmental Protection Agency, 1995. SCREEN3 User's Guide. Publication No. EPA–454/B–95–004. U.S. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 95–222766)

26. Perry, S.G., D.J. Burns and A.J. Cimorelli, 1990. User's Guide to CTDMPLUS: Volume 2. The Screening Mode (CTSCREEN). Publication No. EPA–600/8–90–087. U.S. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 91–136564)

27. Mills, M.T., R.J. Paine, E.A. Insley and B.A. Egan, 1987. The Complex Terrain Dispersion Model Terrain Preprocessor System—User's Guide and Program Description. Publication No. EPA–600/8–88–003. U.S. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 88–162094)

28. Burns, D.J., S.G. Perry and A.J. Cimorelli, 1991. An Advanced Screening Model for Complex Terrain Applications. Paper presented at the 7th Joint Conference on Applications of Air Pollution Meteorology (cosponsored by the American Meteorological Society and the Air & Waste Management Association), January 13–18, 1991, New Orleans, LA.

29. Environmental Research and Technology, 1987. User's Guide to the Rough Terrain Diffusion Model (RTDM), Rev. 3.20. ERT Document No. P–D535–585. Environmental Research and Technology, Inc., Concord, MA. (NTIS No. PB 88–171467)

30. Meng, Z.D. Dabdub and J.H. Seinfeld, 1997. Chemical Coupling between Atmospheric Ozone and Particulate Matter. *Science*, 277: 116–119.

31. Hidy, G.M, P.M. Roth, J.M. Hales and R.D. Scheffe, 1998. Fine Particles and Oxidant Pollution: Developing an Agenda for Cooperative Research. *JAWMA*, 50: 613–632.

32. Environmental Protection Agency, 2005. Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hr Ozone NAAQS (Draft Final). Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Latest version available on SCRAM Web site as *draft-final-O3.pdf*; *see* subsection 2.3)

33. Environmental Protection Agency, 2005. Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the PM–2.5 NAAQS and Regional Haze Goals. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (As of May 2005, this document has not been finalized; latest version available on SCRAM Web site as *draft-pm.pdf; see* subsection 2.3)

34. Environmental Protection Agency, 1987. PM–10 SIP Development Guideline. Publication No. EPA–450/2–86–001. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 87–206488)

35. U.S. Forest Service, 1996. User Assessment of Smoke-Dispersion Models for Wildland Biomass Burning. USDA, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW–GTR–379. 30pp. (NTIS No. PB 97–163380)

36. Hanrahan, P.L., 1999. The Polar Volume Polar Ratio Method for Determining NO_2 / NO_X Ratios in Modeling—Part I: Methodology. *J. Air & Waste Manage. Assoc.*, 49: 1324–1331.

37. Environmental Protection Agency, 1997. Guidance for Siting Ambient Air Monitors around Stationary Lead Sources. Publication No. EPA–454/R–92–009R. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 97–208094)

38. Environmental Protection Agency, 1993. Lead Guideline Document. Publication No. EPA–452/R–93–009. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 94–111846)

39. Environmental Protection Agency, 1998. EPA Third-Generation Air Quality Modeling System. Models-3, Volume 9b: User Manual. Publication No. EPA–600/R–98/069(b). Office of Research and Development, Washington, D.C.

40. Gery, M.W. and R.R. Crouse, 1991. User's Guide for Executing OZIPR. Publication No. EPA–600/8–90–069. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB 91–175877)

41. Environmental Protection Agency, 2002. User's Guide to the Regulatory Modeling System for Aerosols and Deposition (REMSAD) Version 7. Prepared for Environmental Protection Agency under Contract No. GS–10F–0124J by ICF Consulting, July 2002. (Available at *http://www.epa.gov/scram001/*)

42. Environmental Protection Agency, 2004. EPA–CMB8.2 Users Manual. Publication No. EPA–452/R–04–011. Office of Air Quality Planning & Standards, Research Triangle Park, NC; December 2004. (Available at *http://www.ega.gov/scram001/*)

43. Environmental Protection Agency, 2004. Protocol for Applying and Validating the CMB Model for $PM_{2.5}$ and VOC. Publication No. EPA–451/R–04–001. Office of Air Quality Planning & Standards, Research Triangle Park, NC; December 2004. (Available at *http://www.ega.gov/scram001/*)

44. Environmental Protection Agency, 1988. Chemical Mass Balance Model Diagnostics. Publication No. EPA–450/4–88–005. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 88–208319)

45. Paatero, P. and U. Tapper, 1994. Positive Matrix Factorization: A Non-

negative Factor Model with Optimal Utilization of Error Estimates of Data Values. *Environmetrics*, 5: 111–126. (Other documents related to PMF may be accessed via FTP at *ftp://rock.helsinki.fi/pub/misc/pmf.*)

46. Lewis, C.W., G.A. Norris, R.C. Henry and T.L. Conner, 2003. Source Apportionment of Phoenix PM–2.5 Aerosol with the Unmix Receptor Model. *Journal of the Air & Waste Management Association*, 53(3): 325–338.

47. Environmental Protection Agency, 1994. Guidelines for PM10 Sampling and Analysis Applicable to Receptor Modeling. Publication No. EPA–452/R–94–009. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 94–177441)

48. Environmental Protection Agency, 1992. Guideline for Modeling Carbon Monoxide from Roadway Intersections. Publication No. EPA–454/R–92–005. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93–210391)

49. Environmental Protection Agency, 1992. User's Guide for CAL3QHC Version 2: A Modeling Methodology for Predicting Pollutant Concentrations near Roadway Intersections. Publication No. EPA–454/R–92–006. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93–210250)

50. Environmental Protection Agency, 1992. Evaluation of CO Intersection Modeling techniques Using a New York City Database. Publication No. EPA–454/R–92–004. Office of Air Quality Planning & Standards, RTP, NC 27711. (NTIS No. PB 93–105559)

51. Environmental Protection Agency, 1995. Addendum to the User's Guide to CAL3QHC Version 2.0. Staff Report. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Available at *http://www.epa.gov/scram001/*)

52. Shannon, J.D., 1987. Mobile Source Modeling Review. A report prepared under a cooperative agreement with the Environmental Protection Agency. 5pp. (Docket No. A–88–04, II–J–2)

53. Environmental Protection Agency, 1991. Emission Inventory Requirements for Carbon Monoxide State Implementation Plans. Publication No. EPA–450/4–91–011. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 92–112150)

54. Environmental Protection Agency, 1992. Guideline for Regulatory Application of the Urban Airshed Model for Areawide Carbon Monoxide. Publication No. EPA–450/4–92–011a and b. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS Nos. PB 92–213222 and PB 92–213230)

55. Environmental Protection Agency, 1992. Technical Support Document to Aid States with the Development of Carbon Monoxide State Implementation Plans. Publication No. EPA–452/R–92–003. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 92–233055)

56. Chu, S.H. and E.L. Meyer, 1991. Use of Ambient Ratios to Estimate Impact of NO_X Sources on Annual NO_2 Concentrations. Proceedings, 84th Annual Meeting & Exhibition of the Air & Waste Management Association, Vancouver, B.C.; 16–21 June 1991. (16pp.) (Docket No. A–92–65, II–A–9)

57. Cole, H.S. and J.E. Summerhays, 1979. A Review of Techniques Available for Estimation of Short-Term NO_2 Concentrations. *Journal of the Air Pollution Control Association*, 29(8): 812–817.

58. U.S. Department of Housing and Urban Development, 1980. Air Quality Considerations in Residential Planning. U.S. Superintendent of Documents, Washington, DC. (GPO Order Nos. 023–000–00577–8, 023–000–00576–0, 023–000–00575–1)

59. Environmental Protection Agency, 1986. Evaluation of Short-Term Long-Range Transport Models, Volumes I and II. Publication Nos. EPA–450/4–86–016a and b. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS Nos. PB 87–142337 and PB 87–142345)

60. Environmental Protection Agency, 1998. Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long-Range Transport Impacts. Publication No. EPA–454/R–98–019. Office of Air Quality Planning & Standards, Research Triangle Park, NC.(NTIS No. PB 99–121089)

61. National Acid Precipitation Assessment Program (NAPAP), 1991. Acid Deposition: State of Science and Technology. Volume III Terrestrial, Materials, Health and Visibility Effects. Report 24, *Visibility: Existing and Historical Conditions—Causes and Effects* Edited by Patricia M. Irving. Washington, DC 129pp.

62. National Research Council, 1993. Protecting Visibility in National Parks and Wilderness Areas. National Academy Press, Washington, DC 446pp.

63. Environmental Protection Agency, 1992. Workbook for Plume Visual Impact Screening and Analysis (Revised). Publication No. EPA–454/R–92–023. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93–223592)

64. Environmental Protection Agency, 1981. Guideline for Use of Fluid Modeling to Determine Good Engineering Practice (GEP) Stack Height. Publication No. EPA–450/4–81–003. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 82–145327)

65. Lawson, Jr., R.E. and W.H. Snyder, 1983. Determination of Good Engineering Practice Stack Height: A Demonstration Study for a Power Plant. Publication No. EPA–600/3–83–024. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB 83–207407)

66. Environmental Protection Agency, 1985. Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations), Revised. Publication No. EPA–450/4–80–023R. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 85–225241)

67. Snyder, W.H. and R.E. Lawson, Jr., 1985. Fluid Modeling Demonstration of Good Engineering-Practice Stack Height in Complex Terrain. Publication No. EPA–600/3–85–022. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB 85–203107)

68. Bennett, M.J, M.E. Yansura, I.G. Hornyik, J.M. Nall, D.G. Caniparoli and C.G. Ashmore, 2002. Evaluation of the CALPUFF Long-range Transport Screening Technique by Comparison to Refined CALPUFF Results for Several Power Plants in Both the Eastern and Western United States. Proceedings of the Air & Waste Management Association's 95th Annual Conference, June 23–27, 2002; Baltimore, MD. Paper #43454.

69. Environmental Protection Agency, 1999. Guideline of Data Handling Conventions for the PM NAAQS. Publication No. EPA–454/R–99–008. Office of Air Quality Planning & Standards, Research Triangle Park. (NTIS PB 99–149023)

70. Turner, D.B., 1969. Workbook of Atmospheric Dispersion Estimates. PHS Publication No. 999–AP–26. U.S. Department of Health, Education and Welfare, Public Health Service, Cincinnati, OH. (NTIS No. PB–191482)

71. McElroy, J.L. and F. Pooler, Jr., 1968. St. Louis Dispersion Study, Volume II—Analysis. National Air Pollution Control Administration Publication No. AP–53, U.S. Department of Health, Education and Welfare, Public Health Service, Arlington, VA. (NTIS No. PB–190255)

72. Irwin, J.S., 1978. Proposed Criteria for Selection of Urban Versus Rural Dispersion Coefficients. (Draft Staff Report). Meteorology and Assessment Division, U.S. Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A–80–46, II-B–8)

73. Auer, Jr., A.H., 1978. Correlation of Land Use and Cover with Meteorological Anomalies. *Journal of Applied Meteorology*, 17(5): 636–643.

74. Pasquill, F., 1976. Atmospheric Dispersion Parameters in Gaussian Plume Modeling, Part II. Possible Requirements for Change in the Turner Workbook Values. Publication No. EPA–600/4–76–030b. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB–258036/3BA)

75. Turner, D.B., 1964. A Diffusion Model for an Urban Area. *Journal of Applied Meteorology*, 3(1): 83–91.

76. Briggs, G.A., 1975. Plume Rise Predictions. Chapter 3 in Lectures on Air Pollution and Environmental Impact Analyses. American Meteorological Society, Boston, MA; pp. 59–111.

77. Hanna, S.R., G.A. Briggs and R.P. Hosker, Jr., 1982. Plume Rise. Chapter 2 in *Handbook on Atmospheric Diffusion*. Technical Information Center, U.S. Department of Energy, Washington, DC; pp. 11–24. DOE/TIC–11223 (DE 82002045)

78. Weil, J.C., L.A. Corio and R.P. Brower, 1997. A PDF dispersion model for buoyant plumes in the convective boundary layer. *Journal of Applied Meteorology*, 36: 982–1003.

79. Stull, R.B., 1988. An Introduction to Boundary Layer Meteorology. Kluwer Academic Publishers, Boston, MA. 666pp.

80. Environmental Protection Agency, 1988. User's Guide to SDM—A Shoreline Dispersion Model. Publication No. EPA–450/

4–88–017. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 89–164305)

81. Environmental Protection Agency, 1987. Analysis and Evaluation of Statistical Coastal Fumigation Models. Publication No. EPA–450/4–87–002. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 87–175519)

82. Environmental Protection Agency, 1995. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (Fifth Edition, AP–42: GPO Stock No. 055–000–00500–1), and Supplements A–D; Volume II: Mobile Sources (Fifth Edition). Office of Air Quality Planning & Standards, Research Triangle Park, NC. Volume I can be downloaded from EPA's Internet Web site at *http://www.epa.gov/ttn/chief/ap42.html*; Volume II can be downloaded from *http://www.epa.gov/omswww/ap42.htm*

83. Environmental Protection Agency, 1987. Ambient Air Monitoring Guidelines for Prevention of Significant Deterioration (PSD). Publication No. EPA–450/4–87–007. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 90–168030)

84. Stauffer, D.R. and Seaman, N.L., 1990. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Monthly Weather Review*, 118: 1250–1277.

85. Stauffer, D.R., N.L. Seaman and F.S. Binkowski, 1991. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part II: Effect of data assimilation within the planetary boundary layer. *Monthly Weather Review*, 119: 734–754.

86. Grell, G.A., J. Dudhia, and D.R. Stauffer, 1994. A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5). *NCAR Technical Note*, NCAR/TN–398+STR, National Center for Atmospheric Research, Boulder, CO; 138pp. *http://www.mmm.ucar.edu/mm5/mm5-home.html*

87. Landsberg, H.E. and W.C. Jacobs, 1951. Compendium of Meteorology. American Meteorological Society, Boston, MA; pp. 976–992.

88. Burton, C.S., T.E. Stoeckenius and J.P. Nordin, 1983. The Temporal Representativeness of Short-Term Meteorological Data Sets: Implications for Air Quality Impact Assessments. Systems Applications, Inc., San Rafael, CA. (Docket No. A–80–46, II-G–11)

89. Solar and Meteorological Surface Observation Network, 1961–1990; 3-volume CD–ROM. Version 1.0, September 1993. Produced jointly by National Climatic Data Center and National Renewable Energy Laboratory. Can be ordered from NOAA National Data Center's Internet Web site at *http://www.NNDC.NOAA.GOV/*.

90. Hourly United States Weather Observations, 1990–1995 (CD–ROM). October 1997. Produced jointly by National Climatic Data Center and Environmental Protection Agency. Can be ordered from NOAA National Data Center's Internet Web site at *http://lwf.ncdc.noaa.gov/oa/ncdc.html*

91. Radiosonde Data of North America, 1946–1996; 4-volume CD–ROM. August 1996. Produced jointly by Forecast Systems laboratory and National Climatic Data Center. Can be ordered from NOAA National Data Center's Internet Web site at *http://lwf.ncdc.noaa.gov/oa/ncdc.html*

92. Environmental Protection Agency, 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications. Publication No. EPA–454/R–99–005. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (PB 2001–103606) (Available at *http://www.epa.gov/scram001/*)

93. ASTM D5527: Standard Practice for Measuring Surface Winds and Temperature by Acoustic Means. (1994)

94. ASTM D5741: Standard Practice for Characterizing Surface Wind Using Wind Vane and Rotating Anemometer. (1996)

95. Environmental Protection Agency, 1995. Quality Assurance for Air Pollution Measurement Systems, Volume IV—Meteorological Measurements. Publication No. EPA600/R–94/038d. Office of Air Quality Planning & Standards, Research Triangle Park, NC. *Note:* for copies of this handbook, you may make inquiry to ORD Publications, 26 West Martin Luther King Dr., Cincinatti, OH 45268. Phone (513) 569–7562 or (800) 490–9198 (automated request line)

96. Bowen, B.M., J.M. Dewart and A.I. Chen, 1983. Stability Class Determination: A Comparison for One Site. Proceedings, Sixth Symposium on Turbulence and Diffusion. American Meteorological Society, Boston, MA; pp. 211–214. (Docket No. A–92–65, II–A–7)

97. Environmental Protection Agency, 1993. An Evaluation of a Solar Radiation/Delta-T (SRDT) Method for Estimating Pasquill-Gifford (P–G) Stability Categories. Publication No. EPA–454/R–93–055. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 94–113958)

98. Irwin, J.S., 1980. Dispersion Estimate Suggestion #8: Estimation of Pasquill Stability Categories. Office of Air Quality Planning & Standards, Research Triangle Park, NC (Docket No. A–80–46, II–B–10)

99. Mitchell, Jr., A.E. and K.O. Timbre, 1979. Atmospheric Stability Class from Horizontal Wind Fluctuation. Presented at 72nd Annual Meeting of Air Pollution Control Association, Cincinnati, OH; June 24–29, 1979. (Docket No. A–80–46, II–P–9)

100. Smedman—Hogstrom, A. and V. Hogstrom, 1978. A Practical Method for Determining Wind Frequency Distributions for the Lowest 200m from Routine Meteorological Data. *J. of Applied Meteorology*, 17(7): 942–954.

101. Smith, T.B. and S.M. Howard, 1972. Methodology for Treating Diffusivity. MRI 72 FR–1030. Meteorology Research, Inc., Altadena, CA. (Docket No. A–80–46, II–P–8)

102. Environmental Protection Agency, 2004. User's Guide for the AERMOD Meteorological Preprocessor (AERMET). Publication No. EPA–454/B–03–002. U.S. Environmental Protection Agency, Research Triangle Park, NC. (Available at *http://www.epa.gov/scram001/*)

103. Environmental Protection Agency, 1993. PCRAMMET User's Guide. Publication No. EPA–454/R–96–001. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 97–147912)

104. Environmental Protection Agency, 1996. Meteorological Processor for Regulatory Models (MPRM) User's Guide. Publication No. EPA–454/B–96–002. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 96–180518)

105. Paine, R.J., 1987. User's Guide to the CTDM Meteorological Preprocessor Program. Publication No. EPA–600/8–88–004. Office of Research & Development, Research Triangle Park, NC. (NTIS No. PB 88–162102)

106. Scire, J.S., F.R. Francoise, M.E. Fernau and R.J. Yamartino, 1998. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Tech, Inc., Concord, MA. (*http://www.src.com/calpuff/calpuff1.htm*)

107. Environmental Protection Agency, 1984. Calms Processor (CALMPRO) User's Guide. Publication No. EPA–901/9–84–001. Office of Air Quality Planning & Standards, Region I, Boston, MA. (NTIS No. PB 84–229467)

108. Fox, D.G., 1984. Uncertainty in air quality modeling. *Bulletin of the American Meteorological Society*, 65(1): 27–36.

109. Burton, C.S., 1981. The Role of Atmospheric Models in Regulatory Decision-Making: Summary Report. Systems Applications, Inc., San Rafael, CA. Prepared under contract No. 68–01–5845 for U.S. Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A–80–46, II–M–6)

110. Environmental Protection Agency, 1981. Proceedings of the Second Conference on Air Quality Modeling, Washington, DC. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Docket No. A–80–46, II–M–16)

111. Hanna, S.R., 1989. Confidence limits for air quality model evaluations, as estimated by bootstrap and jackknife resampling methods. *Atmospheric Environment*, 23(6): 1385–1398.

112. Cox, W.M. and J.A. Tikvart, 1990. A statistical procedure for determining the best performing air quality simulation model. *Atmos. Environ.*, 24A(9): 2387–2395.

113. Oreskes, N.K., K. Shrader-Frechette and K. Beliz, 1994. Verification, validation and confirmation of numerical models in the earth sciences. *Science*, 263: 641–646.

114. Dekker, C.M., A. Groenendijk, C.J. Sliggers and G.K. Verboom, 1990. Quality Criteria for Models to Calculate Air Pollution. Lucht (Air) 90, Ministry of Housing, Physical Planning and Environment, Postbus 450, 2260 MB Leidschendam, The Netherlands; 52pp.

115. Weil, J.C., R.I. Sykes and A. Venkatram, 1992. Evaluating air-quality models: review and outlook. *Journal of Applied Meteorology*, 31: 1121–1145.

116. Cole, S.T. and P.J. Wicks, Editors (1995): Model Evaluation Group: Report of the Second Open Meeting. EUR 15990 EN, European Commission, Directorate-General XII, Environmental Research Programme, L–2920 Luxembourg; 77pp.

117. Hanna, S.R., 1982. Natural Variability of Observed Hourly SO_2 and CO Concentrations in St. Louis. *Atmospheric Environment*, 16(6): 1435–1440.

118. Bowne, N.E., 1981. Validation and Performance Criteria for Air Quality Models.

Appendix F in Air Quality Modeling and the Clean Air Act: Recommendations to EPA on Dispersion Modeling for Regulatory Applications. American Meteorological Society, Boston, MA; pp. 159–171. (Docket No. A–80–46, II–A–106)

119. Bowne, N.E. and R.J. Londergan, 1983. Overview, Results, and Conclusions for the EPRI Plume Model Validation and Development Project: Plains Site. EPRI EA–3074. Electric Power Research Institute, Palo Alto, CA.

120. Moore, G.E., T.E. Stoeckenius and D.A. Stewart, 1982. A Survey of Statistical Measures of Model Performance and Accuracy for Several Air Quality Models. Publication No. EPA–450/4–83–001. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 83–260810)

121. Rhoads, R.G., 1981. Accuracy of Air Quality Models. Staff Report. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (Docket No. A–80–46, II–G–6)

122. Hanna, S.R., 1993. Uncertainties in air quality model predictions. *Boundary-Layer Meteorology*, 62: 3–20.

123. Pasquill, F., 1974. Atmospheric Diffusion, 2nd Edition. John Wiley and Sons, New York, NY; 479pp.

124. Morgan, M.G. and M. Henrion, 1990. Uncertainty, A Guide to Dealing With Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press. New York, NY; 332pp.

125. Irwin, J.S., K. Steinberg, C. Hakkarinen and H. Feldman, 2001. Uncertainty in Air Quality Modeling for Risk Calculations. (CD–ROM) Proceedings of Guideline on Air Quality Models: A New Beginning. April 4–6, 2001, Newport, RI, Air & Waste Management Association. Pittsburgh, PA; 17pp.

126. Austin, B.S., T.E. Stoeckenius, M.C. Dudik and T.S. Stocking, 1988. User's Guide to the Expected Exceedances System. Systems Applications, Inc., San Rafael, CA. Prepared under Contract No. 68–02–4352 Option I for the U.S. Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A–88–04, II–I–3)

127. Thrall, A.D., T.E. Stoeckenius and C.S. Burton, 1985. A Method for Calculating Dispersion Modeling Uncertainty Applied to the Regulation of an Emission Source. Systems Applications, Inc., San Rafael, CA. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A–80–46, IV–G–1)

128. ''Ten years of Harmonisation activities: Past, present and future'' at *http://www.dmu.dk/AtmosphericEnvironment/Harmoni/Conferences/Belgirate/BelgiratePapers.asp.*

129. ''A platform for model evaluation'' at *http://www.dmu.dk/AtmosphericEnvironment/Harmoni/Conferences/Belgirate/BelgiratePapers.asp.*

APPENDIX A TO APPENDIX W OF PART 51—SUMMARIES OF PREFERRED AIR QUALITY MODELS

Table of Contents

A.0 Introduction and Availability

(1) This appendix summarizes key features of refined air quality models preferred for specific regulatory applications. For each model, information is provided on availability, approximate cost (where applicable), regulatory use, data input, output format and options, simulation of atmospheric physics, and accuracy. These models may be used without a formal demonstration of applicability provided they satisfy the recommendations for regulatory use; not all options in the models are necessarily recommended for regulatory use.

(2) Many of these models have been subjected to a performance evaluation using comparisons with observed air quality data. Where possible, several of the models contained herein have been subjected to evaluation exercises, including (1) statistical performance tests recommended by the American Meteorological Society and (2) peer scientific reviews. The models in this appendix have been selected on the basis of the results of the model evaluations, experience with previous use, familiarity of the model to various air quality programs, and the costs and resource requirements for use.

(3) Codes and documentation for all models listed in this appendix are available from EPA's Support Center for Regulatory Air Models (SCRAM) Web site at *http://www.epa.gov/scram001*. Documentation is also available from the National Technical Information Service (NTIS), *http://www.ntis.gov* or U.S. Department of Commerce, Springfield, VA 22161; phone: (800) 553–6847. Where possible, accession numbers are provided.

A.1 AMS/EPA Regulatory Model—AERMOD

References

Environmental Protection Agency, 2004. AERMOD: Description of Model Formulation. Publication No. EPA–454/R–03–004. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; September 2004. (Available at *http://www.epa.gov/scram001/*)

Cimorelli, A. *et al.*, 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization. *Journal of Applied Meteorology,* 44(5): 682–693.

Perry, S. *et al.*, 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part II: Model Performance against 17 Field Study Databases. *Journal of Applied Meteorology,* 44(5): 694–708.

Environmental Protection Agency, 2004. User's Guide for the AMS/EPA Regulatory Model—AERMOD. Publication No. EPA–454/B–03–001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; September 2004. (Available at *http://www.epa.gov/scram001/*)

Environmental Protection Agency, 2004. User's Guide for the AERMOD Meteorological Preprocessor (AERMET). Publication No. EPA–454/B–03–002. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; November 2004. (Available at *http://www.epa.gov/scram001/*)

Environmental Protection Agency, 2004. User's Guide for the AERMOD Terrain Preprocessor (AERMAP). Publication No. EPA–454/B–03–003. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; October 2004. (Available at *http://www.epa.gov/scram001/*)

Schulman, L.L., D.G. Strimaitis and J.S. Scire, 2000. Development and evaluation of the PRIME plume rise and building downwash model. *Journal of the Air and Waste Management Association,* 50: 378–390.

Availability

The model codes and associated documentation are available on EPA's Internet SCRAM Web site (Section A.0).

Abstract

AERMOD is a steady-state plume dispersion model for assessment of pollutant concentrations from a variety of sources. AERMOD simulates transport and dispersion from multiple point, area, or volume sources based on an up-to-date characterization of the atmospheric boundary layer. Sources may be located in rural or urban areas, and receptors may be located in simple or complex terrain. AERMOD accounts for building wake effects (i.e., plume downwash) based on the PRIME building downwash algorithms. The model employs hourly sequential preprocessed meteorological data to estimate concentrations for averaging times from one hour to one year (also multiple years). AERMOD is designed to operate in concert with two pre-processor codes: AERMET processes meteorological data for input to AERMOD, and AERMAP processes terrain elevation data and generates receptor information for input to AERMOD.

a. Recommendations for Regulatory Use

(1) AERMOD is appropriate for the following applications:

- Point, volume, and area sources;
- Surface, near-surface, and elevated releases;
- Rural or urban areas;
- Simple and complex terrain;
- Transport distances over which steady-state assumptions are appropriate, up to 50km;
- 1-hour to annual averaging times; and
- Continuous toxic air emissions.

(2) For regulatory applications of AERMOD, the regulatory default option should be set, i.e., the parameter DFAULT should be employed in the MODELOPT record in the COntrol Pathway. The DFAULT option requires the use of terrain elevation data, stack-tip downwash, sequential date checking, and does not permit the use of the model in the SCREEN mode. In the regulatory default mode, pollutant half life or

decay options are not employed, except in the case of an urban source of sulfur dioxide where a four-hour half life is applied. Terrain elevation data from the U.S. Geological Survey 7.5-Minute Digital Elevation Model (*edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html*) or equivalent (approx. 30-meter resolution) should be used in all applications. In some cases, exceptions of the terrain data requirement may be made in consultation with the permit/SIP reviewing authority.

b. Input Requirements

(1) Source data: Required input includes source type, location, emission rate, stack height, stack inside diameter, stack gas exit velocity, stack gas temperature, area and volume source dimensions, and source elevation. Building dimensions and variable emission rates are optional.

(2) Meteorological data: The AERMET meteorological preprocessor requires input of surface characteristics, including surface roughness (zo), Bowen ratio, and albedo, as well as, hourly observations of wind speed between 7zo and 100m (reference wind speed measurement from which a vertical profile can be developed), wind direction, cloud cover, and temperature between zo and 100m (reference temperature measurement from which a vertical profile can be developed). Surface characteristics may be varied by wind sector and by season or month. A morning sounding (in National Weather Service format) from a representative upper air station, latitude, longitude, time zone, and wind speed threshold are also required in AERMET (instrument threshold is only required for site specific data). Additionally, measured profiles of wind, temperature, vertical and lateral turbulence may be required in certain applications (e.g., in complex terrain) to adequately represent the meteorology affecting plume transport and dispersion. Optionally, measurements of solar, or net radiation may be input to AERMET. Two files are produced by the AERMET meteorological preprocessor for input to the AERMOD dispersion model. The surface file contains observed and calculated surface variables, one record per hour. The profile file contains the observations made at each level of a meteorological tower (or remote sensor), or the one-level observations taken from other representative data (e.g., National Weather Service surface observations), one record per level per hour.

(i) Data used as input to AERMET should possess an adequate degree of representativeness to insure that the wind, temperature and turbulence profiles derived by AERMOD are both laterally and vertically representative of the source area. The adequacy of input data should be judged independently for each variable. The values for surface roughness, Bowen ratio, and albedo should reflect the surface characteristics in the vicinity of the meteorological tower, and should be adequately representative of the modeling domain. Finally, the primary atmospheric input variables including wind speed and direction, ambient temperature, cloud cover, and a morning upper air sounding should also be adequately representative of the source area.

(ii) For recommendations regarding the length of meteorological record needed to perform a regulatory analysis with AERMOD, see Section 8.3.1.

(3) Receptor data: Receptor coordinates, elevations, height above ground, and hill height scales are produced by the AERMAP terrain preprocessor for input to AERMOD. Discrete receptors and/or multiple receptor grids, Cartesian and/or polar, may be employed in AERMOD. AERMAP requires input of Digital Elevation Model (DEM) terrain data produced by the U.S. Geological Survey (USGS), or other equivalent data. AERMAP can be used optionally to estimate source elevations.

c. Output

Printed output options include input information, high concentration summary tables by receptor for user-specified averaging periods, maximum concentration summary tables, and concurrent values summarized by receptor for each day processed. Optional output files can be generated for: a listing of occurrences of exceedances of user-specified threshold value; a listing of concurrent (raw) results at each receptor for each hour modeled, suitable for post-processing; a listing of design values that can be imported into graphics software for plotting contours; an unformatted listing of raw results above a threshold value with a special structure for use with the TOXX model component of TOXST; a listing of concentrations by rank (e.g., for use in quantile-quantile plots); and, a listing of concentrations, including arc-maximum normalized concentrations, suitable for model evaluation studies.

d. Type of Model

AERMOD is a steady-state plume model, using Gaussian distributions in the vertical and horizontal for stable conditions, and in the horizontal for convective conditions. The vertical concentration distribution for convective conditions results from an assumed bi-Gaussian probability density function of the vertical velocity.

e. Pollutant Types

AERMOD is applicable to primary pollutants and continuous releases of toxic and hazardous waste pollutants. Chemical transformation is treated by simple exponential decay.

f. Source-Receptor Relationships

AERMOD applies user-specified locations for sources and receptors. Actual separation between each source-receptor pair is used. Source and receptor elevations are user input or are determined by AERMAP using USGS DEM terrain data. Receptors may be located at user-specified heights above ground level.

g. Plume Behavior

(1) In the convective boundary layer (CBL), the transport and dispersion of a plume is characterized as the superposition of three modeled plumes: The direct plume (from the stack), the indirect plume, and the penetrated plume, where the indirect plume accounts for the lofting of a buoyant plume near the top of the boundary layer, and the penetrated plume accounts for the portion of a plume that, due to its buoyancy, penetrates above the mixed layer, but can disperse downward and re-enter the mixed layer. In the CBL, plume rise is superposed on the displacements by random convective velocities (Weil *et al.*, 1997).

(2) In the stable boundary layer, plume rise is estimated using an iterative approach, similar to that in the CTDMPLUS model (see A.5 in this appendix).

(3) Stack-tip downwash and buoyancy induced dispersion effects are modeled. Building wake effects are simulated for stacks less than good engineering practice height using the methods contained in the PRIME downwash algorithms (Schulman, *et al.*, 2000). For plume rise affected by the presence of a building, the PRIME downwash algorithm uses a numerical solution of the mass, energy and momentum conservation laws (Zhang and Ghoniem, 1993). Streamline deflection and the position of the stack relative to the building affect plume trajectory and dispersion. Enhanced dispersion is based on the approach of Weil (1996). Plume mass captured by the cavity is well-mixed within the cavity. The captured plume mass is re-emitted to the far wake as a volume source.

(4) For elevated terrain, AERMOD incorporates the concept of the critical dividing streamline height, in which flow below this height remains horizontal, and flow above this height tends to rise up and over terrain (Snyder *et al.*, 1985). Plume concentration estimates are the weighted sum of these two limiting plume states. However, consistent with the steady-state assumption of uniform horizontal wind direction over the modeling domain, straight-line plume trajectories are assumed, with adjustment in the plume/receptor geometry used to account for the terrain effects.

h. Horizontal Winds

Vertical profiles of wind are calculated for each hour based on measurements and surface-layer similarity (scaling) relationships. At a given height above ground, for a given hour, winds are assumed constant over the modeling domain. The effect of the vertical variation in horizontal wind speed on dispersion is accounted for through simple averaging over the plume depth.

i. Vertical Wind Speed

In convective conditions, the effects of random vertical updraft and downdraft velocities are simulated with a bi-Gaussian probability density function. In both convective and stable conditions, the mean vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

Gaussian horizontal dispersion coefficients are estimated as continuous functions of the parameterized (or measured) ambient lateral turbulence and also account for buoyancy-induced and building wake-induced turbulence. Vertical profiles of lateral turbulence are developed from measurements and similarity (scaling) relationships. Effective turbulence values are determined from the portion of the vertical profile of lateral turbulence between the plume height and the receptor height. The effective lateral turbulence is then used to estimate horizontal dispersion.

k. Vertical Dispersion

In the stable boundary layer, Gaussian vertical dispersion coefficients are estimated as continuous functions of parameterized vertical turbulence. In the convective boundary layer, vertical dispersion is characterized by a bi-Gaussian probability density function, and is also estimated as a continuous function of parameterized vertical turbulence. Vertical turbulence profiles are developed from measurements and similarity (scaling) relationships. These turbulence profiles account for both convective and mechanical turbulence. Effective turbulence values are determined from the portion of the vertical profile of vertical turbulence between the plume height and the receptor height. The effective vertical turbulence is then used to estimate vertical dispersion.

l. Chemical Transformation

Chemical transformations are generally not treated by AERMOD. However, AERMOD does contain an option to treat chemical transformation using simple exponential decay, although this option is typically not used in regulatory applications, except for sources of sulfur dioxide in urban areas. Either a decay coefficient or a half life is input by the user. Note also that the Plume Volume Molar Ratio Method (subsection 5.1) and the Ozone Limiting Method (subsection 5.2.4) and for point-source NO_2 analyses are available as non-regulatory options.

m. Physical Removal

AERMOD can be used to treat dry and wet deposition for both gases and particles.

n. Evaluation Studies

American Petroleum Institute, 1998. Evaluation of State of the Science of Air Quality Dispersion Model, Scientific Evaluation, prepared by Woodward-Clyde Consultants, Lexington, Massachusetts, for American Petroleum Institute, Washington, D.C., 20005–4070.

Brode, R.W., 2002. Implementation and Evaluation of PRIME in AERMOD. Preprints of the 12th Joint Conference on Applications of Air Pollution Meteorology, May 20–24, 2002; American Meteorological Society, Boston, MA.

Brode, R.W., 2004. Implementation and Evaluation of Bulk Richardson Number Scheme in AERMOD. 13th Joint Conference on Applications of Air Pollution Meteorology, August 23–26, 2004; American Meteorological Society, Boston, MA.

Environmental Protection Agency, 2003. AERMOD: Latest Features and Evaluation Results. Publication No. EPA–454/R–03–003. U.S. Environmental Protection Agency, Research Triangle Park, NC. Available at *http://www.epa.gov/scram001/.*

A.2 Buoyant Line and Point Source Dispersion Model (BLP)

Reference

Schulman, Lloyd L., and Joseph S. Scire, 1980. Buoyant Line and Point Source (BLP) Dispersion Model User's Guide. Document P–7304B. Environmental Research and Technology, Inc., Concord, MA. (NTIS No. PB 81–164642; also available at *http://www.epa.gov/scram001/*)

Availability

The computer code is available on EPA's Internet SCRAM Web site and also on diskette (as PB 2002–500051) from the National Technical Information Service (see Section A.0).

Abstract

BLP is a Gaussian plume dispersion model designed to handle unique modeling problems associated with aluminum reduction plants, and other industrial sources where plume rise and downwash effects from stationary line sources are important.

a. Recommendations for Regulatory Use

(1) The BLP model is appropriate for the following applications:

- Aluminum reduction plants which contain buoyant, elevated line sources;
- Rural areas;
- Transport distances less than 50 kilometers;
- Simple terrain; and
- One hour to one year averaging times.

(2) The following options should be selected for regulatory applications:

(i) Rural (IRU=1) mixing height option;

(ii) Default (no selection) for plume rise wind shear (LSHEAR), transitional point source plume rise (LTRANS), vertical potential temperature gradient (DTHTA), vertical wind speed power law profile exponents (PEXP), maximum variation in number of stability classes per hour (IDELS), pollutant decay (DECFAC), the constant in Briggs' stable plume rise equation (CONST2), constant in Briggs' neutral plume rise equation (CONST3), convergence criterion for the line source calculations (CRIT), and maximum iterations allowed for line source calculations (MAXIT); and

(iii) Terrain option (TERAN) set equal to 0.0, 0.0, 0.0, 0.0, 0.0, 0.0

(3) For other applications, BLP can be used if it can be demonstrated to give the same estimates as a recommended model for the same application, and will subsequently be executed in that mode.

(4) BLP can be used on a case-by-case basis with specific options not available in a recommended model if it can be demonstrated, using the criteria in Section 3.2, that the model is more appropriate for a specific application.

b. Input Requirements

(1) Source data: point sources require stack location, elevation of stack base, physical stack height, stack inside diameter, stack gas exit velocity, stack gas exit temperature, and pollutant emission rate. Line sources require coordinates of the end points of the line, release height, emission rate, average line source width, average building width, average spacing between buildings, and average line source buoyancy parameter.

(2) Meteorological data: surface weather data from a preprocessor such as PCRAMMET which provides hourly stability class, wind direction, wind speed, temperature, and mixing height.

(3) Receptor data: locations and elevations of receptors, or location and size of receptor grid or request automatically generated receptor grid.

c. Output

(1) Printed output (from a separate post-processor program) includes:

(2) Total concentration or, optionally, source contribution analysis; monthly and annual frequency distributions for 1-, 3-, and 24-hour average concentrations; tables of 1-, 3-, and 24-hour average concentrations at each receptor; table of the annual (or length of run) average concentrations at each receptor;

(3) Five highest 1-, 3-, and 24-hour average concentrations at each receptor; and

(4) Fifty highest 1-, 3-, and 24-hour concentrations over the receptor field.

d. Type of Model

BLP is a gaussian plume model.

e. Pollutant Types

BLP may be used to model primary pollutants. This model does not treat settling and deposition.

f. Source-Receptor Relationship

(1) BLP treats up to 50 point sources, 10 parallel line sources, and 100 receptors arbitrarily located.

(2) User-input topographic elevation is applied for each stack and each receptor.

g. Plume Behavior

(1) BLP uses plume rise formulas of Schulman and Scire (1980).

(2) Vertical potential temperature gradients of 0.02 Kelvin per meter for E stability and 0.035 Kelvin per meter are used for stable plume rise calculations. An option for user input values is included.

(3) Transitional rise is used for line sources.

(4) Option to suppress the use of transitional plume rise for point sources is included.

(5) The building downwash algorithm of Schulman and Scire (1980) is used.

h. Horizontal Winds

(1) Constant, uniform (steady-state) wind is assumed for an hour.

Straight line plume transport is assumed to all downwind distances.

(2) Wind speeds profile exponents of 0.10, 0.15, 0.20, 0.25, 0.30, and 0.30 are used for stability classes A through F, respectively. An option for user-defined values and an option to suppress the use of the wind speed profile feature are included.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Rural dispersion coefficients are from Turner (1969), with no adjustment made for variations in surface roughness or averaging time.

(2) Six stability classes are used.

k. Vertical Dispersion

(1) Rural dispersion coefficients are from Turner (1969), with no adjustment made for variations in surface roughness.

(2) Six stability classes are used.

(3) Mixing height is accounted for with multiple reflections until the vertical plume standard deviation equals 1.6 times the

mixing height; uniform mixing is assumed beyond that point.

(4) Perfect reflection at the ground is assumed.

l. Chemical Transformation

Chemical transformations are treated using linear decay. Decay rate is input by the user.

m. Physical Removal

Physical removal is not explicitly treated.

n. Evaluation Studies

Schulman, L.L. and J.S. Scire, 1980. Buoyant Line and Point Source (BLP) Dispersion Model User's Guide, P–7304B. Environmental Research and Technology, Inc., Concord, MA.

Scire, J.S. and L.L. Schulman, 1981. Evaluation of the BLP and ISC Models with SF_6 Tracer Data and SO_2 Measurements at Aluminum Reduction Plants. APCA Specialty Conference on Dispersion Modeling for Complex Sources, St. Louis, MO.

A.3 CALINE3

Reference

Benson, Paul E., 1979. CALINE3—A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets. Interim Report, Report Number FHWA/CA/TL–79/23. Federal Highway Administration, Washington, DC (NTIS No. PB 80–220841).

Availability

The CALINE3 model is available on diskette (as PB 95–502712) from NTIS. The source code and user's guide are also available on EPA's Internet SCRAM Web site (Section A.0).

Abstract

CALINE3 can be used to estimate the concentrations of nonreactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of ''at-grade,'' ''fill,'' ''bridge,'' and ''cut section'' highways located in relatively uncomplicated terrain. The model is applicable for any wind direction, highway orientation, and receptor location. The model has adjustments for averaging time and surface roughness, and can handle up to 20 links and 20 receptors. It also contains an algorithm for deposition and settling velocity so that particulate concentrations can be predicted.

a. Recommendations for Regulatory Use

CALINE–3 is appropriate for the following applications:

- Highway (line) sources;
- Urban or rural areas;
- Simple terrain;
- Transport distances less than 50 kilometers; and
- One-hour to 24-hour averaging times.

b. Input Requirements

(1) Source data: up to 20 highway links classed as ''at-grade,'' ''fill,'' ''bridge,'' or ''depressed''; coordinates of link end points; traffic volume; emission factor; source height; and mixing zone width.

(2) Meteorological data: wind speed, wind angle (measured in degrees clockwise from the Y axis), stability class, mixing height, ambient (background to the highway) concentration of pollutant.

(3) Receptor data: coordinates and height above ground for each receptor.

c. Output

Printed output includes concentration at each receptor for the specified meteorological condition.

d. Type of Model

CALINE–3 is a Gaussian plume model.

e. Pollutant Types

CALINE–3 may be used to model primary pollutants.

f. Source-Receptor Relationship

(1) Up to 20 highway links are treated.

(2) CALINE–3 applies user input location and emission rate for each link. User-input receptor locations are applied.

g. Plume Behavior

Plume rise is not treated.

h. Horizontal Winds

(1) User-input hourly wind speed and direction are applied.

(2) Constant, uniform (steady-state) wind is assumed for an hour.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Six stability classes are used.

(2) Rural dispersion coefficients from Turner (1969) are used, with adjustment for roughness length and averaging time.

(3) Initial traffic-induced dispersion is handled implicitly by plume size parameters.

k. Vertical Dispersion

(1) Six stability classes are used.

(2) Empirical dispersion coefficients from Benson (1979) are used including an adjustment for roughness length.

(3) Initial traffic-induced dispersion is handled implicitly by plume size parameters.

(4) Adjustment for averaging time is included.

l. Chemical Transformation

Not treated.

m. Physical Removal

Optional deposition calculations are included.

n. Evaluation Studies

Bemis, G.R. *et al.*, 1977. Air Pollution and Roadway Location, Design, and Operation—Project Overview. FHWA–CA–TL–7080–77–25, Federal Highway Administration, Washington, DC.

Cadle, S.H. *et al.*, 1976. Results of the General Motors Sulfate Dispersion Experiment, GMR–2107. General Motors Research Laboratories, Warren, MI.

Dabberdt, W.F., 1975. Studies of Air Quality on and Near Highways, Project 2761. Stanford Research Institute, Menlo Park, CA.

Environmental Protection Agency, 1986. Evaluation of Mobile Source Air Quality Simulation Models. EPA Publication No. EPA–450/4–86–002. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 86–167293)

A.4 CALPUFF

References

Scire, J.S., D.G. Strimaitis and R.J. Yamartino, 2000. A User's Guide for the CALPUFF Dispersion Model (Version 5.0). Earth Tech, Inc., Concord, MA.

Scire J.S., F.R. Robe, M.E. Fernau and R.J. Yamartino, 2000. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Tech, Inc., Concord, MA.

Availability

The model code and its documentation are available at no cost for download from the model developers' Internet Web site: *http://www.src.com/calpuff/calpuff1.htm.* You may also contact Joseph Scire, Earth Tech, Inc., 196 Baker Avenue, Concord, MA 01742; Telephone: (978) 371–4270; Fax: (978) 371–2468; e-mail: *JScire@alum.mit.edu.*

Abstract

CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion modeling system that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF is intended for use on scales from tens of meters from a source to hundreds of kilometers. It includes algorithms for near-field effects such as stack tip downwash, building downwash, transitional buoyant and momentum plume rise, rain cap effects, partial plume penetration, subgrid scale terrain and coastal interactions effects, and terrain impingement as well as longer range effects such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, vertical wind shear effects, overwater transport, plume fumigation, and visibility effects of particulate matter concentrations.

a. Recommendations for Regulatory Use

(1) CALPUFF is appropriate for long range transport (source-receptor distances of 50 to several hundred kilometers) of emissions from point, volume, area, and line sources. The meteorological input data should be fully characterized with time-and-space-varying three dimensional wind and meteorological conditions using CALMET, as discussed in paragraphs 8.3(d) and 8.3.1.2(d) of Appendix W.

(2) CALPUFF may also be used on a case-by-case basis if it can be demonstrated using the criteria in Section 3.2 that the model is more appropriate for the specific application. The purpose of choosing a modeling system like CALPUFF is to fully treat stagnation, wind reversals, and time and space variations of meteorological conditions on transport and dispersion, as discussed in paragraph 7.2.8(a).

(3) For regulatory applications of CALMET and CALPUFF, the regulatory default option should be used. Inevitably, some of the model control options will have to be set specific for the application using expert judgment and in consultation with the appropriate reviewing authorities.

b. Input Requirements

Source Data:

1. Point sources: Source location, stack height, diameter, exit velocity, exit temperature, base elevation, wind direction specific building dimensions (for building downwash calculations), and emission rates for each pollutant. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying point source parameters may be entered from an external file.

2. Area sources: Source location and shape, release height, base elevation, initial vertical distribution (σ_z) and emission rates for each pollutant. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying area source parameters may be entered from an external file. Area sources specified in the external file are allowed to be buoyant and their location, size, shape, and other source characteristics are allowed to change in time.

3. Volume sources: Source location, release height, base elevation, initial horizontal and vertical distributions (σ_y, σ_z) and emission rates for each pollutant. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying volume source parameters may be entered from an external file. Volume sources with buoyancy can be simulated by treating the source as a point source and entering initial plume size parameters—initial (σ_y, σ_z)—to define the initial size of the volume source.

4. Line sources: Source location, release height, base elevation, average buoyancy parameter, and emission rates for each pollutant. Building data may be entered for line source emissions experiencing building downwash effects. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying line source parameters may be entered from an external file.

Meteorological Data (different forms of meteorological input can be used by CALPUFF):

1. Time-dependent three-dimensional (3–D) meteorological fields generated by CALMET. This is the preferred mode for running CALPUFF. Data inputs used by CALMET include surface observations of wind speed, wind direction, temperature, cloud cover, ceiling height, relative humidity, surface pressure, and precipitation (type and amount), and upper air sounding data (wind speed, wind direction, temperature, and height) and air-sea temperature differences (over water). Optional 3–D meteorological prognostic model output (e.g., from models such as MM5, RUC, Eta and RAMS) can be used by CALMET as well (paragraph 8.3.1.2(d)). CALMET contains an option to be run in ''No-observations'' mode (Robe et al., 2002), which allows the 3–D CALMET meteorological fields to be based on prognostic model output alone, without observations. This allows CALMET and CALPUFF to be run in prognostic mode for forecast applications.

2. Single station surface and upper air meteorological data in CTDMPLUS data file formats (SURFACE.DAT and PROFILE.DAT files) or AERMOD data file formats. These options allow a vertical variation in the meteorological parameters but no horizontal spatial variability.

3. Single station meteorological data in ISCST3 data file format. This option does not account for variability of the meteorological parameters in the horizontal or vertical, except as provided for by the use of stability-dependent wind shear exponents and average temperature lapse rates.

Gridded terrain and land use data are required as input into CALMET when Option 1 is used. Geophysical processor programs are provided that interface the modeling system to standard terrain and land use data bases available from various sources such as the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA).

Receptor Data:

CALPUFF includes options for gridded and non-gridded (discrete) receptors. Special subgrid-scale receptors are used with the subgrid-scale complex terrain option. An option is provided for discrete receptors to be placed at ground-level or above the local ground level (i.e., flagpole receptors). Gridded and subgrid-scale receptors are placed at the local ground level only.

Other Input:

CALPUFF accepts hourly observations of ozone concentrations for use in its chemical transformation algorithm. Monthly concentrations of ammonia concentrations can be specified in the CALPUFF input file, although higher time-resolution ammonia variability can be computed using the POSTUTIL program. Subgrid-scale coastlines can be specified in its coastal boundary file. Optional, user-specified deposition velocities and chemical transformation rates can also be entered. CALPUFF accepts the CTDMPLUS terrain and receptor files for use in its subgrid-scale terrain algorithm. Inflow boundary conditions of modeled pollutants can be specified in a boundary condition file. Liquid water content variables including cloud water/ice and precipitation water/ice can be used as input for visibility analyses and other CALPUFF modules.

c. Output

CALPUFF produces files of hourly concentrations of ambient concentrations for each modeled species, wet deposition fluxes, dry deposition fluxes, and for visibility applications, extinction coefficients. Postprocessing programs (PRTMET, CALPOST, CALSUM, APPEND, and POSTUTIL) provide options for summing, scaling, analyzing and displaying the modeling results. CALPOST contains options for computing of light extinction (visibility) and POSTUTIL allows the re-partitioning of nitric acid and nitrate to account for the effects of ammonia limitation (Scire *et al.*, 2001; Escoffier-Czaja and Scire, 2002). CALPUFF contains an options to output liquid water concentrations for use in computing visible plume lengths and frequency of icing and fogging from cooling towers and other water vapor sources. The CALPRO Graphical User Interface (GUI) contains options for creating graphics such as contour plots, vector plots and other displays when linked to graphics software.

d. Type of Model

(1) CALPUFF is a non-steady-state time- and space-dependent Gaussian puff model. CALPUFF treats primary pollutants and simulates secondary pollutant formation using a parameterized, quasi-linear chemical conversion mechanism. Pollutants treated include SO_2, $SO_4^{=}$, NO_X (i.e., NO + NO_2), HNO_3, NO_3^{-}, NH_3, PM–10, PM–2.5, toxic pollutants and others pollutant species that are either inert or subject to quasi-linear chemical reactions. The model includes a resistance-based dry deposition model for both gaseous pollutants and particulate matter. Wet deposition is treated using a scavenging coefficient approach. The model has detailed parameterizations of complex terrain effects, including terrain impingement, side-wall scrapping, and steep-walled terrain influences on lateral plume growth. A subgrid-scale complex terrain module based on a dividing streamline concept divides the flow into a lift component traveling over the obstacle and a wrap component deflected around the obstacle.

(2) The meteorological fields used by CALPUFF are produced by the CALMET meteorological model. CALMET includes a diagnostic wind field model containing parameterized treatments of slope flows, valley flows, terrain blocking effects, and kinematic terrain effects, lake and sea breeze circulations, a divergence minimization procedure, and objective analysis of observational data. An energy-balance scheme is used to compute sensible and latent heat fluxes and turbulence parameters over land surfaces. A profile method is used over water. CALMET contains interfaces to prognostic meteorological models such as the Penn State/NCAR Mesoscale Model (e.g., MM5; Section 12.0, ref. 86), as well as the RAMS, Ruc and Eta models.

e. Pollutant Types

CALPUFF may be used to model gaseous pollutants or particulate matter that are inert or which undergo quasi-linear chemical reactions, such as SO_2, SO_4 =, NO_X (*i.e.*, NO + NO_2), HNO_3, NO_3-, NH_3, PM–10, PM–2.5 and toxic pollutants. For regional haze analyses, sulfate and nitrate particulate components are explicitly treated.

f. Source-Receptor Relationships

CALPUFF contains no fundamental limitations on the number of sources or receptors. Parameter files are provided that allow the user to specify the maximum number of sources, receptors, puffs, species, grid cells, vertical layers, and other model parameters. Its algorithms are designed to be suitable for source-receptor distances from tens of meters to hundreds of kilometers.

g. Plume Behavior

Momentum and buoyant plume rise is treated according to the plume rise equations of Briggs (1975) for non-downwashing point sources, Schulman and Scire (1980) for line sources and point sources subject to building downwash effects using the Schulman-Scire downwash algorithm, and Zhang (1993) for buoyant area sources and point sources affected by building downwash when using the PRIME building downwash method. Stack tip downwash effects and partial plume penetration into elevated temperature inversions are included. An algorithm to treat horizontally-oriented vents and stacks with rain caps is included.

h. Horizontal Winds

A three-dimensional wind field is computed by the CALMET meteorological model. CALMET combines an objective analysis procedure using wind observations with parameterized treatments of slope flows, valley flows, terrain kinematic effects, terrain blocking effects, and sea/lake breeze circulations. CALPUFF may optionally use single station (horizontally-constant) wind fields in the CTDMPLUS, AERMOD or ISCST3 data formats.

i. Vertical Wind Speed

Vertical wind speeds are not used explicitly by CALPUFF. Vertical winds are used in the development of the horizontal wind components by CALMET.

j. Horizontal Dispersion

Turbulence-based dispersion coefficients provide estimates of horizontal plume dispersion based on measured or computed values of σ_v. The effects of building downwash and buoyancy-induced dispersion are included. The effects of vertical wind shear are included through the puff splitting algorithm. Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.

k. Vertical Dispersion

Turbulence-based dispersion coefficients provide estimates of vertical plume dispersion based on measured or computed values of σ_w. The effects of building downwash and buoyancy-induced dispersion are included. Vertical dispersion during convective conditions is simulated with a probability density function (pdf) model based on Weil *et al.* (1997). Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.

l. Chemical Transformation

Gas phase chemical transformations are treated using parameterized models of SO_2 conversion to SO_4= and NO conversion to NO_3-, HNO_3, and NO_2. Organic aerosol formation is treated. The POSTUTIL program contains an option to re-partition HNO_3 and NO_3- in order to treat the effects of ammonia limitation.

m. Physical Removal

Dry deposition of gaseous pollutants and particulate matter is parameterized in terms of a resistance-based deposition model. Gravitational settling, inertial impaction, and Brownian motion effects on deposition of particulate matter is included. CALPUFF contains an option to evaluate the effects of plume tilt resulting from gravitational settling. Wet deposition of gases and particulate matter is parameterized in terms of a scavenging coefficient approach.

n. Evaluation Studies

Berman, S., J.Y. Ku, J. Zhang and S.T. Rao, 1977. Uncertainties in estimating the mixing depth—Comparing three mixing depth models with profiler measurements, *Atmospheric Environment,* 31: 3023–3039.

Chang, J.C., P. Franzese, K. Chayantrakom and S.R. Hanna, 2001. Evaluations of CALPUFF, HPAC and VLSTRACK with Two Mesoscale Field Datasets. *Journal of Applied Meteorology,* 42(4): 453–466.

Environmental Protection Agency, 1998. Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long-Range Transport Impacts. EPA Publication No. EPA–454/R–98–019. Office of Air Quality Planning & Standards, Research Triangle Park, NC.

Irwin, J.S., 1997. A Comparison of CALPUFF Modeling Results with 1997 INEL Field Data Results. In *Air Pollution Modeling and its Application, XII.* Edited by S.E. Gyrning and N. Chaumerliac. Plenum Press, New York, NY.

Irwin, J.S., J.S. Scire and D.G. Strimaitis, 1996. A Comparison of CALPUFF Modeling Results with CAPTEX Field Data Results. In *Air Pollution Modeling and its Application, XI.* Edited by S.E. Gyrning and F.A. Schiermeier. Plenum Press, New York, NY.

Morrison, K, Z–X Wu, J.S. Scire, J. Chenier and T. Jeffs-Schonewille, 2003. CALPUFF-Based Predictive and Reactive Emission Control System. 96th A&WMA Annual Conference & Exhibition, 22–26 June 2003; San Diego, CA.

Schulman, L.L., D.G. Strimaitis and J.S. Scire, 2000. Development and evaluation of the PRIME Plume Rise and Building Downwash Model. JAWMA, 50: 378–390.

Scire, J.S., Z–X Wu, D.G. Strimaitis and G.E. Moore, 2001. The Southwest Wyoming Regional CALPUFF Air Quality Modeling Study—Volume I. Prepared for the Wyoming Dept. of Environmental Quality. Available from Earth Tech at *http://www.src.com.*

Strimaitis, D.G., J.S. Scire and J.C. Chang, 1998. Evaluation of the CALPUFF Dispersion Model with Two Power Plant Data Sets. Tenth Joint Conference on the Application of Air Pollution Meteorology, Phoenix, Arizona. American Meteorological Society, Boston, MA. January 11–16, 1998.

A.5 Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS)

Reference

Perry, S.G., D.J. Burns, L.H. Adams, R.J. Paine, M.G. Dennis, M.T. Mills, D.G. Strimaitis, R.J. Yamartino and E.M. Insley, 1989. User's Guide to the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS). Volume 1: Model Descriptions and User Instructions. EPA Publication No. EPA–600/8–89–041. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 89–181424)

Perry, S.G., 1992. CTDMPLUS: A Dispersion Model for Sources near Complex Topography. Part I: Technical Formulations. *Journal of Applied Meteorology,* 31(7): 633–645.

Availability

This model code is available on EPA's Internet SCRAM Web site and also on diskette (as PB 90–504119) from the National Technical Information Service (Section A.0).

Abstract

CTDMPLUS is a refined point source Gaussian air quality model for use in all stability conditions for complex terrain applications. The model contains, in its entirety, the technology of CTDM for stable and neutral conditions. However, CTDMPLUS can also simulate daytime, unstable conditions, and has a number of additional capabilities for improved user friendliness. Its use of meteorological data and terrain information is different from other EPA models; considerable detail for both types of input data is required and is supplied by preprocessors specifically designed for CTDMPLUS. CTDMPLUS requires the parameterization of individual hill shapes using the terrain preprocessor and the association of each model receptor with a particular hill.

a. Recommendation for Regulatory Use

CTDMPLUS is appropriate for the following applications:

- Elevated point sources;
- Terrain elevations above stack top;
- Rural or urban areas;
- Transport distances less than 50 kilometers; and
- One hour to annual averaging times when used with a post-processor program such as CHAVG.

b. Input Requirements

(1) Source data: For each source, user supplies source location, height, stack diameter, stack exit velocity, stack exit temperature, and emission rate; if variable emissions are appropriate, the user supplies hourly values for emission rate, stack exit velocity, and stack exit temperature.

(2) Meteorological data: For applications of CTDMPLUS, multiple level (typically three or more) measurements of wind speed and direction, temperature and turbulence (wind fluctuation statistics) are required to create the basic meteorological data file (''PROFILE''). Such measurements should be obtained up to the representative plume height(s) of interest (*i.e.*, the plume height(s) under those conditions important to the determination of the design concentration). The representative plume height(s) of interest should be determined using an appropriate complex terrain screening procedure (*e.g.*, CTSCREEN) and should be documented in the monitoring/modeling protocol. The necessary meteorological measurements should be obtained from an appropriately

sited meteorological tower augmented by SODAR and/or RASS if the representative plume height(s) of interest is above the levels represented by the tower measurements. Meteorological preprocessors then create a SURFACE data file (hourly values of mixed layer heights, surface friction velocity, Monin-Obukhov length and surface roughness length) and a RAWINsonde data file (upper air measurements of pressure, temperature, wind direction, and wind speed).

(3) Receptor data: receptor names (up to 400) and coordinates, and hill number (each receptor must have a hill number assigned).

(4) Terrain data: user inputs digitized contour information to the terrain preprocessor which creates the TERRAIN data file (for up to 25 hills).

c. Output

(1) When CTDMPLUS is run, it produces a concentration file, in either binary or text format (user's choice), and a list file containing a verification of model inputs, *i.e.*,

- Input meteorological data from ''SURFACE'' and ''PROFILE''.
- Stack data for each source.
- Terrain information.
- Receptor information.
- Source-receptor location (line printer map).

(2) In addition, if the case-study option is selected, the listing includes:

- Meteorological variables at plume height.
- Geometrical relationships between the source and the hill.
- Plume characteristics at each receptor, *i.e.*,

—Distance in along-flow and cross flow direction
—Effective plume-receptor height difference
—Effective σ_y & σ_z values, both flat terrain and hill induced (the difference shows the effect of the hill)
—Concentration components due to WRAP, LIFT and FLAT.

(3) If the user selects the TOPN option, a summary table of the top 4 concentrations at each receptor is given. If the ISOR option is selected, a source contribution table for every hour will be printed.

(4) A separate disk file of predicted (1-hour only) concentrations (''CONC'') is written if the user chooses this option. Three forms of output are possible:

(i) A binary file of concentrations, one value for each receptor in the hourly sequence as run;

(ii) A text file of concentrations, one value for each receptor in the hourly sequence as run; or

(iii) A text file as described above, but with a listing of receptor information (names, positions, hill number) at the beginning of the file.

(3) Hourly information provided to these files besides the concentrations themselves includes the year, month, day, and hour information as well as the receptor number with the highest concentration.

d. Type of Model

CTDMPLUS is a refined steady-state, point source plume model for use in all stability conditions for complex terrain applications.

e. Pollutant Types

CTDMPLUS may be used to model non-reactive, primary pollutants.

f. Source-Receptor Relationship

Up to 40 point sources, 400 receptors and 25 hills may be used. Receptors and sources are allowed at any location. Hill slopes are assumed not to exceed 15°, so that the linearized equation of motion for Boussinesq flow are applicable. Receptors upwind of the impingement point, or those associated with any of the hills in the modeling domain, require separate treatment.

g. Plume Behavior

(1) As in CTDM, the basic plume rise algorithms are based on Briggs' (1975) recommendations.

(2) A central feature of CTDMPLUS for neutral/stable conditions is its use of a critical dividing-streamline height (H_c) to separate the flow in the vicinity of a hill into two separate layers. The plume component in the upper layer has sufficient kinetic energy to pass over the top of the hill while streamlines in the lower portion are constrained to flow in a horizontal plane around the hill. Two separate components of CTDMPLUS compute ground-level concentrations resulting from plume material in each of these flows.

(3) The model calculates on an hourly (or appropriate steady averaging period) basis how the plume trajectory (and, in stable/neutral conditions, the shape) is deformed by each hill. Hourly profiles of wind and temperature measurements are used by CTDMPLUS to compute plume rise, plume penetration (a formulation is included to handle penetration into elevated stable layers, based on Briggs (1984)), convective scaling parameters, the value of H_c, and the Froude number above H_c.

h. Horizontal Winds

CTDMPLUS does not simulate calm meteorological conditions. Both scalar and vector wind speed observations can be read by the model. If vector wind speed is unavailable, it is calculated from the scalar wind speed. The assignment of wind speed (either vector or scalar) at plume height is done by either:

- Interpolating between observations above and below the plume height, or
- Extrapolating (within the surface layer) from the nearest measurement height to the plume height.

i. Vertical Wind Speed

Vertical flow is treated for the plume component above the critical dividing streamline height (H_c); see ''Plume Behavior''.

j. Horizontal Dispersion

Horizontal dispersion for stable/neutral conditions is related to the turbulence velocity scale for lateral fluctuations, σ_v, for which a minimum value of 0.2 m/s is used. Convective scaling formulations are used to estimate horizontal dispersion for unstable conditions.

k. Vertical Dispersion

Direct estimates of vertical dispersion for stable/neutral conditions are based on observed vertical turbulence intensity, *e.g.*, σ_w (standard deviation of the vertical velocity fluctuation). In simulating unstable (convective) conditions, CTDMPLUS relies on a skewed, bi-Gaussian probability density function (pdf) description of the vertical velocities to estimate the vertical distribution of pollutant concentration.

l. Chemical Transformation

Chemical transformation is not treated by CTDMPLUS.

m. Physical Removal

Physical removal is not treated by CTDMPLUS (complete reflection at the ground/hill surface is assumed).

n. Evaluation Studies

Burns, D.J., L.H. Adams and S.G. Perry, 1990. Testing and Evaluation of the CTDMPLUS Dispersion Model: Daytime Convective Conditions. Environmental Protection Agency, Research Triangle Park, NC.

Paumier, J.O., S.G. Perry and D.J. Burns, 1990. An Analysis of CTDMPLUS Model Predictions with the Lovett Power Plant Data Base. Environmental Protection Agency, Research Triangle Park, NC.

Paumier, J.O., S.G. Perry and D.J. Burns, 1992. CTDMPLUS: A Dispersion Model for Sources near Complex Topography. Part II: Performance Characteristics. *Journal of Applied Meteorology,* 31(7): 646–660.

A.6 Offshore and Coastal Dispersion Model (OCD)

Reference

DiCristofaro, D.C. and S.R. Hanna, 1989. OCD: The Offshore and Coastal Dispersion Model, Version 4. Volume I: User's Guide, and Volume II: Appendices. Sigma Research Corporation, Westford, MA. (NTIS Nos. PB 93–144384 and PB 93–144392; also available at *http://www.epa.gov/scram001/*)

Availability

This model code is available on EPA's Internet SCRAM Web site and also on diskette (as PB 91–505230) from the National Technical Information Service (see Section A.0). Official contact at Minerals Management Service: Mr. Dirk Herkhof, Parkway Atrium Building, 381 Elden Street, Herndon, VA 20170, Phone: (703) 787–1735.

Abstract

(1) OCD is a straight-line Gaussian model developed to determine the impact of offshore emissions from point, area or line sources on the air quality of coastal regions. OCD incorporates overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline. Hourly meteorological data are needed from both offshore and onshore locations. These include water surface temperature, overwater air temperature, mixing height, and relative humidity.

(2) Some of the key features include platform building downwash, partial plume penetration into elevated inversions, direct use of turbulence intensities for plume dispersion, interaction with the overland internal boundary layer, and continuous shoreline fumigation.

a. Recommendations for Regulatory Use

OCD has been recommended for use by the Minerals Management Service for emissions located on the Outer Continental Shelf (50 FR 12248; 28 March 1985). OCD is applicable for overwater sources where onshore receptors are below the lowest source height. Where onshore receptors are above the lowest source height, offshore plume transport and dispersion may be modeled on a case-by-case basis in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

b. Input Requirements

(1) Source data: Point, area or line source location, pollutant emission rate, building height, stack height, stack gas temperature, stack inside diameter, stack gas exit velocity, stack angle from vertical, elevation of stack base above water surface and gridded specification of the land/water surfaces. As an option, emission rate, stack gas exit velocity and temperature can be varied hourly.

(2) Meteorological data (over water): Wind direction, wind speed, mixing height, relative humidity, air temperature, water surface temperature, vertical wind direction shear (optional), vertical temperature gradient (optional), turbulence intensities (optional).

(2) Meteorological data:

Over land: Surface weather data from a preprocessor such as PCRAMMET which provides hourly stability class, wind direction, wind speed, ambient temperature, and mixing height are required.

Over water: Hourly values for mixing height, relative humidity, air temperature, and water surface temperature are required; if wind speed/direction are missing, values over land will be used (if available); vertical wind direction shear, vertical temperature gradient, and turbulence intensities are optional.

(3) Receptor data: Location, height above local ground-level, ground-level elevation above the water surface.

c. Output

(1) All input options, specification of sources, receptors and land/water map including locations of sources and receptors.

(2) Summary tables of five highest concentrations at each receptor for each averaging period, and average concentration for entire run period at each receptor.

(3) Optional case study printout with hourly plume and receptor characteristics. Optional table of annual impact assessment from non-permanent activities.

(4) Concentration files written to disk or tape can be used by ANALYSIS postprocessor to produce the highest concentrations for each receptor, the cumulative frequency distributions for each receptor, the tabulation of all concentrations exceeding a given threshold, and the manipulation of hourly concentration files.

d. Type of Model

OCD is a Gaussian plume model constructed on the framework of the MPTER model.

e. Pollutant Types

OCD may be used to model primary pollutants. Settling and deposition are not treated.

f. Source-Receptor Relationship

(1) Up to 250 point sources, 5 area sources, or 1 line source and 180 receptors may be used.

(2) Receptors and sources are allowed at any location.

(3) The coastal configuration is determined by a grid of up to 3600 rectangles. Each element of the grid is designated as either land or water to identify the coastline.

g. Plume Behavior

(1) As in ISC, the basic plume rise algorithms are based on Briggs' recommendations.

(2) Momentum rise includes consideration of the stack angle from the vertical.

(3) The effect of drilling platforms, ships, or any overwater obstructions near the source are used to decrease plume rise using a revised platform downwash algorithm based on laboratory experiments.

(4) Partial plume penetration of elevated inversions is included using the suggestions of Briggs (1975) and Weil and Brower (1984).

(5) Continuous shoreline fumigation is parameterized using the Turner method where complete vertical mixing through the thermal internal boundary layer (TIBL) occurs as soon as the plume intercepts the TIBL.

h. Horizontal Winds

(1) Constant, uniform wind is assumed for each hour.

(2) Overwater wind speed can be estimated from overland wind speed using relationship of Hsu (1981).

(3) Wind speed profiles are estimated using similarity theory (Businger, 1973). Surface layer fluxes for these formulas are calculated from bulk aerodynamic methods.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Lateral turbulence intensity is recommended as a direct estimate of horizontal dispersion. If lateral turbulence intensity is not available, it is estimated from boundary layer theory. For wind speeds less than 8 m/s, lateral turbulence intensity is assumed inversely proportional to wind speed.

(2) Horizontal dispersion may be enhanced because of obstructions near the source. A virtual source technique is used to simulate the initial plume dilution due to downwash.

(3) Formulas recommended by Pasquill (1976) are used to calculate buoyant plume enhancement and wind direction shear enhancement.

(4) At the water/land interface, the change to overland dispersion rates is modeled using a virtual source. The overland dispersion rates can be calculated from either lateral turbulence intensity or Pasquill-Gifford curves. The change is implemented where the plume intercepts the rising internal boundary layer.

k. Vertical Dispersion

(1) Observed vertical turbulence intensity is not recommended as a direct estimate of vertical dispersion. Turbulence intensity should be estimated from boundary layer theory as default in the model. For very stable conditions, vertical dispersion is also a function of lapse rate.

(2) Vertical dispersion may be enhanced because of obstructions near the source. A virtual source technique is used to simulate the initial plume dilution due to downwash.

(3) Formulas recommended by Pasquill (1976) are used to calculate buoyant plume enhancement.

(4) At the water/land interface, the change to overland dispersion rates is modeled using a virtual source. The overland dispersion rates can be calculated from either vertical turbulence intensity or the Pasquill-Gifford coefficients. The change is implemented where the plume intercepts the rising internal boundary layer.

l. Chemical Transformation

Chemical transformations are treated using exponential decay. Different rates can be specified by month and by day or night.

m. Physical Removal

Physical removal is also treated using exponential decay.

n. Evaluation Studies

DiCristofaro, D.C. and S.R. Hanna, 1989. OCD: The Offshore and Coastal Dispersion Model. Volume I: User's Guide. Sigma Research Corporation, Westford, MA.

Hanna, S.R., L.L. Schulman, R.J. Paine and J.E. Pleim, 1984. The Offshore and Coastal Dispersion (OCD) Model User's Guide, Revised. OCS Study, MMS 84–0069. Environmental Research & Technology, Inc., Concord, MA. (NTIS No. PB 86–159803).

Hanna, S.R., L.L. Schulman, R.J. Paine, J.E. Pleim and M. Baer, 1985. Development and Evaluation of the Offshore and Coastal Dispersion (OCD) Model. *Journal of the Air Pollution Control Association,* 35: 1039–1047.

Hanna, S.R. and D.C. DiCristofaro, 1988. Development and Evaluation of the OCD/API Model. Final Report, API Pub. 4461, American Petroleum Institute, Washington, DC.

A. REFERENCES

Benson, P.E., 1979. CALINE3—A Versatile Dispersion Model for Predicting Air Pollution Levels Near Highways and Arterial Streets. Interim Report, Report Number FHWA/CA/TL–79/23. Federal Highway Administration, Washington, DC.

Briggs, G.A., 1975. Plume Rise Predictions. Lectures on Air Pollution and Environmental Impact Analyses. American Meteorological Society, Boston, MA, pp. 59–111.

Briggs, G.A., 1984. Analytical Parameterizations of Diffusion: The Convective Boundary Layer. *Journal of Climate and Applied Meteorology,* 24(11): 1167–1186.

Environmental Protection Agency, 1980. Recommendations on Modeling (October 1980 Meetings). Appendix G to: Summary of Comments and Responses on the October 1980 Proposed Revisions to the Guideline on Air Quality Models. Meteorology and Assessment Division, Office of Research and Development, Research Triangle Park, NC 27711.

Environmental Protection Agency, 1998. Interagency Workgroup on Air Quality

Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long-Range Transport Impacts. Publication No. EPA–454/R–98–019. (NTIS No. PB 99–121089).

Escoffier-Czaja, C. and J.S. Scire, 2002. The Effects of Ammonia Limitation on Nitrate Aerosol Formation and Visibility Impacts in Class I Areas. Twelfth AMS/AWMA Conference on the Application of Air Pollution Meteorology, 20–24 May 2002; Norfolk, VA.

Gifford, F.A., Jr. 1976. Turbulent Diffusion Typing Schemes—A Review. *Nuclear Safety,* 17: 68–86.

Horst, T.W., 1983. A Correction to the Gaussian Source-depletion Model. In *Precipitation Scavenging, Dry Deposition and Resuspension*. H. R. Pruppacher, R.G. Semonin and W.G.N. Slinn, eds., Elsevier, NY.

Hsu, S.A., 1981. Models for Estimating Offshore Winds from Onshore Meteorological Measurements. *Boundary Layer Meteorology,* 20: 341–352.

Huber, A.H. and W.H. Snyder, 1976. Building Wake Effects on Short Stack Effluents. Third Symposium on Atmospheric Turbulence, Diffusion and Air Quality, American Meteorological Society, Boston, MA.

Irwin, J.S., 1979. A Theoretical Variation of the Wind Profile Power-Law Exponent as a Function of Surface Roughness and Stability. *Atmospheric Environment,* 13: 191–194.

Liu, M.K. *et al.*, 1976. The Chemistry, Dispersion, and Transport of Air Pollutants Emitted from Fossil Fuel Power Plants in California: Data Analysis and Emission Impact Model. Systems Applications, Inc., San Rafael, CA.

Pasquill, F., 1976. Atmospheric Dispersion Parameters in Gaussian Plume Modeling Part II. Possible Requirements for Change in the Turner Workbook Values. Publication No. EPA–600/4–76–030b. Office of Air Quality Planning & Standards, Research Triangle Park, NC 27711.

Petersen, W.B., 1980. User's Guide for HIWAY–2 A Highway Air Pollution Model. Publication No. EPA–600/8–80–018. Office of Research & Development, Research Triangle Park, NC 27711. (NTIS PB 80–227556)

Rao, T.R. and M.T. Keenan, 1980. Suggestions for Improvement of the EPA–HIWAY Model. *Journal of the Air Pollution Control Association,* 30: 247–256 (and reprinted as Appendix C in Petersen, 1980).

Robe, F.R., Z–X. Wu and J.S. Scire, 2002: Real-time SO_2 Forecasting System with Combined ETA Analysis and CALPUFF Modeling. Proceedings of the 8th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 14–17 October 2002; Sofia, Bulgaria.

Schulman, L.L. and J.S. Scire, 1980: Buoyant Line and Point Source (BLP) dispersion model user's guide. The Aluminum Association; Washington, DC. (*See* A.2 in this appendix.)

Schulman, L.L. and S.R. Hanna, 1986. Evaluation of Downwash Modification to the Industrial Source Complex Model. *Journal of the Air Pollution Control Association,* 36: 258–264.

Segal, H.M., 1983. Microcomputer Graphics in Atmospheric Dispersion Modeling. *Journal of the Air Pollution Control Association,* 23: 598–600.

Snyder, W.H., R.S. Thompson, R.E. Eskridge, R.E. Lawson, I.P. Castro, J.T. Lee, J.C.R. Hunt, and Y. Ogawa, 1985. The structure of the strongly stratified flow over hills: Dividing streamline concept. *Journal of Fluid Mechanics,* 152: 249–288.

Turner, D.B., 1969. Workbook of Atmospheric Dispersion Estimates. PHS Publication No. 999–26. U.S. Environmental Protection Agency, Research Triangle, Park, NC 27711.

Weil, J.C. and R.P. Brower, 1984. An Updated Gaussian Plume Model for Tall Stacks. *Journal of the Air Pollution Control Association,* 34: 818–827.

Weil, J.C., 1996. A new dispersion algorithm for stack sources in building wakes, Paper 6.6. Ninth Joint Conference on Applications of Air Pollution Meteorology with A&WMA, January 28–February 2, 1996. Atlanta, GA.

Weil, J.C., L.A. Corio, and R.P. Brower, 1997. A PDF dispersion model for buoyant plumes in the convective boundary layer. *Journal of Applied Meteorology,* 36: 982–1003.

Zhang, X., 1993. A computational analysis of the rise, dispersion, and deposition of buoyant plumes. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Zhang, X. and A.F. Ghoniem, 1993. A computational model for the rise and dispersion of wind-blown, buoyancy-driven plumes—I. Neutrally stratified atmosphere. *Atmospheric Environment,* 15: 2295–2311.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

MAR 24 2011

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

MEMORANDUM

SUBJECT: Area Designations for the 2010 Revised Primary Sulfur Dioxide National Ambient Air Quality Standards

FROM: Stephen D. Page, Director
Office of Air Quality Planning and Standards

TO: Regional Air Division Directors, Regions I-X

This memorandum provides information on the schedule and process for designating areas for the purpose of implementing the 2010 revised primary sulfur dioxide (SO_2) national ambient air quality standard (NAAQS). In addition, it identifies factors EPA intends to evaluate in determining boundaries for areas designated nonattainment. We recommend that states and tribes consider and address these factors when identifying boundaries for their area designation recommendations. Please share this information with the state and tribal agencies in your Region.

On June 2, 2010, Administrator Jackson signed the revised primary SO_2 NAAQS (75 FR 35520, published on June 22, 2010) after review of the existing two primary SO_2 standards, promulgated on April 30, 1971 (36 FR 8187). EPA established the revised primary SO_2 standard at 75 parts per billion (ppb) which is attained when the 3-year average of the 99^{th} percentile of 1-hour daily maximum concentrations does not exceed 75 ppb. The Administrator has determined that this is the level necessary to provide protection of public health with an adequate margin of safety, especially for children, the elderly and those with asthma. These groups are particularly susceptible to the health effects associated with breathing SO_2.

General approach and schedule. Clean Air Act (CAA) section 107(d) directs states to submit their SO_2 designation recommendations to EPA by June 3, 2011. If EPA intends to modify any state's boundary recommendation, EPA will notify the state no later than 120 days prior to its action to promulgate designations (i.e., February 2012 for designations to be promulgated in June 2012), and the state will have an opportunity to comment on EPA's intended modifications and provide additional information for EPA to consider. Section 107(d) requires EPA to promulgate initial area designations by June 3, 2012, which is 2 years after promulgation of the revised primary standard. While the language in section 107 specifically addresses states, we intend to follow the same process for tribes, pursuant to section 301(d) of the CAA and the Tribal Authority Rule (40 CFR Part 49). Therefore, we intend to designate tribal areas, in consultation with the tribes, on the same schedule as state designations. If a state or tribe does not submit designation recommendations, EPA will promulgate the designations that it deems appropriate.

Sections III through VI of the preamble to the final rule promulgating the revised primary SO_2 NAAQS describe the approach EPA anticipates using for designations for the 1-hour SO_2 standard. EPA anticipates taking an analytic approach that uses both air quality monitoring and modeling information for designations. Such an approach, if adopted, would be consistent with EPA's historic practices for SO_2 NAAQS implementation. In that preamble we acknowledged that in some cases, monitoring data may be the more technically appropriate information for determining compliance with the 1-hour NAAQS. (See e.g., 75 FR at 35552, n. 22). We also recognized that a single monitor may generally not be adequate to fully characterize ambient concentrations of SO_2, including the maximum ground level concentrations that exist around stationary SO_2 sources, particularly when measuring for a 1-hour standard. (See 75 FR at 35551). Refined dispersion models are able to characterize SO_2 air quality impacts from the modeled sources across the domain of interest on an hourly basis with a high degree of spatial resolution, thus overcoming the limitations of an approach based solely on monitoring.

Attachment 2 summarizes three possible designations and the criteria for initial designations of the 1-hour SO_2 primary standard that EPA expects to apply. As stated in the preamble, we do not believe it would be realistic or appropriate to expect states to complete modeling for all significant sources of SO_2 and assess the results in time for the designation recommendations the Act requires be submitted to EPA by June 3, 2011. (See 75 FR at 35570-71). Therefore, we do not generally expect states to provide refined dispersion modeling information along with their initial designation recommendations. However, EPA does intend to consider, as appropriate, available air quality monitoring and modeling information submitted by states or tribes in support of their recommendations.

States and tribes should identify areas as attainment, nonattainment or unclassifiable on the basis of available information. Given the currently limited network of SO_2 monitors, and our expectation that states will not yet have completed appropriate modeling of all significant SO_2 sources, we anticipate that most areas of the country will be designated "unclassifiable." If a state or tribe, following receipt of an EPA 120-day letter, has additional information that it wants EPA to consider with respect to a designation recommendation that EPA plans to modify, we request that such information be submitted within 60 days after receiving EPA's letter. This will help ensure that EPA can fully consider any such information prior to issuing final designations.

Also, although not required by statute, in order to consider public input in the designation process, we plan to provide a 30-day public comment period immediately following issuance of EPA's letters responding to the recommendations made by states and tribes. Attachment 1 is this anticipated schedule.

The preamble to the final NAAQS rulemaking includes a general discussion of states' statutory planning and emissions control responsibilities under each of the three possible designations. The CAA directs states with areas designated as "nonattainment" for SO_2 to develop and submit a plan within 18 months after designation providing for attainment as expeditiously as practicable, but no later than 5 years after the initial designation date. (See CAA sections 191-193). The CAA also directs states to submit by June 3, 2013, a SIP demonstrating an adequate program to implement, maintain and enforce the SO_2 NAAQS. Generally, these infrastructure plans for attainment areas are not expected to include an attainment demonstration. However, in light of the incomplete monitoring and modeling data available at the time of designations, for areas designated unclassifiable, we would expect states to include in these plans demonstrations of expeditious attainment and maintenance of the SO_2 NAAQS. EPA is developing separate guidance on developing SIP revisions for the SO_2 standard and we intend to seek public review and comment on that guidance document.

Identifying an area that is in violation of the SO_2 NAAQS. Section 107(d)(1) of the CAA defines an area as "nonattainment" if it is violating the NAAQS or if it is contributing to a violation in a nearby area. Thus, the first step in making designations is to identify through monitoring or appropriate modeling areas violating the NAAQS. In assessing whether monitoring data indicate a violation, EPA intends to use the most recent three consecutive years of quality-assured, certified air quality data in the EPA Air Quality System (AQS),[1] using data from Federal Reference Method (FRM) and Federal Equivalent Method (FEM) monitors that are sited and operated in accordance with 40 CFR Parts 50 and 58. Procedures for using monitored air quality data to determine whether a violation has occurred are given in 40 CFR Part 50 Appendix T, as revised in conjunction with the final rule for the 2010 SO_2 NAAQS. We expect that in providing their recommendations to EPA, states and tribes would review available SO_2 monitoring data from 2008 through 2010. Prior to EPA issuing letters to states and tribes concerning any intended modifications to their recommendations, data from 2011 may become available. If this is the case, EPA intends to also consider 2011 SO_2 air quality monitoring data in formulating any intended modifications to state and tribal recommendations.

Air quality monitoring data affected by exceptional events may be excluded from use in identifying a violation if they meet the criteria for exclusion, as specified in the final rule

[1] This information is available on EPA's website at www.epa.gov/ttn/airs/airsaqs/.

'Treatment of Data Influenced by Exceptional Events" (72 FR 13560; March 22, 2007) codified in 40 CFR Parts 50 and 51. In section VII.B of the SO_2 NAAQS final rule preamble, we discussed schedules for states and tribes to flag data influenced by exceptional events and submit related documentation specifically for SO_2 data collected from 2008 through 2010 used in the initial designations process. These schedules are contained in Table 1 of 40 CFR 50.14 and require initial data flagging by October 1, 2010 and detailed documentation submittal by June 1, 2011. This should assure that any exceptional events claim asserted by a state or tribe can be fully considered by EPA before final designations.

States and tribes may also choose to use available air quality modeling results to indicate a violation of the NAAQS. Attachment 3 provides further guidance on the appropriate refined dispersion modeling analysis that could be used to support designation recommendations. Such modeling could include using the AERMOD dispersion model, with allowable source emissions and emissions limitation credit for stacks no higher than good engineering practice. As noted above (and in the preamble to the final SO_2 primary NAAQS rulemaking), we recognize that it is not realistic to expect states or tribes to complete this type of modeling for all significant sources of SO_2 in the time available for providing designation recommendations. Where the time and resources to conduct refined dispersion modeling are limited, we believe it is reasonable to focus first on the most significant sources of SO_2 emissions, and on those sources that are most likely to contribute to a violation. We recognize that this approach means that all areas where SO_2 NAAQS violations may be occurring might not be identified in the initial round of area designations. States are expected to address any such areas in the course of developing the SIPs due by June 3, 2013.

Identifying attainment areas. EPA may initially designate an area as attainment if it is clear that it meets the SO_2 NAAQS. EPA does not believe it would be appropriate to do so without appropriate refined dispersion modeling and, where available, air quality monitoring data indicating no violations of the NAAQS. In the absence of information clearly demonstrating a designation of "attainment" or "nonattainment," EPA intends to designate the area as "unclassifiable."

Determining nonattainment area boundaries. As a pollutant that arises from direct emissions, SO_2 concentrations are highest relatively close to the source(s) and much lower at greater distances due to dispersion. Thus, SO_2 concentration patterns resemble those of other directly emitted pollutants like lead and differ from those of photochemically-formed (secondary) pollutants such as ozone. Accordingly, consistent with our approach under other NAAQS, we expect to consider the county line as the starting point for determining SO_2 nonattainment areas. As discussed further in Attachment 2, EPA intends to consider several factors when determining the final nonattainment boundaries. We believe it is appropriate to evaluate each potential nonattainment area on a case-by-case basis, and to recognize that area-specific analyses conducted by states, tribes and/or EPA may support a boundary with either a larger or smaller area than the county boundary.

A nonattainment area should contain the area violating the NAAQS (e.g., the area around a violating monitor), as well as any adjacent areas (e.g., counties or portions thereof) that contain emissions sources contributing to the violation. (See CAA section 107(d)(1)(A)(i)). Consequently, we recommend that states and tribes base their boundary recommendations on an evaluation of five factors: 1) air quality data; 2) emissions-related data; 3) meteorology; 4) geography/topography and 5) jurisdictional boundaries, as well as other available data. Dispersion modeling, as discussed in Attachment 3, can be a helpful tool in this evaluation because it allows the model user to simultaneously assess multiple factors. States and tribes may identify and evaluate other relevant factors or circumstances specific to a particular area.

While EPA generally believes that in the absence of other relevant information it is appropriate to use county boundaries to define nonattainment areas, we recognize that the five-factor analysis and other information may support designating only a portion of a county as "nonattainment." For example, a topographical feature may divide a county into two separate air basins, or contributing sources may be clustered in only a portion of a county. For defining partial county boundaries, EPA recommends the use of well-defined jurisdictional lines such as township borders, immovable landmarks such as major roadways or other permanent and readily identifiable boundaries.

Determining attainment area boundaries. In areas without a violating monitor, refined dispersion modeling could be used to help determine that an area with SO_2 sources is in attainment for the 1-hour SO_2 NAAQS. An attainment area boundary cannot contain any area that exceeds the NAAQS or any area containing sources that are causing or contributing to a violating area. (See CAA section 107(d)(1)(A)(i)). County boundaries may be appropriate for defining attainment areas in the absence of other information that would help define a more specific boundary around the modeled source(s).

While we believe this memorandum provides helpful guidance on how boundaries would be determined for SO_2 designations, the guidance contained herein is not binding on states, tribes the public or EPA. The final basis for determining nonattainment area boundaries will be addressed in EPA's action to initially designate areas under the 2010 SO_2 standard. When EPA promulgates designations, those determinations will be final and binding on states, tribes, the public and EPA.

Attachment 1 is a timeline of key dates in the designations process for the revised 2010 SO_2 NAAQS. Attachment 2 identifies the primary five factors that EPA plans to consider in evaluating and making decisions on nonattainment area boundaries. Attachment 3 is the modeling guidance that states and tribes should use to support designation recommendations, including appropriate area boundaries.

Staff members at EPA's Office of Air Quality Planning and Standards are available for assistance and consultation throughout the designations process. General questions on this guidance may be directed to Valerie Broadwell (919) 541-3310 or Doug Solomon (919) 541-4132. Modeling-related questions may be directed to James Thurman (919) 541-2703.

Attachments: 3

cc: Scott Mathias, OAQPS
Lydia Wegman, OAQPS
Richard Wayland, OAQPS
Greg Green, OAQPS
Margo Oge, OTAQ
Kevin McLean, OGC
Sara Schneeberg, OGC

ATTACHMENT 1

TIMELINE FOR 2010 Primary SO_2 NAAQS DESIGNATION PROCESS	
Milestone	**Date***
EPA promulgates SO_2 NAAQS	June 3, 2010
States and tribes flag exceptional event-influenced SO_2 monitoring data from 2008-2009	October 1, 2010
States and tribes flag exceptional event-influenced SO_2 monitoring data from 2010; provide detailed documentation to support all 2008-2010 claims	No later than June 1, 2011
States and tribes submit recommendations for area designations to EPA	No later than June 3, 2011
EPA notifies states and tribes concerning any intended modifications to their recommendations (120-day letters)	o/a February 3, 2012 (no later than 120 days prior to final designations)
EPA publishes public notice of state and tribal recommendations and EPA's intended modifications and initiates 30-day public comment period	o/a February 20, 2012
End of 30-day public comment period	o/a March 20, 2012
States and tribes submit additional information to demonstrate why an EPA modification is inappropriate	o/a April 3, 2012
EPA promulgates final SO_2 area designations	No later than June 3, 2012

* o/a = on or about

Note: This schedule assumes EPA has sufficient information to promulgate designations within 2 years. In the event EPA determines that insufficient information is available to do so, the Clean Air Act allows EPA to extend the designation process, but no later than June 3, 2013.

ATTACHMENT 2

Determining Designations and Appropriate Area Boundaries for the 1-hour, 75 ppb SO_2 NAAQS

Nonattainment	*Attainment*	*Unclassifiable* (all other areas)
An area where monitoring data or an appropriate modeling analysis indicate a violation.	An area that has no monitored violations and which has an appropriate modeling analysis, if needed, and any other relevant information demonstrating no violations.	An area that has no monitored violations and lacks an appropriate modeling analysis, if needed, or other appropriate information sufficient to support an alternate designation.

Attainment area boundaries. Areas designated as "attainment" should be supported by information clearly demonstrating that there are no violations of the SO_2 NAAQS inside the area boundary. This could consist of appropriate air quality dispersion modeling and, where available, air quality monitoring data. As provided in Attachment 3, appropriate modeling would include using the AERMOD dispersion model, with allowable source emissions and emissions limitation credit for stacks no higher than good engineering practice. County boundaries may be appropriate for defining attainment areas in the absence of other information that would help define a more specific boundary around the modeled source(s). In the absence of information clearly demonstrating a designation of "attainment" or "nonattainment," EPA intends to designate the area as "unclassifiable."

Nonattainment area boundaries. EPA intends to use the county as the analytical starting point for assessing the appropriate geographic boundaries of a SO_2 nonattainment area. As a framework for area-specific analyses to support final boundary determinations, we intend to evaluate the five factors listed below, as well as other relevant available information. The purpose of evaluating these factors is to determine the appropriate boundaries encompassing the area meeting the CAA's definition of "nonattainment area" i.e., an area violating the SO_2 standard and any nearby areas contributing to the violating area. The modeling guidance in Attachment 3 discusses how modeling could be used to address several of these factors simultaneously. When considered as a whole, results may support nonattainment boundaries that are either larger or smaller than the analytical starting point.

1. **Air quality data.** We intend to review SO_2 air quality monitoring data, including the design value calculated for each monitor in the area, for the most recent 3-year period. Areas where monitoring data indicate a violation of the 1-hour, 75 ppb primary SO_2 standard will be designated as "nonattainment." Source-oriented modeling may also be used to assess air quality in a particular location. Attachment 3 provides further guidance on using refined dispersion modeling for this type of assessment.

2. **Emissions-related data** (location of sources and potential contribution to ambient SO_2 concentrations). We intend to examine allowable emissions of SO_2 from sources located in

and around the violating area. Significant emissions levels in a nearby area indicate the potential for the area to contribute to observed or modeled violations of the NAAQS. We intend to review data from the latest National Emissions Inventory or other relevant sources of the data, such as state inventories or inventories from other federal sources. We would also consider any additional information we receive on federally-enforceable emissions controls that are not reflected in recent inventories but which will require compliance before final designations are issued.

3. **Meteorology** (weather/transport patterns). We intend to evaluate meteorological data to help determine how weather conditions, including wind speed and direction, affect the plume of sources contributing to ambient SO_2 concentrations. Where feasible, we would consider results from source-oriented dispersion modeling.

4. **Geography/topography** (mountain ranges or other air basin boundaries). We intend to examine the physical features of the land that might affect the distribution of SO_2 over an area. Mountains or other physical features may affect the distribution of emissions, and may help define boundaries.

5. **Jurisdictional boundaries** (e.g., counties, air districts, pre-existing nonattainment areas, reservations, metropolitan planning organizations). Once the geographic area associated with the area violating the SO_2 standard and the nearby area contributing to violations are determined, we intend to consider existing jurisdictional boundaries for the purposes of providing a clearly defined legal boundary for carrying out the air quality planning and enforcement functions for the nonattainment area. If an existing jurisdictional boundary is used to help define the nonattainment area, it should encompass all of the area that has been identified as meeting the nonattainment definition. Where existing jurisdictional boundaries are not adequate to describe the nonattainment area, other clearly defined and permanent landmarks or geographic coordinates may be used.

EPA plans to consider these factors, along with any other relevant information, in determining whether to make modifications to the boundary recommendations made by states and tribes. The factors listed above, while generally comprehensive, are not intended to be exhaustive. States and tribes may submit additional information they believe is relevant for EPA to consider. Any information provided to support a boundary recommendation for a nonattainment area should show that: 1) violations are not occurring in nearby portions that are excluded from the recommended nonattainment area; and 2) the excluded portions do not contain emission sources that contribute to the monitored or modeled violation.

ATTACHMENT 3

Modeling Guidance for SO_2 NAAQS Designations

1. Purpose

On June 2, 2010, Administrator Jackson signed a final rulemaking notice that revised the primary SO_2 NAAQS (75 FR 35520, published on June 22, 2010) after review of the existing two primary SO_2 standards, promulgated on April 30, 1971 (36 FR 8187).[1] EPA established the revised primary SO_2 standard at 75 parts per billion (ppb) which is attained when the 3-year average of the 99th percentile of 1-hour daily maximum concentrations does not exceed 75 ppb. In the final rule preamble, EPA outlined an expected analytic approach to determining compliance with the new NAAQS that would include the use of both modeling and monitoring. EPA believes this analytic approach to determining compliance with the new 1-hour NAAQS would be the generally more technically appropriate and accurate means of assessing peak 1-hour SO_2 concentrations, and would be consistent with historic (past and more recent) implementation practice of using models to determine compliance with the SO_2 NAAQS.

While this guidance explains the use of modeling for NAAQS designations, it does not preclude the fact that monitoring data may be more technically appropriate than modeling in some cases. In cases where there is complete air quality data from FRM or FEM SO2 monitors, that data would be considered by EPA in designating areas as attainment or nonattainment. (See 75 FR at 35570). The guidance presented here is for cases where modeling is used in support of the designations process.

Dispersion modeling could be used in these initial designations to a limited degree (as could monitoring) but would likely be used to a larger extent subsequently as the basis for re-designation of nonattainment and unclassifiable areas to attainment. As the preamble to the rule promulgating the new 1-hour SO_2 NAAQS noted, EPA does not think it realistic or appropriate to expect states to complete modeling for all significant sources of SO_2 and assess the results in time for the designation recommendations the Act requires be submitted by June 2011. (See 75 FR at 35570-71). Therefore, we do not generally expect states to provide modeling information along with their initial designation recommendations. However, EPA does intend to consider, as appropriate, available monitoring data and modeling information submitted by states or tribes in support of their recommendations.

This guidance explains the expected application of dispersion models to support the designations process regarding:

[1] EPA publicly disseminated a copy of the signed notice on June 3, 2010, and therefore treats June 3, 2010, as the date of the rule's promulgation, for purposes of the deadlines in CAA section 107(d).

1. the use of modeling to inform the nonattainment boundaries for areas with violating ambient air quality monitors if the presumptive county boundaries are not used (either to expand the boundaries outside the county or shrink the boundary within the county); and
2. The use of modeling in areas without a violating monitor as evidence of attainment of the NAAQS (showing no violations or contributions to violations of the standard).

This guidance is consistent with EPA's *Guideline on Air Quality Models*, or Appendix W to 40 CFR Part 51, and other relevant modeling guidance issued to support regulatory programs. When the need for interpretation of this guidance arises, the user should consult with the appropriate Regional Modeling Contact[2].

Also as indicated in the preamble of the 1-hour SO_2 NAAQS final rule, we intend to issue additional guidance describing the development of an approvable 110(a)(1) implementation plans for areas designated "unclassifiable" that will include technical direction on how to conduct refined dispersion modeling to demonstrate future NAAQS attainment.

2. Guidance on Air Quality Models

Much of this guidance is based on EPA's *Guideline on Air Quality Models*, also published as Appendix W of 40 CFR Part 51. Appendix W is the primary source of information on the regulatory application of air quality models for State Implementation Plan (SIP) revisions for existing sources and for New Source Review (NSR) and Prevention of Significant Deterioration (PSD) programs. Air quality modeling in support of this designations process would need to employ air quality dispersion models[3] that properly address the source-oriented nature of SO_2 and, thus, should rely upon the principles and techniques in Appendix W.

Appendix W was originally published in April 1978 and was incorporated by reference in the regulations for the Prevention of Significant Deterioration of Air Quality, Title 40, Code of Federal Regulations (CFR) sections 51.166 and 52.21 in June 1978 (43 FR 26382-26388). The purpose of Appendix W guidelines is to promote consistency in the use of modeling within the air quality management process. These guidelines are periodically revised to ensure that new model developments or expanded regulatory requirements are incorporated.

Clarifications and interpretations of modeling procedures become official EPA guidance through several courses of action: 1) the procedures are published as regulations or guidelines; 2)

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[2] List of Regional Modeling Contacts by EPA Regional Office is available from SCRAM website at: http://www.epa.gov/ttn/scram/guidance_cont_regions.htm

[3] Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations.

the procedures are formally transmitted as guidance to Regional Office managers; 3) the procedures are formally transmitted as guidance to Regional Modeling Contacts as a result of a Regional consensus on technical issues; or 4) the procedures are a result of decisions by the EPA's Model Clearinghouse that effectively establish national precedent. Formally located in the Air Quality Modeling Group (AQMG) of EPA's Office of Air Quality Planning and Standards (OAQPS), the Model Clearinghouse is the single EPA focal point for the review of criteria pollutant modeling techniques for specific regulatory applications. Model Clearinghouse and related Clarification memoranda involving decisions with respect to interpretation of modeling guidance are available at the Support Center for Regulatory Atmospheric Modeling (SCRAM) website.[4]

Recently issued EPA guidance of relevance for consideration in modeling for designations includes:

- "Applicability of Appendix W Modeling Guidance for the 1-hour SO_2 NAAQS" August 23, 2010—confirming that Appendix W guidance is applicable for NSR/PSD permit modeling for the new SO_2 NAAQS.
- "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard" March 1, 2011– provides additional guidance regarding NO_2 permit modeling and also relevant to SO_2.

The following sections will provide reference to the relevant sections of Appendix W and other existing guidance with summaries as necessary. Please refer to those original guidance documents for full discussion and consult with the appropriate EPA Regional Modeling Contact if questions arise about interpretation on modeling techniques and procedures.

3. Model selection

Preferred air quality models for use in regulatory applications are addressed in Appendix A of EPA's GUIDELINE ON AIR QUALITY MODELS. If a model is to be used for a particular application, the user should follow the guidance on the preferred model for that application. These models may be used without an area specific formal demonstration of applicability as long as they are used as indicated in each model summary of Appendix A. Further recommendations for the application of these models to specific source problems are found in subsequent sections of Appendix W. In 2005, the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was promulgated as EPA's preferred near-field dispersion modeling for a wide range of regulatory applications in all types of terrain based on extensive developmental and performance evaluation.

[4] The Support Center for Regulatory Atmospheric Modeling (SCRAM) website is available at: http://www.epa.gov/ttn/scram/.

For area designations under the 1-hour SO_2 primary NAAQS, AERMOD should be used unless use of an alternative model can be justified (Section 3.2, Appendix W), such as the Buoyant Line and Point Source Dispersion Model (BLP). As outlined in the August 23, 2010 clarification memo "Applicability of Appendix W Modeling Guidance for the 1-hour SO_2 National Ambient Air Quality Standard", AERMOD is the preferred model for single source modeling to address the 1-hour SO_2 NAAQS as part of the NSR/PSD permit programs. AERMOD is appropriate to inform this designations process because SO_2 concentrations result from direct emissions from combustion sources so that concentrations are highest relatively close to sources and are much lower at greater distances due to dispersion. Given the source-oriented nature of this pollutant (See, e.g., 75 FR at 35570), dispersion models are the most appropriate air quality modeling tools to predict the near-field concentrations of this pollutant.

The AERMOD modeling system includes several components. The regulatory components are:

- AERMOD: the dispersion model (U.S. EPA, 2004a)
- AERMAP: the terrain processor for AERMOD (U.S. EPA, 2004b)
- AERMET: the meteorological data processor for AERMOD (U.S. EPA, 2004c)
- BPIPPRIME: the building input processor (U.S. EPA, 2004d)

and non-regulatory components are:

- AERSURFACE: the surface characteristics processor for AERMET (U.S. EPA, 2008)
- AERSCREEN: a recently released screening version of AERMOD (U.S. EPA, 2011b)

Before running AERMOD, the user should become familiar with the user's guides associated with the modeling components listed above and the AERMOD Implementation Guide (AIG) (U.S. EPA, 2009). The AIG lists several recommendations for applications of AERMOD which would be applicable for designations modeling.

4. Modeling domain

Selection of the modeling domain is important in terms of how many sources to explicitly model and what kind of receptor network to create. Two questions may arise in model domain selection:

1. Where to center the modeling domain?, and
2. How large should the modeling domain be? (i.e., in terms of the number of sources to model and size of the receptor network in order to account for the areas of impact).

If the modeling is being performed to inform the nonattainment boundary around a violating monitor, the domain should be centered on the violating monitor. If the modeling is being done to show compliance with the NAAQS in the absence of a violating monitor, the domain should be centered on the dominant source in an area, that is, the source or sources expected to contribute the most to SO_2 air quality levels. In both cases, the domain should then extend to include nearby sources that are thought to cause or contribute to a potential NAAQS violation, as explained further below in Section 4.1.

The determination of sources to include in modeling is a multi-step process. If modeling is being performed for a violating monitor, the first basic step would be to gather information and analyze the emission sources within 50 km of the monitor, which is the nominal distance at which EPA considers most steady-state Gaussian plume models are applicable. In some cases where large SO_2 sources are scattered outside of the 50 km radius, it may be necessary to extend the modeling domain beyond 50 km or conduct multiple AERMOD modeling exercises with the overall region broken down to several AERMOD runs covering different areas of the potential nonattainment area. For these situations, consultation with the appropriate EPA Regional Modeling Contact is recommended.

4.1 Determining sources to model

As stated above, the determination of sources to explicitly model is a multi-step process:

1. The spatial distribution of all sources within 50 km of the violating monitor or dominant source should be analyzed and initially assumed to be included in refined dispersion modeling. For the purposes of designations it is reasonable to initially focus on the most significant sources of SO_2 emissions, e.g., sources emitting greater than 100 tons per year. Please note, however, that sources less than 100 tons can be potential contributors to a NAAQS violation, especially sources with short stacks and/or located in complex terrain (i.e., where receptor elevation is above stack height).
2. Sources should be examined and attempts made to determine if any sources can be accounted for without explicitly modeling them, i.e., use of monitored background concentrations. Accounting for such sources through the use of a background monitor will depend upon how well that monitor reflects impacts from those sources.
3. Sources found not to be representative by monitored background should also be examined through the use of screening models to see if they should or should not be included in the refined modeling. We recommend the use of EPA's new screening model AERSCREEN (U.S. EPA, 2011b) and following recommendations based on pre-existing screening guidance (U.S. EPA, 1992). For small isolated sources, screening may be useful on a source by source basis. However, for a cluster of small sources, their cumulative impact should also be assessed. Individual sources may not be significant by themselves, but together they could cause a NAAQS violation or significantly contribute to a NAAQS violation. Although AERSCREEN does not output a design value

concentration based on the 99th percentile form of the 1-hour SO_2 standard, it does output the overall maximum 1-hour concentration which could be used as a conservative estimate for comparison with the NAAQS and EPA's suggested interim significant impact level (SIL) for the 1-hour SO_2 NAAQS of 3 ppb[5]. If the maximum 1-hour concentration output from AERSCREEN violates the NAAQS, it does not mean that the source is in nonattainment, but that the source should be evaluated using refined dispersion modeling (See Step 3 below for more details).

Figure 1 shows a hypothetical monitor with circles of 50 km and 10 km radii centered over it. Based on this figure, an example application of these three steps is described below.

Step 1: Figure 1 shows facility emissions ranging from less than one ton to over 100 tons per year within 50 km of the violating monitor. Most of the smaller facilities (less than ten tons) are located north of the violating monitor. There are two 100+ ton emitters near the monitor and two 100+ ton emitters west-southwest of the monitor. At this point, it could be initially assumed that all facilities should be included in refined modeling.

Step 2: Determine whether any source or sources can be accounted for by a representative background monitor. In Figure 1, there are two other monitors in the area, one north and one south of the violating monitor. The northernmost monitor may be representative of the facilities north (white and yellow dots) of the violating monitor and the southern monitor may be representative of the sources southeast (white and blue dots) of the violating monitor. Background concentrations should be calculated following the guidance in Section 7 below.

Step 3: Screening modeling may be used to determine additional sources or combinations of sources to be excluded from refined modeling, especially smaller sources whose impacts may be largely dependent on their stack parameters (height, exit velocity, etc.). AERSCREEN could be used to eliminate such sources through screening modeling. AERSCREEN does not output an SO_2 design value but does output the overall maximum 1-hour concentration for an individual stack. If a facility contains more than one emission point or stack, each stack should be processed in AERSCREEN and the maximum 1-hour concentrations can be added together to represent impacts from the whole facility after running AERSCREEN. While AERSCREEN can be used with the surface characteristics of the source being screened, given the documented sensitivity of AERMOD to surface characteristics (Brode et al., 2008), it may be useful to also model the source in AERSCREEN using the surface characteristics of the meteorological site being used in the refined modeling as well, to ensure that the source is below de minimis impact levels with either set of surface characteristics.

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[5] The 3 ppb interim SIL for new 1-hour SO2 NAAQS was provided by EPA for states to consider using for PSD program in the August 23, 2010 memorandum "Guidance Concerning the Implementation of the 1-hour SO2 NAAQS for the Prevention of Significant Deterioration Program"

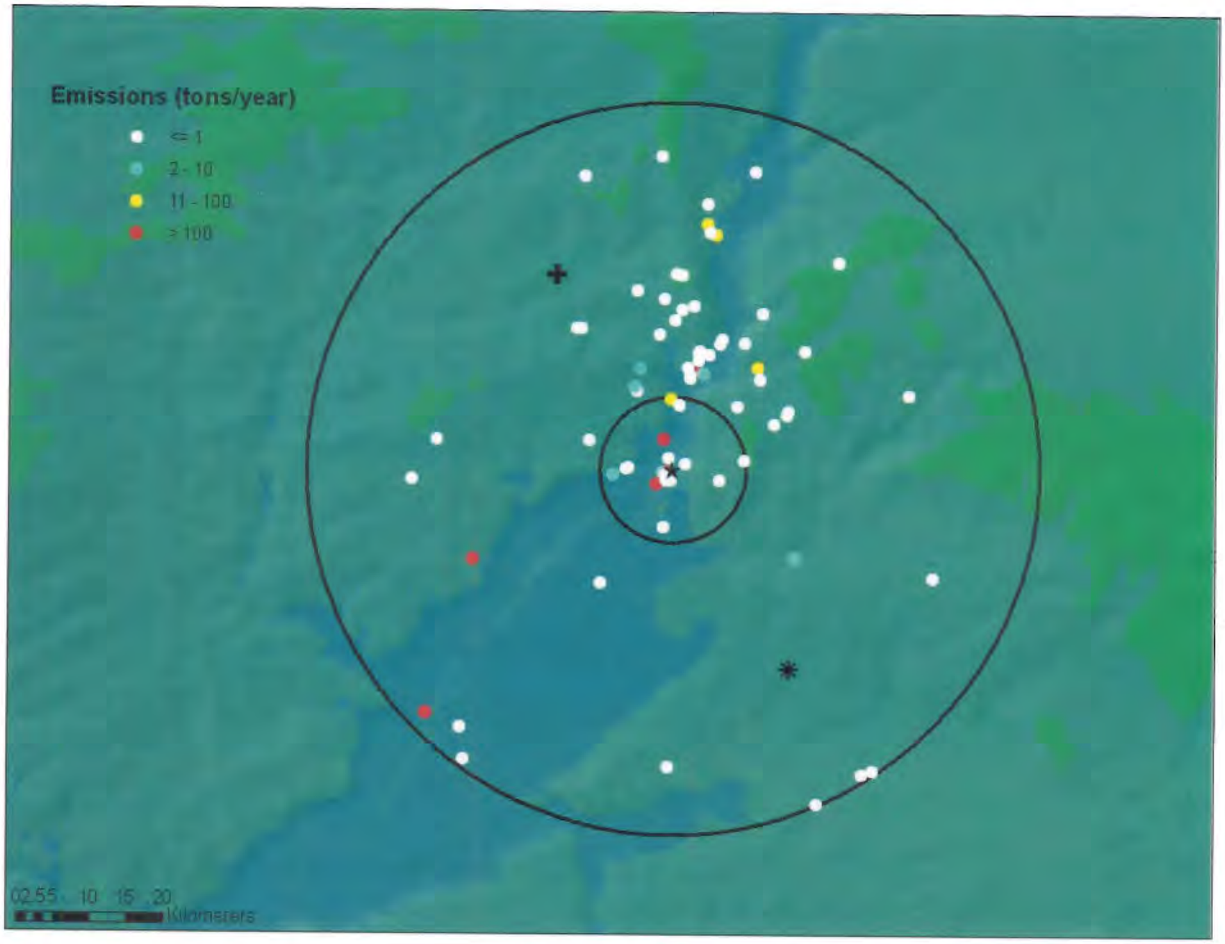

FIGURE 1. HYPOTHETICAL EXAMPLE OF VIOLATING MONITOR (STAR) WITH EMISSIONS (CIRCLES) WITHIN 50 KM (LARGE CIRCLE) AND 10 KM (INNER CIRCLE). NOTE: OTHER MONITORS ARE SHOWN BY PLUS SIGN AND ASTERISKS, WHILE SHADED CONTOURS REPRESENT TERRAIN.

When analyzing AERSCREEN output, the following general criteria could be followed:

- If the facility's maximum 1-hour concentration exceeds 75 ppb, then the source should be included in refined dispersion modeling.
- If the facility's maximum 1-hour concentration is below 75 ppb but above the suggested interim 1-hour significant impact level of 3 ppb or the state's 1-hour SIL, it should be included in the refined modeling.
- If the facility's maximum 1-hour concentration is below the suggested interim 1-hour significant impact level or the state's 1-hour SIL, that source may not have to be

included in refined modeling. However, the facility should not be excluded on the sole basis of being below the SIL without first looking at surrounding sources and their maximum 1-hour concentrations. The case may arise when there are several small sources that singularly are below the SIL but their cumulative impact may lead to concentrations that contribute to violations of the NAAQS.

In summary for the example in Figure 1, the smaller sources below 1 ton of emissions to the north of the monitor may be best represented with the use of background monitor concentrations. Other sources between 1 and 10 tons that are not represented by background monitors could be excluded based on screening results, depending on their stack parameters and terrain. The smaller sources (less than 1 ton) within 10 km of the monitor location may also screen out. The 100+ ton sources near the edge of the 50 km domain should be included in refined modeling. The largest emitters very close to the sources should be included in refined modeling as they are likely contributing to potential NAAQS violations and are not reflected in background monitors.

This is just one example of how to determine the modeling domain and sources to model. In some cases, an analysis out to 50 km may not be needed. Please consult with the appropriate EPA Regional Office modeler if there is uncertainty in deciding which sources to explicitly model, which sources to represent based on background monitoring, and/or which to exclude from refined modeling using screening modeling.

4.2 Receptor grid

The model receptor grid is unique to the particular situation and depends on the size of the modeling domain, the number of modeled sources, and complexity of the terrain. Receptors should be placed in areas that are considered ambient air (i.e., where the public generally has access) and placed out to a distance such that areas of violation can be detected from the model output to help determine the size of nonattainment areas. Receptor placement should be of sufficient density to provide resolution needed to detect significant gradients in the concentrations with receptors placed closer together near the source to detect local gradients and placed farther apart away from the source. In addition, the user should place receptors at key locations such as around facility fence lines (which define the ambient air boundary for a particular source) or monitor locations (for comparison to monitored concentrations for model evaluation purposes). The receptor network should cover the modeling domain. An example receptor grid for a single source is shown in Figure 2a with an example grid with multiple sources shown in Figure 2b. In Figure 2a, receptors are located every 50 m within one kilometer of the source and then every 100 m from one to two kilometers. From two to 10 km, the receptor spacing is 250 m and every 500 m outside of 10 km of the source. The modeling domain is centered on an isolated facility and extends out to 10 km in the east-west and north-south direction. Figure 2b shows an example grid for a multi-source area. Two sources are modeled with a fine grid of receptors 1 km (50 m spacing) around each source embedded within a 10x10 km grid (250 m spacing). The 10x10 km grid is then embedded within a 20x20 km grid with coarser spacing (500 m).

If modeling indicates elevated levels of SO_2 (near the standard) near the edge of the receptor grid, consideration of expanding the grid or conducting an additional modeling run centered on the area of concern should be investigated. As noted above, terrain complexity should also be considered when setting up the receptor grid. If complex terrain is included in the model calculations, AERMOD requires that receptor elevations be included in the model inputs. In those cases, the AERMAP terrain processor (U.S. EPA, 2004b) should be used to generate the receptor elevations and hill heights. The latest version of AERMAP (09040) can process either Digitized Elevation Model (DEM) or National Elevation Data (NED) data files. The AIG recommends the use of NED data since it is more up to date than DEM data, which is no longer updated (Section 4.3 of the AIG).

5. Source inputs

This section provides guidance on source characterization to develop appropriate inputs for dispersion modeling with the AERMOD modeling system. Section 5.1 provides guidance on use of allowable vs. actual emission levels, Section 5.2 covers guidance on Good Engineering Practice (GEP) stack heights, Section 5.3 provides details on source configuration and source types, Section 5.4 provides details on urban/rural determination of the sources, and Section 5.5 provides general guidance on source grouping, which may be important for design value calculations.

5.1 Allowable vs. Actual emissions

Consistent with past SO_2 modeling guidance (Section 4.5.2 of U.S. EPA (1994)) and regulatory modeling for other programs (Appendix W, Section 8.1), dispersion modeling for the purposes of designations should be based on the use of maximum allowable emissions or federally enforceable permit limits. Also consistent with past and current guidance, in the absence of allowable emissions or federally enforceable permit limits, potential to emit emissions (i.e., design capacity) should be used. Because of the short-term nature of the new SO_2 NAAQS, the maximum short term or hourly emission rate should be input into AERMOD for each modeled hour. As stated in the August 23, 2010 memo,

> "Since short-term SO_2 standards ($\leq$ 24 hours) have been in existence for decades, existing SO_2 emission inventories used to support modeling for compliance with the 3-hour and 24-hour SO_2 standards should serve as a useful starting point, and may be adequate in many cases for use in assessing compliance with the new 1-hour SO_2 standard since issues identified in Table 8-2 of Appendix W related to short-term vs. long-term emission estimates may have already been addressed."

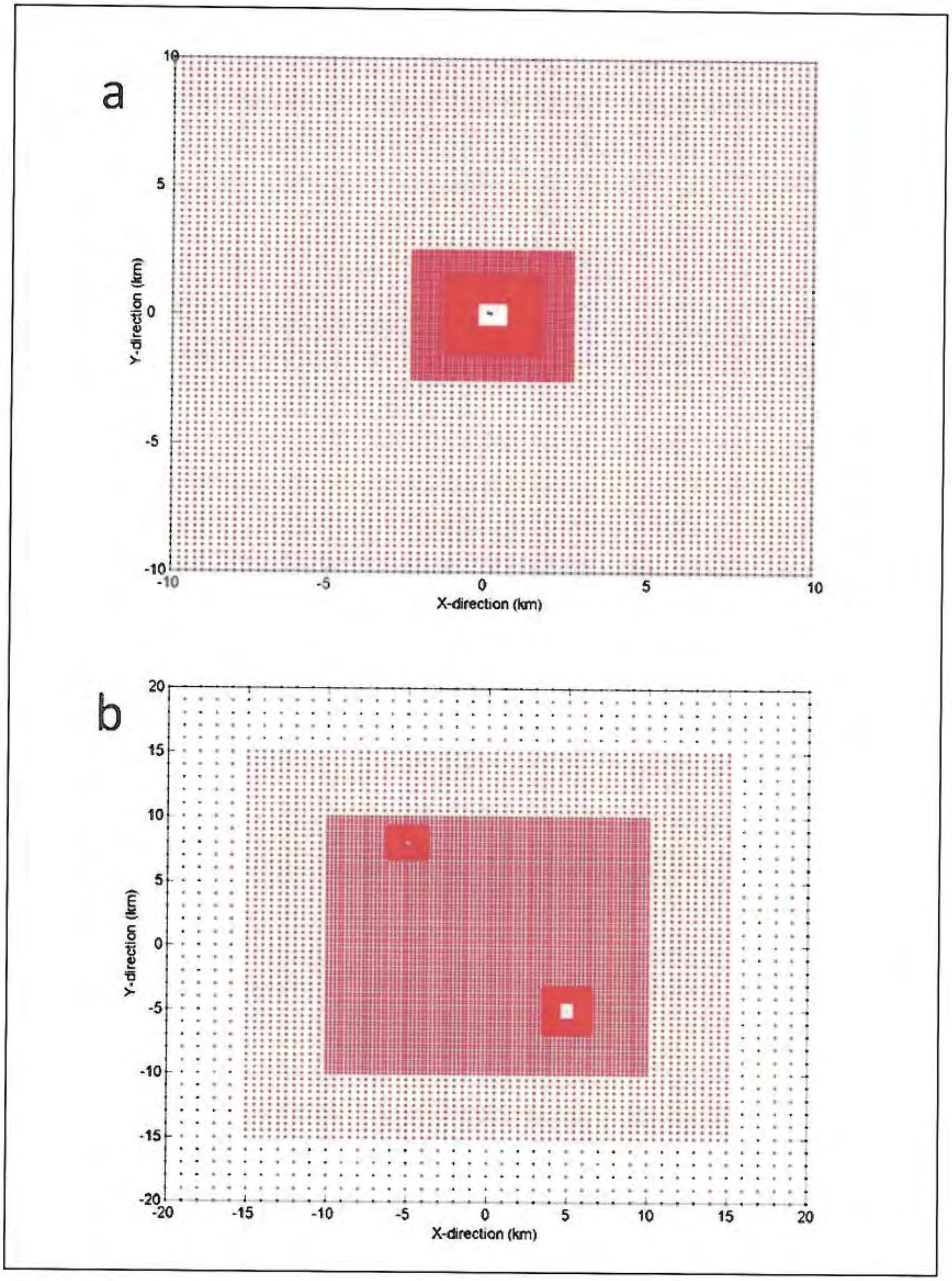

FIGURE 2. EXAMPLE RECEPTOR GRIDS WITH (A) A GRID CENTERED ON AN ISOLATED SOURCE WITH FENCELINE RECEPTORS SHOWN IN BLUE AND THE EMISSION POINTS SHOWN IN BLACK, AND (B) A GRID WITH MULTIPLE SOURCES.

The existing SO_2 inventories used for permitting or SIP demonstrations should contain the necessary emissions information for designations-related modeling. If short-term emissions are not readily available, they may be calculated using the methodology shown in Table 8-2 of Appendix W. For an example calculation of short term emissions, see the June 28, 2010 memorandum "Applicability of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard." Although the example is for NO_2, the calculation methodology would be the same for SO_2.

Regarding the use of allowable emissions and modeling of intermittent emissions sources, from such sources as emergency generators and startup/shutdown emissions, the inclusion of such emissions for the purpose of modeling for SO_2 designations should follow the recommendations in the March 1, 2011 memo "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard." As stated in this memo, EPA believes the most appropriate data to use for compliance demonstrations for the 1-hour NO_2 NAAQS are those based on emissions scenarios that are continuous enough or frequent enough to contribute significantly to the annual distribution of maximum daily 1-hour concentrations. Although the referenced guidance in this memo is for NO_2 permit modeling, the common 1 hour averaging time and form of both the NO_2 and SO_2 standards makes this modeling guidance applicable to the 1-hour SO_2 NAAQS and, thus, applicable to SO_2 modeling in support of designations. For more details, refer to the NO_2 memo. If any questions arise regarding preparation of emissions inputs for dispersions modeling including intermittent emissions from sources, then users should consult the appropriate EPA Regional Modeling Contact.

5.2 Good Engineering Practice (GEP) stack height

Consistent with previous SO_2 modeling guidance (U.S. EPA, 1994) and Section 6.2.2 of Appendix W, for stacks with heights that are within the limits of Good Engineering Practice (GEP), actual heights should be used in modeling. Under EPA's regulations at 40 CFR 51.100, GEP height, H_g, is determined to be the greater of:

- 65 m, measured from the ground-level elevation at the base of the stack;
- For stacks in existence on January 12, 1979, and for which the owner or operator had obtained all applicable permits or approvals required under 40 CFR Parts 51 and 52

  $$H_g=2.5H$$

  provided the owner or operator produces evidence that this equation was actually relied on in designing the stack or establishing an emission limitation to ensure protection against downwash;

For all other stacks,

$$H_g = H + 1.5L,$$

where H is the height of the nearby structure(s) measured from the ground-level elevation at the base of the stack and L is the lesser dimension of height or projected width of nearby structure(s), or

- the height demonstrated by a fluid model or a field study approved by EPA or the State/local agency which ensures that the emissions from a stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes, eddy effects created by the source itself, nearby structures or nearby terrain features.

For more details about GEP, see the Guideline for Determination of Good Engineering Practice Stack Height Technical Support Document (U.S. EPA, 1985).

If stack heights exceed GEP, then GEP heights should be used with the individual stack's other parameters (temperature, diameter, exit velocity). For stacks modeled with actual heights below GEP, building downwash should be considered as this can impact concentrations near the source (Section 6.2.2b, Appendix W). If building downwash is being considered, the BPIPPRIME program (U.S. EPA, 2004d) should be used to input building parameters for AERMOD. More information about buildings and stacks is in Section 5.3.

5.3 Source configurations and source types

An accurate characterization of the modeled facilities is critical for refined dispersion modeling, including accurate stack parameters and physical plant layout. Accurate stack parameters should be determined for the emissions being modeled. Since modeling would be done with maximum allowable or potential emissions levels at each stack, the stack's parameters such as exit temperature, diameter, and exit velocity should reflect those emissions levels. Accurate locations (i.e. latitude and longitude or Universal Transverse Mercator (UTM) coordinates and datum)[6] of the modeled emission sources are also important, as this can affect the impact of an emission source on receptors, determination of stack base elevation, and relative location to any nearby building structures. Not only are accurate stack locations needed, but accurate information for any nearby buildings is important. This information would include location and orientation relative to stacks and building size parameters (height, and corner coordinates of tiers) as these parameters are input into BPIPPRIME to calculate building

[6] Latitudes and longitudes to four decimal places position a stack within 30 feet of its actual location and five decimal places place a stack within three feet of its actual location. Users should use the greatest precision available.

parameters for AERMOD. If stack locations and or building information are not accurate, downwash will not be accurately accounted for in AERMOD.

Emission source type characterization within the modeling environment is also important. As stated in the AERMOD User's Guide (U.S. EPA, 2004a), emissions sources can be characterized as several different source types: POINT sources, capped stacks (POINTCAP), horizontal stacks (POINTHOR), VOLUME sources, OPENPIT sources, rectangular AREA sources, circular area sources (AREACIRC), and irregularly shaped area sources (AREAPOLY). Note that POINTCAP and POINTHOR are not part of the regulatory default option in AERMOD because the user must invoke the BETA option in the model options keyword MODELOPT while not including the "DFAULT" modeling option for these options to work properly. While most sources can be characterized as POINT sources, some sources, such as fugitive releases or nonpoint sources (emissions from ports, airports, or smaller point sources with no accurate locations) may be best characterized as VOLUME or AREA type sources. If questions arise about proper source characterization or typing, users should consult the appropriate EPA Regional Modeling Contact.

5.4 Urban/rural determination

For any dispersion modeling exercise, the urban or rural determination of a source is important in determining the boundary layer characteristics that affect the model's prediction of downwind concentrations. Figure 3 gives example maximum 1-hour concentration profiles for a 10 meter stack (Figure 3a) and a 100 m stack (Figure 3b) based on urban vs. rural designation. The urban population used for the examples is 100,000. In Figure 3a, the urban concentration is much higher than the rural concentration for distances less than 750 m from the stack but then drops below the rural concentration beyond 750 m. For the taller stack in Figure 3b, the urban concentration is much higher than the rural concentration even as distances increase from the source. These profiles show that the urban or rural designation of a source can be quite important.

In addition, for SO_2 modeling, the urban/rural determination is important because AERMOD invokes a 4-hour half life[7] for urban SO_2 sources. This would only be done for urban sources when the POLLUTID keyword in AERMOD is set to "SO2" and the MODELOPT keyword includes the DFAULT option. Rural sources within the same AERMOD run would not be affected. If the DFAULT option is not included with the MODELOPT keyword, the 4-hour half life would not be used and the user would specify the 4-hour half life using the HALFLIFE or DCAYCOEFF keywords in order to account for the chemical transformation. See Section 3.2.6 of the AERMOD User's Guide (U.S. EPA, 2004a) for more details about these keywords. If the user invokes the HALFLIFE or DCAYCOEEF option, then any rural sources included in

[7] Over a 4-hour period, SO_2 concentrations decrease by half from the initial value.

the modeling would need to be run in separate AERMOD runs so that they are not subject to the 4-hour half life. Note that if the DFAULT option is used, the rural sources would not need to be in a separate run from the urban sources. Determining whether a source is urban or rural can be done using the methodology outlined in Section 7.2.3 of Appendix W and recommendations outlined in Sections 5.1 through 5.3 in the AIG (U.S. EPA, 2009). In summary, there are two methods of urban/rural classification described in Section 7.2.3 of Appendix W.

The first method of urban determination is a land use method (Appendix W, Section 7.2.3c). In the land use method, the user analyzes the land use within a 3 km radius of the source using the meteorological land use scheme described by Auer (1978). Using this methodology, a source is considered urban if the land use types, I1 (heavy industrial), I2 (light-moderate industrial), C1 (commercial), R2 (common residential), and R3 (compact residential) are 50% or more of the area within the 3 km radius circle. Otherwise, the source is considered a rural source. The second method uses population density and is described in Section 7.2.3d of Appendix W. As with the land use method, a circle of 3 km radius is used. If the population density within the circle is greater than 750 people/km^2, then the source is considered urban. Otherwise, the source is modeled as a rural source. Of the two methods, the land use method is considered more definitive (Section 7.2.3e, Appendix W).

Caution should be exercised with either classification method. As stated in Section 5.1 of the AIG (U.S. EPA, 2009), when using the land use method, a source may be in an urban area but located close enough to a body of water or other non-urban land use category to result in an erroneous rural classification for the source. The AIG in Section 5.1 cautions users against using the land use scheme on a source by source basis, but advises considering the potential for urban heat island influences across the full modeling domain. When using the population density method, Section 7.2.3e of Appendix W states, "Population density should be used with caution and should not be applied to highly industrialized areas where the population density may be low and thus a rural classification would be indicated, but the area is sufficiently built-up so that the urban land use criteria would be satisfied..." With either method, Section 7.2.3(f) of Appendix W recommends modeling all sources within an urban complex as urban, even if some sources within the complex would be considered rural using either the land use or population density method.

Another consideration that may need attention by the user and is discussed in Section 5.1 of the AIG relates to tall stacks located within or adjacent to small to moderate size urban areas. In such cases, the stack height or effective plume height for very buoyant sources may extend above the urban boundary layer height. The application of the urban option in AERMOD for these types of sources may artificially limit the plume height. The use of the urban option may not be appropriate for these sources, since the actual plume is likely to be transported over the urban boundary layer. Section 5.1 of the AIG gives details on determining if a tall stack should be modeled as urban or rural, based on comparing the stack or effective plume height to the urban boundary layer height. The 100 m stack illustrated in Figure 3b, may be such an example as the urban boundary layer height for this stack would be 189 m (based on a

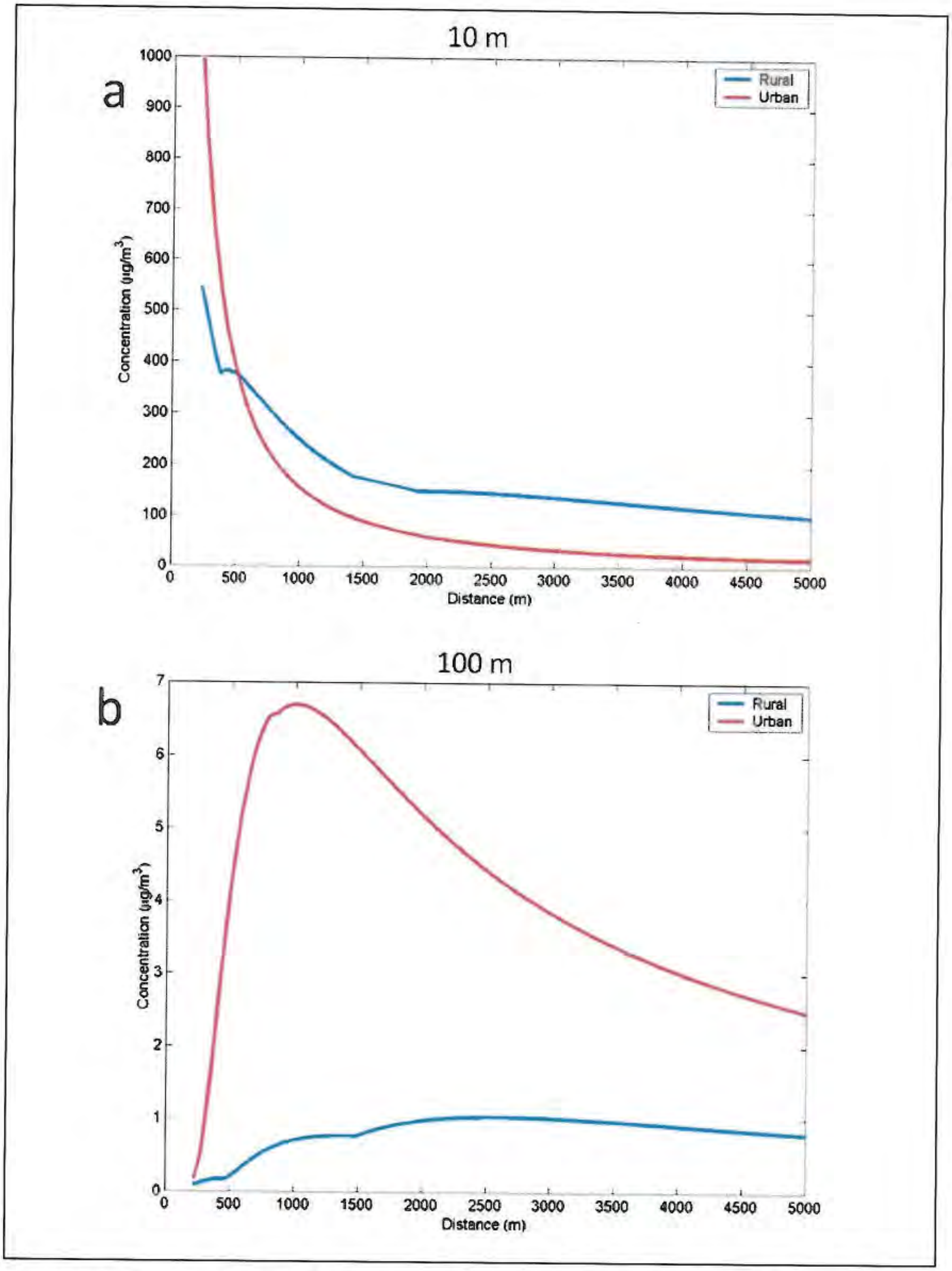

FIGURE 3. URBAN (RED) AND RURAL (BLUE) CONCENTRATION PROFILES FOR (A) 10 M BUOYANT STACK RELEASE, AND (B) 100 M BUOYANT STACK RELEASE.

population of 100,000) and equation 104 of the AERMOD formulation document (Cimorelli, et al., 2004). This equation is:

$$z_{iuc} = z_{iuo}\left(\frac{P}{P_o}\right)^{1/4} \qquad (1)$$

where z_{iuo} is a reference height of 400 m corresponding to a reference population P_o of 2,000,000 people.

Given that the stack is a buoyant release, the plume may extend above the urban boundary layer and may be best characterized as a rural source, even if it were near an urban complex. Exclusion of these elevated sources from application of the urban option would need to be justified on a case-by-case basis in consultation with the appropriate EPA Regional Modeling Contact.

AERMOD requires the input of urban population when utilizing the urban option. Population can be entered to one or two significant digits (i.e., an urban population of 1,674,365 can be entered as 1,700,000). Users can enter multiple urban areas and populations using the URBANOPT keyword in the runstream file (U.S. EPA, 2004a). If multiple urban areas are entered, AERMOD requires that each urban source be associated with a particular urban area or AERMOD model calculations will abort. Urban populations can be determined by using a method described in Section 5.2 of the AIG (U.S. EPA, 2009).

5.5 Source groups

In AERMOD, individual emission sources' concentration results can be combined into groups using the SRCGROUP keyword (Section 3.3.11 of the AERMOD User's Guide (U.S, EPA, 2004a). The user can automatically calculate a total concentration (from all sources) using the SRCGROUP ALL keyword. For the purposes of designations and design value calculations, source group ALL should be used, especially if all sources in the modeling domain are modeled in one AERMOD run. Design values should be calculated from the total concentrations (all sources and background). For the purposes of designations modeling, individual source contributions outputs to the total concentration may not be necessary. However, if individual facility contributions are needed for deciding which facilities to include in the nonattainment or attainment area, source groups by facility should be used. To avoid any confusion, source groups that are used to calculate the design value concentrations or determine source contributions to design values should be mutually exclusive (i.e. an emission source should not be in two source groups). This would be especially important if the design value concentrations are calculated outside of AERMOD by adding the individual groups together to calculate a total concentration (See Section 8.1 of this document for examples). If individual source groups that are used in design value concentrations are not mutually exclusive, there would be double counting of concentrations when calculating design values either in AERMOD or outside of AERMOD.

6. Meteorological data

Section 6 gives guidance on the selection of meteorological data for input into AERMOD. Much of the guidance from Section 8.3 of Appendix W is applicable to designations modeling and is summarized here. In Section 6.2.1, the use of a new tool, AERMINUTE (U.S. EPA, 2011a), is introduced. AERMINUTE is an AERMET pre-processor that calculates hourly averaged winds from ASOS (Automated Surface Observing System) 1-minute winds.

6.1 Surface characteristics and representativeness

The selection of meteorological data that are input into a dispersion model should be considered carefully. The selection of data should be based on spatial and climatological (temporal) representativeness (Appendix W, Section 8.3). The representativeness of the data is based on: 1) the proximity of the meteorological monitoring site to the area under consideration, 2) the complexity of terrain, 3) the exposure of the meteorological site, and 4) the period of time during which data are collected. Sources of meteorological data are: National Weather Service (NWS) stations, site-specific or onsite data, and other sources such as universities, Federal Aviation Administration (FAA), military stations, and others. Appendix W addresses spatial representativeness issues in Sections 8.3.a and 8.3.c.

Spatial representativeness of the meteorological data can be adversely affected by large distances between the source and receptors of interest and the complex topographic characteristics of the area (Appendix W, Section 8.3.a and 8.3.c). If the modeling domain is large enough such that conditions vary drastically across the domain then the selection of a single station to represent the domain should be carefully considered. Also, care should be taken when selecting a station if the area has complex terrain. While a source and meteorological station may be in close proximity, there may be complex terrain between them such that conditions at the meteorological station may not be representative of the source. An example would be a source located on the windward side of a mountain chain with a meteorological station a few kilometers away on the leeward side of the mountain. Spatial representativeness for off-site data should also be assessed by comparing the surface characteristics (albedo, Bowen ratio, and surface roughness) of the meteorological monitoring site and the analysis area. When processing meteorological data in AERMET (U.S. EPA, 2004c), the surface characteristics of the meteorological site should be used [Section 8.3.c of Appendix Wand the AERSURFACE User's Guide (U.S. EPA 2008)]. Spatial representativeness should also be addressed for each meteorological variable separately. For example, temperature data from a meteorological station several kilometers from the analysis area may be considered adequately representative, while it may be necessary to collect wind data near the plume height (Section 8.3.c of Appendix W).

Surface characteristics can be calculated in several ways. For details see Section 3.1.2 of the AIG (U.S. EPA, 2009). EPA has developed a tool, AERSURFACE (U.S. EPA, 2008) to aid in the determination of surface characteristics. The current version of AERSURFACE uses 1992 National Land Cover Data. Note that the use of AERSURFACE is not a regulatory requirement but the methodology outlined in Section 3.1.2 of the AIG should be followed unless an alternative method can be justified.

6.2 Meteorological inputs

Appendix W states in Section 8.3.1.1 that the user should acquire enough meteorological data to ensure that worst-case conditions are adequately represented in the model results. Appendix W states that 5 years of NWS meteorological data or at least one year of site-specific data should be used(Section 8.3.1.2, Appendix W) and should be adequately representative of the study area. If one or more years (including partial years) of site-specific data are available, those data are preferred. While the form of the SO_2 NAAQS contemplates obtaining three years of monitoring data, this does not preempt the use of 5 years of NWS data or at least one year of site-specific data in the modeling. The 5-year average based on the use of NWS data, or an average across one or more years of available site specific data, serves as an unbiased estimate of the 3-year average for purposes of modeling demonstrations of compliance with the NAAQ (See the August 23, 2010 Clarification Memorandum on "Applicability of Appendix W Modeling Guidance for the 1-hour SO_2 National Ambient Air Quality Standard"). See the memorandum for more details on the use of 5 years of NWS data or at least one year of site-specific data and applicability to the NAAQS.

6.2.1 NWS data

NWS data are available from the National Climatic Data Center (NCDC) in many formats, with the most common one in recent years being the Integrated Surface Hourly data (ISH). Most available formats can be processed by AERMET. As stated in Section 6.1, when using data from an NWS station alone or in conjunction with site-specific data, the data should be spatially and temporally representative of conditions at the modeled sources.

A recently discovered issue with ASOS is that 5-second wind data that are used to calculate the 2-minute average winds are truncated rather than rounded to whole knots. For example, a wind of 2.9 knots is reported as 2 knots, not 3 knots. To account for this truncation of NWS winds (either standard observation or AERMINUTE output), an adjustment of ½ knot or 0.26 m/s is added to the winds in stage 3 AERMET processing. For more details refer to the AERMET User's Guide (U.S. EPA, 2004c) and/or the appropriate EPA Regional Modeling Contact.

6.2.1.1 AERMINUTE

In AERMOD, concentrations are not calculated for variable wind (i.e., missing wind direction) and calm conditions, resulting in zero concentrations for those hours. Since the SO_2 NAAQS is a one hour standard, these light wind conditions may be the controlling meteorological circumstances in some cases because of the limited dilution that occurs under low wind speeds which can lead to higher concentrations. The exclusion of a greater number of instances of near-calm conditions from the modeled concentration distribution may therefore lead to underestimation of daily maximum 1-hour concentrations for calculation of the design value.

To address the issues of calm and variable winds associated with the use of NWS meteorological data, EPA has developed a preprocessor to AERMET, called AERMINUTE (U.S. EPA, 2011a) that can read 2-minute ASOS winds and calculate an hourly average. Beginning with year 2000 data, NCDC has made freely available, the 1-minute winds, reported every minute from the ASOS network. The AERMINUTE program reads these 2-minute winds and calculates an hourly average wind. In AERMET (U.S. EPA, 2004c), these hourly averaged winds replace the standard observation time winds read from the archive of meteorological data. This results in a lower number of calms and missing winds and an increase in the number of hours used in averaging concentrations. For more details regarding the use of NWS data in regulatory applications see Section 8.3.2 of Appendix W and for more information about the processing of NWS data in AERMET and AERMINUTE, see the AERMET (U.S. EPA, 2004c) and AERMINUTE User's guides (U.S. EPA, 2011a).

6.2.2 Site-specific data

The use of site-specific meteorological data is the best way to achieve spatial representativeness. AERMET can process a variety of formats and variables for site-specific data. The use of site-specific data for regulatory applications is discussed in detail in Section 8.3.3 of Appendix W. Due to the range of data that can be collected onsite and the range of formats of data input to AERMET, the user should consult Appendix W, the AERMET User's Guide (U.S. EPA, 2004c), and Meteorological Monitoring Guidance for Regulatory Modeling Applications (U.S. EPA, 2000). Also, when processing site-specific data for an urban application, Section 3.3 of the AERMOD Implementation Guide offers recommendations for data processing. In summary, the guide recommends that site-specific turbulence measurements should not be used when applying AERMOD's urban option, in order to avoid double counting the effects of enhanced turbulence due to the urban heat island.

6.2.3 Upper air data

AERMET requires full upper air soundings to calculate the convective mixing height. For AERMOD applications in the U.S., the early morning sounding, usually the 1200 UTC (Universal Time Coordinate) sounding, is typically used for this purpose. Upper air soundings can be obtained from the Radiosonde Data of North America CD for the period 1946-1997. Upper air soundings for 1994 through the present are also available for free download from the Radiosonde Database Access website. Users should choose all levels or mandatory and significant pressure levels[8] when selecting upper air data. Selecting mandatory levels only would not be adequate for input into AERMET as the use of just mandatory levels would not provide an adequate characterization of the potential temperature profile.

7. Background concentration

The inclusion of ambient background concentrations to the model results is important in determining cumulative impacts. The modeled contribution to the cumulative analysis should follow the form of the standard and be calculated as described in Section 2.6.1.2 of the August 23, 2010 clarification memo on "Applicability of Appendix W Modeling Guidance for the 1-hour SO_2 National Ambient Air Quality Standard." This memo suggested a "first tier" approach to including a uniform monitored background contribution based on adding the overall highest hourly background SO_2 concentration from a representative monitor to the modeled design value. We recognize that this approach could be overly conservative in many cases and may also be prone to reflecting source-oriented impacts, increasing the potential for double-counting of modeled and monitored contributions. As discussed in EPA's March 1, 2011 memo "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 Ambient Air Quality Standard," we recommend a less conservative "first tier" approach for a uniform monitored background concentration based on the monitored design values for the latest 3-year period, regardless of the years of meteorological data used in the modeling. Adjustments to this approach may be considered in consultation with the appropriate EPA Regional Modeling Contact with adequate justification and documentation of how the background concentration was calculated.

Section 8.2.2 of Appendix W gives guidance on background concentrations for isolated single sources and is also applicable for multi-source areas. One option is, as described in Section 8.2.2.b:

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[8] By international convention, mandatory levels are in millibars: 1,000, 850, 700, 500, 400, 300, 200, 150, 100, 50, 30, 20, 10,7 5, 3, 2, and 1. Significant levels may vary depending on the meteorological conditions at the upper-air station

"Use air quality data in the vicinity of the source to determine the background concentration for the averaging times of concern. Determine the mean background concentration at each monitor by excluding concentrations when the source in question is impacting the monitor… For shorter time periods, the meteorological conditions accompanying concentrations of concern should be identified. Concentrations for meteorological conditions of concern, at monitors, not impacted by the source in question, should be averaged for separate averaging time to determine the average background value. Monitoring sites inside a 90° degree sector downwind of the source may be used to determine the area of impact."

When no monitors are located in the vicinity of the sources being modeled a "regional site" (i.e., one that is located away from the area of interest but is impacted by similar natural and distant man-made sources) may be used to determine background (Section 8.2.2.c, Appendix W). In multi-source areas, background includes two components, nearby sources and other sources (Section 8.2.3 of Appendix W). Nearby sources are those sources that are expected to cause a significant concentration gradient in the vicinity of the source or sources under consideration, and should be explicitly modeled. Identification of nearby sources calls for professional judgment and consultation with the appropriate EPA Regional Modeling Contact. For other sources, such as natural sources, minor sources and distant major sources, the methodology of Section 8.2.2 should be used.

EPA's March 1, 2011 memo "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 Ambient Air Quality Standard," describes an appropriate methodology of calculating temporally varying background monitored concentrations by hour of day and season (excluding periods when the source in question is expected to impact the monitored concentration). The methodology for NO_2 is to use the 98^{th} percentile concentration for each hour of the day by season and average across three years. This same methodology is applicable to SO_2 designations modeling based on use of the 99^{th} percentile by hour of day and season for background concentration excluding periods when the dominant source(s) are influencing the monitored concentration (i.e., 99^{th} percentile, or 4^{th} highest, concentrations for hour 1 for January or winter, 99^{th} percentile concentrations for hour 2 for January or winter, etc.). Recent updates included in AERMOD allow for the inclusion of temporally varying background concentrations in the design value calculation in combination with modeling results.

An illustrative example is shown in Figure 4. Shown are the NAAQS standard concentration, the monitor's 3-year average design value, and 3-year averages of the 99^{th} percentile concentrations by season and hour of day. To calculate the 99^{th} percentile concentration for a season and hour of day combination, the second highest concentration for that combination should be selected. Also shown are 3-year averages of the 99^{th} percentile concentration by hour of day (across all seasons), and the average concentration by hour of day across the three years[9]. In this example, the winter background concentrations show a distinct diurnal variability, with less for each of the other seasons.

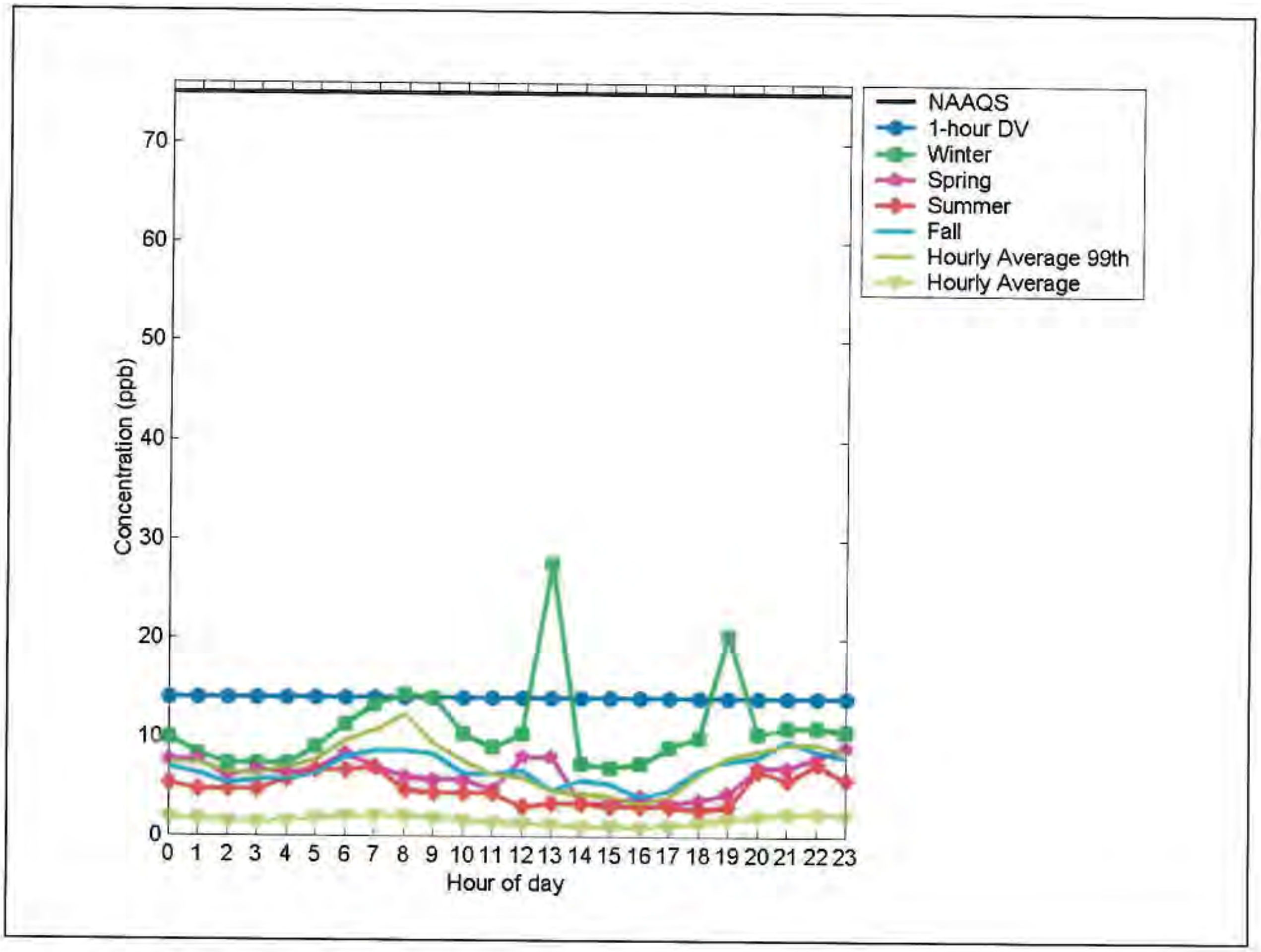

FIGURE 4. SO_2 MONITORED CONCENTRATIONS FOR VARIOUS AVERAGING TIMES.

It should be also noted here that the conventions regarding reporting time differ between ambient air quality monitoring, where the observation time is based on the hour-beginning convention, and meteorological monitoring where the observation is based on the hour-ending time. Thus, ambient monitoring data reported for hour 00 should be paired with meteorological data for hour 01, etc. This is important when incorporating time-varying background

[9] Modelers should use the 1st-highest value for more detailed pairings, such as month by hour-of-day or season by hour-of-day and day-of-week

concentrations in the AERMOD calculations, which allow for temporally varying background concentrations.

8. Determining design value metrics

Designations modeling will provide predictions of SO_2 design values at each receptor that includes contributions from all modeled sources and background. Based on the form of the 1-hour SO_2 NAAQS, the design value should be calculated as the average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations averaged across the modeled years.

8.1 Design value calculation methodology

Whether design values are calculated within AERMOD or outside of AERMOD, to calculate a design value to compare against the standard, the following steps should be followed:

1. At each receptor, for each hour of the modeled period, calculate a total concentration across all sources including background concentrations if applicable. This can be done in AERMOD using SRCGROUP ALL or by adding individual source groups outside of AERMOD, using hourly POSTFILEs. If the user is totaling the concentrations outside of AERMOD, the source groups need to be mutually exclusive, i.e. no one source should be in multiple source groups.
2. From the total concentrations calculated in step 1, obtain the 1-hour maximum concentration at each receptor for each modeled day.
3. From the output of step 2, for each year modeled, calculate the 99th percentile (4th highest) daily maximum 1-hour concentration at each receptor. If modeling 5 years of meteorological data, this results in five 99th percentile concentrations at each receptor.
4. Average the 99th percentile (or 4th highest) concentrations across the modeled years to obtain a design value at each receptor.
5. Modeled source contributions to a NAAQS violation can be determined by analyzing the hourly concentrations from the individual source groups corresponding to the same hour as the 4th daily maximum 1-hour concentration from each year. (See 75 FR at 35540). For example, a receptor has a 5-year average design value of 200.8 mg/m^3 (or approximately 77 ppb) and AERMOD was modeled for the period January 1, 2005 through December 31, 2009 for four source groups. From the AERMOD output, the user can determine the date of the 4th highest daily maximum 1-hour concentrations that are used to calculate the 5-year average design value. Table 1 shows the 4th highest daily maximum 1-hour concentrations for each year and associated dates that are used in the design value calculation.

TABLE 1. 4TH HIGHEST DAILY MAXIMUM 1-HOUR CONCENTRATIONS (μG/M^3) FOR 2005-2009.

Date (YYMMDDHH)	Concentration
05080101	200.1
06073105	201.5
07080403	207.1
08072705	197.1
09080104	198.1
5-YEAR AVG.	200.8

If output by source group is available, the user can extract each source group's concentration at each of the hours listed in Table 1. Table 2 shows example source contributions for each hour shown in Table 1 and indicates that Source 1 is the main contributor to the design value for all hours.

TABLE 2. SOURCE CONTRIBUTIONS TO 4TH HIGHEST DAILY MAXIMUM 1-HOUR CONCENTRATIONS (μG/M^3) AND 5-YEAR AVERAGE DESIGN VALUES.

Date (YYMMDDHH)	TOTAL	SOURCE 1	SOURCE 2	SOURCE 3	SOURCE 4
05080101	200.1	155.1	25.1	1.5	18.4
06073105	201.5	157.4	26.2	0.5	17.4
07080403	207.1	161.5	20.5	2.1	23.0
08072705	197.1	159.2	23.1	1.7	13.1
09080104	198.1	155.3	22.6	2.0	18.2
5-YEAR AVG.	200.8	157.7	23.5	1.6	18.0

8.2 Running AERMOD and implications for design value calculations

Recent enhancements to AERMOD include options to aid in the calculation of design values for comparison with the SO_2 NAAQS. These enhancements include:

- The output of daily maximum 1-hour concentrations by receptor for each day in the modeled period for a specified source group. This is the MAXDAILY output option in AERMOD.
- The output, for each rank specified on the RECTABLE output keyword, of daily maximum 1-hour concentrations by receptor for each year for a specified source group. This is the MXDYBYYR output option.
- The MAXDCONT option, which shows the contribution of each source group to the high ranked values for a specified target source group, paired in time and space. The user can specify a range of ranks to analyze, or specify an upper bound rank, i.e. 4th highest, and a lower threshold value, such as the NAAQS for the target source group. The model will

process each rank within the range specified, but will stop after the first rank (in descending order of concentration) that is below the threshold, specified by the user. A warning message will be generated if the threshold is not reached within the range of ranks analyzed (based on the range of ranks specified on the RECTABLE keyword). This option may be needed to aid in determining which sources to include in a nonattainment area.

Ideally, all explicitly modeled sources, receptors, and background should be modeled in one AERMOD run for all modeled years. In this case, the use of the one of the above output options can be used in AERMOD to calculate design values for comparison to the NAAQS and determine the area's attainment status and/or inform attainment/nonattainment boundaries. The use of these options in AERMOD allows AERMOD to internally calculate concentration metrics that can be used to calculate design values and therefore lessen the need for large output files, i.e. hourly POSTFILES.

However, there may be situations where a single AERMOD run with all explicitly modeled sources is not preferred. These situations often arise due to runtime or storage space considerations during the AERMOD modeling. Sometimes separate AERMOD runs are done for each facility or group of facilities, or by year, or the receptor network is divided into separate sub-networks. In some types of these situations, the MAXDAILY, MXDYBYYR, or MAXDCONT output option may not be an option for design value calculations, especially if all sources are not included in a single run. If the user wishes to utilize one of the three output options, then care should be taken in developing the model inputs to ensure accurate design value calculations.

Situations that would effectively preclude the use of the MAXDAILY, MXDYBYYR, and MAXDCONT option to calculate meaningful AERMOD design value calculations include the following examples:

- Separate AERMOD runs for each source or groups of sources.
    - Designations modeling includes 10 facilities for five years of NWS data and each facility is modeled for five years in a separate AERMOD run, resulting in 10 separate AERMOD runs.
- Separate AERMOD runs for each source and each modeled year.
    - 10 facilities are modeled for 5 years of NWS data. Each facility is modeled separately for each year, resulting in fifty individual AERMOD runs.

In the two situations listed above, the MAXDAILY, MXDYBYYR, or, MAXDCONT option would not be useful as the different AERMOD runs do not include a total concentration with contributions from all facilities. In these situations the use of hourly POSTFILES, which can be quite large, and external post-processing would be needed to calculate design values.

Situations that may use the MAXDAILY, MXDYBYYR, or, MAXDCONT option but may necessitate some external post-processing afterwards to calculate a design value include:

- The receptor network is divided into sections and an AERMOD run, with all sources and years, is made for each network.
  - A receptor network of 20,000 receptors is divided into four 5,000 receptor sub-networks. Ten facilities are modeled with five years of NWS data in one AERMOD run for each receptor network, resulting in four AERMOD runs. After the AERMOD runs are complete, the MAXDAILY, MXDYBYYR, or, MAXDCONT results for each network can be re-combined into the larger network.
- All sources and receptors are modeled in an AERMOD run for each year.
- Ten facilities are modeled with five years of NWS data. All facilities are modeled with all receptors for each year individually, resulting in five AERMOD runs. MAXDAILY, MXDYBYYR, or, MAXDCONT output can be used and post-processed to generate the necessary design value concentrations. The receptor network is divided and each year is modeled separately for each sub-network with all sources.

  Ten facilities are modeled with five years of NWS data for 20,000 receptors. The receptor network is divided into four 5,000 receptor networks. For each sub-network, all ten facilities are modeled for each year separately, resulting in twenty AERMOD runs. MAXDAILY, MXDYBYYR, or, MAXDCONT output can be used and post-processed to generate the necessary design value concentrations.

9. Use of modeling results to inform nonattainment/attainment boundaries

Dispersion modeling is a tool that could be used to examine the spatial extent of potential violations of the 1-hour SO_2 NAAQS. Thus, in accordance with this guidance, refined dispersion modeling could be used to inform boundary determinations in support of the SO_2 designations process, i.e.

1. For an area that contains a violating monitor, modeling could be used to inform decisions on the appropriate nonattainment boundary in conjunction with other factors listed in Attachment 2.
2. For an area without a violating monitor, modeling could be used as evidence of an area's attainment status and also to inform decisions on the appropriate (attainment or nonattainment) boundary.

The shape and size of the nonattainment or attainment area is recommended by the state and either adopted or modified by EPA. For initial designations, it is expected that states will focus on areas with violating monitors. If a county contains a violating monitor, that county would be considered in nonattainment. If there are no violating monitors and no dispersion modeling results to show attainment or nonattainment, that county would generally be considered unclassifiable.

9.1 Nonattainment area boundaries

For nonattainment areas (those with a violating monitor), modeling could be used to refine the nonattainment area boundaries from the presumptive county boundaries in conjunction with other factors such as those listed in Attachment 2. This could include reducing the nonattainment area from the presumptive county to a smaller area or expanding the boundary beyond the county if sources outside the county contribute to a NAAQS violation in the county. A nonattainment area boundary should contain the area that exceeds the NAAQS and include sources that may cause or contribute to a NAAQS exceedance. Figure 4 shows a hypothetical example of modeling of an area that exceeds the NAAQS (either through monitoring or modeling). In each panel of Figure 5, the black dot represents the emission source. In Figure 5a, the contours in orange and red are design values that exceed the NAAQS. Figures 5b-5d show different approaches to establishing the nonattainment boundary so that the orange and red contours are within the boundary. In Figure 5b, the hypothetical nonattainment boundary is a circle, centered on the area shown as violating the NAAQS, while Figure 5c shows the hypothetical nonattainment boundary as a rectangle. Finally, Figure 5d shows a hypothetical nonattainment boundary as an irregular polygon in shape, perhaps based on jurisdictional boundaries or other landmarks such as roads.

Figure 6 illustrates a hypothetical example for a multi-source situation that is in nonattainment. In the example, there are five sources (denoted by blue dots) in a modeling domain that covers four counties (A, B, C, and D). The modeling domain is centered on the violating monitor (star). The orange contour represents concentrations above the NAAQS. As in the single source example shown in Figure 5, the nonattainment area could be circular, rectangular, or irregularly shaped using jurisdictional boundaries. In this example, the hypothetical nonattainment boundary would be defined by the northern portion of County A and the southern portion of County C. Since multiple sources are involved, the hypothetical nonattainment boundary should be extended to cover those sources that cause or contribute to a NAAQS violation. In this hypothetical example, Sources 2 and 5 are the largest contributing sources to the potential NAAQS violation so the nonattainment boundaries would include those two sources.

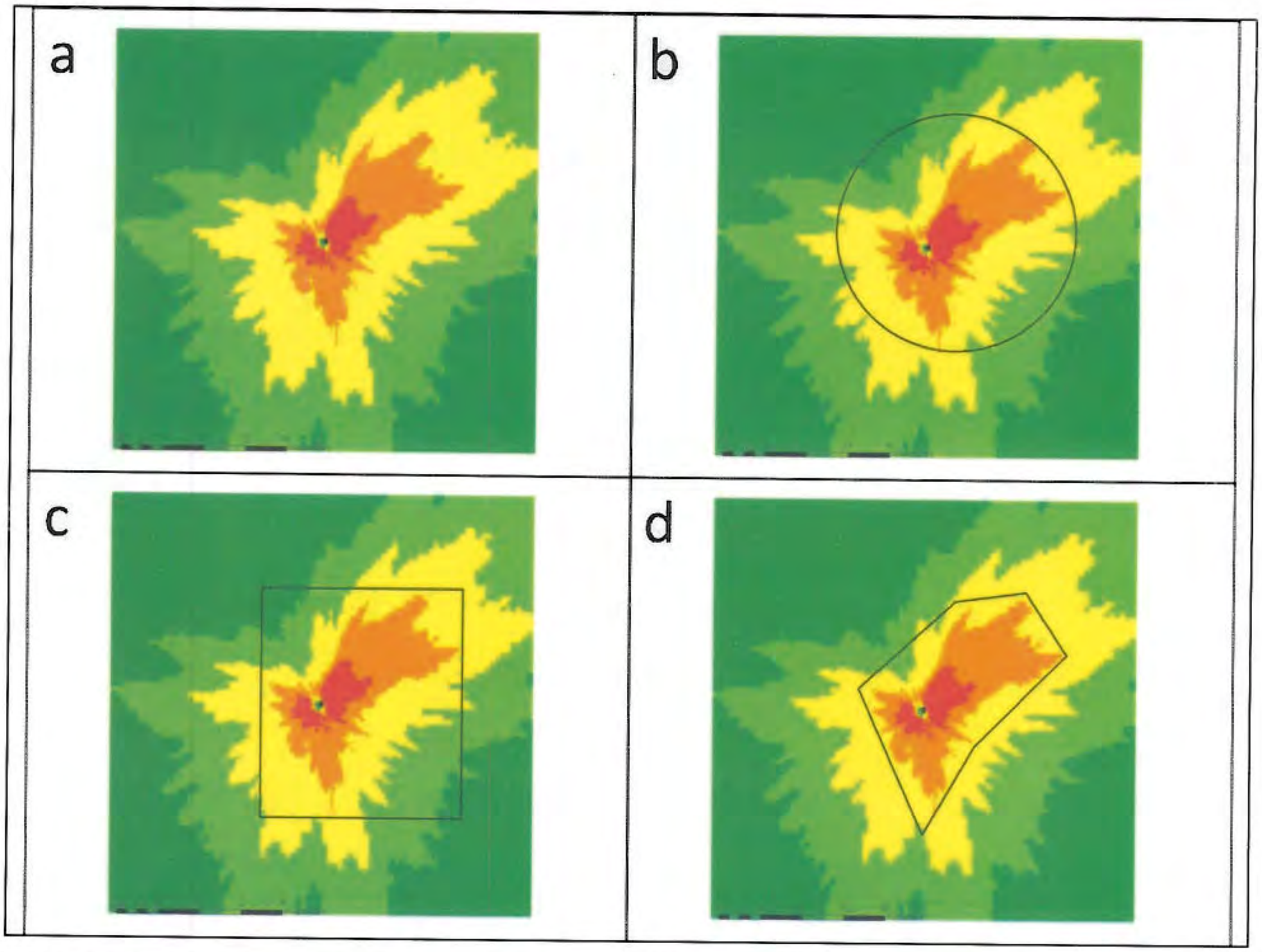

FIGURE 5. HYPOTHETICAL EXAMPLE OF A MODELED NAAQS VIOLATION (RED AND ORANGE CONTOURS) AND POSSIBLE NONATTAINMENT AREA BOUNDARIES DEFINED BY (B) CIRCLE, (C) RECTANGLE, AND (D) AN IRREGULAR POLYGON.

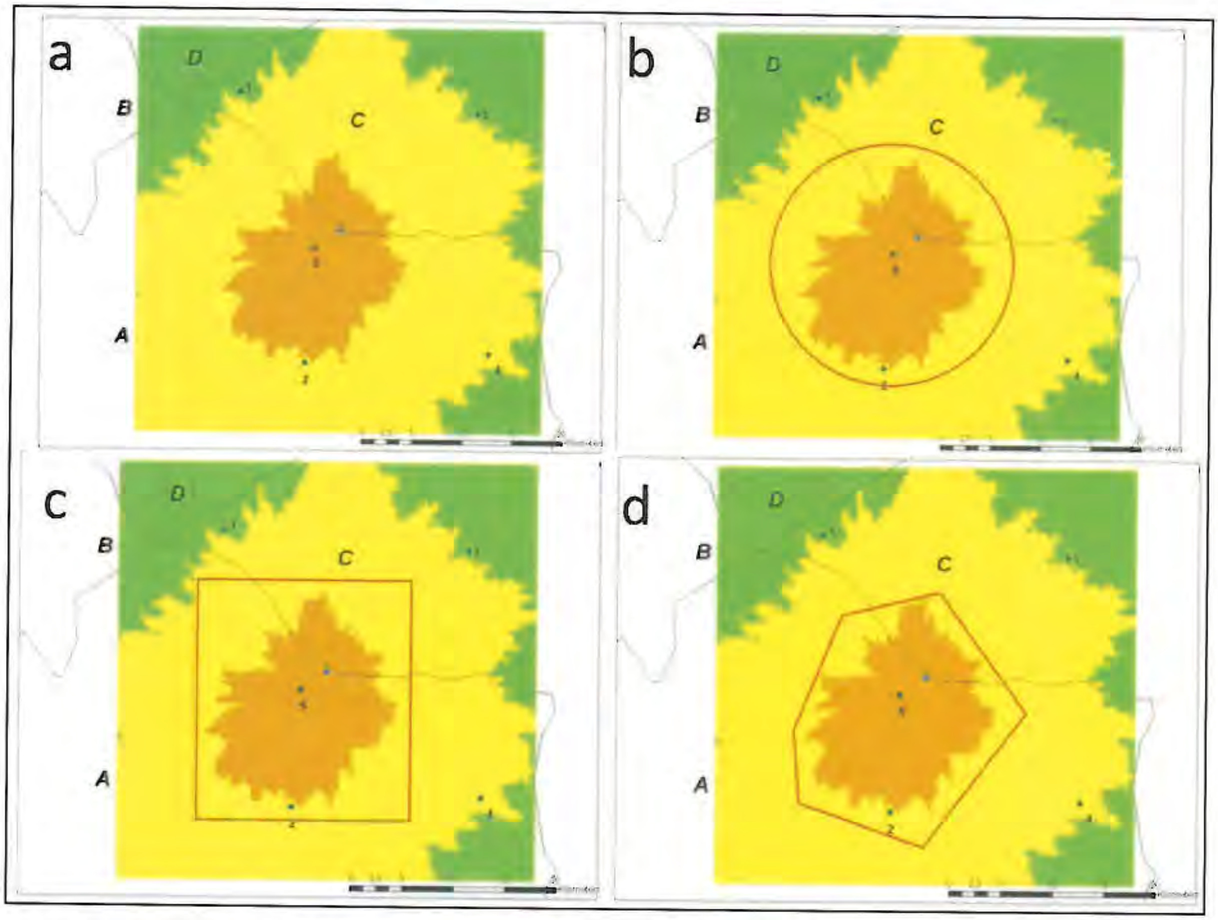

FIGURE 6. HYPOTHETICAL EXAMPLE OF A MULTI-SOURCE AREA WITH MODELED NAAQS VIOLATIONS (ORANGE CONTOUR) AND POSSIBLE NONATTAINMENT AREA BOUNDARIES DEFINED BY (B) CIRCLE, (C) RECTANGLE, AND (D) AN IRREGULAR POLYGON.

9.2 Attainment area boundaries

In areas without a violating monitor, modeling could be used to help determine that an area with SO_2 emitting sources is in attainment for the 1-hour SO_2 NAAQS. An attainment area boundary could not contain any area that exceeds the NAAQS or any area containing sources that are causing or contributing to a violating area. When considering attainment area boundaries, there will be no predicted area of violation from dispersion modeling so that other factors would need to be considered if the boundary is not determined by using the county presumptive boundary. Figure 7 illustrates a group of sources where a monitored design value does not exceed the NAAQS and modeling also does not show any concentration levels in excess of the NAAQS. In this case, the state could recommend that county A be considered attainment, since the monitor and modeling do not show violations of the NAAQS. Also, if there are other sources in the remaining three counties (i.e., B, C, or D) and their modeled concentration levels do not show violations of the NAAQS, then these counties could also be recommended as part of the attainment area.

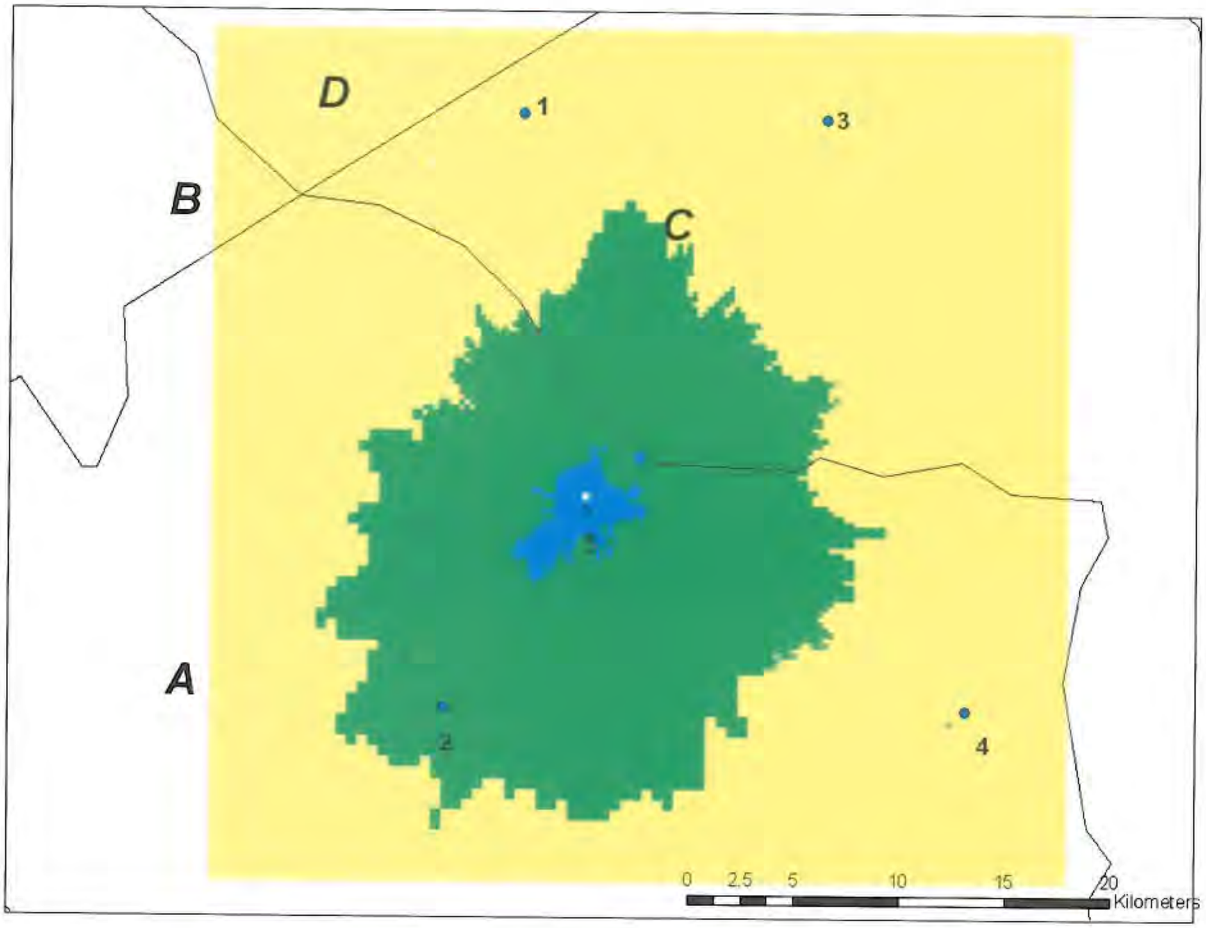

FIGURE 7. HYPOTHETICAL EXAMPLE FOR AN AREA WITH A MONITOR (STAR) THAT DOES NOT VIOLATE THE NAAQS AND MODELING RESULTS FOR SOURCES (BLUE DOTS) THAT DO NOT SHOW A VIOLATION OF THE NAAQS.

10. Documentation

It is expected that the state would submit a modeling and analysis protocol that details the methodology and model inputs before commencement of the modeling exercise. This information should support the states' recommended designations, and provide a basis for EPA's evaluation of the recommendations. The protocol should include the following:

- Characterization of the nonattainment problem or characterization of the modeled area in absence of a violating monitor,
- An emissions analysis around the violating monitor or area under consideration for designations in absence of a violating monitor, and
- Methodology for preparing air quality and meteorology inputs including choice of meteorological data and representativeness of the data.

Additionally, the documentation should include:

- Summary and analysis of modeling results, and
- Provision of modeling data inputs and outputs in electronic form.

A meeting with the appropriate EPA Regional Modeling Contact and other technical and planning staff to discuss the modeling and analysis protocol is recommended before submitting the protocol and beginning any refined modeling.

11. Summary

In summary, we emphasize the following key points of this modeling guidance:

- AERMOD is EPA's preferred near-field dispersion model for regulatory applications and is applicable for SO_2 designations modeling consistent with EPA's *Guideline on Air Quality Models*, also published as Appendix W of 40 CFR Part 51.
- Sources should be modeled with maximum allowable 1-hour or short-term emission rates in the designations modeling based on continuous operations at the source.
- Modeling should be done with five years of representative NWS meteorological data or at least one year of site specific meteorology.
- Background concentrations can be included as:
    - "First tier" approach based on monitored design values added to modeled design values; or
    - Temporally varying based on the 99^{th} percentile monitored concentrations by hour of day and season added to modeled design values.
- Dispersion modeling results could be used to inform the nonattainment or attainment areas in conjunction with other designations factors.
- States should submit a modeling and analysis protocol that details the methodology and model inputs before commencement of the modeling exercise. This information should support the states' recommended designations, and provide a basis for EPA's evaluation of the recommendations.

- At any time during the designations process when there are questions regarding modeling or interpretation of this guidance, the appropriate EPA Regional Modeling Contact should be consulted.

12. References

Auer, Jr., A.H., 1978: Correlation of Land Use and Cover with Meteorological Anomalies. Journal of Applied Meteorology, 17(5), 636-643.

Brode, R., K. Wesson, J. Thurman, and C. Tillerson, 2008: AERMOD Sensitivity to the Choice of Surface Characteristics, Paper 811, Air And Waste Management Association Annual Conference.

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine, R. B. Wilson, R. F. Lee, W. D. Peters, R. W. Brode, and J. O. Paumier, 2004: AERMOD: Description of Model Formulation, EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC.

U.S. EPA, 1985: Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations), Revised. EPA-450/4-80-023R. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 1992: Screening Procedures for Estimating the Air Quality Impact of Stationary Sources. EPA-454/R-92-019. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 1994: SO_2 Guideline Document. EPA-452/R-95-008. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 2000: Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 2004a: User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 2004b: User's Guide for the AERMOD Terrain Preprocessor(AERMAP). EPA-454/B-03-003. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

U.S. EPA, 2004c: User's Guide for the AERMOD Meteorological Preprocessor (AERMET). EPA-454/B-03-002. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 2004d: User's Guide to the Building Profile Input Program. EPA-454/R-93-038. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

U.S. EPA, 2005. *Guideline on Air Quality Models*. 40 CFR Part 51 Appendix W.

U.S. EPA, 2008: AERSURFACE User's Guide. EPA-454/B-08-001. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

U.S. EPA, 2009: AERMOD Implementation Guide. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

U.S EPA, 2011a: AERMINUTE User's Guide. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

U.S EPA, 2011b: AERSCREEN User's Guide. EPA-454-/B-11-001. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

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Air

Meteorological Monitoring Guidance for Regulatory Modeling Applications

EPA-454/R-99-005

Meteorological Monitoring Guidance

for Regulatory Modeling Applications

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

February 2000

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This report has been reviewed by the U.S. Environmental Protection Agency (EPA) and has been approved for publication as an EPA document. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This document updates the June 1987 EPA document, "On-Site Meteorological Program Guidance for Regulatory Modeling Applications", EPA-450/4-87-013. The most significant change is the replacement of Section 9 with more comprehensive guidance on remote sensing and conventional radiosonde technologies for use in upper-air meteorological monitoring; previously this section provided guidance on the use of sodar technology. The other significant change is the addition to Section 8 (Quality Assurance) of material covering data validation for upper-air meteorological measurements. These changes incorporate guidance developed during the workshop on upper-air meteorological monitoring in July 1998.

Editorial changes include the deletion of the "on-site" qualifier from the title and its selective replacement in the text with "site specific"; this provides consistency with recent changes in Appendix W to 40 CFR Part 51. In addition, Section 6 has been updated to consolidate and provide necessary context for guidance in support of air quality dispersion models which incorporate boundary layer scaling techniques.

The updated document (like the June 1987 document) provides guidance on the collection of meteorological data for use in regulatory modeling applications. It is intended to guide the EPA Regional Offices and States in reviewing proposed meteorological monitoring plans, and as the basis for advice and direction given to applicants by the Regional Offices and States. To facilitate this process, recommendations applicable to regulatory modeling applications are summarized at the end of each section. Alternate approaches, if these recommendations can not be met, should be developed on a case-by-case basis in conjunction with the Regional Office.

ACKNOWLEDGMENTS

The original (June 1987) document was prepared by the On-site Meteorological Data Work Group, formed in December 1985 and chaired by Roger Brode, EPA-OAQPS. Its members and their contributions are as follows: Edward Bennett, NY State DEC, Section 6.6; Roger Brode, EPA-OAQPS, Sections 1.0, 2.0 and 4.0; James Dicke, EPA-OAQPS, Section 5.2; Robert Eskridge, EPA-ASRL, Sections 6.2 and 6.3; Mark Garrison, EPA-Region III, Sections 3.2 and 9.0; John Irwin, EPA-ASRL, Sections 6.1 and 6.4; Michael Koerber, EPA-Region V, Sections 3.1 and 3.3; Thomas Lockhart, Meteorological Standards Institute, Section 8.0; Timothy Method, EPA-Region V, Section 3.4; Stephen Perkins, EPA-Region I, Sections 6.5 and 7.0; and Robert Wilson, EPA-Region 10, Sections 5.1 and 8.6, and parts of Sections 8.1, 8.2, and 8.5. Through their internal reviews and discussions, all of the work group members contributed to shaping the document as a whole. The work group wishes to acknowledge the time and effort of those, both within and outside of EPA, who provided technical review comments on the document. The work group also acknowledges the support and helpful guidance of Joseph A. Tikvart, EPA-OAQPS.

The June 1995 reissue of the document was prepared by Desmond T. Bailey with secretarial assistance from Ms. Brenda Cannady. Technical advice and guidance was provided by John Irwin.

The February 1999 reissue of the document provides updated material for Sections 8 (Quality Assurance) and 9 (Upper-Air Meteorological Monitoring). This material is the product of a workshop conducted at EPA facilities in Research Triangle Park, NC in July 1998. The workshop was conducted for EPA by Sharon Douglas of Systems Applications Inc. and three expert chairpersons: Ken Schere (U.S. EPA); Charles (Lin) Lindsey (Northwest Research Associates, Inc.); and Thomas Lockhart (Meteorological Standards Institute). Participants to the workshop were selected based on their expertise in atmospheric boundary layer measurements and/or the use of such data in modeling. Workshop participants were provided copies of the mock-up for review prior to the workshop, and were tasked to finalize the document during the workshop. The mock-up was prepared by Desmond Bailey (U.S. EPA) based on a draft report prepared under contract to EPA by Sonoma Technology, Inc. (SAI) entitled, "Guidance for Quality Assurance and Management of PAMS Upper-Air Meteorological Data". The latter report was written by Charles Lindsey and Timothy Dye (SAI) and Robert Baxter (Parsons Engineering Science Inc).

The two dozen participants to the workshop represented various interest groups including: remote sensing equipment vendors; local, state, and federal regulatory staff; the NOAA laboratories; university staff; and private consultants. Participants to the workshop were as follows: Desmond T. Bailey (Host), Alex Barnett (AVES), Mike Barth (NOAA Forecast Systems Lab), Bob Baxter (Parsons Engineering Science, Inc.), William B. Bendel (Radian International, LLC), Jerry Crescenti (U.S. Department of Commerce/NOAA), Sharon Douglas (Systems Applications Intl., Inc, Workshop Coordinator), Tim Dye (Sonoma Technology, Inc.), Leo Gendron (ENSR), Gerry Guay (Alaska Dept. of Environmental Conservation), Mark Huncik (CP&L), John Higuchi (SCAQMD), John Irwin (U.S. Environmental Protection Agency. Host),

David Katz (Climatronics), Shawn Kendall (Phelps Dodge Corporation), Don Lehrman (T & B Systems), Charles (Lin) Lindsey (Northwest Research Associates, Inc., Chairperson), Thomas Lockhart (Meteorological Standards Institute, Chairperson), Louis Militana (Roy F. Weston, Inc), Bill B. Murphey (Georgia Dept. of Natural Resources), Kenneth L. Schere (U.S. Environmental Protection Agency ORD, Chairperson), Nelson Seaman (Pennsylvania State University), Dr. Volker Thiermann (SCINTEC Atmospharemesstechnik AG), Stan Vasa (Southern Company Services), John White (North Carolina Division of Air Quality), Dr. J. Allen Zak (NASA Langley Research Center/VIGYAN, Inc.).

Peer review of the an April 1999 draft of this document was provided by Rob Wilson (U.S. EPA, Region 10) and Larry Truppi (U.S. EPA, NERL).

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1. INTRODUCTION

1.1 Background

This document provides guidance for the collection and processing of meteorological data for general use in air quality modeling applications. Such applications include those required in support of air quality regulations as specified in the Guideline on Air Quality Models. Guidance which specifically relates to a regulatory application is so indicated; in addition, recommendations affecting regulatory modeling applications are summarized at the end of individual sections.

Guidance is provided for the in situ monitoring of primary meteorological variables (wind direction, wind speed, temperature, humidity, pressure, and radiation) for remote sensing of winds, temperature, and humidity, and for processing of derived meteorological variables such as stability, mixing height, and turbulence. Most of the guidance is generic in that it supports most categories of air quality models including: steady-state, non-steady-state, Gaussian, and non-Gaussian models. However, material in some sections is probably more useful in support of some types of models than others. For example, the primary focus of the guidance on site selection (Section 3) is the collection of data at single locations for support of steady-state modeling applications. Non-steady-state modeling applications generally require gridded meteorological data using measurements at multiple sites. Support for such applications is provided to the extent that this guidance may be used for selecting sites to monitor the significant meteorological regimes that may need to be represented in these applications. Site selection criteria in these cases must be evaluated in concert with the objectives of the overall network; this falls in the category of network design and is beyond the scope of this document. Similarity, though generically useful, the guidance on upper-air meteorological monitoring (Section 9) is perhaps most useful in support of applications employing gridded meteorological data bases.

One of the most important decisions in preparing for an air quality modeling analysis involves the selection of the meteorological data base; this is the case whether one is selecting a site for monitoring, or selecting an existing data base. These decisions almost always lead to similar questions: “Is the site (are the data) representative?” This question is addressed in Section 3.1.

Minimal guidance is provided on the use of airport data; e.g., for use in filling gaps in site-specific data bases (Section 6.8). For practical purposes, because airport data were readily available, most regulatory modeling was initially performed using these data; however, one should be aware that airport data, in general, do not meet this guidance. The significant deviations to this guidance are discussed in Section 6.7.

The following documents provide necessary background and documentation for this guidance and are incorporated by reference: "Guideline on Air Quality Models" as published in Appendix W to 40 CFR Part 51 **[1]**; "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements" **[2]**; "On-site

Meteorological Instrumentation Requirements to Characterize Diffusion from Point Sources" **[3]**, "Standard for Determining Meteorological Information at Nuclear Power Sites" **[4]**.

1.2 Organization of Document

Section 2 provides general information on the instruments used for in-situ measurements of wind speed, wind direction, temperature, temperature difference, humidity, precipitation, pressure, and solar radiation. These variables are considered primary in that they are generally measured directly.

Section 3 provides guidance on siting and exposure of meteorological towers and sensors for the in-situ measurement of the primary meteorological variables. Specific guidance is provided for siting in simple terrain (Section 3.2), complex terrain (Section 3.3), coastal locations (Section 3.4), and urban locations (Section 3.5). The issue of representativeness is addressed in Section 3.1.

Section 4 provides guidance for recording of meteorological data.

Section 5 provides guidance on system performance.

Section 6 provides guidance for processing of meteorological data.

Section 7 provides guidance on data reporting and archiving.

Section 8 provides guidance on the quality assurance and quality control.

Section 9 provides guidance for the most widely used technologies employed for monitoring upper-air meteorological conditions; these include radiosondes and ground-based remote sensing platforms: sodar (Sound Detection and Ranging), radar (Radio Detection and Ranging), and RASS (Radio Acoustic Sounding System).

References are listed in Section 10.

2. PRIMARY METEOROLOGICAL VARIABLES

This section provides general information on the instruments used for in situ measurements of wind speed, wind direction, temperature, temperature difference, humidity, precipitation, pressure, and solar radiation. These variables are considered primary in that they are generally measured directly. Derived variables, such as atmospheric stability, mixing height, and turbulence are discussed in Section 6. Remote sensing platforms for measurements of winds, temperature, and humidity are discussed in Section 9; these variables, when determined using remote sensing, are not measured directly, but are derived from other measurements.

The choice of an instrument for a particular application should be guided by the data quality objectives of the application; as a minimum, these objectives should include the accuracy and resolution of the data needed by the application - recommended data quality objectives for regulatory dispersion modeling applications are provided in Section 5.0. Other considerations which may compete with the data quality objectives include the cost of the instrument, the need for and cost of routine maintenance, and the competing needs of ruggedness and sensitivity. One should also note that the cost of a successful monitoring program does not end with the purchase of the sensors; depending on the instrument, additional costs may be incurred for signal conditioning and recording hardware. There are also the costs involved in siting, installation, and calibration of the equipment, as well as costs associated with the quality assurance and processing of the data.

The focus in the following is on those classes of instruments that are considered best suited for routine in situ monitoring programs, and which generally have had the widest use. Additional information and illustrations for the instruments described in this section may be found in references **[2]**, **[5]**, **[6]**, **[7]**, and **[8]**.

2.1 Wind Speed

Although wind is a vector quantity and may be measured and processed as such, it is common to measure and/or process the scalar components of the wind vector separately; i.e., wind speed (the magnitude of the wind vector) and wind direction (the orientation of the wind vector). Wind speed determines the amount of initial dilution experienced by a plume, and appears in the denominator of the steady-state Gaussian dispersion equation (in the non-steady-state puff model, the wind speed determines the plume/puff transport). In addition, wind speed is used in the calculation of plume rise associated with point source releases, to estimate aerodynamic effects in downwash calculations, and, in conjunction with other variables, in the determination of atmospheric stability (Section 6.4.4). Instruments used for in situ monitoring of wind speed are of two types: those which employ mechanical sensors (e.g., cup and propeller anenometers) and those which employ non-mechanical sensors (hot wire anenometers and sonic anenometers). The non-mechanical sensors are beyond the scope of this guidance and are not addressed in the following; however, this should not preclude their use. When these types of instruments are to be used in support of regulatory actions, prior approval should be obtained from the reviewing authority as to how the data will be collected, processed, and quality assurred. Guidance on the use of remote sensing platforms for measuring wind speed is provided in Section 9.

2.1.1 Cup Anemometers

The rotating cup anemometer consists of three, four, and sometimes six hemispherical or cone-shaped cups mounted symmetrically about a vertical axis of rotation. The three cup anemometer is recommended; this design has been shown to exert a more uniform torque throughout a revolution. The rate of rotation of the cups is essentially linear over the normal range of measurements, with the linear wind speed being about 2 to 3 times the linear speed of a point on the center of a cup, depending on the dimensions of the cup assembly and the materials from which the sensor is made **[5]**. Sensors with high accuracy at low wind speeds and a low starting threshold should be used (see Section 5). Light weight materials (e.g., molded plastic or polystyrene foam) should be employed to achieve a starting threshold (lowest speed at which a rotating anemometer starts and continues to turn when mounted in its normal position) of ≤ 0.5 m/s.

2.1.2 Vane-oriented and Fixed-mount Propeller Anemometers

The vane-oriented propeller anemometer usually consists of a two, three or four-balded propeller which rotates on a horizontal pivoted shaft that is turned into the wind by a vane. Most current versions of this type of anemometer use propellers that are based on a modified helicoid. The dynamic characteristics of the vane should be matched with those of the propeller.

There are several propeller anemometers which employ lightweight molded plastic or polystyrene foam for the propeller blades to achieve threshold speeds of ≤ 0.5 m/s. This type of anemometer may be applied to collecting mean wind speeds for input to models to determine dilution estimates and/or transport estimates. Because of their relatively quick response times, some having distance constants of about one meter, these sensors are also suitable for use in determining the standard deviation of the along-wind-speed fluctuations, σ_u. Care should be taken, however, in selecting a sensor that will provide an optimal combination of such characteristics as durability and sensitivity for the particular application.

The variation of output speed with the approach angle of the wind follows nearly a cosine response for some helicoid propeller anemometers. This relationship permits the use of two orthogonal fixed-mount propellers to determine the vector components of the horizontal wind. A third propeller with a fixed mount rotating about a vertical axis may be used to determine the vertical component of the wind, and also the standard deviation of the vertical wind, σ_w. It should be noted that deviation of the response from a true cosine for large approach angles (e.g., 80-90°) may lead to underestimations of the vertical wind component without special calibration of the output signal. Users of vertical propeller anemometers should consult with the manufacturer on proper handling of the data.

2.1.3 Wind Speed Transducers

There are several mechanisms that can be used to convert the rate of the cup or propeller rotations to an electrical signal suitable for recording and/or processing. The four most commonly used types of transducers are the DC generator, the AC generator, the electrical-contact, and the interrupted light beam. Many DC and AC generator types of transducers in common use have limitations in terms of achieving low thresholds and quick response times. Some DC generator transducers are limited because the combined effect of brush and bearing friction give a threshold speed above 0.5 m/s (above 1.0 mph). However, some anemometers employ miniaturized DC generators which allow thresholds below 0.5 m/s to be achieved. The AC generator transducers eliminate the brush friction, but care must be exercised in the design of the signal conditioning circuitry to avoid spurious oscillations in the output signal that may be produced at low wind speeds. Electrical-contact transducers are used to measure the "run-of-the-wind"; i.e., the amount of air (measured as a distance) passing a fixed point in a given time interval; wind speed is calculated by dividing run-of-the-wind measurements by the time interval. The interrupted light beam (light chopping) transducer is frequently used in air quality applications because of the lower threshold that can be achieved by the reduction in friction. This type of transducer uses either a slotted shaft or a slotted disk, a photo emitter and a photo detector. The cup or propeller assembly rotates the slotted shaft or disk, creating a pulse each time the light passes through a slot and falls on the photo detector. The frequency output from this type of transducer is handled in the same way as the output from an AC generator. Increasing the number of slots to about 100, thereby increasing the pulse rate, eliminates signal conditioning problems which may arise with lower frequencies. The frequency output from an AC generator or a light chopping transducer may be transmitted through a signal conditioner and converted to an analog signal for various recording devices, such as a continuous strip chart or a multi point recorder, or through an analog-to-digital (A/D) converter to a microprocessor type of digital recorder. Several modern data loggers can accept the frequency type signal directly, eliminating the need for additional signal conditioning. The recording and processing of the data are covered in more detail in Sections 4.0 and 6.0, respectively.

2.2 Wind Direction

Wind direction is generally defined as the orientation of the wind vector in the horizontal. Wind direction for meteorological purposes is defined as the direction from which the wind is blowing, and is measured in degrees clockwise from true north. Wind direction determines the transport direction of a plume or puff in air quality modeling applications. The standard deviation of the wind direction, σ_A, or the standard deviation of the elevation angle, σ_E, may also be used, in conjunction with wind speed, to derive the atmospheric stability category (Section 6.4). Wind direction may be measured directly using a wind vane (Section 2.2.1) or may be derived from measurements of wind speed components (Section 2.2.2).

2.2.1 Wind Vanes

The conventional wind vane consists of a tail section attached to one end of a horizontal shaft which, in turn, is mounted on a vertical axis; the tail and shaft rotate in a horizonal plane. The wind vane measures the azimuth angle of the wind. Wind vanes and tail fins should be constructed from light weight materials. The starting threshold (lowest speed at which a vane will turn to within 5º of the true wind direction from an initial displacement of 10º) should be ≤ 0.5 ms^{-1}. Overshoot must be ≤ 25% and the damping ratio should lie between 0.4 and 0.7.

Bi-directional vanes (bivanes) measure both the azimuth and elevation angles of the wind vector. The bivane generally consists of either an annular fin or two flat fins perpendicular to each other, counterbalanced and mounted on a gimbal so that the unit can rotate freely both horizontally and vertically. Bivanes require greater care and are not generally suited for routine monitoring. Data from bivanes, consequently, should only be used on a case by case basis with the approval of the reviewing authority.

2.2.2 U-V and UVW Systems

Another method of obtaining the horizontal and/or vertical wind direction is through the use of orthogonal fixed-mount propeller anemometers, the U-V or UVW systems. The horizontal and, in the case of UVW systems, the vertical, wind direction can be determined computationally from the orthogonal wind speed components. The computational methods are based on the fact that the variation of output speed with the approach angle of the wind follows nearly a cosine response for some helicoid propeller anemometers.

2.2.3 Wind Direction Transducers

Many kinds of simple commutator type transducers utilize brush contacts to divide the wind direction into eight or 16 compass point sectors. However, these transducers do not provide adequate resolution to characterize transport for most air quality modeling applications.

A fairly common transducer for air quality modeling applications is a 360° potentiometer. The voltage across the potentiometer varies directly with the wind direction. A commonly used solution to the discontinuity that occurs across the small gap in a single potentiometer is to place a second potentiometer 180° out of phase with the first one **[5]**. In this case the voltage output corresponds to a 0° to 540° scale. This transducer utilizes a voltage discriminator to switch between the "upper" and "lower" potentiometers at appropriate places on the scale. This technique eliminates chart "painting" which occurs on strip chart recorders when the wind oscillates across north (i.e., between 0 and full scale). A disadvantage is that chart resolution is reduced by one third.

Another type of transducer being used is a wind direction resolver, which is a variable phase transformer where the phase change is a function of the shaft rotation angle. This system alleviates the maintenance problems associated with the friction caused by the wiper in a potentiometer; however, this type of transducer is more expensive and requires more complex signal conditioning circuity.

2.2.4 Standard Deviation and Turbulence Data

The standard deviation of the azimuth and elevation angles of the wind vector, σ_A and σ_E, respectively can be related to the dispersive capabilities of the atmosphere, in particular, to the dispersion coefficients σ_y and σ_z which characterize plume concentration distributions in commonly-used Gaussian models. These quantities can be used as inputs to algorithms to determine Pasquill stability categories (see Section 6.4.4), or may also be treated as turbulence data for direct input to certain Gaussian models. The σ values should be computed directly from high-speed analog or digital data records (Section 6.1). If a sigma meter or sigma computer is used, care should be taken that the results are not biased by smoothing of the data, and to ensure that the methods employed accurately treat the 0-360° crossover and use an adequate number of samples (at least 360 per averaging period, see Section 6.1.4). The comparability of results from the sigma computer to the direct statistical approach should be demonstrated. To accurately determine σ_A and σ_E, the wind direction sensors must possess certain minimum response characteristics. The most important in this regard is the damping ratio, which should be between 0.4 to 0.7 (see Section 5.2). The wind direction should also be recorded to a resolution of 1 degree in order to calculate the standard deviation.

2.3 Temperature and Temperature Difference

This section addresses both the measurement of ambient air temperature at a single level and the measurement of the temperature difference between two levels. The ambient temperature is used in determining the amount of rise experienced by a buoyant plume. The vertical temperature difference is used in calculating plume rise under stable atmospheric conditions, and is also used in determining Monin-Obukhov length, a stability parameter (Section 6.4.5).

2.3.1 Classes of Temperature Sensors

Sensors used for monitoring ambient temperature include: wire bobbins, thermocouples, and thermistors. Platinum resistance temperature detectors (RTD) are among the more popular sensors used in ambient monitoring; these sensors provide accurate measurements and maintain a stable calibration over a wide temperature range. The RTD operates on the basis of the resistance changes of certain metals, usually platinum or copper, as a function of temperature. These two metals are the most commonly used because they show a fairly linear increase of resistance with rising temperature **[5]**. "Three wire" and "four wire" RTDs are commonly used to compensate for lead resistance errors. A second type of resistance change thermometer is the thermistor, which is made from a mixture of metallic oxides fused together. The thermistor generally gives a larger resistance change with temperature than the RTD. Because the relation between resistance and temperature for a thermistor is non-linear, systems generally are designed to use a combination of two or more thermistors and fixed resistors to produce a nearly linear response over a specific temperature range **[5, 8]**.

Thermoelectric sensors work on the principle of a temperature dependent electrical current flow between two dissimilar metals. Such sensors, called thermocouples, have some special handling requirements for installation in order to avoid induction currents from nearby AC sources, which can cause errors in measurement **[5]**. Thermocouples are also susceptible to spurious voltages caused by moisture. For these reasons, their usefulness for routine field measurements is limited.

2.3.2 Response Characteristics

The response of temperature sensors can be characterized by a first order linear differential equation. The time constant for temperature sensors, i.e. the time taken to respond to 63% of a step change in the temperature, is a function of the air density and wind speed or ventilation rate. The time constant for a mercury-in-glass thermometer is about l minute for a ventilation rate of 5 m/s **[5, 6]**. Time constants for platinum resistance temperature detectors (RTDs) and for thermistors mounted in a typical probe are about 45 seconds. These are adequate response times for monitoring programs (see Section 5.2).

2.3.3 Temperature Difference

The basic sensor requirements for measuring vertical temperature difference are essentially the same as for a simple ambient temperature measurement. However, matched sensors and careful calibration are required to achieve the desired accuracy of measurement. The ambient temperature measurement is often taken from one of the sensors used to measure the differential temperature. A number of systems are commercially available that utilize a special translator module to process the signal difference between the two component sensors. Through signal processing, the accuracy of the differential temperature can be calibrated to the level of resolution of the component systems.

2.3.4 Sources of Error

One of the largest sources of error in any temperature system is due to solar radiation. Temperature sensors must be adequately shielded from the influences of direct or reflected solar radiation in order to provide representative measurements. A well ventilated shelter may be adequate for surface temperature measurements but would be impractical for levels higher than a few meters above ground. Tower-mounted sensors are generally housed in aspirated radiation shields. It is advisable to utilize motor driven aspirators to ensure adequate ventilation. Care should also be taken that moisture not be allowed to come in contact with the sensor or the inside surfaces of the radiation shield. In some sensors moisture will change the electrical properties of the sensor, causing error. In others, the evaporative cooling will cause the temperature reading to be too low. For temperature difference measurements, sensors should be housed in identical aspirated radiation shields with equal exposures.

2.4 Humidity

2.4.1 Humidity Variables

Humidity is a general term related to the amount of moisture in the air; humidity variables include vapor pressure, dew point temperature, specific humidity, absolute humidity, and relative humidity. With the exception of relative humidity, all of the above variables provide a complete specification of the amount of water vapor in the air; in the case of relative humidity, measurements of temperature and pressure are also required. Humidity is an important variable in determining impacts from moist sources, such as cooling towers; it is also used in modeling ozone chemistry.

2.4.2 Types of Instrumentation

There are basically two types of sensors for measuring humidity, psychrometers and hygrometers. The psychrometer, consists of two thermometers, one of which is covered with a wet wick (the wet bulb) and a mechanism for ventilating the pair. Evaporation lowers the temperature of the wet bulb; the difference in temperature from the dry bulb (the wet bulb depression) is a measure of the amount of moisture in the air. While still in use at many observing stations, psychrometers are generally not suitable for routine monitoring programs. However, they can be used as secondary standards in audit procedures.

Hygrometers are a class of instruments that measure the physical effect that moisture has on a substances, such as hair. For example, the lithium chloride hygrometer uses a probe impregnated with lithium chloride solution. Voltage is supplied to the electrodes in the probe until an equilibrium temperature is reached based on the conductivity of the lithium chloride. The dew point hygrometer, uses a cooled mirror as a sensor; in this case, the temperature of the mirror is monitored to determine the temperature at which dew (or frost) first appears. Such condensation typically disrupts the path of a light beam reflecting off of the cooled surface, causing it to be heated until the condensation disappears. Once the condensation is gone, the surface is cooled again until condensation forms. These oscillating heating and cooling cycles define an average dew point temperature. The temperature of the surface is typically measured by a linear thermistor or a platinum RTD. The thin film capacitor hygrometer measures humidity by detecting the change in capacitance of a thin polymer film; this sensor has a relatively fast response compared to other types of hygrometers.

If possible, humidity sensors should be housed in the same aspirated radiation shield as the temperature sensor. The humidity sensor should be protected from contaminants such as salt, hydrocarbons, and other particulates. The best protection is the use of a porous membrane filter which allows the passage of ambient air and water vapor while keeping out particulate matter.

2.5 Precipitation

Precipitation data, although primarily used in wet deposition modeling, are also used for consistency checks in data review and validation. The two main classes of precipitation measuring devices suitable for meteorological programs are the tipping bucket rain gauge and the weighing rain gauge. Both types of gauge measure total liquid precipitation. Both types of gauge may also be used to measure the precipitation rate, but the tipping bucket is preferable for that application. A third type, the optical rain gauge, has not yet been adequately developed for widespread use.

The tipping bucket rain gauge is probably the most common type of instrument in use for meteorological programs. The rainfall is collected by a cylinder, usually about 8 to 12 inches in diameter, and funneled to one of two small "buckets" on a fulcrum. Each bucket is designed to collect the equivalent of 0.01 inches (0.3 mm) of precipitation, then tip to empty its contents and bring the other bucket into position under the funnel. Each tip of the bucket closes an electrical contact which sends a signal to a signal conditioner for analog and/or digital recording. These are fairly reliable and accurate instruments. Measurement errors may occur if the funnel is too close to the top of the cylinder, resulting in an underestimate of precipitation due to water splashing out of the cylinder, especially during heavy rainfall. Underestimates may also occur during heavy rainfall because precipitation is lost during the tipping action. Inaccuracies may also result if the tipping bucket assembly or the entire gauge is not leveled properly when installed. Tipping buckets are generally equipped with heaters to melt the snow in cold climates, however, the total precipitation may be underestimated due to evaporation of the frozen precipitation caused by the heating element. It would be preferable for the heater to be thermostatically controlled, rather than operate continuously, to avoid underestimation due to evaporation that may also occur during periods of light rain or drizzle. Underestimation of precipitation, especially snowfall, may also result from cases where the gauge is not adequately sheltered from the influence of the wind. A wind shield should therefore be used in climates that experience snowfall. Strong winds can also cause the buckets to tip, resulting in spurious readings.

The weighing rain gauge has the advantage that all forms of precipitation are weighed and recorded as soon as they fall into the gauge. No heater is needed to melt the snow, except to prevent snow and ice buildup on the rim of the gauge, alleviating the problem of evaporation of snow found with the heated tipping bucket gauge. Antifreeze is often used to melt the snow in the bucket. However, the weighing gauge requires more frequent tending than the tipping bucket gauge, and is more sensitive to strong winds causing spurious readings. The weight of precipitation is recorded on a chart mounted on a clock-driven drum for later data reduction. Weighing systems are also available which provide an electrical signal for digital processing.

2.6 Pressure

Atmospheric or barometric pressure can provide information to the meteorologist responsible for reviewing data that may be useful in evaluating data trends, and is also used in conjunction with air quality measurements. There are two basic types of instruments available for measuring atmospheric pressure, the mercury barometer and the aneroid barometer.

The mercury barometer measures the height of a column of mercury that is supported by the atmospheric pressure. It is a standard instrument for many climatological observation stations, but it does not afford automated data recording.

Another common type of pressure instrument is the aneroid barometer which consists of two circular disks bounding an evacuated volume. As the pressure changes, the disks flex, changing their relative spacing which is sensed by a mechanical or electrical element and transmitted to a transducer. A barograph is usually an aneroid barometer whose transducer is a mechanical linkage between the bellows assembly and an ink pen providing a trace on a rotating drum. A more sophisticated aneroid barometer providing a digital output has been developed consisting of a ceramic plate substrate sealed between two diaphragms. Metallic areas on the ceramic substrate form one plate of a capacitor, with the other plate formed by the two diaphragms. The capacitance between the internal electrode and the diaphragms increases linearly with applied pressure. The output from this barometer is an electronic signal that can be processed and stored digitally **[5]**.

2.7 Radiation

Solar and/or net radiation data are used to determine atmospheric stability (Section 6.4.2), for calculating various surface-layer parameters used in dispersion modeling (Section 6.6), for estimating convective (daytime) mixing heights, and for modeling photochemical reactions.

Solar radiation refers to the electromagnetic energy in the solar spectrum (0.10 to 4.0 µm wavelength); the latter is commonly classified as ultraviolet (0.10 to 0.40 µm), visible light (0.40 to 0.73 µm), and near-infrared (0.73 to 4.0 µm) radiation. Net radiation includes both solar radiation (also referred to as short-wave radiation) and terrestrial or long-wave radiation; the sign of the net radiation indicates the direction of the flux (a negative value indicates a net upward flux of energy).

Pyranometers are a class of instruments used for measuring energy fluxes in the solar spectrum. These instruments are configured to measure what is referred to as global solar radiation; i.e., direct plus diffuse (scattered) solar radiation incidence on a horizontal surface. The sensing element of the typical pyranometer is protected by a clear glass dome which both protects the sensing element, and functions as a filter preventing entry of energy outside the solar spectrum (i.e., long-wave radiation). The glass domes used on typical pyranometers are transparent to wavelengths in the range of 0.28 to 2.8 µm. Filters can be used instead of the clear glass dome to measure radiation in different spectral intervals; e.g., ultraviolet radiation.

WMO specifications for several classes of pyranometers are given in Table 2-1 **[9]**. First class and secondary standard pyranometers typically employ a thermopile for the sensing element. The thermopile consists of a series of thermojunction pairs, an optically black primary junction, and an optically white reference junction (in some pyranometers, the reference thermojunction is embedded in the body of the instrument). The temperature difference between the primary and reference junctions which results when the pyranometer is operating generates an electrical potential proportional to the solar radiation. Second class pyranometers typically employ photo-cells for the sensing element. Though less costly than other types of pyranometers, the spectral response of the photovoltaic pyranometer is limited to the visible spectrum.

First class or second class pyranometers should normally be used for measuring global solar radiation, depending on the application. If the solar radiation data are to be used in procedures for estimating stability (Section 6.4) then second class (photovoltaic) pyranometers are acceptable. For most other applications, first class or secondary standard pyranometers should be used. Applications requiring ultraviolet (UV) radiation data should not employ photovoltaic measurements as these instruments are not sensitive to UV radiation.

Table 2-1

Classification of Pyranometers [9]

Characteristic	Units	Secondary Standard	First Class	Second Class
Resolution	W m^{-2}	±1	±5	±10
Stability	%FS*	±1	±2	±5
Cosine Response	%	< ±3	< ±7	< ±15
Azimuth Response	%	< ±3	< ±5	< ±10
Temperature Response	%	±1	±2	±5
Nonlinearity	%FS*	±0.5	±2	±5
Spectral Sensitivity	%	±2	±5	±10
Response Time (99%)	seconds	< 25	< 60	< 240

* Percent of full scale

2.8 Recommendations

Light weight three cup anemometers (Section 2.1.1) or propeller anemometers (Section 2.1.2) should be used for measuring wind speed. Sensors with high accuracy at low wind speeds and a low starting threshold should be used (see Section 5). Light weight, low friction systems which meet the performance specifications given in Section 5.0 should be used. Heaters should be employed to protect against icing in cold climates. Sonic anenometers and hot wire *anenometers may be used with the approval of the reviewing authority. These instruments are especially suited for use in direct measurements of turbulence.*

Wind direction should be measured directly using a wind vane (Section 2.2.1) or may be derived from measurements of wind speed components (Section 2.2.2). Light weight, low friction systems which meet the performance specifications given in Section 5.0 should be used. Heaters should be employed to protect against icing in cold climates. Bivanes are regarded as research grade instruments and are not generally suited for routine monitoring. Data from bivanes may be used on a case by case basis with the approval of the reviewing authority.

Temperature and temperature difference should be measured using resistance temperature devices which meet the performance specifications of Section 5.0. Thermoelectric sensors (thermocouples) are not recommended because of their limited accuracy and complex circuitry.

Humidity should be measured using a dew point, lithium chloride, or thin-film capacitor hygrometer. The hygrometer should meets the performance specifications in Section 5.0.

Precipitation should be measured with a weighing or tipping bucket rain gauge. In cold climates, the gauge should be equipped with a heater and a wind shield.

Atmospheric pressure should be measured with an aneroid barometer which meets the performance specifications given in Section 5.0

First class or second class pyranometers should normally be used for measuring global solar radiation, depending on the application. If the solar radiation data are to be used in procedures for estimating stability (Section 6.4) then second class (photovoltaic) pyranometers are acceptable. For most other applications, first class or secondary standard pyranometers should be used. Applications requiring ultraviolet (UV) radiation data should not employ photovoltaic measurements as these instruments are not sensitive to UV radiation.

Recommended performance specifications for the primary meteorological variables are provided in Table 5-1.

3. SITING AND EXPOSURE

This section provides guidance on siting and exposure of meteorological towers and sensors for the in situ measurement of the primary meteorological variables. Specific guidance is provided for siting in simple terrain (Section 3.2), in complex terrain (Section 3.3), in coastal locations (Section 3.4), and in urban locations (Section 3.5). The issue of representativness is addressed in Section 3.1.

As a general rule, meteorological sensors should be sited at a distance which is beyond the influence of obstructions such as buildings and trees; this distance depends upon the variable being measured as well as the type of obstruction. The other general rule is that the measurements should be representative of meteorological conditions in the area of interest; the latter depends on the application. Secondary considerations such as accessibility and security must be taken into account, but should not be allowed to compromise the quality of the data. In addition to routine quality assurance activities (see Section 8), annual site inspections should be made to verify the siting and exposure of the sensors. Approval for a particular site selection should be obtained from the permit granting agency prior to any site preparation activities or installation of any equipment.

3.1 Representativeness

One of the most important decisions in preparing for an air quality modeling analysis involves the selection of the meteorological data base; this is the case whether one is selecting a site for monitoring, or selecting an existing data base. These decisions almost always lead to similar questions: "Is the site (are the data) representative?" Examples eliciting a negative response abound; e.g., meteorological data collected at a coastal location affected by a land/sea breeze circulation would generally not be appropriate for modeling air quality at an inland site located beyond the penetration of the sea breeze. One would hope that such examples could be used in formulating objective criteria for use in evaluating representativeness in general. Though this remains a possibility, it is not a straight forward task - this is due in part to the fact that representativeness is an exact condition; a meteorological observation, data base, or monitoring site, either is, or is not representative within the context of whatever criteria are prescribed. It follows that, a quantitative method does not exist for determining representativeness absolutely. Given the above, it should not be surprising that there are no generally accepted analytical or statistical techniques to determine representativeness of meteorological data or monitoring sites.

3.1.1 Objectives for Siting

Representativeness has been defined as "the extent to which a set of measurements taken in a space-time domain reflects the actual conditions in the same or different space-time domain taken on a scale appropriate for a specific application" **[10]**. The space-time and application aspects of the definition as relates to site selection are discussed in the following.

In general, for use in air quality modeling applications, meteorological data should be representative of conditions affecting the transport and dispersion of pollutants in the “area of interest” as determined by the locations of the sources and receptors being modeled. In many instances, e.g. in complex terrain, multiple monitoring sites may be required to adequately represent spatial variations in meteorological conditions affecting transport and/or dispersion.

In steady-state modeling applications, one typically focuses on the meteorological conditions at the release height of the source or sources, or the plume height in the case of buoyant sources. Representativeness for steady-state modeling applications must necessarily be assessed in concert with the steady-state assumption that meteorological conditions are constant within the space-time domain of the application; as typically applied, measurements for a single location, somewhere near the source, are assumed to apply, without change, at all points in the modeling domain. Consistency would call for site selection criteria consistent with the steady-state assumption; i.e., to the extent possible, sites should perhaps be selected such that factors which cause spatial variations in meteorological conditions, are invariant over the spatial domain of the application, whatever that might be. Such factors would include surface characteristics such as ground cover, surface roughness, the presence or absence of water bodies, etc. Similarly, the representativeness of existing third-party data bases should be judged, in part, by comparing the surface characteristics in the vicinity of the meteorological monitoring site with the surface characteristics that generally describe the analysis domain.

Representativeness has an entirely different interpretation for non-steady-state modeling applications which commonly employ three dimensional gridded meteorological fields based on measurements at multiple sites. The meteorological processors which support these applications are designed to appropriately blend available NWS data, local site-specific data, and prognostic mesoscale data; empirical relationships are then used to diagnostically adjust the wind fields for mesoscale and local-scale effects **[11]**, **[12]** . These diagnostic adjustments can be improved through the use of strategically placed site-specific meteorological observations. Support for such applications is provided to the extent that this guidance can be used for selecting sites to monitor the significant meteorological regimes that may need to be represented in these applications. Site selection for such applications (often more than one location is needed) falls in the category of network design and is beyond the scope of this document. Model user’s guides should be consulted for meteorological data requirements and guidance on network design for these applications.

3.1.2 Factors to Consider

Issues of representativeness will always involve case-by-case subjective judgements; consequently, experts knowledgeable in meteorological monitoring and air quality modeling should be included in the site selection process. The following information is provided for consideration in such decisions. Readers are referred to a 1982 workshop report **[10]** on representativeness for further information on this topic.

- It is important to recognize that, although certain meteorological variables may be considered unrepresentative of another site (for instance, wind direction or wind speed), other variables may be representative (such as temperature, dew point, cloud cover). Exclusion of one variable does not necessarily exclude all. For instance, one can argue that weather observations made at different locations are likely to be similar if the observers at each location are within sight of one another - a stronger argument can be made for some types of observations (e.g., cloud cover) than others. Although, by no means a sufficient condition, the fact that two observers can "see" one another supports a conclusion that they would observe similar weather conditions.
- In general, the representativeness of the meteorological data used in an air quality modeling analysis is dependent on the proximity of the meteorological monitoring site to the “area-of-interest”.
- Spatial representativeness of the data will almost always be adversely affected (degraded) by increasing the distance between the sources and receptors (increasing the size of the area-of-interest).
- Although proximity of the meteorological monitoring site is an important factor, representativeness is not simply a function of distance. In some instances, even though meteorological data are acquired at the location of the pollutant source, they may not correctly characterize the important atmospheric dispersion conditions; e.g., dispersion conditions affecting sources located on the coast are strongly affected by off-shore air/sea boundary conditions - data collected at the source would not always reflect these conditions.
- Representativeness is a function of the height of the measurement. For example, one can expect more site-to-site variability in measurements taken close to the surface compared to measurements taken aloft. As a consequence, upper-air measurements are generally representative of much larger spatial domains then are surface measurements.
- Where appropriate, data representativeness should be viewed in terms of the appropriateness of the data for constructing realistic boundary layer profiles and three dimensional meteorological fields.
- Factors that should be considered in selecting a monitoring site in complex terrain include: the aspect ratio and slope of the terrain, the ratios of terrain height to stack height and plume height, the distance of the source from the terrain feature, and the effects of terrain features on meteorological conditions, especially wind speed and wind direction.

3.2 Simple Terrain Locations

For the purposes of this guidance, the term “simple terrain” is intended to mean any site where terrain effects on meteorological measurements are non-significant. The definition of significance depends on the application; for regulatory dispersion modeling applications, significance is determined by comparing stack-top height to terrain height - terrain which is below stack-top is classified as simple terrain **[1]**

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3.2.1 Wind Speed and Wind Direction

3.2.1.1 Probe placement

The standard exposure height of wind instruments over level, open terrain is 10 m above the ground **[9]**. Open terrain is defined as an area where the distance between the instrument and any obstruction is at least ten times the height of that obstruction **[2, 4, 9]**. The slope of the terrain in the vicinity of the site should be taken into account when determining the relative height of the obstruction **[2]**. An obstruction may be man-made (such as a building or stack) or natural (such as a hill or a tree). The sensor height, its height above obstructions, and the height/character of nearby obstructions should be documented. Where such an exposure cannot be obtained, the anemometer should be installed at such a height that it is reasonably unaffected by local obstructions and represents the approximate wind values that would occur at 10 m in the absence of the obstructions. This height, which depends on the extent, height, and distance of obstructions and on site availability, should be determined on a case-by-case basis. Additional guidance on the evaluation of vertical profiles (Section 6.1.3) and surface roughness (Section 6.4.2) may be helpful in determining the appropriate height.

If the source emission point is substantially above 10 m, then additional wind measurements should be made at stack top or 100 m, whichever is lower **[1]**. In cases with stack heights of 200 m or above, the appropriate measurement height should be determined by the Regional Office on a case-by-case basis. Because maximum practical tower heights are on the order of 100 m, wind data at heights greater than 100 m will most likely be determined by some other means. Elevated wind measurements can be obtained via remote sensing (see Section 9.0). Indirect values can be estimated by using a logarithmic wind-speed profile relationship. For this purpose, instruments should be located at multiple heights (at least three) so that site-specific wind profiles can be developed.

3.2.1.2 Obstructions

Buildings. Aerodynamic effects due to buildings and other major structures, such as cooling towers, should be avoided to the extent possible in the siting of wind sensors; such effects are significant, not only in the vicinity of the structures themselves, but at considerable distances downwind. Procedures for assessing aerodynamic effects have been developed from observing such effects in wind tunnels **[13]**, **[14]**. Wind sensors should only be located on building rooftops as a last resort; in such cases, the sensors should be located at a sufficient height above the rooftop to avoid the aerodynamic wake. This height can be determined from on-site measurements (e.g., smoke releases) or wind tunnel studies. As a rule of thumb, the total depth of the building wake is estimated to be approximately 2.5 times the height of the building **[1]**.

Trees. In addition to the general rules concerning obstructions noted above, additional considerations may be important for vegetative features (e.g., growth rates). Seasonal effects should also be considered for sites near deciduous trees. For dense, continuous forests where an open exposure cannot be obtained, measurements should be taken at 10m above the height of the general vegetative canopy.

Towers. Sensors mounted on towers are frequently used to collect wind speed measurements at more than one height. To avoid the influence of the structure itself, closed towers, stacks, cooling towers, and similar solid structures should not be used to support wind instruments. Open-lattice towers are preferred. Towers should be located at or close to plant elevation in an open area representative of the area of interest.

Wind instruments should be mounted on booms at a distance of at least twice the diameter/diagonal of the tower (from the nearest point on the tower) into the prevailing wind direction or wind direction of interest **[2]**. Where the wind distribution is strongly bimodal from opposite directions, such as in the case of up-valley and down-valley flows, then the booms should be at right angles to the predominant wind directions. The booms must be strong enough so that they will not sway or vibrate sufficiently to influence standard deviation values in strong winds. Folding or collapsible towers are not recommended since they may not provide sufficient support to prevent such vibrations, and also may not be rigid enough to ensure proper instrument orientation. The wind sensors should be located at heights of minimum tower density (i.e., minimum number of diagonal cross-members) and above/below horizontal cross-members **[2]**. Since practical considerations may limit the maximum boom length, wind sensors on large towers (e.g., TV towers and fire look-out towers) may only provide accurate measurements over a certain arc. In such cases, two systems on opposite sides of the tower may be needed to provide accurate measurements over the entire 360°. If such a dual system is used, the method of switching from one system to the other should be carefully specified. A wind instrument mounted on top of a tower should be mounted at least one tower diameter/diagonal above the top of the tower structure.

Surface roughness. The surface roughness over a given area reflects man-made and natural obstructions, and general surface features. These roughness elements effect the horizontal and vertical wind patterns. Differences in the surface roughness over the area of interest can create differences in the wind pattern that may necessitate additional measurement sites. A method of estimating surface roughness length, z_o, is presented in Section 6.4.2. If an area has a surface roughness length greater than 0.5 m, then there may be a need for special siting considerations (see discussion in Sections 3.3 and 3.5).

3.2.1.3 Siting considerations

A single well-located measurement site can be used to provide representative wind measurements for non-coastal, flat terrain, rural situations. Wind instruments should be placed taking into account the purpose of the measurements. The instruments should be located over level, open terrain at a height of 10 m above the ground, and at a distance of at least ten times the height of any nearby obstruction. For elevated releases, additional measurements should be made at stack top or 100 m, whichever is lower **[1]**. In cases with stack heights of 200 m or above, the appropriate measurement height should be determined by the Regional Office on a case-by-case basis.

3.2.2 Temperature, Temperature Difference, and Humidity

The siting and exposure criteria for temperature, temperature difference and humidity are similar. Consequently, these variables are discussed as a group in the following; exceptions are noted as necessary.

3.2.2.1 Probe placement

Ambient temperature and humidity should be measured at 2 m, consistent with the World Meteorological Organization (WMO) standards for ambient measurements **[9]**. Probe placement for temperature difference measurements depend on the application.. For use in estimating surface layer scaling parameters (Section 6.6.4), the temperature difference should be measured between $20z_0$ and $100z_0$; the same recommendation applies to temperature difference measurements for use in estimating the P-G stability category using the solar radiation delta-T method (Section 6.4.4.2). For use in estimating stable plume rise, temperature difference measurements should be made across the plume rise layer, a minimum separation of 50 m is recommended. For sites that experience large amounts of snow, adjustments to the temperature measurement height may be necessary, however, the ambient temperature measurement should not extend above 10 m. For analysis of cooling tower impacts, measurements of temperature and humidity should also be obtained at source height and within the range of final plume height. The measurement of temperature difference for analysis of critical dividing streamline height, H_{crit}, a parameter used in complex terrain modeling, is discussed in Section 3.3.3.

Temperature and humidity sensors should be located over an open, level area at least 9 m in diameter. The surface should be covered by short grass, or, where grass does not grow, the natural earth surface **[2, 9]**. Instruments should be protected from thermal radiation (from the earth, sun, sky, and any surrounding objects) and adequately ventilated using aspirated shields. Forced aspiration velocity should exceed 3 m/s, except for lithium chloride dew cells which operate best in still air **[2]**. If louvered shelters are used instead for protection (at ground level only), then they should be oriented with the door facing north (in the Northern Hemisphere). Temperature and humidity data obtained from naturally-ventilated shelters will be subject to large errors when wind speeds are light (less than about 3 m/s).

Temperature and humidity sensors on towers should be mounted on booms at a distance of about one diameter/diagonal of the tower (from the nearest point on the tower) **[2]**. In this case, downward facing aspiration shields are necessary.

3.2.2.2 Obstructions

Temperature and humidity sensors should be located at a distance of at least four times the height of any nearby obstruction and at least 30 m from large paved areas **[2]**, **[15]**. Other situations to avoid include: large industrial heat sources, rooftops, steep slopes, sheltered hollows, high vegetation, shaded areas, swamps, areas where frequent snow drifts occur, low places that hold standing water after rains, and the vicinity of air exhausts (e.g., from a tunnel or subway) **[2, 9]**.

3.2.2.3 Siting considerations

In siting temperature sensors, care must be taken to preserve the characteristics of the local environment, especially the surface. Protection from thermal radiation (with aspirated radiation shields) and significant heat sources and sinks is critical. Siting recommendations are similar for humidity measurements, which may be used for modeling input in situations involving moist releases, such as cooling towers. For temperature difference measurements, sensors should be housed in identical aspirated radiation shields with equal exposure.

3.2.3 Precipitation

3.2.3.1 Probe placement

A rain gauge should be sited on level ground so the mouth is horizontal and open to the sky **[2]**. The underlying surface should be covered with short grass or gravel. The height of the opening should be as low as possible (minimum: 30 cm), but should be high enough to avoid splashing in from the ground.

Rain gauges mounted on towers should be located above the average level of snow accumulation **[15]**. In addition, collectors should be heated if necessary to properly measure frozen precipitation **[4]**.

3.2.3.2 Obstructions

Nearby obstructions can create adverse effects on precipitation measurements (e.g., funneling, reflection, and turbulence) which should be avoided. On the other hand, precipitation measurements may be highly sensitive to wind speed, especially where snowfall contributes a significant fraction of the total annual precipitation. Thus, some sheltering is desirable. The need to balance these two opposite effects requires some subjective judgment.

The best exposure may be found in orchards, openings in a grove of trees, bushes, or shrubbery, or where fences or other objects act together to serve as an effective wind-break. As a general rule, in sheltered areas where the height of the objects and their distance to the instrument is uniform, their height (above the instrument) should not exceed twice the distance (from the instrument) **[15]**. In open areas, the distance to obstructions should be at least two, and preferably four, times the height of the obstruction. It is also desirable in open areas which experience significant snowfall to use wind shields such as those used by the National Weather Service **[2, 9, 15]**.

3.2.3.3 Siting considerations

In view of the sensitivity to wind speed, every effort should be made to minimize the wind speed at the mouth opening of a precipitation gauge. This can be done by using wind shields. Where snow is not expected to occur in significant amounts or with significant frequency, use of wind shields is less important. However, the catch of either frozen or liquid precipitation is influenced by turbulent flow at the collector, and this can be minimized by the use of a wind shield.

3.2.4 Pressure

Although atmospheric pressure may be used in some modeling applications, it is not a required input variable for steady-state modeling applications. Moreover, the standard atmospheric pressure for the station elevation may often be sufficient for those applications which require station pressure; the model user's guide should be checked for specific model requirements.

3.2.5 Radiation

3.2.5.1 Probe placement

Pyranometers used for measuring incoming (solar) radiation should be located with an unrestricted view of the sky in all directions during all seasons, with the lowest solar elevation angle possible. Sensor height is not critical for pyranometers. A tall platform or rooftop is a desirable location **[2]**. Net radiometers should be mounted about 1 m above the ground **[2]**.

3.2.5.2 Obstructions

Pyranometers should be located to avoid obstructions casting a shadow on the sensor at any time. Also, light colored walls and artificial sources of radiation should be avoided **[2]**. Net radiometers should also be located to avoid obstructions to the field of view both upward and downward **[2]**.

3.2.5.3 Siting considerations

Solar radiation measurements should be taken in open areas free of obstructions. The ground cover under a net radiometer should be representative of the general site area. The given application will govern the collection of solar or net radiation data.

3.3 Complex Terrain Locations

For the purposes of this guidance, the term "complex terrain" is intended to mean any site where terrain effects on meteorological measurements may be significant. Terrain effects include aerodynamic wakes, density-driven slope flows, channeling, flow accelerations over the crest of terrain features, etc.; these flows primarily affect wind speed and wind direction measurements, however, temperature and humidity measurements may also be affected. The definition of significance depends on the application; for regulatory dispersion modeling applications, significance is determined by comparing stack-top height and/or an estimated plume height to terrain height - terrain which is below stack-top is classified as simple terrain (see Section 3.2), terrain between stack-top height and plume height is classified as intermediate terrain, and terrain which is above plume height is classified as complex terrain **[1]**.

Vertical gradients and/or discontinuities in the vertical profiles of meteorological variables are often significant in complex terrain. Consequently, measurements of the meteorological variables affecting transport and dispersion of a plume (wind direction, wind speed, and σ_θ) should be made at multiple levels in order to ensure that data used for modeling are representative of conditions at plume level. The ideal arrangement in complex terrain involves siting a tall tower between the source and the terrain feature of concern. The tower should be tall enough to provide measurements at plume level. Other terrain in the area should not significantly affect plume transport in a different manner than that measured by the tower. Since there are not many situations where this ideal can be achieved, a siting decision in complex terrain will almost always be a compromise. Monitoring options in complex terrain range from a single tall tower to multiple tall towers supplemented by data from one or more remote sensing platforms. Other components of the siting decision include determining tower locations, deciding whether or not a tower should be sited on a nearby terrain feature, and determining levels (heights) for monitoring. Careful planning is essential in any siting decision. Since each complex terrain situation has unique features to consider, no specific recommendations can be given to cover all cases. However, the siting process should be essentially the same in all complex terrain situations. Recommended steps in the siting process are as follows:

- Define the variables that are needed for a particular application.
- Develop as much information as possible to define what terrain influences are likely to be important. This should include examination of topographic maps of the area with terrain above physical stack height outlined. Preliminary estimates of plume rise should be made to determine a range of expected plume heights. If any site specific meteorological data are available, they should be analyzed to see what can be learned about the specific

terrain effects on air flow patterns. An evaluation by a meteorologist based on a site visit would also be desirable.

- Examine alternative measurement locations and techniques for required variables. Advantages and disadvantages of each technique/location should be considered, utilizing as a starting point the discussions presented above and elsewhere in this document.
- Optimize network design by balancing advantages and disadvantages.

It is particularly important in complex terrain to consider the end use of each variable separately. Guidance and concerns specific to the measurement of wind speed, wind direction, and temperature difference in complex terrain are discussed in the following sections.

3.3.1 Wind Speed

For use in plume rise calculations, wind speed should be measured at stack top or 100 m, whichever is lower. Ideally, the wind speed sensor should be mounted on a tower located near stack base elevation; however, a tower located on nearby elevated terrain may be used in some circumstances. In this latter case, the higher the tower above terrain the better (i.e. less compression effect); a 10-meter tower generally will not be sufficient. The measurement location should be evaluated for representativeness of both the dilution process and plume rise.

Great care should be taken to ensure that the tower is not sheltered in a closed valley (this would tend to over-estimate the occurrence of stable conditions) or placed in a location that is subject to streamline compression effects (this would tend to underestimate the occurrence of stable conditions). It is not possible to completely avoid both of these concerns. If a single suitable location cannot be found, then alternative approaches, such as multiple towers or a single tall tower supplemented by one or more remote sensing platforms should be considered in consultation with the Regional Office.

3.3.2 Wind Direction

The most important consideration in siting a wind direction sensor in complex terrain is that the measured direction should not be biased in a particular direction that is not experienced by the pollutant plume. For example, instruments on a meteorological tower located at the bottom of a well-defined valley may measure directions that are influenced by channeling or density-driven up-slope or down-slope flows. If the pollutant plume will be affected by the same flows, then the tower site is adequate. Even if the tower is as high as the source's stack, however, appreciable plume rise may take the plume out of the valley influence and the tower's measured wind direction may not be appropriate for the source (i.e., biased away from the source's area of critical impact).

The determination of potential bias in a proposed wind direction measurement is not an easy judgement to make. Quite often the situation is complicated by multiple flow regimes, and the existence of bias is not evident. This potential must be considered, however, and a rationale developed for the choice of measurement location. Research has indicated that a single wind measurement location/site may not be adequate to define plume transport direction in some situations. While the guidance in this document is concerned primarily with means to obtain a single hourly averaged value of each variable, it may be appropriate to utilize more than one measurement of wind direction to calculate an "effective" plume transport direction for each hour.

3.3.3 Temperature Difference

The requirements of a particular application should be used as a guide in determining how to make measurements of vertical temperature difference in complex terrain. Stable plume rise and the critical dividing streamline height (H_{crit}), which separates flow that tends to move around a hill (below H_{crit}) from flow that tends to pass over a hill (above H_{crit}), are both sensitive to the vertical temperature gradient. The height ranges of interest are from stack top to plume height for the former and from plume height to the top of the terrain feature for the latter. The direct measurement of the complete temperature profile is often desirable but not always practical. The following discussion presents several alternatives for measuring the vertical temperature gradient along with some pros and cons.

Tower measurement: A tower measurement of temperature difference can be used as a representation of the temperature profile. The measurement should be taken between two elevated levels on the tower (e.g. 50 and 100 meters) and should meet the specifications for temperature difference discussed in Section 5.0. A separation of 50 m between the two sensors is preferred. The tower itself could be located at stack base elevation or on elevated terrain: optimum location depends on the height of the plume. Both locations may be subject to radiation effects that may not be experienced by the plume if it is significantly higher than the tower.

The vertical extent of the temperature probe may be partially in and partially out of the surface boundary layer, or may in some situations be entirely contained in the surface boundary layer while the plume may be above the surface boundary layer.

Balloon-based temperature measurements: Temperature profiles taken by balloon-based systems can provide the necessary information but are often not practical for developing a long-term data base. One possible use of balloon-based temperature soundings is in developing better "default" values of the potential temperature gradient on a site-specific basis. A possible approach would be to schedule several periods of intensive soundings during the course of a year and then derive appropriate default values keyed to stability category and wind speed and/or other appropriate variables. The number and scheduling of these intensive periods should be established as part of a sampling protocol.

Deep-layer absolute temperature measurements: If the vertical scale of the situation being modeled is large enough (200 meters or more), it may be acceptable to take the difference between two independent measurements of absolute temperature (i.e., temperature measurements would be taken on two different towers, one at plant site and one on terrain) to serve as a surrogate measurement of the temperature profile. This approach must be justified on a case-by-case basis, and should be taken only with caution. Its application should be subject to the following limitations:

- Depth of the layer should be 200 meters at a minimum;
- The measurement height on each tower should be at least 60 meters;
- Horizontal separation of the towers should not exceed 2 kilometers;
- No internal boundary layers should be present, such as near shorelines; and
- Temperature profiles developed with the two-tower system should be verified with a program of balloon-based temperature profile measurements.

3.4 Coastal Locations

The unique meteorological conditions associated with local scale land-sea breeze circulations necessitate special considerations. For example, a stably stratified air mass over water can become unstable over land due to changes in roughness and heating encountered during daytime conditions and onshore flow. An unstable thermal internal boundary layer (TIBL) can develop, which can cause rapid downward fumigation of a plume initially released into the stable onshore flow. To provide representative measurements for the entire area of interest, multiple sites would be needed: one site at a shoreline location (to provide 10 m and stack height/plume height wind speed), and additional inland sites perpendicular to the orientation of the shoreline to provide wind speed within the TIBL, and estimates of the TIBL height. Where terrain in the vicinity of the shoreline is complex, measurements at additional locations, such as bluff tops, may also be necessary. Further specific measurement requirements will be dictated by the data input needs of a particular model. A report prepared for the Nuclear Regulatory Commission **[16]** provides a detailed discussion of considerations for conducting meteorological measurement programs at coastal sites.

3.5 Urban Locations

Urban areas are characterized by increased heat flux and surface roughness. These effects, which vary horizontally and vertically within the urban area, alter the wind pattern relative to the outlying rural areas (e.g., average wind speeds are decreased). The close proximity of buildings in downtown urban areas often precludes strict compliance with the previous sensor exposure guidance. For example, it may be necessary to locate instruments on the roof of the tallest available building. In such cases, the measurement height should take into account the proximity of nearby tall buildings and the difference in height between the building (on which the instruments are located) and the other nearby tall buildings.

In general, multiple sites are needed to provide representative measurements in a large urban area. This is especially true for ground-level sources, where low-level, local influences, such as street canyon effects, are important, and for multiple elevated sources scattered over an urban area. However, due to the limitations of the recommended steady-state guideline models (i.e. they recognize only a single value for each input variable on an hourly basis), and resource and practical constraints, the use of a single site is necessary. At the very least, the single site should be located as close as possible to the source in question.

3.6 Recommendations

Recommendations for siting and exposure of in situ meteorological sensors in simple terrain are as follows:

> *Sensors for wind speed and wind direction should be located over level, open terrain at a height of 10 m above ground level and at a distance at least ten times the height of nearby obstructions. For elevated releases, additional measurements should be made at stack top or 100 m, whichever is lower. Monitoring requirements for stacks 200 m and above should be determined in consultation with the appropriate EPA Regional Office.*
>
> *Temperature sensors should be located at 2 m. Probe placement for temperature difference measurements depend on the application. For use in estimating surface layer stability, the measurement should be made between* $20z_0$ *and* $100z_0$*; the same recommendation applies to temperature difference measurements for use in estimating the P-G stability category using the solar radiation delta-T method. For use in estimating stable plume rise, temperature difference measurements should be made across the plume rise layer, a minimum separation of 50 m is recommended for this application. Temperature sensors should be shielded to protect them from thermal radiation and any significant heat sources or sinks.*
>
> *Pyranometers used for measuring incoming (solar) radiation should be located with an unrestricted view of the sky in all directions during all seasons. Sensor height is not critical for pyranometers; a tall platform or rooftop is an acceptable location. Net radiometers should be mounted about 1 m above ground level.*

Specific recommendations applicable to siting and exposure of meteorological instruments in complex terrain are not possible. Generally, one should begin the process by conducting a screening analysis to determine, among other things, what terrain features are likely to be important; the screening analysis should also identify potential worse case meteorological conditions. This information should then be used to design a monitoring plan for the specific application.

Special siting considerations also apply to coastal and urban sites. Multiple sites, though often desirable, may not always be possible in these situations. In general, site selection for meteorological monitoring in support of regulatory modeling applications in coastal and urban locations should be conducted in consultation with the appropriate EPA Regional Office.

If the recommendations in this section cannot be achieved, then alternate approaches should be developed in consultation with the appropriate EPA Regional Office. Approval of site *selection for meteorological monitoring should be obtained from the permit granting authority prior to installation of any equipment.*

4. METEOROLOGICAL DATA RECORDING

The various meteorological data recording systems available range in complexity from very simple analog or mechanical pulse counter systems to very complex multichannel, automated, microprocessor-based digital data acquisition systems. The function of these systems is to process the electrical output signals from various sensors/transducers and convert them into a form that is usable for display and subsequent analysis. The sensor outputs may come in the form of electrical DC voltages, currents of varying amperage, and/or frequency-varying AC voltages.

4.1 Signal Conditioning

The simpler analog systems utilize the electrical output from a transducer to directly drive the varying pen position on a strip chart. For some variables, such as wind run (total passage of wind) and precipitation, the transducer may produce a binary voltage (either "on" or "off") which is translated into an event mark on the strip chart. Many analog systems and virtually all digital systems require a signal conditioner to translate the transducer output into a form that is suitable for the remainder of the data acquisition system. This translation may include amplifying the signal, buffering the signal (which in effect isolates the transducer from the data acquisition system), or converting a current (amperage) signal into a voltage signal.

4.2 Recording Mechanisms

Both analog and digital systems have a variety of data recording mechanisms or devices available. Analog data may be recorded as continuous traces on a strip chart or as event marks on a chart, as previously described, or as discrete samples on a multi point recorder. The multi point recorder will generally sample each of several variables once every several seconds. The traces for the different variables are differentiated by different colors of ink or by channel numbers printed on the chart next to the trace, or by both. The data collected by digital data acquisition systems may be recorded in hard copy form by a printer or terminal either automatically or upon request, and are generally also recorded on some machine-readable medium such as a magnetic disk storage or tape storage device or a solid-state (nonmagnetic) memory cartridge. Digital systems have several advantages over analog systems in terms of the speed and accuracy of handling the data, and are therefore preferred as the primary recording system. Analog systems may still be useful as a backup to minimize the potential for data loss. For wind speed and wind direction, the analog strip chart records can also provide valuable information to the person responsible for evaluating the data..

4.3 Analog-to-Digital Conversion

A key component of any digital data acquisition system is the analog-to-digital (A/D) converter. The A/D converter translates the analog electrical signal into a binary form that is suitable for subsequent processing by digital equipment. In most digital data acquisition systems a single A/D converter is used for several data channels through the use of a multiplexer. The rate at which the multiplexer channel switches are opened and closed determines the sampling rates for the channels - all channels need not be sampled at the same the frequency.

4.4 Data Communication

Depending on the type of system, there may be several data communication links. Typically the output signals from the transducers are transmitted to the on-site recording devices directly via hardwire cables. For some applications involving remote locations the data transmission may be accomplished via a microwave telemetering system or perhaps via telephone lines with a dial-up or dedicated line modem system.

4.5 Sampling Rates

The recommended sampling rate for a digital data acquisition system depends on the end use of the data. Substantial evidence and experience suggest that 360 data values evenly spaced during the sampling interval will provide estimates of the standard deviation to within 5 or 10% **[3]**. Estimates of the mean should be based on at least 60 samples to obtain a similar level of accuracy. Sometimes fewer samples will perform as well, but no general guide can be given for identifying these cases before sampling; in some cases, more frequent sampling may be required. If single-pass processing (as described in Section 6.2.1) is used to compute the mean scalar wind direction, then the output from the wind direction sensor (wind vane) should be sampled at least once per second to insure that consecutive values do not differ by more than 180 degrees.

The sampling rate for multi point analog recorders should be at least once per minute. Chart speeds should be selected to permit adequate resolution of the data to achieve the system accuracies recommended in Section 5.1. The recommended sampling rates are minimum values; the accuracy of the data will generally be improved by increasing the sampling rate.

4.6 Recommendations

A microprocessor-based digital data acquisition system should be used as the primary data recording system; analog data recording systems may be used as a backup. Wind speed and wind direction analog recording systems should employ continuous-trace strip-charts; other variables may be recorded on multi point charts. The analog charts used for backup should provide adequate resolution to achieve the system accuracies recommended in Section 5.1.

Estimates of means should be based on at least 60 samples (one sample per minute for an hourly mean). Estimates of the variance should be based on at least 360 samples (six samples per minute for an hourly variance). If single-pass processing is used to calculate the mean scalar wind direction then the output from the wind vane should be sampled at least once per second.

5. SYSTEM PERFORMANCE

5.1 System Accuracies

Accuracy is the amount by which a measured variable deviates from a value accepted as true or standard. Accuracy can be thought of in terms of individual component accuracy or overall system accuracy. For example, the overall accuracy of a wind speed measurement system includes the individual component accuracies of the cup or propeller anemometer, signal conditioner, analog-to-digital converter, and data recorder.

The accuracy of a measurement system can be estimated if the accuracies of the individual components are known. The system accuracy would be the square root of the sum of the squares of the random component accuracies **[17]**. The accuracies recommended for meteorological monitoring systems are listed in Table 5-1. These are stated in terms of overall system accuracies, since it is the data from the measurement system which are used in air quality modeling analyses. Recommended measurement resolutions, i.e., the smallest increments that can be distinguished, are also provided in Table 5-1. These resolutions are considered necessary to maintain the recommended accuracies, and are also required in the case of wind speed and wind direction for computations of standard deviations.

Table 5-1

Recommended System Accuracies and Resolutions

Meteorological Variable	System Accuracy	Measurement Resolution
Wind Speed (horizontal and vertical)	± (0.2 m/s + 5% of observed)	0.1 m/s
Wind Direction (azimuth and elevation)	± 5 degrees	1.0 degree
Ambient Temperature	± 0.5 °C	0.1 °C
Vertical Temperature Difference	± 0.1 °C	0.02 °C
Dew Point Temperature	± 1.5 °C	0.1 °C
Precipitation	± 10% of observed or ± 0.5 mm	0.3 mm
Pressure	± 3 mb (0.3 kPa)	0.5 mb
Solar Radiation	± 5% of observed	10 W/m^2

The recommendations provided in Table 5-1 are applicable to microprocessor-based digital systems (the primary measurement system). For analog systems, used as backup, these recommendations may be relaxed by 50 percent. The averaging times associated with the recommended accuracies correspond to the averaging times associated with the end use of the data (nominally, 1-hour averaging for regulatory modeling applications) and with the audit methods recommended to evaluate system accuracies.

5.2 Response Characteristics of Meteorological Sensors

The response characteristics of the sensors used in meteorological monitoring must be known to ensure that data are appropriate for the intended application. For example, an anemometer designed to endure the rigors experienced on an ocean buoy would not be suitable for monitoring fine scale turbulence in a wind tunnel; the latter application requires a more sensitive instrument with a faster response time (e.g., a sonic anemometer). On the other hand, a sonic anemometer is probably unnecessary if the data are to be used only to calculate hourly averages for use in a dispersion model. Recommended response characteristics for meteorological sensors used in support of air quality dispersion modeling are given in Table 5-2. Definitions of terms commonly associated with instrument response characteristics (including the terms used in Table 5-2) are provided in the following.

Calm. Any average wind speed below the starting threshold of the wind speed or direction sensor, whichever is greater **[4]**.

Damping ratio. The motion of a vane is a damped oscillation and the ratio in which the amplitude of successive swings decreases is independent of wind speed. The damping ratio, h, is the ratio of actual damping to critical damping. If a vane is critically damped, h=l and there is no overshoot in response to sudden changes in wind direction **[18] [19] [20]**.

Delay distance. The length of a column of air that passes a wind vane such that the vane will respond to 50% of a sudden angular change in wind direction **[19]** The delay distance is commonly specified as "50% recovery" using "10° displacement" **[2, 3]**.

Distance constant. The distance constant of a sensor is the length of fluid flow past the sensor required to cause it to respond to 63.2%, i.e., l - l/e, of the increasing step-function change in speed **[19,20]**. Distance constant is a characteristic of cup and propeller (rotational) anemometers.

Range. This is a general term which usually identifies the limits of operation of a sensor, most often within which the accuracy is specified.

Threshold (starting speed). The wind speed at which an anemometer or vane first starts to perform within its specifications20.

Time constant. The time constant is the period that is required for a (temperature) sensor to respond to 63.2%, i.e., l - l/e, of the step-wise change (in temperature). The term is applicable to any "first-order" sensors, those that respond asymptotically to a step change in the variable being measured, e.g., temperature, pressure, etc.

Table 5-2

Recommended Response Characteristics for Meteorological Sensors

Meteorological Variable	Sensor Specification(s)	
Wind Speed		
Horizontal	Starting Speed:	≤ 0.5 m/s
	Distance Constant:	≤ 5 m
Vertical	Starting Speed:	≤ 0.25 m/s
	Distance Constant:	≤ 5 m
Wind Direction	Starting Speed:	≤ 0.5 m/s @ 10 deg.
	Damping Ratio:	0.4 to 0.7
	Delay Distance:	≤ 5 m
Temperature	Time Constant:	≤ 1 minute
Temperature Difference	Time Constant:	≤ 1 minute
Dew Point Temperature	Time Constant:	≤ 30 minutes
	Range:	-30°C to +30°C
Solar Radiation	Time Constant:	5 sec.
	Operating Range:	-20°C to +40°C
	Spectral Response:	285 nm to 2800 nm

Several publications are available that either contain tabulations of reported sensor response characteristics **[18]**, **[21]** or specify, suggest or recommend values for certain applications **[2, 3, 9]**. Moreover, many manufacturers are now providing this information for the instruments they produce **[21]**. An EPA workshop report on meteorological instrumentation **[3]** expands on these recommendations for certain variables.

Manufacturers of meteorological instruments should provide evidence that the response characteristics of their sensors have been determined according to accepted scientific/technical methods, e.g., ASTM standards **[22]**. Verifying a manufacturer's claims that a meteorological sensor possesses the recommended response characteristics (Table 5-2) is another matter; such verification can accurately be accomplished only in a laboratory setting. In leu of a laboratory test, one must rely on quality assurance performance audit procedures (Section 8.4) - the latter will normally provide assurance of satisfactory performance.

5.3 Data Recovery

5.3.1 Length of Record

The duration of a meteorological monitoring program should be set to ensure that worst-case meteorological conditions are adequately represented in the data base; the minimum duration for most dispersion modeling applications is one year. Recommendations on the length of record for regulatory dispersion modeling as published in The Guideline on Air Quality Models **[1]** are: five years of National Weather Service (NWS) meteorological data or at least one year of site-specific data. Consecutive years from the most recent, readily available 5-year period are preferred.

5.3.2 Completeness Requirement

Regulatory analyses for the short-term ambient air quality standards (1 to 24-hour averaging) involve the sequential application of a dispersion model to every hour in the analysis period (one to five years); such analyses require a meteorological record for every hour in the analysis period. Substitution for missing or invalid data is used to meet this requirement. Applicants in regulatory modeling analyses are allowed to substitute for up to 10 percent of the data; conversely, the meteorological data base must be 90 percent complete (before substitution) in order to be acceptable for use in regulatory dispersion modeling. The following guidance should be followed for purposes of assessing compliance with the 90 percent completeness requirement:

- Lost data due to calibrations or other quality assurance procedures is considered missing data.
- A variable is not considered missing if data for a backup, collocated sensor is available.
- A variable is not considered missing if backup data from an analog system; which meets the applicable response, accuracy and resolution criteria; are available.

- Site specific measurements for use in stability classification are considered equivalent such that the 90 percent requirement applies to stability and not to the measurements (e.g., σ_E and σ_A) used for estimating stability.
- The 90 percent requirement applies on a quarterly basis such that 4 consecutive quarters with 90 percent recovery are required for an acceptable one-year data base.
- The 90 percent requirement applies to each of the variables wind direction, wind speed, stability, and temperature and to the joint recovery of wind direction, wind speed, and stability.

Obtaining the 90 percent goal will necessarily require a commitment to routine preventive maintenance and strict adherence to approved quality assurance procedures (Sections 8.5 and 8.6). Some redundancy in sensors, recorders and data logging systems may also be necessary. With these prerequisites, the 90 percent requirement should be obtainable with available high quality instrumentation. Applicants failing to achieve such are required to continue monitoring until 4 consecutive quarters of acceptable data with 90 percent recovery have been obtained. Substitutions for missing data are allowed, but may not exceed 10 percent of the hours (876 hours per year) in the data base. Substitution procedures are discussed in Section 6.8.

5.4 Recommendations

Recommended system accuracies and resolutions for meteorological data acquisition systems are given in Table 5-l. These requirements apply to the primary measurement system and assume use of a microprocessor digital recording system. If an analog system is used for backup, the values for system accuracy may be relaxed by 50 percent. Recommended response characteristics for meteorological sensors are given in Table 5-2. Manufacturer's documentation verifying an instrument's response characteristics should be reviewed to ensure that verification tests are conducted in a laboratory setting according to accepted scientific/technical methods. Data bases for use in regulatory dispersion modeling applications should be 90 percent complete (before substitution). The 90 percent requirement applies to each meteorological variable separately and to the joint recovery of wind direction, wind speed, and stability. Compliance with the 90 percent requirement should be assessed on a quarterly basis.

6. METEOROLOGICAL DATA PROCESSING

This section provides guidance for processing of meteorological data for use in air quality modeling as follows: Section 6.1 (Averaging and Sampling Strategies), Section 6.2 (Wind Direction, and Wind Speed), Section 6.3 (Temperature), Section 6.4 (Stability), Section 6.5 (Mixing Height), Section 6.6 (Boundary Layer Parameters), Section 6.7 (Use of Airport Data), and Section 6.8 (Treatment of Missing Data). Recommendations are summarized in Section 6.9.

6.1 Averaging and Sampling Strategies

Hourly averaging may be assumed unless stated otherwise; this is in keeping with the averaging time used in most regulatory air quality models. The hourly averaging is associated with the end product of data processing (i.e., the values that are passed on for use in modeling). These hourly averages may be obtained by averaging samples over an entire hour or by averaging a group of shorter period averages. If the hourly average is to be based on shorter period averages, then it is recommended that 15-minute intervals be used. At least two valid 15-minute periods are required to represent the hourly period. The use of shorter period averages in calculating an hourly value has advantages in that it minimizes the effects of meander under light wind conditions in the calculation of the standaard deviation of the wind direction, and it provides more complete information to the meteorologist reviewing the data for periods of transition. It also may allow the recovery of data that might otherwise be lost if only part of the hour is missing.

Sampling strategies vary depending on the variable being measured, the sensor employed, and the accuracy required in the end use of the data. The recommended sampling averaging times for wind speed and wind direction measurements is 1-5 seconds; for temperature and temperature difference measurements, the recommended sample averaging time is 30 seconds **[3]**.

6.2 Wind Direction and Wind Speed

This section provides guidance for processing of in situ measurements of wind direction and wind speed using conventional in situ sensors; i.e., cup and propeller anemometers and wind vanes. Guidance for processing of upper-air wind measurements obtained with remote sensing platforms is provided in Section 9. Recommendations are provided in the following for processing of winds using both scalar computations (Section 6.2.1) and vector computations (Section 6.2.2). Unless indicated otherwise, the methods recommended in Sections 6.2.1 and 6.2.2 employ single-pass processing; these methods facilitate real-time processing of the data as it is collected. Guidance on the treatment of calms is provided in Section 6.2.3. Processing of data to obtain estimates of turbulence parameters is addressed in Section 6.2.4. Guidance on the use of a power-law for extrapolating wind speed with height is provided in Section 6.2.5. The notation for this section is defined in Table 6-2.

Table 6-1

Notation Used in Section 6.2

Observed raw data

u_i	signed magnitude of the horizontal component of the wind vector (i.e., the wind speed)
θ_i	azimuth angle of the wind vector, measured clockwise from north (i.e., the wind direction)
w_i	signed magnitude of the vertical component of the wind vector
ϕ_i	elevation angle of the wind vector (bivane measurement)
N	the number of valid observations

Scalar wind computations

$\overline{u}$, $\overline{U}$	scalar mean wind speed
$\overline{u_h}$	harmonic mean wind speed
$\overline{\theta}$	mean azimuth angle of the wind vector (i.e. the mean wind direction)
$\overline{w}$	mean value of the vertical component of the wind speed
$\overline{\phi}$	mean elevation angle of the wind vector
σ_u	standard deviation of the horizontal component of the wind speed
σ_A, σ_θ	standard deviation of the azimuth angle of the wind
σ_w	standard deviation of the vertical component of the wind speed
σ_E, σ_ϕ	standard deviation of the elevation angle of the wind

Vector wind computations

$\overline{U}_{RV}$	resultant mean wind speed
$\overline{\theta}_{RV}$	resultant mean wind direction
$\overline{\theta}_{UV}$	unit vector mean wind direction
V_e	magnitude of the east-west component of the resultant vector mean wind (positive towards east)
V_n	magnitude of the north-south component of the resultant vector mean wind (positive towards the north)
V_x	magnitude of the east-west component of the unit vector mean wind
V_y	magnitude of the north-south component of the unit vector mean wind
x,y,z	standard right-hand-rule coordinate system with x-axis aligned towards the east.

6.2.1 Scalar Computations

The scalar mean wind speed is:

$$\bar{u} = \frac{1}{N} \sum_{1}^{N} u_i \qquad (6.2.1)$$

The harmonic mean wind speed is:

$$\overline{u_h} = \left(\frac{1}{N} \sum_{1}^{N} \frac{1}{u_i} \right)^{-1} \qquad (6.2.2)$$

The standard deviation of the horizontal component of the wind speed is:

$$\sigma_u = \left[\frac{1}{N} \left\{ \sum_{1}^{N} u_i^2 - \frac{1}{N} \left(\sum_{1}^{N} u_i \right)^2 \right\} \right]^{1/2} \qquad (6.2.3)$$

The wind direction is a circular function with values between l and 360 degrees. The wind direction discontinuity at the beginning/end of the scale requires special processing to compute a valid mean value. A single-pass procedure developed by Mitsuta and documented in reference **[23]** is recommended. The method assumes that the difference between successive wind direction samples is less than 180 degrees; to ensure such, a sampling rate of once per second or greater should be used (see Section 6.2.4). Using the Mitsuta method, the scalar mean wind direction is computed as:

$$\bar{\theta} = \frac{1}{N} \sum_{1}^{N} D_i \qquad (6.2.4)$$

where $D_i = \theta_i$; for I = 1

$D_i = D_{i-1} + \delta_i + 360$; for $\delta_i < -180$ and I > 1

$D_i = D_{i-1} + \delta_i$; for $|\delta_i| < 180$ and I > 1

$D_i = D_{i-1} + \delta_i - 360$; for $\delta_i > 180$ and I > 1

D_i is undefined for $\delta_i = 180$ and I > 1

$\delta_i = \theta_i - D_{i-1}$; for I > 1

θ_i is the azimuth angle of the wind vane for the i^{th} sample.

The following notes/cautions apply to the determination of the scalar mean wind direction using Equation. 6.2.4:

- If the result is less than zero or greater than 360, increments of 360 degrees should be added or subtracted, as appropriate, until the result is between zero and 360 degrees.
- Erroneous results may be obtained if this procedure is used to post-process sub-hourly averages to obtain an hourly average. This is because there can be no guarantee that the difference between successive sub-hourly averages will be less than 180 degrees.

The scalar mean wind direction, as defined in Equation. 6.2.4, retains the essential statistical property of a mean value, namely that the deviations from the mean must sum to zero:

$$\sum (\theta_i - \bar{\theta}) = 0 \qquad \textbf{(6.2.5)}$$

By definition, the same mean value must be used in the calculation of the variance of the wind direction and, likewise, the standard deviation (the square root of the variance). The variance of the wind direction is given by:

$$\sigma_\theta^2 = \frac{1}{N} \sum (\theta_i - \bar{\theta})^2 \qquad \textbf{(6.2.6)}$$

The standard deviation of the wind direction using the Mitsuta method is given by:

$$\sigma_A = \sigma_\theta = \left[\frac{1}{N} \left\{ \sum_1^N D_i^2 - \frac{1}{N} \left(\sum_1^N D_i \right)^2 \right\} \right]^{1/2} \qquad \textbf{(6.2.7)}$$

Cases may arise in which the sampling rate is insufficient to assure that differences between successive wind direction samples are less than 180 degrees. In such cases, approximation formulas may be used for computing the standard deviation of the wind direction. Mardia **[24]** shows that a suitable estimate of the standard deviation (in radian measure) is:

$$\sigma_A = \sigma_\theta = \left[-2 \ln(R) \right]^{1/2} \qquad \textbf{(6.2.8)}$$

where

$$R = (Sa^2 + Ca^2)^{1/2}$$

$$Sa = \frac{1}{N} \sum_1^N \sin(\theta_i)$$

$$Ca = \frac{1}{N} \sum_1^N \cos(\theta_i)$$

Several methods for calculating the standard deviation of the wind direction were evaluated by Turner **[25]**; a method developed by Yamartino **[26]** was found to provide excellent results for most cases. The Yamartino method is given in the following:

$$\sigma_A = \sigma_\theta = \arcsin(\epsilon)\ [1. + 0.1547\ \epsilon^3] \qquad (6.2.9)$$

where

$$\epsilon = \left[1. - \left(\overline{\sin(\theta_i)}^{\,2} + \overline{\cos(\theta_i)}^{\,2} \right)\right]^{1/2}$$

Note that hourly σ_θ values computed using 6.2.7, 6.2.8, or 6.2.9 may be inflated by contributions from long period oscillations associated with light wind speed conditions (e.g., wind meander). To minimize the effects of wind meander, the hourly σ_θ (for use e.g., in stability determinations - see Section 6.4.4.4) should be calculated based on four 15-minute values averaged as follows:

$$\sigma_\theta(1\text{-}hr) = \left[\left\{ (\sigma_{\theta_1})^2 + (\sigma_{\theta_2})^2 + (\sigma_{\theta_3})^2 + (\sigma_{\theta_4})^2 \right\} /4 \right]^{1/2} \qquad (6.2.10)$$

The standard deviation of the vertical component of the wind speed is:

$$\sigma_w = \left[\frac{1}{N} \left\{ \sum_1^N w_i^2 - \frac{1}{N} \left(\sum_1^N w_i \right)^2 \right\} \right]^{1/2} \qquad (6.2.11)$$

Similarly, the standard deviation of the elevation angle of the wind vector is:

$$\sigma_E = \sigma_\phi = \left[\frac{1}{N} \left\{ \sum_1^N \phi_i^2 - \frac{1}{N} \left(\sum_1^N \phi_i \right)^2 \right\} \right]^{1/2} \qquad (6.2.12)$$

Equation 6.2.12 is provided for completeness only. The bivane, which is used to measure the elevation angle of the wind, is regarded as a research grade instrument and is not recommended for routine monitoring applications. See Section 6.2.3 for recommendations on estimating σ_ϕ.

6.2.2 Vector Computations

From the sequence of N observations of θ_i and u_i, the mean east-west, V_e, and north-south, V_n, components of the wind are:

$$V_e = -\frac{1}{N} \sum u_i \sin(\theta_i) \qquad (6.2.13)$$

$$V_n = -\frac{1}{N} \sum u_i \cos(\theta_i) \qquad (6.2.14)$$

The resultant mean wind speed and direction are:

$$\overline{U}_{RV} = (V_e^2 + V_n^2)^{1/2} \qquad (6.2.15)$$

$$\overline{\theta}_{RV} = ArcTan\ (V_e/V_n) + FLOW \qquad (6.2.16)$$

where

$$FLOW \begin{array}{l} = +180; \quad for\ ArcTan(V_e/V_n) < 180 \\ = -180; \quad for\ ArcTan(V_e/V_n) > 180 \end{array}$$

Equation 6.2.16 assumes the angle returned by the ArcTan function is in degrees. This is not always the case and depends on the computer processor. Also, the ArcTan function can be performed several ways. For instance, in FORTRAN either of the following forms could be used:

ATAN(V_e/V_n)

or *ATAN2*(V_e, V_n).

The ATAN2 form avoids the extra checks needed to insure that V_n is nonzero, and is defined over a full 360 degree range.

The unit vector approach to computing mean wind direction is similar to the vector mean described above except that the east-west and north-south components are not weighted by the wind speed. Using the unit vector approach, equations 6.2.13 and 6.2.14 become:

$$V_x = -\frac{1}{N} \sum Sin\ \theta_i \qquad (6.2.17)$$

$$V_y = -\frac{1}{N} \sum Cos\theta_i \qquad (6.2.18)$$

The unit vector mean wind direction is:

$$\overline{\theta}_{UV} = ArcTan\ (V_x/V_y) + FLOW \qquad \textbf{(6.2.19)}$$

where

$$FLOW \begin{array}{l} = +180; \quad for\ ArcTan(V_x/V_y) < 180 \\ = -180; \quad for\ ArcTan(V_x/V_y) > 180 \end{array}$$

In general, the unit vector result will be comparable to the scalar average wind direction, and may be used to model plume transport.

6.2.3 Treatment of Calms

Calms, periods with little or no air movement, require special consideration in air quality evaluations; one of the more important considerations involves model selection. If the limiting air quality conditions are associated with calms, then a non-steady-state model, such as CALPUFF **[27]**, should be used. The use of a time varying 3-dimensional flow field in this model enables one to simulate conditions which are not applicable to steady-state models; e.g., recirculations and variable trajectories. Guidance for preparing meteorological data for use in CALPUFF is provided in the user's guide to the meteorological processor for this model **[28]**.

Steady-state models may be used for regulatory modeling applications if calms are not expected to be limiting for air quality. Calms require special treatment in such applications to avoid division by zero in the steady-state dispersion algorithm. EPA recommended steady-state models such as ISCST accomplish this with routines that nullify concentrations estimates for calm conditions and adjust short-term and annual average concentrations as appropriate. The EPA CALMPRO **[29]** program post-processes model output to achieve the same effect for certain models lacking this built-in feature. For similar reasons, to avoid unrealistically high concentration estimates at low wind speeds (below the values used in validations of these models - about 1 m/s) EPA recommends that wind speeds less than 1 m/s be reset to 1 m/s for use in steady-state dispersion models; the unaltered data should be retained for use in non-steady-state modeling applications. Calms should be identified in processed data files by flagging the appropriate records; user's guides for the model being used should be consulted for model specific flagging conventions.

For the purposes of this guidance and for the objective determination of calm conditions applicable to in situ monitoring, a calm occurs when the wind speed is below the starting threshold of the anemometer or vane, whichever is greater. For site-specific monitoring (using the recommended thresholds for wind direction and wind speed given in Table 5-2) a calm occurs when the wind speed is below 0.5 m/s. One should be aware that the frequency of calms are typically higher for NWS data bases because the sensors used to measure wind speed and wind direction have a higher threshold - typically 2 kts (1 m/s) - see Section 6.7.

6.2.4 Turbulence

6.2.4.1 Estimating σ_E from σ_w

Applications requiring the standard deviation of the elevation angle of the wind (e.g., see Section 6.4.4) should use the following approximation:

$$\sigma_E = \sigma_w / \overline{u} \qquad (6.2.20)$$

where σ_E is the standard deviation of the elevation angle of the wind (radians)

σ_w is the standard deviation of the vertical component of the wind speed (m/s)

$\overline{u}$ is the scalar mean wind speed (m/s).

Weber et. al. **[30]** reported good performance for an evaluation using data measured at the Savannah River Laboratory for wind speeds greater than 2 m/s. In a similar study, Deihl **[31]** reported satisfactory performance for wind speeds greater than 2 m/s. In the Deihl study, the performance varied depending on the overall turbulence intensity. It is concluded from these studies that σ_E is best approximated by $\sigma_w/\overline{u}$ when wind speeds are greater than 2 m/s, and σ_E is greater than 3 degrees.

6.2.5 Wind Speed Profiles

Dispersion models recommended for regulatory applications employ algorithms for extrapolating the input wind speed to the stack-top height of the source being modeled; the wind speed at stack-top is used for calculating transport and dilution. This section provides guidance for implementing these extrapolations using default parameters and recommends procedures for developing site specific parameters for use in place of the defaults.

For convenience, in non-complex terrain up to a height of about 200 m above ground level, it is assumed that the wind profile is reasonably well approximated as a power-law of the form:

$$U_z = U_r (Z/Z_r)^p \qquad (6.2.21)$$

where U_z = the scalar mean wind speed at height z above ground level

U_r = the scalar mean wind speed at some reference height Z_r, typically 10 m

p = the power-law exponent.

The power-law exponent for wind speed typically varies from about 0.1 on a sunny afternoon to about 0.6 during a cloudless night. The larger the power-law exponent the larger the vertical gradient in the wind speed. Although the power-law is a useful engineering approximation of the average wind speed profile, actual profiles will deviate from this relationship.

Site-specific values of the power-law exponent may be determined for sites with two levels of wind data by solving Equation (6.2.20) for p:

$$p = \frac{\ln(U) - \ln(U_r)}{\ln(Z) - \ln(Z_r)} \qquad \textbf{(6.2.21)}$$

As discussed by Irwin **[32]**, wind profile power-law exponents are a function of stability, surface roughness and the height range over which they are determined. Hence, power-law exponents determined using two or more levels of wind measurements should be stratified by stability and surface roughness. Surface roughness may vary as a function of wind azimuth and season of the year (see Section 6.4.2). If such variations occur, this would require azimuth and season dependent determination of the wind profile power-law exponents. The power-law exponents are most applicable within the height range and season of the year used in their determination. Use of these wind profile power-law exponents for estimating the wind at levels above this height range or to other seasons should only be done with caution. The default values used in regulatory models are given in Table 6-2.

Table 6-2

Recommended Power-law Exponents for Urban and Rural Wind Profiles

Stability Class	Urban Exponent	Rural Exponent
A	0.15	0.07
B	0.15	0.07
C	0.20	0.10
D	0.25	0.15
E	0.30	0.35
F	0.30	0.55

The following discussion presents a method for determining at what levels to specify the wind speed on a multi-level tower to best represent the wind speed profile in the vertical. The problem can be stated as, what is the percentage error resulting from using a linear interpolation over a height interval (between measurement levels), given a specified value for the power-law exponent. Although the focus is on wind speed, the results are equally applicable to profiles of other meteorological variables that can be approximated by power laws.

Let U_l represent the wind speed found by linear interpolation and U the "correct" wind speed. Then the fractional error is:

$$FE = (U_l - U)/U \qquad \textbf{(6.2.22)}$$

The fractional error will vary from zero at both the upper, Z_u, and lower, Z_l, bounds of the height interval, to a maximum at some intervening height, Z_m. If the wind profile follows a power law, the maximum fractional error and the height at which it occurs are:

$$FE_{\max} = \frac{(Z_l/Z_r)^p - (Z_m/Z_r)^p + A(Z_m - Z_l)/(Z_u - Z_l)}{(Z_m/Z_r)^p} \qquad \textbf{(6.2.23)}$$

where
$$A = (Z_u/Z_r)^p - (Z_l/Z_r)^p$$

and
$$Z_m = [pZ_l/(p-1)] - [p/(p-1)]\ (Z_l/Z_r)^p\ (Z_u - Z_l)/A$$

As an example, assume p equals 0.34 and the reference height, Z_r, is 10 m. Then for the following height intervals, the maximum percentage error and the height at which it occurs are:

Interval (m)	Maximum Error (%)	Height of Max Error (m)
2 - 10	-6.83	4.6
10 - 25	-2.31	16.0
25 - 50	-1.33	35.6
50 - 100	-1.33	71.2

As expected, the larger errors occur for the lower heights where the wind speed changes most rapidly with height. Thus, sensors should be spaced more closely together in the lower heights to best approximate the actual profile. Since the power-law is only an approximation of the actual profile, errors can occur that are larger than those estimated using (6.2.22). Even with this limitation, the methodology is useful for determining the optimum heights to place a limited number of wind sensors. The height Z_m represents the optimum height to place a third sensor given the location of the two surrounding sensors.

6.3 Temperature

Temperature is used in calculations to determine plume rise (Section 6.3.1), mixing height (Section 6.5), and various surface-layer parameters (Section 6.6). Unless indicated otherwise, ambient temperature measurements should be used in these calculations. Although not essential, the ambient temperature may also be used for consistency checking in QA procedures. Applications of vertical temperature gradient measurements are discussed in Section 6.3.2.

6.3.1 Use in Plume-Rise Estimates

Temperature is used in calculating the initial buoyancy flux in plume rise calculations as follows:

$$F = g(T_p - T_e)V/T_p \qquad \textbf{(6.3.1)}$$

where the subscripts p and e indicate the plume and environmental values, respectively, and V is the volume flux **[13]**.

6.3.2 Vertical Temperature Gradient

Vertical temperature gradient measurements are used for classifying stability in the surface layer, in various algorithms for calculating surface scaling parameters, and in plume rise equations for stable conditions. For all of these applications the relative accuracy and resolution of the thermometers are of critical importance. Recommended heights for temperature gradient measurements in the surface layer are 2 m and 10 m. For use in estimating plume rise in stable conditions, the vertical temperature gradient should be determined using measurements across the plume rise layer; a minimum height separation of 50 m is recommended for this application.

6.4 Stability

Stability typing is employed in air quality dispersion modeling to facilitate estimates of lateral and vertical dispersion parameters [e.g., the standard deviation of plume concentration in the lateral (σ_y) and vertical (σ_z)] used in Gaussian plume models. The preferred stability typing scheme, recommended for use in regulatory air quality modeling applications is the scheme proposed in an article by Pasquill in 1961 **[33]**; the dispersion parameters associated with this scheme [often referred to as the Pasquill-Gifford (P-G) sigma curves] are used by default in most of the EPA recommended Gaussian dispersion models.

Table 6-3 provides a key to the Pasquill stability categories as originally defined; though impractical for routine application, the original scheme provided a basis for much of the developmental work in dispersion modeling. For routine applications using the P-G sigmas, the Pasquill stability category (hereafter referred to as the P-G stability category) should be calculated using the method developed by Turner **[34]**; Turner's method is described in Section 6.4.1. Subsequent sections describe alternative methods for estimating the P-G stability category when representative cloud cover and ceiling data are not available. These include a radiation-based method which uses measurements of solar radiation during the day and delta-T at night (Section 6.4.2) and turbulence-based methods which use wind fluctuation statistics (Sections 6.4.3 and 6.4.4). Procedures for the latter are based on the technical note published by Irwin in 1980 **[35]**; user's are referred to the technical note for background on the estimation of P-G stability categories.

Table 6-3

Key to the Pasquill Stability Categories

	Daytime Insolation			Nighttime cloud cover	
Surface wind speed (m/s)	Strong	Moderate	Slight	Thinly overcast or ≥4/8 low cloud	≤ 3/8
< 2	A	A - B	B	-	-
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

Strong insolation corresponds to sunny, midday, midsummer conditions in England; slight insolation corresponds to similar conditions in midwinter. Night refers to the period from one hour before sunset to one hour after sunrise. The neutral category, D, should be used regardless of wind speed, for overcast conditions during day or night.

6.4.1 Turner's method

Turner **[34]** presented a method for determining P-G stability categories from data that are routinely collected at National Weather Service (NWS) stations. The method estimates the effects of net radiation on stability from solar altitude (a function of time of day and time of year), total cloud cover, and ceiling height. Table 6-4 gives the stability class (1=A, 2=B,...) as a function of wind speed and net radiation index. Since the method was developed for use with NWS data, the wind speed is given in knots. The net radiation index is related to the solar altitude (Table 6-5) and is determined from the procedure described in Table 6-6. Solar altitude can be determined from the Smithsonian Meteorological Tables **[36]**. For EPA regulatory modeling applications, stability categories 6 and 7 (F and G) are combined and considered category 6.

Table 6-4

Turner's Key to the P-G Stability Categories

Wind Speed		Net Radiation Index						
(knots)	(m/s)	4	3	2	1	0	-1	-2
0,1	0 - 0.7	1	1	2	3	4	6	7
2,3	0.8 - 1.8	1	2	2	3	4	6	7
4,5	1.9 - 2.8	1	2	3	4	4	5	6
6	2.9 - 3.3	2	2	3	4	4	5	6
7	3.4 - 3.8	2	2	3	4	4	4	5
8,9	3.9 - 4.8	2	3	3	4	4	4	5
10	4.9 - 5.4	3	3	4	4	4	4	5
11	5.5 - 5.9	3	3	4	4	4	4	4
≥ 12	≥ 6.0	3	4	4	4	4	4	4

Table 6-5

Insolation Class as a Function of Solar Altitude

Solar Altitude Φ (degrees)	Insolation	Insolation Class Number
$60 < \Phi$	strong	4
$35 < \Phi \leq 60$	moderate	3
$15 < \Phi \leq 35$	slight	2
$\Phi \leq 15$	weak	1

Table 6-6

Procedure for Determining the Net Radiation Index

1. If the total cloud[1] cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).

2. For nighttime: (from one hour before sunset to one hour after sunrise):
   (a) If total cloud cover $\leq$ 4/10, use net radiation index equal to -2.

   (b) If total cloud cover > 4/10, use net radiation index equal to -1.

3. For daytime:

   (a) Determine the insolation class number as a function of solar altitude from Table 6-5.

   (b) If total cloud cover $\leq$5/10, use the net radiation index in Table 6-4 corresponding to the isolation class number.

   © If cloud cover >5/10, modify the insolation class number using the following six steps.

   (l) Ceiling <7000 ft, subtract 2.

   (2) Ceiling $\geq$7000 ft but <16000 ft, subtract 1.

   (3) total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings $\geq$7000 ft since cases with 10/10 coverage below 7000 ft are considered in item 1 above.)

   (4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.

   (5) If modified insolation class number is less than 1, let it equal 1.

   (6) Use the net radiation index in Table 6-4 corresponding to the modified insolation class number.

[1] *Although Turner indicates total cloud cover, opaque cloud cover is implied by Pasquill and is preferred; EPA recommended meteorological processors, MPRM and PCRAMMET, will accept either.*

6.4.2 Solar radiation/delta-T (SRDT) method

The solar radiation/delta-T (SRDT) method retains the basic structure and rationale of Turner's method while obviating the need for observations of cloud cover and ceiling. The method, outlined in Table 6-7, uses the surface layer wind speed (measured at or near 10 m) in combination with measurements of total solar radiation during the day and a low-level vertical temperature difference (ΔT) at night (see Section 3.1.2.1 for guidance on probe placement for measurement of the surface layer ΔT). The method is based on Bowen et al. **[37]** with modifications as necessary to retain as much as possible of the structure of Turner's method.

Table 6-7

Key to Solar Radiation Delta-T (SRDT) Method for Estimating

Pasquill-Gifford (P-G) Stability Categories

DAYTIME

	Solar Radiation (W/m^2)			
Wind Speed (m/s)	≥ 925	925 - 675	675 - 175	< 175
< 2	A	A	B	D
2 - 3	A	B	C	D
3 - 5	B	B	C	D
5 - 6	C	C	D	D
≥ 6	C	D	D	D

NIGHTTIME

	Vertical Temperature Gradient	
Wind Speed (m/s)	< 0	≥ 0
< 2.0	E	F
2.0 - 2.5	D	E
≥ 2.5	D	D

6.4.3 σ_E method

The σ_E method (Tables 6-8a and 6-8b) is a turbulence-based method which uses the standard deviation of the elevation angle of the wind in combination with the scalar mean wind speed.

The criteria in Table 6-8a and Table 6-8b are for data collected at 10m and a roughness length of 15 cm. Wind speed and direction data collected within the height range from $20z_0$ to $100z_0$ should be used. For sites with very low roughness, these criteria are slightly modified. The lower bound of measurement height should never be less than 1.0 m; the upper bound should never be less than 10 m. To obtain 1-hour averages, the recommended sampling duration is 15 minutes, but it should be at least 3 minutes and may be as long as 60 minutes. The relationships employed in the estimation methods assume conditions are steady state. This is more easily achieved if the sampling duration is less than 30 minutes.

Table 6-8a

Vertical Turbulence[a] Criteria for Initial Estimate of Pasquill-Gifford (P-G) Stability Category. For use with Table 6-7b.

Initial estimate of P-G stability category	Standard deviation of wind elevation angle σ_E (degrees)
A	$11.5 \le \sigma_E$
B	$10.0 \le \sigma_E < 11.5$
C	$7.8 \le \sigma_E < 10.0$
D	$5.0 \le \sigma_E < 7.8$
E	$2.4 \le \sigma_E < 5.0$
F	$\sigma_E < 2.4$

[a] As indicated by the standard deviation of the elevation angle of the wind vector, σ_ϕ. Sigma-E and σ_E are aliases for σ_ϕ.

Table 6-8b

Wind Speed Adjustments for Determining Final Estimate of P-G Stability Category from σ_E. For use with Table 6-8a.

	Initial estimate of P-G Category	10-meter wind speed (m/s)	Final estimate of P-G Category
Daytime	A	$u < 3$	A
	A	$3 \le u < 4$	B
	A	$4 \le u < 6$	C
	A	$6 \le u$	D
	B	$u < 4$	B
	B	$4 \le u < 6$	C
	B	$6 \le u$	D
	C	$u < 6$	C
	C	$6 \le u$	D
	D, E, or F	ANY	D
Nighttime	A	ANY	D
	B	ANY	D
	C	ANY	D
	D	ANY	D
	E	$u < 5$	E
	E	$5 \le u$	D
	F	$u < 3$	F
	F	$3 \le u < 5$	E
	F	$5 \le u$	D

If the site roughness length is other than 15 cm, the category boundaries listed in Table 6-8a may need to be adjusted. As an initial adjustment, multiply the Table 6-8a values by:

$$(z_o/15)^{0.2}$$

where z_o is the site roughness in centimeters. This factor, while theoretically sound, has not had widespread testing. It is likely to be a useful adjustment for cases when z_o is greater than 15 cm. It is yet problematical whether the adjustment is as useful for cases when z_o is less than 15 cm.

If the measurement height is other than 10 m, the category boundaries listed in Table 6-8a will need to be adjusted. As an initial adjustment, multiply the lower bound values by:

$$\mathbf{(Z/10)}^{P_\phi}$$

where Z is the measurement height in meters. The exponent P_ϕ is a function of the P-G stability category with values as follows:

P-G Stability	P_ϕ
A	0.02
B	0.04
C	0.01
D	-0.14
E	-0.31

The above suggestions summarize the results of several studies conducted in fairly ideal circumstances. It is anticipated that readers of this document are often faced with conducting analyses in less than ideal circumstances. Therefore, before trusting the Pasquill category estimates, the results should be spot checked. This can easily be accomplished. Choose cloudless days. In mid-afternoon during a sunny day, categories A and B should occur. During the few hours just before sunrise, categories E and F should occur. The bias, if any, in the turbulence criteria will quickly be revealed through such comparisons. Minor adjustments to the category boundaries will likely be needed to tailor the turbulence criteria to the particular site characteristics, and should be made in consultation with the reviewing agency.

6.4.4 σ_A method

The σ_A method (Tables 6-9a and 6-9b) is a turbulence-based method which uses the standard deviation of the wind direction in combination with the scalar mean wind speed. The criteria in Table 6-9a and Table 6-9b are for data collected at 10 m and a roughness length of 15 cm. Wind speed and direction data collected within the height range from $20z_o$ to $100z_o$ should be used. For sites with very low roughness, these criteria are slightly modified. The lower bound measurement height should never be less than 1 m. The upper bound should never be less than 10 m. To obtain 1-hour averages, the recommended sampling duration is 15 minutes, but it should be at least 3 minutes and may be as long as 60 minutes. The relationships employed in the estimation methods assume conditions are steady state. This is more easily achieved if the sampling duration is less than 30 minutes. To minimize the effects of wind meander, the 1-hour σ_A is defined using 15-minute values (see Equation. 6.2.10).

Table 6-9a

Lateral Turbulence[a] Criteria for Initial Estimate of Pasquill-Gifford (P-G) Stability Category. For use with Table 6-8b.

Initial estimate of P-G stability category	Standard deviation of wind azimuth angle σ_A
A	$22.5 \leq \sigma_A$
B	$17.5 \leq \sigma_A < 22.5$
C	$12.5 \leq \sigma_A < 17.5$
D	$7.5 \leq \sigma_A < 12.5$
E	$3.8 \leq \sigma_A < 7.5$
F	$\sigma_A < 3.8$

[a] As indicated by the standard deviation of the azimuth angle of the wind vector, σ_θ. Sigma-A, Sigma-Theta, and σ_A are aliases for σ_θ.

Table 6-9b

Wind Speed Adjustments for Determining Final Estimate of P-G Stability Category from σ_A. For use with Table 6-9a.

Initial estimate of P-G Category		10-meter wind speed (m/s)	Final estimate of P-G Category
Daytime	A	u < 3	A
	A	3 ≤ u < 4	B
	A	4 ≤ u < 6	C
	A	6 ≤ u	D
	B	u < 4	B
	B	4 ≤ u < 6	C
	B	6 ≤ u	D
	C	u < 6	C
	C	6 ≤ u	D
	D, E, or F	ANY	D
Nighttime	A	u < 2.9	F
	A	2.9 ≤ u < 3.6	E
	A	3.6 ≤ u	D
	B	u < 2.4	F
	B	2.4 ≤ u < 3.0	E
	B	3.0 ≤ u	D
	C	u < 2.4	E
	C	2.4 ≤ u	D
	D	ANY	D
	E	u < 5	E
	E	5 ≤ u	D
	E		
	F	u < 3	F
	F	3 ≤ u < 5	E
	F	5 ≤ u	D

.

If the site roughness length is other than 15 cm, the category boundaries listed in Table 6-9a may need adjustment. As an initial adjustment, multiply the values listed by:

$$(z_o/15)^{0.2}$$

where z_o is the site roughness in centimeters. This factor, while theoretically sound, has not had widespread testing. It is likely to be a useful adjustment for cases when z_o is greater than 15 cm. It is yet problematical whether the adjustment is as useful for cases when z_o is less than 15 cm.

If the measurement height is other than 10 m, the category boundaries listed in Table 6-9a will need adjustment. As an initial adjustment, multiply the lower bound values listed by:

$$(Z/10)^{P_\theta}$$

where Z is the measurement height in meters.

The exponent P_θ is a function of the P-G stability category with values as follows:

P-G Stability	P_θ
A	-0.06
B	-0.15
C	-0.17
D	-0.23
E	-0.38

The above suggestions summarize the results of several studies conducted in fairly ideal circumstances. It is anticipated that readers of this document are often faced with conducting analyses in less than ideal circumstances. Therefore, before trusting the Pasquill category estimates, the results should be spot checked. This can easily be accomplished. Choose cloudless days. In mid-afternoon during a sunny day, categories A and B should occur. During the few hours just before sunrise, categories E and F should occur. The bias, if any, in the turbulence criteria will quickly be revealed through such comparisons. Minor adjustments to the category boundaries will likely be needed to tailor the turbulence criteria to the particular site characteristics, and should be made in consultation with the reviewing agency.

6.4.5 Accuracy of stability category estimates

By virtue of its historic precedence and widespread use, EPA considers Turner's method **[34]** to be the benchmark procedure for determining P-G stability. Evaluations performed in developing the SRDT method indicate that this method identifies the same P-G stability category as Turner's method (Section 6.4.1) about 60 percent of the time and is within one category about 90 percent of the time (EPA, 1994) **[38]**. Results are not available comparing the performance of the σ_A and σ_E methods outlined above in this section. However, there are comparison results for similar methods. From these studies, it is concluded that the methods will estimate the same stability category about 50 percent of the time and will be within one category about 90 percent of the time. Readers are cautioned that adjustment of the turbulence criteria resulting from spot checks is necessary to achieve this performance. For additional information on stability classification using wind fluctuation statistics, see references **[39]**, **[40]**, **[41]**, and **[42]**.

6.5 Mixing Height

For the purposes of this guidance, mixing height is defined as the height of the layer adjacent to the ground over which an emitted or entrained inert non-buoyant tracer will be mixed (by turbulence) within a time scale of about one hour or less **[43]**. Taken literally, the definition means that routine monitoring of the mixing height is generally impractical. For routine application, alternative methods are recommended for estimating mixing heights based on readily available data.

The Holzworth method **[44]** is recommended for use when representative NWS upper-air data are available. This procedure relies on the general theoretical principle that the lapse rate is roughly dry adiabatic (no change in potential temperature with height) in a well-mixed daytime convective boundary layer (CBL); the Holzworth method is described in Section 6.5.1. Other alternatives include using estimates of mixing heights provided in CBL model output (Weil and Brower **[45]**; Paine **[46]**) and mixing heights derived from remote sensing measurements of turbulence or turbulence related parameters; the latter are discussed in Section 9.1.1.

6.5.1 The Holzworth Method

The Holzworth method **[44]** provides twice-per-day (morning and afternoon) mixing heights based on calculations using routine NWS upper-air data. The morning mixing height is calculated as the height above ground at which the dry adiabatic extension of the morning minimum surface temperature plus 5°C intersects the vertical temperature profile observed at 1200 Greenwich Mean Time (GMT). The minimum temperature is determined from the regular hourly airways reports from 0200 through 0600 Local Standard Time (LST). The "plus 5°C " was intended to allow for the effects of the nocturnal and early morning urban heat island since NWS upper-air stations are generally located in rural or suburban surroundings. However, it can also be interpreted as a way to include the effects of some surface heating shortly after sunrise. Thus, the time of the urban morning mixing height coincides approximately with that of the typical diurnal maximum concentration of slow-reacting pollutants in many cities, occurring around the morning commuter rush hours.

The afternoon mixing height is calculated in the same way, except that the maximum surface temperature observed from 1200 through 1600 LST is used. Urban-rural differences of maximum surface temperature are assumed negligible. The typical time of the afternoon mixing height may be considered to coincide approximately with the usual mid-afternoon minimum concentration of slow-reacting urban pollutants.

Hourly mixing heights, for use in regulatory dispersion modeling, are interpolated from these twice per day estimates. The recommended interpolation procedure is provided in the user's guide for the Industrial Source Complex (ISC) dispersion model **[47]**.

6.6 Boundary Layer Parameters

This section provides recommendations for monitoring in support of air quality dispersion models which incorporate boundary layer scaling techniques. The applicability of these techniques is particularly sensitive to the measurement heights for temperature and wind speed; the recommendations for monitoring, given in Section 6.6.4, consequently, focus on the placement of the temperature and wind speed sensors. A brief outline of boundary layer theory, given in the following, provides necessary context for these recommendations. The references for this section **[48]**, **[49]**, **[50]**, **[51]**, **[52]**, **[53]**, **[54]**, **[55]**, **[56]**, **[57]**, **[58]**, **[59]** provide more detailed information on boundary layer theory.

The Atmospheric Boundary Layer (ABL) can be defined as the lower layer of the atmosphere, where processes which contribute to the production or destruction of turbulence are significant; it is comprised of two layers, a lower surface layer, and a so-called "mixed" upper layer. The height of the ABL during daytime roughly coincides with the height to which pollutants are mixed (the mixing height, Section 6.5). During night-time stable conditions, the mixing height (h) is an order of magnitude smaller than the maximum daytime value over land; at night, h is typically below the top of the surface-based radiation inversion **[57]**.

The turbulent structure of the ABL is determined by the amount of heat released to the atmosphere from the earth's surface (sensible heat flux) and by interaction of the wind with the surface (momentum flux). This structure can be described using three length scales: z (the height above the surface), h (the mixing height), and L (the Obukhov length). The Obukhov length is defined by the surface fluxes of heat $H = \rho C_p \overline{w'\theta'}$ and momentum $u_*^2 = -\overline{u'w'}$, and reflects the height at which contributions to the turbulent kinetic energy from buoyancy and shear stress are comparable; the Obukhov length is defined as:

$$L = \frac{-u_*^3}{k\,(g/\theta)\,\overline{w'\theta'}} \qquad \textbf{(6.6.1)}$$

where k is the von Karman constant, θ is the mean potential temperature within the surface layer, g/θ is a buoyancy parameter, and u_* is the friction velocity. The three length scales define two independent non-dimensional parameters: a relative height scale (z/h), and a stability index (h/L)**[56]**.

Alternatives to the measurement of the surface fluxes of heat and momentum for use in (6.6.1) involve relating turbulence to the mean profiles of temperature and wind speed. The Richardson number, the ratio of thermal to mechanical production (destruction) of turbulent kinetic energy, is directly related to another non-dimensional stability parameter (z/L) and, thus, is a good candidate for an alternative to 6.6.1. The gradient Richardson number (R_g) can be approximated by:

$$R_g = \frac{g}{\overline{T}}\,\frac{\Delta\theta}{(\Delta u)^2}\,(z_2 - z_1) \qquad \textbf{(6.6.2)}$$

Large negative Richardson numbers indicate unstable conditions while large positive values indicate stable conditions. Values close to zero are indicative of neutral conditions. Use of (6.6.2) requires estimates of Δu based on measurements of wind speed at two levels in the surface layer; however, the level of accuracy required for these measurements is problematic (Δu is typically the same order of magnitude as the uncertainty in the wind speed measurement). The bulk Richardson number (R_b) which can be computed with only one level of wind speed is a more practical alternative:

$$R_b = \frac{g}{\overline{T}} \frac{\Delta\theta}{u^2} z \qquad \textbf{(6.6.3)}$$

6.6.1 The Profile Method

The bulk Richardson number given in (6.6.3) is perhaps the simplest and most direct approach for characterizing the surface layer. For example, given the necessary surface layer measurements, one can derive both H and u_* from the integrated flux-profile equations: **[51,52]**

$$\Delta u = \frac{u_*}{k} \left[\ln \left(\frac{z_{i+1}}{z_i}\right) - \psi_m\left(\frac{z_{i+1}}{L}\right) + \psi_m\left(\frac{z_i}{L}\right) \right] \qquad \textbf{(6.6.4)}$$

$$\Delta\theta = R \frac{\theta_*}{k} \left[\ln \left(\frac{z_{j+1}}{z_j}\right) - \psi_h\left(\frac{z_{j+1}}{L}\right) + \psi_h\left(\frac{z_j}{L}\right) \right] \qquad \textbf{(6.6.5)}$$

where $\Delta u = (u_{i+1} - u_i)$, $\Delta\theta = (\theta_{j+1} - \theta_j)$; R is a parameter associated with the emperically determined similarity functions, ψ_m and ψ_h . EPA recommends using the emperical functions given in reference **[59]**; in this case the von Karman constant, k = 0.4 and R = 1. The temperature scale θ_* is related to the heat flux by:

$$H = -\rho \, C_p \, u_* \, \theta_* \qquad \textbf{(6.6.6)}$$

Methods for solving the flux profile equations vary depending on what measurements are available. In the general case with two arbitrary levels each of temperature and wind speed [i.e., as in (6.6.4) and (6.6.5)], one can solve for the unknowns (u_*, θ_*, and L) by iteration; when temperature and wind speed are measured at the same heights, approximate analytic solutions can be used. Other simplifications result by replacing the lower wind speed measurement height in (6.6.4), z_i, with the surface roughness length (z_0) **[51,52]** ; see Section 6.6.3 for guidance on estimating surface roughness. A least squares method **[49]** is recommended when wind speed and temperature data are available for three or more levels. To ensure the data are representative of the surface layer, the wind speed and tempreature sensors should be located between $20z_0$ and $100z_0$; for sites with very low roughness, the sensors should be located between 1 and 10 m. Sampling durations for use in computing 1-hour averages should be in the range of 3 to 60 minutes; a sampling duration of 15 minutes or less is recommended if the steady-state assumption is in doubt.

6.6.2 The Energy Budget Method

An equation expressing the partitioning of energy at the surface may be used in place of (6.6.5) when measurements of $\Delta\theta$ are not available**[53, 54, 58]**. The expression for the surface energy budget is:

$$H_0 + \lambda E = Q^* - G \qquad \textbf{(6.6.7)}$$

where λE is the latent heat flux (λ is the latent heat of water vaporization and E is the evaporation rate), Q* is the net radiation and G the soil heat flux. $H_0 + \lambda E$ is the energy flux that is supplied to or extracted from the air, while Q* - G is the source or sink for this energy. Using $H_0 = -\rho C_p u_* \theta_*$, (6.6.7) can be written as:

$$\theta_* = \frac{\lambda E - Q^* + G}{\rho C_p u_*} \qquad \textbf{(6.6.8)}$$

In this equation λE, Q* and G can be parameterized in terms of the total cloud cover N, the solar elevation ϕ, the air temperature T, the friction velocity u_* and θ_* itself. The idea is to use (6.6.8) to write θ_* as a function of the variables N, ϕ, T, and u_*:

$$\theta_* = f_2(N, \phi, T, u_*) \qquad \textbf{(6.6.9)}$$

This equation then replaces (6.6.5). The further procedure of finding θ_* and u_* from (6.6.4) and (6.6.9) by iteration is similar to that used in the profile method.

6.6.3 Surface Roughness Length

The roughness length (z_0) is related to the roughness characteristics of the terrain. Under near-neutral conditions and with a homogeneous distribution of obstacles, a local value of z_0 can be determined from the logarithmic wind profile.

$$U(z) = \frac{u_*}{k} \ln(z/z_0) \qquad \textbf{(6.6.10)}$$

For general application, since typical landscapes almost always contain occasional obstructions, one should attempt to estimate an effective roughness length. The recommended method for estimating the effective roughness length is based on single level gustiness measurements σ_u **[60]**:

$$\frac{\sigma_u}{\overline{u}} = \frac{1}{\ln(z/z_0)} \qquad \textbf{(6.6.11)}$$

Wind measurements for use in (6.6.11) should be made between 20 z_0 and 100 z_0; to select the appropriate measurement level, an initial estimate of the effective roughness length must first be made based on a visual inspection of the landscape (see roughness classifications provided in Table 6-10). The sampling duration for σ_u and $\overline{u}$ should be between 3 and 60 minutes. Data collected for use in estimating the effective surface roughness should be stratified by wind speed (only data for wind speeds greater than 5 m/s should be used) and wind direction sector (using a minimum sector arc width of 30 degrees). Median z_0 values should be computed for each sector; results should then be inspected to determine whether the variation between sectors is significant. An average of the median values should be computed for adjacent sectors if the variation is not significant. Estimates of the effective surface roughness using these procedures are accurate to one significant figure; i.e., a computed value of 0.34 m should be rounded to 0.3 m. Documentation of the successful application of these procedures is provided in reference **[61]**.

Table 6-10

Terrain Classification in Terms of Effective Surface Roughness Length, Z_0

Terrain Description	Z_0 (m)
Open sea, fetch at least 5 km	0.0002
Open flat terrain; grass, few isolated obstacles	0.03
Low crops, occasional large obstacles, x'/h > 20*	0.10
High crops, scattered obstacles, 15 < x'/h < 20*	0.25
Parkland, bushes, numerous obstacles, x'/h 10*	0.50
Regular large obstacle coverage (suburb, forest)	0.50 - 1.0

* x' = typical distance to upwind obstacle; h = height of obstacle

6.6.4 Guidance for Measurements in the Surface Layer

Monin-Obukhov (M-O) similarity theory is strictly applicable to steady-state horizontally homogeneous conditions in the surface layer. The temperature and wind speed measurements for use with M-O theory should be representative of a layer that is both high enough to be above the influence of the individual surface roughness elements and yet low enough to be within the surface layer; as a rule of thumb, the measurements should be made within the layer from $20z_0$ to $100z_0$ above the surface (2 - 10 m for a surface roughness of 0.1 m) **[57]**.

Data quality objectives and, consequently, instrument specifications for monitoring of temperature and wind speed in the surface layer are determined by the limitations imposed during the extreme stability conditions; basically this requires a monitoring design with the capability to resolve the variable gradients in temperature and wind speed that can exist within the surface layer under various conditions.

The depth of the surface layer where M-O similarity theory applies ranges from about one tenth of the ABL depth (h) during neutral conditions (typically 500 - 600 m) to the lesser of $|L|$ or 0.1 h during non-neutral conditions (less than 10 m during extreme stability conditions). This variability in the depth of the surface layer imposes limitations on what can be accomplished with a single fixed set of sensors. To ensure the availability of measurements representative of the entire surface layer during all stability conditions, one should employ a tall-tower (60 m or taller) equipped with wind and temperature sensors at several levels including, as a minimum, 2, 10 and 60 m. In the absence of a tall-tower, a standard 10-meter meteorological tower equipped with a single fixed set of sensors should be employed. Wind speed should be measured at the standard height of 10 m; the temperature difference should be measured between 2 and 10 m (for $z_0 \sim 0.1$ m). The usefulness of such a relatively low-lying measurement configuration lies in its applicability to both stable and unstable atmospheric conditions.

Application of M-O similarity should generally be restricted to low roughness sites located in relatively homogeneous terrain. For such sites, the reliability of the profile method for estimating surface layer parameters is primarily dependent on accurate temperature difference measurements (see Section 3.2.2 for siting and exposure of temperature sensors and Section 5.1 for sensor specifications).

6.7 Use of Airport Data

Airport data refers to surface weather observations collected in support of various NWS and Federal Aviation Administration (FAA) programs; most, although not all, of the surface weather observation sites are located at airports. For practical purposes, because airport data are readily available, most regulatory modeling was initially performed using these data. However, airport data do not meet this guidance - significant deviations include:

- The instruments used at airports are generally more robust and less sensitive than the instruments recommended in this guidance. For example, the thresholds for measuring wind direction and wind speed are higher than is recommended in this guidance; this results in a greater incidence of calms in airport data.
- Wind direction in airport data bases is reported to the nearest ten degrees - one degree resolution of wind direction is recommended in this guidance.
- Airport data for wind direction and wind speed are 2-minute averages; data for other variables, e.g., temperature and pressure are instantaneous readings - hourly averaging is recommended for all variables in this guidance.

Although data meeting this guidance are preferred, airport data continue to be acceptable for use in modeling. In fact observations of cloud cover and ceiling, data which traditionally have been provided by manual observation, are only available routinely in airport data; both of these variables are needed to calculate stability class using Turner's method (Section 6.4.1). The Guideline on Air Quality Models **[1]** recommends that modeling applications employing airport data be based on consecutive years of data from the most recent, readily available 5-year period. Airport data are available on the National Climatic Data Center (NCDC) World Wide Web site at http://www.ncdc.noaa.gov/. Documentation and guidance on NWS surface weather observations is provided in the Federal Meteorological Handbook No. 1 "Surface Weather Observations and Reports" **[62]**.

6.8 Treatment of Missing Data

Missing or invalid data should be flagged or replaced as appropriate depending on the model to be used. Note that the ISCST3 model recognizes specific flags for missing data; however, many models do not recognize flags and will not accept missing or invalid data. For use in these models, data bases with isolated one-hour gaps should be filled with estimates based on persistence or linear interpolation. Application specific procedures should be used for filling longer gaps; guidance for developing such procedures is provided in Section 6.8.1. Substitutions for missing data should only be made to complete the data set for modeling applications; substitution should not be used to attain the 90% completeness requirement for regulatory modeling applications (Section 5.3.2).

6.8.1 Substitution Procedures

This section provides general guidance on substitution procedures for use in completing meteorological data bases prior to their use in modeling. It is intended for use by applicants and reviewing agencies in the development of substitution protocols for application to regulatory air quality dispersion modeling. Substitution protocols should be included in a modeling protocol and submitted for approval to the reviewing authority prior to the modeling analysis.

Substitution procedures will vary depending on the nature of the application, the availability of alternative sources of meteorological data, and the extent of the missing or invalid data. If the data base is such that there are relatively few isolated one-hour gaps, then an interpolation procedure, which is easily automated, may provide the most practical method of substitution. However, it there are lengthy periods with missing or invalid data, then application specific procedures will generally be necessary.

The goal of substitution should be to replace missing data with a "best estimate" so as to minimize the probable error of the estimate. The following suggestions have been prioritized in order of increasing probable error.

Substitution procedures which are considered to be "best estimators" include the following:

- Persistence - Persistence is the use of data from the previous time period (hour). This procedure is applicable for most meteorological variables for isolated one-hour gaps; caution should be used when the gaps occur during day/night transition periods.
- Interpolation - This procedure is applicable for most meteorological variables for isolated one-hour gaps and, depending on circumstances, may be used for more extended periods (several hours) for selected variables; e.g., temperature. As in the case of persistence, caution should be used when the gaps occur during day/night transition periods.
- Profiling - Profiling (profile extrapolation) refers to the procedure in which missing data for one level in a multi-level data base (e.g., data from a meteorological tower) is replaced by an estimate based on data from an alternative level or levels in the same data base. The probable error of the profiling estimate does not increase with the duration of the missing data, as is the case for persistence and interpolation. Consequently, profiling becomes a better estimator compared to persistence and interpolation as the length of the missing data period increases. Profiling based on a power-law should be used for extrapolating wind speed with height; the stability dependent procedure discussed in Section 6.2.5 is recommended. Profiling based on lapse rate should be used for extrapolating temperature with height. Alternatively, with the approval of the reviewing authority, applicants may use site-specific profiling procedures for wind speed and temperature.

Substitution procedures which provide estimators with moderate probable error include the following:

- Substitution from sensors located at comparable levels at nearby locations with similar site-specific (surface-specific) characteristics.
- Persistence when used for more than several hours.
- Interpolation when used for more than several hours.

Substitution procedures which provide estimators with high probable error include the following:

- Substitution from measurements at nearby locations with dissimilar site-specific (surface-specific) characteristics.
- Substitution of a climatological value for a particular time period; e.g., a seasonal or monthly average.
- Substitution of simulated meteorology based, for example, on a boundary layer model.
- Substitution of "dummy data" such as a constant value for a variable.

6.9 Recommendations

The hourly scalar mean wind speed and wind direction should be used in steady-state Gaussian dispersion models. These statistics should be processed using the methods provided in Section 6.2.1; unit vector processing (Section 6.2.2) may also be used to estimate the hourly scalar mean wind direction. The standard deviation of the wind direction should be calculated using the techniques described in Section 6.2.1. Hourly statistics may be obtained by processing samples over an entire hour or by averaging sub-hourly statistics. The recommended sub-hourly averaging interval for wind data processing is 15 minutes; two valid 15-minute averages are required for a valid hourly average.

For the purposes of this guidance, a calm occurs when the wind speed is below the starting threshold of the anemometer or vane, whichever is greater. Calms require special treatment in such applications to avoid division by zero in the steady-state dispersion algorithm. For similar reasons, to avoid unrealistically high concentration estimates at low wind speeds (below the values used in validations of these models - about 1 m/s) EPA recommends that wind speeds less than 1 m/s be reset to 1 m/s for use in steady-state dispersion models; the unaltered data should be retained for use in non-steady-state modeling applications. Calms should be identified in processed data files by flagging the appropriate records; user's guides for the model being used should be consulted for model specific flagging conventions.

Recommended sampling and processing strategies for the primary meteorological variables for various applications are given in Table 6-1.

The Pasquill-Gifford (P-G) stability category should be determined with Turner's method (Section 6.4.1) using site-specific wind speed measurements at or near 10 m and representative *cloud cover and ceiling height. Other approved methods for estimating the P-G stability category, for use when representative cloud cover and ceiling observations are not available, include the solar radiation delta-T (SRDT) method described in Section 6.4.2, and turbulence-based methods using site-specific wind fluctuation statistics:* σ_E *(Section 6.4.3) or* σ_A *(Section 6.4.4). Alternative methods for determining stability category should be evaluated in consultation with the Regional Office.*

Emperical relationships for use in models employing boundary layer scaling techniques should be selected in accordance with a von Karmam constant of 0.4; recmmended emperical relationships are given in reference ***[59]****.*

Missing data should be flagged or replaced as appropriate depending on the model to be used. Isolated one-hour gaps in meteorological data bases used in regulatory modeling should be filled with estimates bases on persistence or interpolation. Application specific procedures should be used to fill longer gaps

If the recommendations in this section cannot be achieved, then alternative approaches should be developed in consultation with the EPA Regional Office.

7. DATA REPORTING AND ARCHIVING

Meteorological data collected for use in regulatory modeling applications should be made available to the regulatory agency as necessary. In some cases, as part of an oversight function, agencies may require periodic or even real-time access to the data as it is being collected. The regulatory agency may, in addition, require long-term archival of meteorological data bases used in some applications [e.g., analyses supporting State Implementation Plan (SIP) actions and Prevention of Significant deterioration (PSD) permits]. Procedures for compliance with such requirements should be worked out with the agency and documented in the monitoring protocol prior to commencement of monitoring.

7.1 Data Reports

The following general recommendations apply to meteorological data bases being prepared for use in regulatory modeling applications. All meteorological data should be reduced to hourly averages using the procedures provided in Section 6. The data should be recorded in chronological order; records should be labeled according to the observation time (defined as the time at the end of the averaging period; i.e., the hour ending). If possible, each data record should contain the data for one hourly observation (one record per hour). The first four fields of each data record should identify the year, month, day and hour of the observation. The data records should be preceded by a header record providing the following information:

- Station name
- Station location (latitude, longitude, and time zone)
- Station elevation
- Period of record and number of records
- Validation level (see Section 8)

A summary report should accompany each meteorological data base prepared for use in regulatory modeling applications. The summary report should provide the following information:

- number and percent of hours with complete/valid data.
- number and percent of hours with valid stability data.
- number and percent of hours with valid wind speed and wind direction data including valid calms.
- list of hours requiring substitutions including identification of the missing variable and the substitution protocol employed.

7.2 Data Archives

Meteorological data used in support of some regulatory actions (e.g, SIP revisions and PSD permit applications) may be needed in support of continuing actions for these regulations and, consequently should be archived by the agency with permit granting authority; normally the State. Such an archive should be designed for the data actually used in the regulatory application - i.e., the processed data, but may also include some raw data. Archival of other raw data is at the discretion of the applicant. The processed meteorological data should be archived initially for one year with provisions for review and extension to five years, ten years, or indefinite. Where data were originally reduced from strip chart records, the charts should also be archived. Original strip chart records should be retained for a minimum of five years. If an archive is to be eliminated, an attempt should be made to contact potential user's who might be affected by such an action.

7.3 Recommendations

Procedures for compliance with reporting and archiving requirements should be worked out with the agency and documented in the monitoring protocol prior to commencement of monitoring.

Meteorological data provided to regulatory agencies for use in modeling should be reduced to hourly averages using the procedures provided in Section 6. The data should be recorded in chronological order; records should be labeled according to the observation time (defined as the time at the end of the averaging period; i.e., the hour ending).

Meteorological data used in support of SIP revisions or PSD permit applications should be archived initially for one year with provisions for review and extension to five years, ten years, or indefinite.

8. QUALITY ASSURANCE AND QUALITY CONTROL

Quality Assurance/Quality Control (QAQC) procedures are required to ensure that the data collected meet standards of reliability and accuracy (see Section 5.1). Quality Control (QC) is defined as those operational procedures that will be routinely followed during the normal operation of the monitoring system to ensure that a measurement process is working properly. These procedures include periodic calibration of the instruments, site inspections, data screening, data validation, and preventive maintenance. The QC procedures should produce quantitative documentation to support claims of accuracy. Quality Assurance (QA) is defined as those procedures that will be performed on a more occasional basis to provide assurance that the measurement process is producing data that meets the data quality objectives (DQO). These procedures include routine evaluation of how the QC procedures are implemented (system audits) and assessments of instrument performance (performance audits).

The QAQC procedures should be documented in a Quality Assurance Project Plan (QAPP) and should include a "sign-off" by the appropriate project or organizational authority. The QAPP should include the following **[63]**:

1. Project description - how meteorology is to be used
2. Project organization - how data validity is supported
3. QA objective - how QA will document validity claims
4. Calibration method and frequency - for meteorology
5. Data flow - from samples to archived valid values
6. Validation and reporting methods - for meteorology
7. Audits - performance and system
8. Preventive maintenance
9. Procedures to implement QA objectives - details
10. Management support - corrective action and reports

It is important that the person providing the QA be independent of the organization responsible for the collection of the data and the maintenance of the measurement systems. Ideally, this person should be employed by an independent company. There should not be any lines of intimidation available to the operators which might be used to influence the QA audit report and actions. With identical goals of valid data, the QA person should encourage the operator to use the same methods the QA person uses (presumably these are the most comprehensive methods) when challenging the measurement system during a performance audit. When this is done, the QA task reduces to spot checks of performance and examination of records thus providing the best data with the best documentation at the least cost.

8.1 Instrument Procurement

The specifications required for the applications for which the data will be used (see Sections 5.0 and 6.0) along with the test method to be used to determine conformance with the specification should be a part of the procurement document. A good QA Plan will require a QA sign-off of the procurement document for an instrument system containing critical requirements. An instrument should not be selected solely on the basis of price and a vague description, without detailed documentation of sensor performance.

8.1.1 Wind Speed

This section provides guidance for procurement of anemometers (i.e., mechanical wind speed sensors employing cups or vane-oriented propellers) which rely on the force of the wind to turn a shaft. Guidance for the procurement of remote sensors for the measurement of wind speed is provided in Section 9. Other types of wind speed sensors (e.g., hot wire anemometers and sonic anemometers) are not commonly used for routine monitoring and are beyond the scope of this guide. An example performance specification for an anemometer is shown in Table 8-1.

Table 8-1

Example Performance Specification for an Anemometer

Range	0.5 m/s to 50 m/s
Threshold[1]	≤ 0.5 m/s
Accuracy (error)[1,2]	≤ (0.2 m/s + 5% of observed)
Distance Constant[1]	≤ 5 m at 1.2 kg/m^3 (at std sea-level density)

[1] As determined by wind tunnel test conducted on production samples in accordance with ASTM D-22.11 test methods

[2] aerodynamic shape (cup or propeller) with permanent serial number to be accompanied by test report, traceable to NBS, showing rate of rotation vs. wind speed at 10 speeds.

The procurement document should ask for (1) the starting torque of the anemometer shaft (with cup or propeller removed) which represents a new bearing condition, and (2) the starting torque above which the anemometer will be out of specification.; when the latter value is exceeded, the bearings should be replaced.

The ASTM test cited above includes a measurement of off-axis response. Some anemometer designs exhibit errors greater than the accuracy specification with off-axis angles of as little as 10 degrees. However, there is no performance specification for this type of error at this time, due to a lack of sufficient data to define what the specification should be.

8.1.2 Wind Direction

This section provides guidance for procurement of wind vanes; i.e., mechanical wind direction sensors which rely on the force of the wind to turn a shaft. Guidance for the procurement of remote sensors for the measurement of wind direction is provided in Section 9.

The wind direction measurement with a wind vane is a relative measurement with respect to the orientation of the direction sensor. There are three parts to this measurement which must be considered in quality assurance. These are: (l) the relative accuracy of the vane performance in converting position to output, (2) the orientation of the vane both horizontal (with respect to "true north") and vertical (with respect to a level plane), and (3) the dynamic response of the vane and conditioning circuit to changes in wind direction.

The procurement document should ask for: (1) the starting torque of the vane shaft (with the vane removed) which represents a new bearing (and potentiometer) condition, and (2) the starting torque above which the vane will be out of specification.; when the latter value is exceeded, the bearings should be replaced. An example performance specification for a wind vane is shown in Table 8-2.

Table 8-2

Example Performance Specification for a Wind Vane

Range	1 to 360 or 540 degrees
Threshold[1]	≤ 0.5 m/s
Accuracy (error)[1]	≤ 3 degrees relative to sensor mount or index
	≤ 5 degrees absolute error for installed system
Delay Distance[1]	≤ 5 m at 1.2 kg/m^3 (at std sea-level density)
Damping Ratio[1]	≥ 0.4 at 1.2 kg/m^3 or
Overshoot[1]	≤ 25% at 1.2 kg/m^3

[1] As determined by wind tunnel test conducted on production samples in accordance with ASTM D-22.11 test methods

The range of 1 to 540 degrees was originally conceived to minimize strip chart "painting" when the direction varied around 360 degrees. It also minimizes errors (but does not eliminate them) when sigma meters are used. It may also provide a means of avoiding some of the "dead band" errors from a single potentiometer. In these days of "smart" data loggers, it is possible to use a single potentiometer (1 to 360 degree) system without excessive errors for either average direction or σ_A.

If the wind direction samples are to be used for the calculation of σ_A, the specification should also include a time constant requirement for the signal conditioner. Direction samples should be effectively instantaneous. At 5 m/s, a 1m delay distance represents 0.2 seconds. A signal conditioner specification of a time constant of <0.2 seconds would insure that the σ_A value was not attenuated by an averaging circuit provided for another purpose.

8.1.3 Temperature and Temperature Difference

When both temperature and differential temperature are required, it is important to specify both accuracy and relative accuracy (not to be confused with precision or resolution). Accuracy is performance compared to truth, usually provided by some standard instrument in a controlled environment. Relative accuracy is the performance of two or more sensors, with respect to one of the sensors or the average of all sensors, in various controlled environments. A temperature sensor specification might read:

Range	-40 to +60 °C.
Accuracy (error)	≤ 0.5 °C.

A temperature difference specification might read:

Range	-5 to +15 °C.
Relative accuracy (error)	≤ 0.1 °C.

While calibrations and audits of both accuracy and relative accuracy are usually conducted in controlled environments, the measurement is made in the atmosphere. The greatest source of error is usually solar radiation. Solar radiation shield specification is therefore an important part of the system specification. Motor aspirated radiation shields (and possibly high performance naturally ventilated shields) will satisfy the less critical temperature measurement. For temperature difference, it is critical that the same design motor aspirated shield be used for both sensors. The expectation is that the errors from radiation (likely to exceed 0.2 °C) will zero out in the differential measurement. A motor aspirated radiation shield specification might read:

Radiation range	-100 to 1300 W/m^2
Flow rate	3 m/s or greater
Radiation error	< 0.2 °C.

8.1.4 Dew Point Temperature

Sensors for measuring dew point temperature can be particularly susceptible to precipitation, wind, and radiation effects. Therefore, care should be taken in obtaining proper (manufacturer-recommended) shielding and aspiration equipment for the sensors. If both temperature and dew point are to be measured, aspirators can be purchased which will house both sensors. If measurements will be taken in polluted atmospheres, gold wire electrodes will minimize corrosion problems. For cooled mirror sensors consideration should be given to the susceptibility of the mirror surface to contamination.

8.1.5 Precipitation

For areas where precipitation falls in a frozen form, consideration should be given to ordering an electrically heated rain and snow gauge. AC power must be available to the precipitation measurement site. For remote sites where AC power is not available, propane-heated gauges can be ordered. However, if air quality measurements are being made at the same location, consideration should be given to the air pollutant emissions in the propane burner exhaust.

Air movement across the top of a gauge can affect the amount of catch. For example, Weiss **[64]** reports that at a wind speed of 5 mph, the collection efficiency of an unshielded gauge decreased by 25%, and at 10 mph, the efficiency of the gauge decreased by 40%. Therefore, it is recommended that all precipitation gauges be installed with an Alter-type wind screen, except in locations where frozen precipitation does not occur.

Exposure is very important for precipitation gauges; the distance to nearby structures should be at least two to four times the height of the structures (see Section 3.1.3). Adequate lengths of cabling must be ordered to span the separation distance of the gauge from the data acquisition system. If a weighing gauge will be employed, a set of calibration weights should be obtained.

8.1.6 Pressure

The barometric pressure sensor should normally have a proportional and linear electrical output signal for data recording. Alternately, a microbarograph can be used with a mechanical recording system. Some barometers operate only within certain pressure ranges; for these, care should be taken that the pressure range is appropriate for the elevation of the site where measurements will be taken.

8.1.7 Radiation

Radiation instruments should be selected from commercially available and field-proven systems. These sensors generally have a low output signal, so that they should be carefully matched with the signal conditioner and data acquisition system. Another consideration in the selection of data recording equipment is the fact that net radiometers have both positive and negative voltage output signals.

8.2 Installation and Acceptance Testing

The installation period is the optimal time to receive appropriate training in instrument principles, operations, maintenance, and troubleshooting, as well as data interpretation and validation. Meteorological consultants as well as some manufacturers and vendors of meteorological instruments provide these services.

An acceptance test is used to determine if an instrument performs according to the manufacturer's specifications **[2]**. Manufacturer's procedures for unpacking, inspection, installation, and system diagnostics should be followed to assure that all components are functioning appropriately. All acceptance-testing activities should be documented in the station log.

8.2.1 Wind Speed

This section provides guidance for the acceptance testing of anemometers (i.e., mechanical wind speed sensors employing cups or vane-oriented propellers) which rely on the force of the wind to turn a shaft. Guidance for the acceptance testing of remote sensors for the measurement of wind speed is provided in Section 9. Other types of wind speed sensors (e.g., hot wire anemometers and sonic anemometers) are not commonly used for routine monitoring and are beyond the scope of this guide.

A technical acceptance test may serve two purposes. First, it can verify that the instrument performs as the manufacturer claims, assuming the threshold, distance constant and transfer function (rate of rotation vs. wind speed) are correct. This test catches shipping damage, incorrect circuit adjustments, poor workmanship, or poor QA by the manufacturer. This level of testing should be equivalent to a field performance audit. The measurement system is challenged with various rates of rotation on the anemometer shaft to test the performance from the transducer in the sensor to the output. The starting torque of the bearing assembly is measured and compared to the range of values provided by the manufacturer (new and replacement).

The other purpose of a technical acceptance test is to determine if the manufacturer really has an instrument which will meet the specification. This action requires a wind tunnel test. The results would be used to reject the instrument if the tests showed failure to comply. An independent test laboratory is recommended for conducting the ASTM method test.

The specification most likely to fail for a low cost anemometer is threshold, if bushings are used rather than quality bearings. A bushing design may degrade in time faster than a well designed bearing assembly and the consequence of a failed bushing may be the replacement of the whole anemometer rather than replacement of a bearing for a higher quality sensor. A receiving inspection cannot protect against this problem. A mean-time-between-failure specification tied to a starting threshold torque test is the only reasonable way to assure quality instruments if quality brand names and model numbers cannot be required.

8.2.2 Wind Direction

This section provides guidance for the acceptance testing of wind vanes; i.e., mechanical wind direction sensors which rely on the force of the wind to turn a shaft. Guidance for the acceptance testing of remote sensors for the measurement of wind direction is provided in Section 9.

A technical acceptance test can verify the relative direction accuracy of the wind vane by employing either simple fixtures or targets within a room established by sighting along a 30-60-90 triangle. There is no acceptance test for sighting or orientation, unless the manufacturer supplies an orientation fixture and claims that the sensor is set at the factory to a particular angle (180 degrees for example) with respect to the fixture.

If σ_A is to be calculated from direction output samples, the time constant of the output to an instantaneous change should be estimated. If the direction output does not change as fast as a test meter on the output can react, the time constant is too long.

If σ_A is calculated by the system, a receiving test should be devised to check its performance. The manual for the system should describe tests suitable for this challenge.

8.2.3 Temperature and Temperature Difference

The simplest acceptance test for temperature and temperature difference would be a two point test, room temperature and a stirred ice slurry. A reasonably good mercury-in-glass thermometer with some calibration pedigree can be used to verify agreement to within l °C. It is important to stir the liquid to avoid local gradients. It should not be assumed that a temperature difference pair will read zero when being aspirated in a room. If care is taken that the air drawn into each of the shields comes from the same well mixed source, a zero reading might be expected.

A second benefit of removing the transducers from the shields for an acceptance test comes to the field calibrator and auditor. Some designs are hard to remove and have short leads. These conditions can be either corrected or noted when the attempt is first made in the less hostile environment of a receiving space.

8.2.4 Dew Point Temperature

A dew point temperature acceptance test at one point inside a building, where the rest of the system is being tested, will provide assurance that connections are correct and that the operating circuits are functioning. The dew point temperature for this test should be measured with a wet-dry psychrometer (Assman type if possible) or some other device in which some measure of accuracy is documented. If it is convenient to get a second point outside the building, assuming that the dew point temperature is different outside (usually true if the building is air conditioned with water removed or added), further confidence in the performance is possible. Of course, the manufacturer's methods for checking parts of the system (see the manual) should also be exercised.

8.2.5 Precipitation

The receiving inspection for a precipitation gauge is straightforward. With the sensor connected to the system, check its response to water (or equivalent weight for weighing gauges) being introduced into the collector. For tipping bucket types, be sure that the rate is less than the equivalent of one inch (25mm) per hour if the accuracy check is being recorded. See the section on calibration (8.3) for further guidance.

8.2.6 Pressure

A check inside the building is adequate for an acceptance test of atmospheric pressure. An aneroid barometer which has been set to agree with the National Weather Service (NWS) equivalent sea-level pressure can be used for comparison. If station pressure is to be recorded by the pressure sensor, be sure that the aneroid is set to agree with the NWS station pressure and not the pressure broadcast on radio or television. A trip to the NWS office may be necessary to set the aneroid for this agreement since the station pressure is sensitive to elevation and the NWS office may be at a different elevation than the receiving location.

8.2.7 Radiation

A simple functional test of a pyranometer or solarimeter can be conducted with an electrical light bulb. With the sensor connected to the system as it will be in the field, cover it completely with a box with all cracks taped with an opaque tape. Any light can bias a "zero" check. The output should be zero. Do not make any adjustments without being absolutely sure the box shields the sensor from any direct, reflected, or diffuse light. Once the zero is recorded, remove the box and bring a bulb (100 watt or similar) near the sensor. Note the output change. This only proves that the wires are connected properly and the sensor is sensitive to light.

If a net radiometer is being checked, the bulb on the bottom should induce a negative output and on the top a positive output. A "zero" for a net radiometer is much harder to simulate. The sensor will (or may) detect correctly a colder temperature on the bottom of the shielding box than the top, which may be heated by the light fixtures in the room. Check the manufacturer's manual for guidance.

8.3 Routine Calibrations

A calibration involves measuring the conformance to or discrepancy from a specification for an instrument and an adjustment of the instrument to conform to the specification.

Documentation of all calibrations should include a description of the system "as found", details of any adjustments to the instrument, and a description of the system "as left"; this documentation is a vital part of the "paper-trail" for any claims of data validity. Calibrations are often confused with performance audits since both involve measuring the conformance of an instrument to a specification; the main difference has to do with the independence of the person performing the audit or calibration - the performance audit should be conducted by a person who is independent of the operating organization - calibrations, on the other hand, are often performed by individuals within the operating organization. Guidance specific to performance audits is provided in Section 8.4.

The guidance provided on calibration procedures in the following applies to in situ meteorological sensors such as would be mounted on a tower (e.g., wind vanes and anemometers) or located at ground level (e.g., a solar radiation sensor). Ideally, a calibration should be performed in an environment as close as possible to laboratory bench-test as conditions allow. For tower mounted sensors this usually involves removing the sensor from tower. The alternative to a bench-test calibration of the in situ sensor is a calibration using a collocated transfer standard; this involves locating an identical standard instrument as close as practical to the instrument being calibrated. The collocated standard transfer method is the most complete calibration/audit method from the standpoint of assessing total system error. However it has two serious drawbacks: 1) it is limited to the conditions that prevailed during the calibration/audit, and 2) it is sensitive to siting and exposure bias.

Calibrations using a bench test or collocated transfer standard are not generally applicable to the upper-air measurement systems; the special procedures required for calibrations and audits of upper-air measurement systems are discussed in Section 9.

Documentation supplied with newly purchased instruments should include the manufacturer's recommended calibration procedures. The guidance on calibration procedures provided in the following is intended to supplement the manufacturer's recommendations; when in doubt, the instrument manufacturer should be consulted.

8.3.1 Sensor Check

There are three types of action which can be considered a sensor check. First, one can look at and perform "housekeeping" services for the sensors. Secondly, one can measure some attribute of the sensor to detect deterioration in anticipation of preventative maintenance. Thirdly, the sensor can be subjected to a known condition whose consequence is predictable through the entire measurement system, including the sensor transducer. Each of these will be addressed for each variable, where appropriate, within the divisions of physical inspection and measurement and accuracy check with known input.

8.3.1.1 Physical inspection

The first level of inspection is visual. The anemometer and vane can be looked at, either directly or through binoculars or a telescope, to check for physical damage or signs of erratic behavior. Temperature shields can be checked for cleanliness. Precipitation gauges can be inspected for foreign matter which might effect performance. The static port for the atmospheric pressure system also can be examined for foreign matter. Solar radiation sensors should be wiped clean at every opportunity.

A better level of physical inspection is a "hands on" check. An experienced technician can feel the condition of the anemometer bearing assembly and know whether or not they are in good condition. This is best done with the aerodynamic shape (cup wheel, propeller, or vane) removed. Caution: Damage to anemometers and vanes is more likely to result from human handling than from the forces of the wind, especially during removal or installation and transport up and down a tower. The proper level of aspiration through a forced aspiration shield can be felt and heard under calm condition.

The best level of sensor check is a measurement. The anemometer and wind vane sensors have bearings which will certainly degrade in time. The goal is to change the bearings or the sensors before the instrument falls below operating specifications. Measurements of starting torque will provide the objective data upon which maintenance decisions can be made and defended. The presence, in routine calibration reports, of starting torque measurements will support the claim for valid data, if the values are less than the replacement torques.

The anemometer, identified by the serial number of the aerodynamic shape, should have a wind tunnel calibration report (see Section 8.1) in a permanent record folder. This is the authority for the transfer function (rate of rotation to wind speed) to be used in the next section. The temperature transducers, identified by serial number, should have calibration reports showing their conformity for at least three points to their generic transfer function (resistance to temperature, usually). These reports should specify the instruments used for the calibration and the method by which the instruments are tied to national standards (NBS). The less important sensors for solar radiation and atmospheric pressure can be qualified during an audit for accuracy.

8.3.1.2 Accuracy check with known input

Two simple tests will determine the condition of the anemometer (assuming no damage is found by the physical inspection). The aerodynamic shape must be removed. The shaft is driven at three known rates of rotation. The rates are known by independently counting shaft revolutions over a measured period of time in synchronization with the measurement system timing. The rates should be meaningful such as the equivalent of 2 m/s, 5 m/s and 10 m/s. Conversion of rates of rotation to wind speed is done with the manufacturer's transfer function or wind tunnel data. For example, if the transfer function is m/s = 1.412 r/s + 0.223, then rates of rotation of 1.3, 3.4 and 6.9 revolutions per second (r/s) would be equivalent to about 2, 5 and 10 m/s. All that is being tested is the implementation of the transfer function by the measuring system. The output should agree within one increment of resolution (probably 0.1 m/s). If problems are found, they might be in the transducer, although failures there are usually catastrophic. The likely source of trouble is the measurement system (signal conditioner, transmitting system, averaging system and recording system).

The second test is for starting torque. This test requires a torque watch or similar device capable of measuring in the range of 0.1 to 10 gm-cm depending upon the specifications provided by the manufacturer.

A successful response to these two tests will document the fact that the anemometer is operating as well as it did at receiving inspection, having verified threshold and accuracy. Changes in distance constant are not likely unless the anemometer design has changed. If a plastic cup is replaced by a stainless steel cup, for example, both the transfer function and the distance constant will likely be different. The distance constant will vary as the inverse of the air density. If a sea-level distance constant is 3.0 m, it may increase to 3.5 m in Denver and 4.3 m at the mountain passes in the Rockies.

For wind direction, a fixture holding the vane, or vane substitute, in positions with a known angle change is a fundamental challenge to the relative accuracy of the wind vane. With this method, applying the appropriate strategy for 360 or 540 degree systems, the accuracy of the sensor can be documented. The accuracy of the wind direction measurement, however, also depends on the orientation of the sensor with respect to true north.

The bearing to distant objects may be determined by several methods. The recommended method employs a solar observation (see Reference 3, p.11) to find the true north-south line where it passes through the sensor mounting location. Simple azimuth sighting devices can be used to find the bearing of some distant object with respect to the north-south line. The "as found" and "as left" orientation readings should report the direction to or from that distant object. The object should be one toward which the vane can be easily aimed and not likely to become hidden by vegetation or construction.

There are two parts of most direction vanes which wear out. One part is the bearing assembly and the other is the transducer, usually a potentiometer. Both contribute to the starting torque and hence the threshold of the sensor. A starting torque measurement will document the degradation of the threshold and flag the need for preventive maintenance. An analog voltmeter or oscilloscope is required to see the noise level of a potentiometer. Transducer noise may not be a serious problem with average values but it is likely to have a profound effect on σ_A.

The dynamic performance characteristics of a wind vane are best measured with a wind tunnel test. A generic test of a design sample is adequate. As with the anemometer, the dynamic response characteristics (threshold, delay distance and damping ratio) are density dependent.

Temperature transducers are reasonably stable, but they may drift with time. The known input for a temperature transducer is a stable thermal mass whose temperature is known by a standard transducer. The ideal thermal mass is one with a time constant on the order of an hour in which there are no thermal sources or sinks to establish local gradients within the mass. It is far more important to know what a mass temperature is than to be able to set a mass to a particular temperature.

For temperature difference systems, the immersion of all transducers in a single mass as described above will provide a zero-difference challenge accurate to about 0.01 °C. When this test is repeated with the mass at two more temperatures, the transducers will have been challenged with respect to how well they are matched and how well they follow the generic transfer function. Mass temperatures in the ranges of 0 to 10 °C, 15 to 25 °C, and 30 to 40 °C are recommended. A maximum difference among the three temperatures (i.e., 0, 20, and 40 °C) is optimum. Once the match has been verified, known resistances can be substituted for the transducers representing temperatures, according to the generic transfer function, selected to produce known temperature difference signals to the signal conditioning circuitry. This known input will challenge the circuitry for the differential measurement.

Precipitation sensors can be challenged by inserting a measured amount of water, at various reasonable rainfall rates such as 25 mm or less per hour. The area of the collector can be measured to calculate the amount of equivalent rainfall which was inserted. The total challenge should be sufficient to verify a 10% accuracy in measurement of water. This does not provide information about errors from siting problems or wind effects.

Dew point temperature (or relative humidity), atmospheric pressure and radiation are most simply challenged in an ambient condition with a collocated transfer standard. An Assmann psychrometer may be used for dew point. An aneroid barometer checked against a local National Weather Service instrument is recommended for atmospheric pressure. Another radiation sensor with some pedigree or manufacturer's certification may be used for pyranometers and net radiometers. A complete opaque cover will provide a zero check.

8.3.2 Signal Conditioner and Recorder Check

For routine calibration of measurement circuits and recorders, use the manufacturer's recommendations. The outputs required by the test described in 8.3.1.2 must be reflected in the recorded values. Wind speed is used as an example in this section. Other variables will have different units and different sensitivities but the principle is the same. For sub-system checks, use the manual for specific guidance.

8.3.2.1 Analog system

Some systems contain "calibration" switches which are designed to test the stability of the circuits and to provide a basis for adjustment if changes occur. These should certainly be exercised during routine calibrations when data loss is expected because of calibration. In the hierarchy of calibrations, wind tunnel is first, known rate of rotation is second, substitute frequency is third and substitute voltage is fourth. The "calibration" switch is either third or fourth.

If analog strip chart recorders are used, they should be treated as separate but vital parts of the measurement system. They simply convert voltage or current to a mark on a time scale printed on a continuous strip of paper or composite material. The output voltage or current of the signal conditioner must be measured with a calibrated meter during the rate of rotation challenge. A simple transfer function, such as 10 m/s per volt, will provide verification of the measurement circuit at the output voltage position. The recorder can be challenged separately by inputting known voltages and reading the mark on the scale, or by noting the mark position when the rate of rotation and output voltage are both known. See the recorder manual for recommendations should problems arise.

This special concern with recorders results from the variety of problems which analog recorders can introduce. A good measurement system can be degraded by an inappropriate recorder selection. If resolution is inadequate to distinguish between 1.3 m/s and 1.5 m/s, a 0.2 m/s accuracy is impossible. If enough resolution is just barely there, changes in paper as a function of relative humidity and changes in paper position as it passes the marking pen and excessive pen weight on the paper can be the limit of accuracy in the measurement. If the strip chart recorder is used only as a monitor and not as a backup for the primary system, its accuracy is of much less importance. The recorder from which data are recovered for archiving is the only recorder subject to measurement accuracy specifications.

8.3.2.2 Digital system

A digital system may also present a variety of concerns to the calibration method. One extreme is the digital system which counts revolutions or pulses directly from the sensor. No signal conditioning is used. All that happens is controlled by the software of the digital system and the capability of its input hardware to detect sensor pulses and only sensor pulses. The same challenge as described in 8.3.1.2 is used. The transfer function used to change rate of rotation to m/s should be found in the digital software and found to be the same as specified by the manufacturer or wind tunnel test. If any difference is found between the speed calculated from the known number of revolutions in the synchronous time period and the speed recorded in the digital recorder, a pulse detection problem is certain. A receiving inspection test may not uncover interference pulses which exist at the measurement site. For solution of this type of problem, see the digital recorder manufacturer's manual or recommendations.

A digital data logger may present different concerns. It may be a device which samples voltages, averages them, and transfers the average to a memory peripheral, either at the site or at the end of a communication link. Conversion to engineering units may occur at almost any point. The routine calibration should look at the output voltage of a signal conditioner as a primary point to assess accuracy of measurement. Analog to digital conversion, averaging and transmission and storage would be expected to degrade the measurement accuracy very little. Such functions should contribute less than 0.05 m/s uncertainty from a voltage input to a stored average value. If greater errors are found when comparing known rates of rotation and known signal conditioning output voltages to stored average wind speed values, check the data logger manual for specifications and trouble-shooting recommendations.

8.3.3 Calibration Data Logs

Site log books must record at least the following:

- Date and time of the calibration period (no valid data)
- Name of calibration person or team members

- Calibration method used (this should identify SOP number and data sheet used)
- Where the data sheet or sheets can be found on site
- Action taken and/or recommended

The data sheet should contain this same information along with the measurement values found and observations made. Model and serial numbers of equipment tested and used for testing must appear. The original report should always be found at the site location and a copy can be used for reports to management (a single-copy carbon form could be used). The truism that "it is impossible to have too many field notes" should be underscored in all training classes for operators and auditors.

8.3.4 Calibration Report

The calibration report may be as simple as copies of the calibration forms with a cover page, summary and recommendations. While the calibration forms kept at the site provide the basis for the operator or the auditor to trace the performance of the instrument system, the copies which become a part of the calibration report provide the basis for management action should such be necessary. The calibration report should travel from the person making out the report through the meteorologist responsible for the determination of data validity to the management person responsible for the project. Any problem should be highlighted with an action recommendation and a schedule for correction. As soon as the responsible management person sees this report the responsibility for correction moves to management, where budget control usually resides. A signature block should be used to document the flow of this information.

8.3.5 Calibration Schedule/Frequency

System calibration and diagnostic checks should be performed at six month intervals, or in accordance with manufacturer's recommendations, whichever is more frequent. The risk of losing data increases with the interval between operational checks. To reduce this risk, routine operational checks should be performed on a daily basis; these daily checks may be performed remotely. On-site inspections and maintenance should be performed on a weekly basis.

8.3.6 Data Correction Based on Calibration Results

Corrections to the raw data are to be avoided. A thorough documentation of an error clearly defined may result in the correction of data (permanently flagged as corrected). For example, if an operator changes the transfer function in a digital logger program and it is subtle enough not to be detected in the quality control inspection of the data stream, but is found at the next calibration, the data may be corrected. The correction can be calculated from the erroneous transfer function and applied to the period starting when the logger program was changed (determined by some objective method such as a log entry) and ending when the error was found and corrected.

Another example might be a damaged anemometer cup or propeller. If an analysis of the data points to the time when the damage occurred, a correction period can be determined. A wind tunnel test will be required to find a new transfer function for the damaged cup or propeller assembly. With the new transfer function defining the true speed responsible for a rate of rotation, and with the assumption that the average period is correctly represented by a steady rate of rotation, a correction can be made and flagged. This is a more risky example and judgment is required since the new transfer function may be grossly different and perhaps non-linear.

8.4 Audits

The audit function has two components, the system audit (in essence, a challenge to the QAPP) and the performance audit (a challenge to the individual measurement systems).

The system audit provides an overall assessment of the commitment to data validity; as such, all commitments made in the QAPP should be subject to challenge. Typical questions asked in the systems audit include: "are standard operating procedures being followed?", "is the station log complete and up-to-date?" All deficiencies should be recorded in the audit report along with an assessment of the likely effect on data quality. Corrective actions related to a systems audit should be obvious if the appropriate questions are asked.

The performance audit is similar to a calibration in terms of the types of activities performed (Section 8.3) - all the performance audit adds is an independent assurance that the calibrations are done correctly and that the documentation is complete and accurate. In the ideal case, when both the auditor and site operator are equally knowledgeable, the auditor functions as an observer while the site operator performs the calibration; in this instance the auditor functions in a "hands-off" mode. In initial audits, since newly hired site operators may have little or no experience with meteorological instruments, the hands-off approach may not be practical or desirable. In these instances, the audit may also function as a training exercise for the site operator.

8.4.1 Audit Schedule and Frequency

An initial audit should be performed within 30 days of the start-up date for the monitoring program. The 30-day period is a compromise between the need for early detection and correction of deficiencies and the time needed for shake-down and training. Follow-up audits should be conducted at six-month intervals.

8.4.2 Audit Procedure

To ensure against conflicts of interest, all audits should be conducted by individuals who are independent of the organizations responsible for the monitoring and/or using the data. This is especially important as the audit will be essential in any legal claims related to data validity. The audit should begin with a briefing stating the goals of the audit and the procedures to be employed - in addition, if any assistance is needed (e.g., in removing a wind vane from a tower) this would be the time to arrange such with the site technicians. An exit interview should be conducted when the audit is finished; management from the organizations involved should be present at both the initial briefing and the exit interview.

8.4.3 Corrective Action and Reporting

A corrective action program is an essential management tool for coordination of the QAQC process. Activities associated with the corrective action program include: review of procedures for reporting deficiencies, problem tracking, planning and implementing measures to correct problems, and tracking of problem resolution. Documentation of corrective actions is included with other information in support of data validity. A sample form for documenting corrective actions can be found in reference **[65]**.

An audit report should be completed and submitted within 30 days of the audit performance. This is an important document in that it provides a basis for any legal claims to data validity. As such, care should be taken to ensure that all statements related to data validity are supportable. Where possible the report should contain copies of the forms used in the audit.

8.5 Routine and Preventive Maintenance

Data quality is dependent on the care taken in routine and preventative maintenance. These functions are the responsibility of the site technicians; given their important QAQC role, they should be fully trained to maintain the equipment. The training program for the site technicians should be addressed in the QAPP. The following additional information on maintenance should also be included in the QAPP:

- A list the site technicians and their alternates
- Procedures and checklists for preventive maintenance
- Schedule for preventive maintenance
- Procedures for maintaining spare components
- A list of the components to be checked and/or replaced

Checklists are an essential component of a routine maintenance program and should be used as a matter of course. The instrument manuals should be used as the starting point for the checklist for each of instruments - a good manual should indicate what components need to be checked and how often. A station checklist should also be developed; this should include the following:

- A List of safety and emergency equipment.
- List of items to be inspected following severe weather.
- A checkoff to ensure there is adequate disk space for on-site storage of the raw data.

- A checkoff to indicate that backup of data has been completed.
- A checkoff to indicate that clocks have been checked and adjusted as necessary.
- A checkoff for the cables and guy wires securing the equipment.

All routine and preventive maintenance activities should be recorded in the station log and/or on the appropriate checklist. The station log and checklist provide the necessary paper trail to support claims of accuracy.

8.5.1 Standard Operating Procedures

Standard operating procedures (SOPs) should be developed that are specific to the operations at a given site. The purpose of an SOP is to spell out operating and QC procedures with the ultimate goal of maximizing data quality and data capture rates. Operations should be performed according to a set of well defined, written SOPs with all actions documented in logs and on prepared forms. SOPs should be written in such a way that if problems are encountered, instructions are provided on actions to be taken. At a minimum, SOPs should address the following:

- Installation, setup, and checkout
- Site operations and calibrations
- Operational checks and preventive maintenance
- Data collection protocols
- Data validation steps
- Data archiving

8.5.2 Preventive Maintenance

8.5.2.1 Wind Speed

The anemometer has just one mechanical system which will benefit from preventive maintenance. That is the bearing assembly. There are two strategies from which to choose. One is to change the bearings (or the entire instrument if a spare is kept for that purpose) on a scheduled basis and the other is to make the change when torque measurements suggest change is in order. The former is most conservative with respect to data quality assuming that any time a torque measurement indicates a bearing problem, the bearing will be changed as a corrective maintenance action.

As routine calibrations become less frequent (8.3.5), the probability increases that a starting torque measurement will be made which indicates the anemometer is outside its performance specification. This will effect both the threshold (by increasing it) and the transfer function (by moving the non-linear threshold toward high speeds). It is unlikely that corrections can be properly made to the data in this case. The consequence might be the loss of a half-year's data, if that is the period for routine calibration. If experience indicates that the anemometer bearing assembly shows serious wear at the end of one year or two years (based on torque measurements), a routine change of bearings at that frequency is recommended.

8.5.2.2 Wind Direction

The wind vane usually has two mechanical systems which will benefit from preventive maintenance. The bearing assembly is one and can be considered in the same way as the anemometer bearing assembly described above. The other is the potentiometer which will certainly "wear out" in time. The usual mode of failure for a potentiometer is to become noisy for certain directions and then inoperative. The noisy stage may not be apparent in the average direction data. If σ_A is calculated, the noise will bias the value toward a higher value. It will probably not be possible to see early appearance of noise in the σ_A data. When it becomes obvious that the σ_A is too high, some biased data may already have been validated and archived. Systems with time constant circuits built into the direction output will both mask the noise from the potentiometer (adding to the apparent potentiometer life) and bias the σ_A toward a lower value. Such circuits should not be used if they influence the actual output capability of the sensor. Each manufacturer may be different in their selection of a source and specifications used in buying potentiometers. The operator needs to get an expected life for the potentiometer from the manufacturer and monitor the real life with a noise sensitive test. An oscilloscope is best and can be used without disrupting the measurement. When potentiometer life expectations have been established, a preventive maintenance replacement on a conservative time basis is recommended.

8.5.2.3 Temperature and Temperature Difference

Aspirated radiation shields use fans which will also fail in time. The period of this failure should be several years. The temperature error resulting from this failure will be easily detected by a QC meteorologist inspecting the data. Some aspirated radiation shields include an air flow monitoring device or a current check which will immediately signal a disruption in aspiration. Preventive maintenance is not required but spare fans should be on the shelf so that a change can be made quickly when failure does occur.

8.5.2.4 Dew Point Temperature

Field calibration checks of the dew point temperature measurement system can be made with a high-quality Assmann-type or portable, motor-aspirated psychrometer. Sling psychrometers should not be used. Several readings should be taken at the intake of the aspirator or shield at night or under cloudy conditions during the day. These field checks should be made at least monthly, or in accordance with manufacturer's suggestions, and should cover a range of relative humidity values.

Periodically (at least quarterly) the lithium chloride in dew cells should be removed and recharged with a fresh solution. The sensor should be field-checked as described above before and at least an hour after the lithium chloride solution replacement.

If cooled-mirror type dew point systems are used, follow the manufacturer's service suggestions initially. The quality of the data from this method of measurement is dependent upon the mirror being kept clean. The frequency of service required to keep the mirror clean is a function of the environment in which the sensor is installed. That environment may vary with seasons or external weather conditions. If changes in dew point temperature of a magnitude larger than can be tolerated are found after service scheduled according to the manufacturer's suggestion, increase the service frequency until the cleaning becomes preventive maintenance rather than corrective service. This period will vary and can be defined only by experience. Station log data must include the "as found" and the "as left" measurements. Dew point temperature does not change rapidly (in the absence of local sources of water) and the difference between the two measurements will usually be the instrument error due to a dirty mirror.

8.5.2.5 Precipitation

The gauge should be inspected at regular intervals using a bubble level to see that the instrument base is mounted level. Also, the bubble level should be placed across the funnel orifice to see that it is level. The wind screen should also be checked to see that it is level, and that it is located l/2 inch above the level of the orifice, with the orifice centered within the screen.

8.5.2.6 Pressure

The output of the pressure sensor should be regularly checked against a collocated instrument. A precision aneroid barometer can be used for this check. The collocated barometer should be occasionally checked against a mercurial barometer reading at a nearby NWS station.

8.5.2.7 Radiation

The optical hemispheres on pyranometers and net radiometers should be cleaned frequently (preferably daily) with a soft, lint-free cloth. The surfaces of the hemispheres should be regularly inspected for scratches or cracks. The detectors should be regularly inspected for any discoloration or deformation. The instruments should be inspected during cool temperatures for any condensation which may form on the interior of the optical surfaces.

While calibrations must be done by the manufacturer, radiation can be field-checked using a recently-calibrated, collocated instrument. Since signal processing is particularly critical for these sensors, the collocated instrument should also use its own signal conditioner and data recording system for the check. This kind of field check should be done every six months.

It is mandatory to log "as found" and "as left" information about the parts of the system which seem to require work. Without this information it becomes difficult, if not impossible, to assess what data are usable and what are not.

8.6 Data Validation and Reporting

Data validation is a process in which suspect data are identified and flagged for additional review and corrective action as necessary. The data validation process provides an additional level of quality assurance for the monitoring program. Some problems that may escape detection during an audit (e.g., a wind vane that occasionally gets stuck) are often easily identified during data validation.

Data validation should be performed by a person with appropriate training in meteorology who has a basic understanding of local meteorological conditions and the operating principles of the instruments.

8.6.1 Preparatory Steps

Preparatory steps prior to data validation include: collection and storage of the raw data, backup, data reduction, transfer of data off-site, and preliminary review. These steps are discussed in the following:

- Collection and storage on-site (as appropriate) of the "raw" signals from the sensors, followed by real-time processing of the "raw" data by the data acquisition system to produce reduced, averaged values of the meteorological variables. The reduced data are stored on the data acquisition system's computer, usually in one or more ASCII files.
- Transfer of the reduced data to a central data processing facility at regular intervals (e.g., daily). Once the data are received at the central facility, they should be reviewed by an experienced data technician as soon as possible to verify the operational readiness of the monitoring site. Backup copies of the data should be prepared and maintained on-site and off-site.

Data collected by the monitoring systems can usually be obtained by polling the data system at a site from the central facility using a personal computer, modem, and standard telecommunications software. Other options that are available for communications with a remote site include leased-line telephone service, local or wide area network (LAN, WAN) connections, Internet access, and satellite telemetry. For immediate turnaround of data, the operator can transfer the data to the central facility using a personal computer equipped with a modem and communications software.

8.6.2 Levels of Validation

A level of validation, for the purposes of this guidance, is a numeric code indicating the degree of confidence in the data. These levels provide some commonality among data collected and quality controlled by different agencies, and help ensure that all data have received a comparable level of validation. Various data validation "levels" that apply to air quality and meteorological data have been defined by Mueller and Watson **[66]** and Watson et al. **[67]**. Basically, four levels of data validation have been defined:

- **Level 0** data validation is essentially raw data obtained directly from the data acquisition systems in the field. Level 0 data have been reduced and possibly reformatted, but are unedited and unreviewed. These data have not received any adjustments for known biases or problems that may have been identified during preventive maintenance checks or audits. These data should be used to monitor the instrument operations on a frequent basis (e.g., daily), but should not be used for regulatory purposes until they receive at least Level 1 validation.
- **Level 1** data validation involves quantitative and qualitative reviews for accuracy, completeness, and internal consistency. Quantitative checks are performed by software screening programs (**see Section 8.7.3.2**) and qualitative checks are performed by meteorologists or trained personnel who manually review the data for outliers and problems. Quality control flags, consisting of numbers or letters, are assigned to each datum to indicate its quality. A list of suggested quality control codes is given in Table 8-3. Data are only considered at Level 1 after final audit reports have been issued and any adjustments, changes, or modifications to the data have been made.
- **Level 2** data validation involves comparisons with other independent data sets. This includes, for example, intercomparing collocated measurements or making comparisons with other upper-air measurement systems.
- **Level 3** validation involves a more detailed analysis when inconsistencies in analysis and modeling results are found to be caused by measurement errors.

8.6.3 Validation Procedures

All necessary supporting material, such as audit reports and any site logs, should be readily available for the level 1 validation. Access to a daily weather archive should be provided for use in relating suspect data with to local and regional meteorological conditions. Any problem data, such as data flagged in an audit, should be corrected prior to the level 1 data validation. The validation procedures described in the following include screening, manual review, and comparison.

Table 8-3

Suggested quality control (QC) codes for meteorological data.

Code	Meaning	Description
0	Valid	Observations that were judged accurate within the performance limits of the instrument.
1	Estimated	Observations that required additional processing because the original values were suspect, invalid, or missing. Estimated data may be computed from patterns or trends in the data (e.g., via interpolation), or they may be based on the meteorological judgment of the reviewer.
2	Calibration applied	Observations that were corrected using a known, measured quantity (e.g., instrument offsets measured during audits).
3	Unassigned	Reserved for future use.
4	Unassigned	Reserved for future use.
5	Unassigned	Reserved for future use.
6	Failed automatic QC check	Observations that were flagged with this QC code did not pass screening criteria set in automatic QC software.
7	Suspect	Observations that, in the judgment of the reviewer, were in error because their values violated reasonable physical criteria or did not exhibit reasonable consistency, but a specific cause of the problem was not identified (e.g., excessive wind shear in an adiabatic boundary layer). Additional review using other, independent data sets (Level 2 validation) should be performed to determine the final validity of suspect observations.
8	Invalid	Observations that were judged inaccurate or in error, and the cause of the inaccuracy or error was known (e.g., winds contaminated by ground clutter or a temperature lapse rate that exceeded the autoconvective lapse rate). Besides the QC flag signifying invalid data, the data values themselves should be assigned invalid indicators.
9	Missing	Observations that were not collected.

8.6.3.1 Data Screening

Screening procedures generally include comparisons of measured values to upper and lower limits; these may be physical limits, such as an instrument threshold, or may be established based on experience or historical data. Other types of procedures employed in screening include assessments based on the rate of change of a variable (in these data that change too rapidly or not at all are flagged as suspect) and assessments based on known physical principles relating two or more variables (e.g., the dew point should never exceed the dry-bulb temperature).

Screening may be regarded as an iterative process in which range checks and other screening criteria are revised as necessary based on experience. For example, an initial QA pass of a data set using default criteria may flag values which upon further investigation are determined to be valid for the particular site. In such cases, one or more follow-up QA passes using revised criteria may be necessary to clearly segregate valid and invalid data. Suggested screening criteria are listed in Table 8-4. Data which fail the screening test should be flagged for further investigation.

8.6.3.2 Manual Review

The manual review should result in a decision to accept or reject data flagged by the screening process. In addition, manual review may help to identify outliers that were missed by screening. This review should be performed by someone with the necessary training in meteorological monitoring.

In the typical manual review, data should be scanned to determine if the reported values are reasonable and in the proper format. Periods of missing data should be noted and investigated. Data should also be evaluated for temporal consistency. This is particularly useful for identifying outliers in hourly data. Outliers should be reviewed with reference to local meteorological conditions. Data are considered to be at Level 1 validation following the manual review and can be used for modeling and analysis.

8.6.3.3 Comparison Program

After the data have passed through the screening program, they should be evaluated in a comparison program. Randomly selected values should be manually compared with other available, reliable data (such as, data obtained from the nearest National Weather Service observing station). At least one hour out of every 10 days should be randomly selected. To account for hour-to-hour variability and the spatial displacement of the NWS station, a block of several hours may be more desirable. All data selected should be checked against corresponding measurements at the nearby station(s). In addition, monthly average values should be compared with climatological normals, as determined by the National Weather Service from records over a 30-year period. If discrepancies are found which can not be explained by the geographic difference in the measurement locations or by regional climatic variations, the data should be flagged as questionable.

Table 8-4

Suggested Data Screening Criteria

Variable	Screening Criteria: Flag data if the value
Wind Speed	- is less than zero or greater than 25 m/s
	- does not vary by more than 0.1 m/s for 3 consecutive hours
	- does not vary by more than 0.5 m/s for 12 consecutive hours
Wind Direction	- is less than zero or greater than 360 degrees
	- does not vary by more than 1 degree for more than 3 consecutive hours
	- does not vary by more than 10 degrees for 18 consecutive hours
Temperature	- is greater than the local record high
	- is less than the local record low
	(The above limits could be applied on a monthly basis.)
	- is greater than a 5°C change from the previous hour
	- does not vary by more than 0.5°C for 12 consecutive hours
Temperature Difference	- is greater than 0.1°C/m during the daytime
	- is less than -0.1°C/m during the night time
	- is greater than 5.0°C or less than -3.0°C
Dew Point Temperature	- is greater than the ambient temperature for the given time period
	- is greater than a 5°C change from the previous hour
	- does not vary by more than 0.5°C for 12 consecutive hours
	- equals the ambient temperature for 12 consecutive hours
Precipitation	- is greater than 25 mm in one hour
	- is greater than 100 mm in 24 hours
	- is less than 50 mm in three months
	(The above values can be adjusted based on local climate.)
Pressure	- is greater than 1060 mb (sea level)
	- is less than 940 mb (sea level)
	(The above values should be adjusted for elevations other than sea level.)
	- changes by more than 6 mb in three hours
Radiation	- is greater than zero at night
	- is greater than the maximum possible for the date and latitude

8.6.3.4 Further Evaluations

Any data which are flagged by the screening program or the comparison program should be evaluated by personnel with meteorological expertise. Decisions must be made to either accept the flagged data, or discard and replace it with back-up or interpolated data, or data from a nearby representative monitoring station (see Section 1). Any changes in the data due to the validation process should be documented as to the reasons for the change. If problems in the monitoring system are identified, corrective actions should also be documented. Any edited data should continue to be flagged so that its reliability can be considered in the interpretation of the results of any modeling analysis which employs the data.

8.6.4 Schedule and Reporting

Data should be retrieved on a daily basis and reviewed for reasonableness to ensure that the instrument is operating properly. Level 1 data validation should be performed as frequently as possible (e.g., bi-weekly or monthly). At a minimum, validation should be done weekly for the first month after the instrument is installed, so that any potential problems can be identified and quickly resolved to avoid significant data losses.

It is important to maintain detailed, accurate records of changes to the data and the data quality control codes. These records will save time and effort if questions arise about specific data at a later date. Reports should include the following information:

- Who performed the quality control validation, type of data validated, and when the validation was completed.
- Any adjustments, deletions, or modifications, with a justification or reason for the change.
- Identification of data points that were flagged as suspect or invalid, and the reason why they were flagged.
- Systematic problems that affected the data.

8.7 Recommendations

Quality Assurance/Quality Control (QAQC) procedures should be documented in a Quality Assurance Project Plan (QAPP) and approved by the appropriate project or organizational authority. These procedures should provide quantitative documentation to support claims of accuracy and should be conducted by persons independent of the organization responsible for the collection of the data and the maintenance of the measurement systems.

Procurement documents for meteorological monitoring systems should include the specifications for instrument systems and should identify the test method by which conformance with the specification will be determined. Persons responsible installing meteorological systems should review documentation provided on conformance-testing and should conduct independent *acceptance tests to verify claims of accuracy. All acceptance-testing activities should be documented in the station log.*

Routine system calibrations and system audits should be performed at the initiation of a monitoring program (within 30 days of start-up) and at least every six months thereafter. More frequent calibrations and audits may be needed in the early stages of the program if problems are encountered, or if valid data retrieval rates are unacceptably low. Documentation of all calibrations should include a description of the system "as found", details of any adjustments to the instrument, and a description of the system "as left"; this documentation is necessary for any claims of data validity.

Regular and frequent routine operational checks of the monitoring system are essential to ensuring high data retrieval rates. These should include visual inspections of the instruments for signs of damage or wear, inspections of recording devices to ensure correct operation and periodic preventive maintenance. The latter should include periodic checks of wind speed and wind direction bearing assemblies, cleaning of aspirated shield screens in temperature systems, removal and recharging (at least quarterly) of lithium chloride dew cells, cleaning of the mirror in cooled mirror dew cells, clearing the precipitation gauge funnel of obstructing debris, and frequent (preferably daily) cleaning of the optical surface of a pyranometer or net radiometer. Also crucial to achieving acceptable valid data retrieval rates is the regular review of the data by an experienced meteorologist. This review should include visual scanning of the data, and automated screening and comparison checks to flag suspect data. This review should be performed weekly, and preferably on a daily basis.

9. UPPER-AIR MONITORING

This section provides guidance for the most widely used technologies employed for monitoring upper-air meteorological conditions; these include radiosondes and ground-based remote sensing platforms: sodar (Sound Detection and Ranging), radar (Radio Detection and Ranging), and RASS (Radio Acoustic Sounding System). While they are not covered in detail, other (emerging) technologies such as lidar (Light Detection and Ranging) may provide alternative means for the collection of upper-air meteorological data.

The material is organized such that information necessary to the understanding of the technology (Sections 9.1 through 9.3) precedes the guidance (Sections 9.4 through 9.7). The sections are as follows: Section 9.1 provides information necessary to the understanding of balloon-based sounding instruments and ground-based remote sensing technologies. Section 9.2 provides information on the performance characteristics of these systems; Section 9.3 discusses monitoring objectives and goals for monitoring of the boundary layer in support of air quality dispersion modeling; Section 9.4 provides guidance on siting and exposure of upper-air monitoring systems; Section 9.5 provides guidance on installation and acceptance testing; Section 9.6 provides guidance on quality assurance; and Section 9.7 provides guidance for data processing and management.

9.1 Fundamentals

Table 9-1 provides an overview of the upper-air monitoring systems included in this guidance. Necessary details describing the operation of each of the monitoring platforms [Radiosonde (9.1.2), Doppler Sodar (9.1.3), Radar Wind Profiler (9.1.4), and RASS (9.1.5)] is preceded by a description of the various meteorological variables that are measured by, or derived from measurements obtained with these platforms

9.1.1 Upper-Air Meteorological Variables

Meteorological variables measured/reported in upper-air monitoring programs include wind direction, wind speed, pressure, temperature, and humidity. With some exceptions (e.g., radiosonde measurements of pressure, temperature, and humidity), the upper-air data for these variables are based on indirect measurements; i.e., the desired variable is derived from measurements of other variables which are measured directly. This is a significant difference from the in situ measurements of these variables; i.e., when monitored in situ (such as from a meteorological tower) these variables are measured directly. This difference has significant implications for calibrations and audits of upper-air measurement systems (see Section 9.6).

Fundamentals related to upper-air monitoring of wind, pressure, temperature, and humidity are presented in the following. This is followed by information on estimating mixing heights and stability for use in dispersion modeling. Although the latter are often included in discussions of upper-air meteorological conditions, they are not really upper-air variables; a more accurate classification of mixing height would describe it as a boundary layer variable which can be derived from upper-air measurements. Stability, as defined for use in dispersion modeling, is a surface layer variable and is not necessarily related to or correlated with upper-air measurements.

Wind Upper-air wind speeds and wind directions are vector-averaged measurements. None of the measurement systems described in the following sections provide a means to measure winds as scaler quantities, as is done with cup and vane sensors mounted on an instrumented tower. While tower-based measurements near the surface are easily obtained, there are very few instrumented tall towers that can provide vertical profiles of upper-air winds over the altitudes needed for some air quality applications.

Upper-air wind data comprise either path averages (radiosondes) or volume averages (remote sensors) rather than point measurements. For air quality programs, where the interest is mainly to characterize winds in the atmospheric boundary layer (ABL) and lower troposphere, radiosonde data are typically averaged over vertical layers with a depth of approximately 45 to 75 meters (m). Wind data provided by sodars are typically averaged over layers that are 5 to 100 m deep, while radar wind profiler data are usually averaged over 60 to 100 meter intervals. The altitude at which the winds are reported is assumed to be the mid-point of the layer over which the winds are averaged. Averaging periods for upper-air wind data also vary depending on the instrument system used. An individual wind data report from a radiosonde sounding system is typically averaged over no more than 30 to 120 seconds, representing averages of 60 to 700 meters. The averaging interval for winds measured by sodars and radar profilers is usually on the order of 15 to 60 minutes.

Upper-air wind data are needed to accurately characterize upper-air transport. For example, observing and resolving the vertical shear of the horizontal wind (both speed and directional changes with height) can be important for air quality model applications. Figure 9-1 shows a plot of upper-air winds measured by a radiosonde sounding system, along with simultaneous profiles of temperature, dew-point temperature, and potential temperature. The wind data are represented in the “wind barb” format, in which the direction of the wind is indicated by the orientation of an arrow's shaft (relative to true north, which is toward the top of the figure), and the wind speed is indicated by the number and length of barbs attached to the shaft. Note the change in wind speed and direction that is evident in the first few hundred meters of the sounding. In this case, below about 280 meters the winds are east-southeasterly. Above this level the winds veer (turn clockwise) with height to become southerly, southwesterly, then westerly. This is a simple example of a pattern that is common in upper-air measurements; in fact, much more complex wind shear conditions are often observed. Wind shear conditions can have important implications with respect to air quality, because of the different transport and turbulence conditions that can exist at different altitudes where air pollutants may be present.

Shear patterns such as those depicted in Figure 9-1 occur in part because of the frictional drag exerted on the atmosphere by the earth's surface. The atmospheric boundary layer is generally defined as the layer of the atmosphere within which the dynamic properties (i.e., winds) and thermodynamic properties (i.e., temperature, pressure, moisture) are directly influenced by the earth's surface. Factors that influence the vertical distribution of winds include horizontal gradients in temperature (thermal wind effects), the development of local temperature and pressure gradients in shoreline settings (land/sea-breeze circulations) and complex terrain environments (mountain-valley airflows), vertical momentum transport by turbulent eddies, and diurnal reductions in frictional stress at night that can lead to the formation of low-level jets. Processes such as these are described in references **[68]** and **[69]**; examples of the effects of such circulations on air quality are described in reference **[70]**.

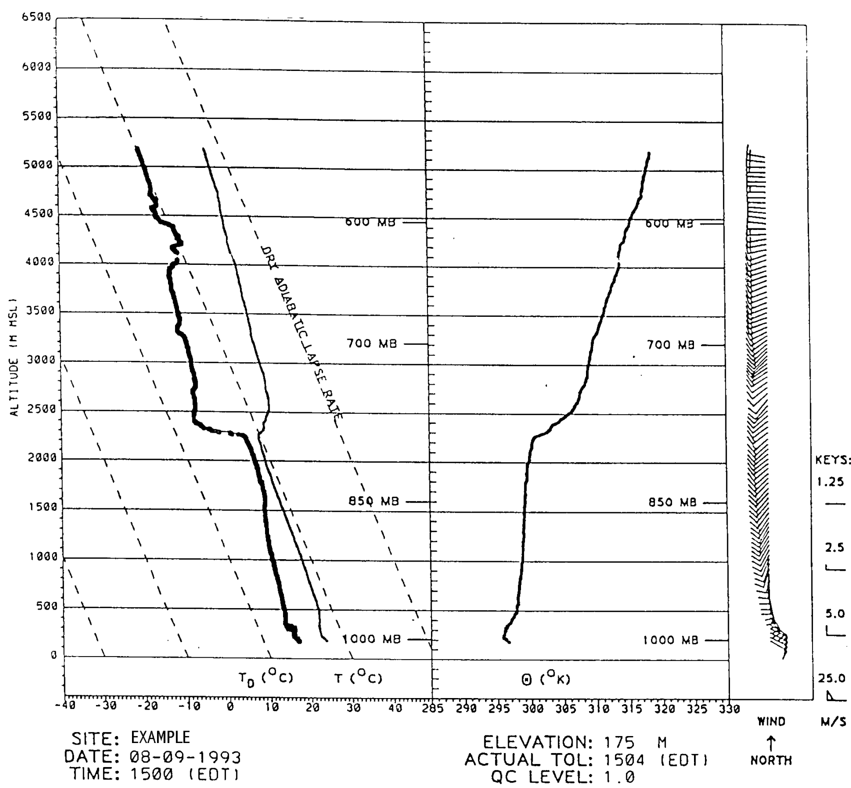

Figure 9-1 Example wind and temperature profiles from a radiosonde sounding system.

Consequently, upper-air wind data are critical to air quality analysis and modeling efforts. The data are used for the assessment of transport characteristics, as direct input to Gaussian dispersion models, and in the initialization and application of meteorological models (that are used to prepare time-varying, three-dimensional meteorological fields for puff and grid-based air quality models).

Upper-air wind speeds are almost always reported in units of meters per second (ms^{-1}) or knots (nautical miles per hour). Wind direction is reported as the direction from which the wind is blowing in degrees (clockwise) relative to true north. Altitude is usually reported in meters or feet and must be defined as corresponding to height above mean sea level or height above ground level. Radiosonde data are typically reported as height above mean sea level (msl), whereas wind data collected by the remote sensing systems are often reported as height above ground level (agl).

Some remote sensing systems described in these guidelines provide a measure of vertical velocity. To date, however, little use has been made of these data in air quality modeling or data analysis applications. Additional work is needed (possibly on a case-by-case basis) to determine the utility of these data for air quality applications.

Pressure Vertical profiles of atmospheric pressure are measured during radiosonde ascents. The remote sensing systems considered in this document do not measure pressure. Pressure data are critical for radiosonde soundings because they are used to calculate the altitude of the sonde (strictly speaking, the geopotential altitude). Differential global position systems (GPS) rawinsonde systems are being developed that will be able to measure the altitude of the sonde directly, but pressure data will still be needed to support many modeling and data analysis efforts. For air quality purposes, pressure data are used in the application of meteorological models, and as direct input to air quality models. Pressure is reported in units of millibars (mb) or hectopascals (hPa).

Temperature Upper-air temperature measurements are most commonly obtained using radiosonde sounding systems. Radiosonde temperature measurements are point measurements. These can be obtained every few seconds, yielding a vertical resolution of a few meters to about 10 m, depending on the rate of ascent of the balloon.

Temperature data can also be obtained using RASS. RASS temperature measurements are volume averages, with a vertical resolution comparable to that of the wind measurements reported by the remote sensing systems (i.e., 50 to 100 m). RASS measures the virtual temperature (T_v) of the air rather than the dry-bulb temperature (T). The virtual temperature of an air parcel is the temperature that dry air would have if its pressure and density were equal to those of a parcel of moist air, and thus T_v is always higher than the dry-bulb temperature. Under hot and humid conditions, the difference between T_v and T is usually on the order of a few (2 to 3) degrees C; at low humidity, differences between T_v and T are small. Given representative moisture and pressure profiles, temperature can be estimated from the virtual temperature measurements.

Temperature data are used widely in air quality analysis and modeling, including the application and evaluation of meteorological models, and as direct input to air quality models. The vertical temperature structure (stability) influences plume rise and expansion and thus the vertical exchange of pollutants. Temperature also affects photolysis and chemical reaction rates. Temperature is reported in degrees Celsius (°C) or Kelvins (K).

Moisture Like pressure, upper-air moisture measurements suitable for air quality applications are primarily obtained using radiosonde sounding systems. The sampling frequency and vertical and temporal resolution of the moisture data are the same as the other thermodynamic variables measured by these systems. Moisture is most commonly measured directly as relative humidity (RH), and is reported as percent RH or as dew-point temperature (T_d) in °C (or frost point temperature). Dew-point depression, the difference between temperature and dew-point temperature ($T - T_d$), is also a commonly reported variable. Some radiosonde sounding systems measure the wet-bulb temperature instead, and determine RH and dew-point temperature through the psychrometric relationship.

Upper-air moisture profiles are used in the initialization and application of meteorological models, and as direct input to air quality models. Moisture data can be important to a successful meteorological modeling effort, because the accurate simulation of convective development (clouds, precipitation, etc.) depends on an accurate representation of the three-dimensional moisture field. Upper-air moisture data are also useful to the understanding of the formation and growth of aerosols, which grow rapidly at high relative humidity (90 to 100 percent).

Mixing Height For the purposes of this guidance, mixing height is defined as the height of the layer adjacent to the ground over which an emitted or entrained inert non-buoyant tracer will be mixed (by turbulence) within a time scale of about one hour or less (adapted from Beyrich **[43]** . This concept of a mixing height was first developed for characterizing dispersion in a daytime convective boundary layer (CBL). Since tracer measurements are impractical for routine application, alternative methods are recommended for estimating mixing heights based on more readily available data (Table 9-2). The Holzworth method **[44]** is recommended for use when representative NWS upper-air data are available. This procedure relies on the general theoretical principle that the lapse rate is roughly dry adiabatic (no change in potential temperature with height) in a well-mixed daytime convective boundary layer (CBL); the Holzworth method is described in Section 6.5.1. Other alternatives include using estimates of mixing heights provided in CBL model output (references **[45]** and **[46]**). Mixing heights derived from remote sensing measurements of turbulence or turbulence related parameters are discussed in the following.

Turbulence, or turbulence related measurements (e.g, backscatter measurements from a sodar or refractive index measurements from a radar wind profiler) though not surrogates for an inert tracer can sometimes be used to estimate mixing heights since, under certain conditions, such measurements correlate with the top of the mixed layer. In looking at these measurements, one attempts to determine depth of the layer adjacent to the surface within which there is continuous or intermittent turbulence; this is a non-trivial exercise since turbulence varies considerably, not only with height, but with time and location. This variability is dependent upon which processes control/dominate the production of turbulence near the surface; these processes are discussed in the following.

The production of turbulent eddies during the daytime is dominated (under clear sky conditions) by heating of the ground surface and (under overcast conditions) by frictional drag. Daytime vertical mixing processes can be vigorous (especially under convective -conditions) and can produce a well mixed or nearly uniform vertical concentration profile of an inert tracer. During the nighttime, there are several processes that contribute to the production of turbulence including wind shear (created near the ground by friction), variations in the geostrophic wind, and the presence of a low-level jet (wind shear both below and above the jet can enhance turbulence). Nighttime vertical mixing processes are typically patchy and intermittent, and not capable of producing a well-mixed uniform vertical concentration profile.

Table 9-2

Methods for Determining Mixing Heights

Platform	Variable Measured	Advantages/limitations
Aircraft LIDAR	Inert tracer	Consistent with the definition of mixing height as used in dispersion modeling. Labor intensive, not practical for routine applications.
Rawinsonde	Potential temperature	A relatively robust technique for estimating the daytime (convective) mixing depth. Limited by the non-continuous nature of rawinsonde launches.
Sodar	Turbulence Acoustic backscatter	Used for continuous monitoring of boundary layer conditions. The range of a sodar, however, is limited; estimates of the mixing height are possible only when the top of the mixed layer is within the range of the sodar. A good tool for monitoring the nocturnal, surface-based temperature inversion - although different from the mixing height, the nocturnal inversion is equally important for modeling nocturnal dispersion conditions.
Radar wind profiler	Refractive index	Used for continuous monitoring of boundary layer conditions.
RASS	Virtual temperature	The virtual temperature profile obtained using a RASS is used to estimate the convective mixing height in the same manner that temperature data are used (limited to the range of the RASS ≈ 1 km..).

Wind turbulence parameters and/or acoustic backscatter profiles derived from sodar data can also be used to estimate mixing height. These data can be used for both daytime and nighttime conditions, but only when the top of the mixing height is within the range of the sodar.

The refractive index structure parameter (C_n^2) calculated from radar wind profiler reflectivity measurements can also be used to estimate mixing height **[71]**. During nighttime hours, however, the mixing height may be below the range of the radar wind profile.

The virtual temperature profile obtained using a RASS instrument can be used to estimate convective mixing height in the same manner that temperature data are used; this is possible only when the mixing height is within the range of the RASS.

Turbulence Some sodars report wind turbulence parameters. In using these parameters, one must remember that sodars measure the vector components of the wind. Furthermore, there may be significant differences in time and space between the sampling of the components so that any derived variables using more than one component may be affected by aliasing. Thus, the derived turbulence parameters from sodars are generally not the same parameters that models expect for input. Numerous studies have been performed comparing sodar-based turbulence statistics with tower-based turbulence statistics. Findings from these studies have generally shown that measurements of the standard deviation of the vertical component of the wind speed (σ_w) are in reasonable agreement , while the standard deviation calculations incorporating more than one component (e.g., σ_θ) are not **[72]**. It is therefore recommended that, unless models are designed to use sodar-type statistical parameters, the use of derived turbulence parameters be limited to single component calculations such as σ_w. Note however that the utility of σ_w will depend upon the resolution of the sodar system.

9.1.2 Radiosonde Sounding System

Radiosonde sounding systems use *in situ* sensors carried aloft by a small, balloon-borne instrument package (the radiosonde, or simply “sonde”) to measure vertical profiles of atmospheric pressure, temperature, and moisture (relative humidity or wet bulb temperature) as the balloon ascends. In the United States, helium is typically used to inflate weather balloons. Hydrogen is also used. The altitude of the balloon is typically determined using thermodynamic variables or through the use of satellite-based Global Positioning Systems (GPS). Pressure is usually measured by a capacitance aneroid barometer or similar sensor. Temperature is typically measured by a small rod or bead thermistor. Most commercial radiosonde sounding systems use a carbon hygristor or a capacitance sensor to measure relative humidity directly, although a wet-bulb sensor is also used by some systems. With a wet bulb, relative humidity and dewpoint are calculated from psychrometric relationships. Ventilation of the sensors occurs as the balloon rises. The temperature sensor is usually coated to minimize radiational heating effects. The humidity sensor is usually shielded in a ventilated duct inside the sonde's enclosure to minimize exposure to solar radiation.

A radiosonde includes electronic subsystems that sample each sensor at regular intervals (e.g., every 2 to 5 seconds), and transmit the data to a ground-based receiver and data acquisition system. Power for the radiosonde is provided by small dry-cell or wet-cell batteries. Most commercial radiosonde systems operate at 404 MHZ or 1680 MHZ. Once the data are received at the ground station, they are converted to engineering units based on calibrations supplied by the manufacturer. The data acquisition system reduces the data in near-real time, calculates the altitude of the balloon, and computes wind speed and direction aloft based on information obtained by the data systems on the position of the balloon as it is borne along by the wind. Commercial systems available today are relatively compact and easy to operate. The radiosondes are typically smaller than a shoebox and weigh only a few hundred grams. Thus, the previous need to use a parachute to slow the radiosonde's descent after the balloon has burst has greatly diminished, although the manufacturer should still be consulted on this matter. The data systems are either personal computer (PC)-based, or self-contained with standard PC-type computer interfaces for data communications (e.g., RS-232). Data are stored on conventional PC-type hard disks and/or diskettes.

Upper-air winds (horizontal wind speed and direction) are determined during radiosonde ascents by measuring the position of the radiosonde relative to the earth's surface as the balloon ascends. By measuring the position of the balloon with respect to time and altitude, wind vectors can be computed that represent the layer-averaged horizontal wind speed and wind direction for successive layers. The position data have typically been obtained using radio direction finding techniques (RDF) or one of the radio navigation (NAVAID) networks. The use of satellite-based GPS is becoming more common.

RDF systems use a tracking device called a radio theodolite to measure the position of the balloon relative to the ground station. The radio theodolite, which resembles a small tracking radar system, measures the azimuth and elevation angles to the radiosonde relative to the ground station. The radio theodolite automatically follows the motion of the balloon by tracking the primary lobe of the radiosonde's transmitter, making adjustments to the tilt and pointing direction of the antenna as it follows the signal from the sonde. The azimuth, elevation, and altitude information is then used by the data system to compute the length and direction of a vector projected onto the earth's surface that represents the resultant motion of the balloon over some suitable averaging period, typically 30 to 120 seconds.

With NAVAID systems, the radiosonde's position is determined by triangulation relative to the locations of the fixed NAVAID transmitters. The radiosonde and ground station have electronic subsystems to measure the time delay in the transmissions from the NAVAID sites and to convert this information into the relative motion of the radiosonde, from which winds aloft are computed.

GPS is a satellite navigation system, which is funded and controlled by the U.S. Department of Defense. The system was designed for and is operated by the U.S. military. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time. GPS wind-finding system sondes consist of a 10-channel GPS (Global Positioning System) receiver as well as a platform for temperature, RH and pressure sensors.

The basic steps in performing a sounding involve: preparing the radiosonde (deploying the sensors, connecting the batteries, etc.); activating the data acquisition system and manually or automatically entering the radiosonde calibration information; inflating the balloon and attaching the sonde; releasing the balloon and activating the tracking system; monitoring the data during the sounding; and performing post-sounding procedures as required (e.g., completing sounding documentation, preparing backups of the data, transferring the data to a central data processing facility, etc.). For air quality programs, the entire procedure requires approximately one hour, and one to two operators. Prior to the release of the radiosonde, an accurate measurement must be made of the surface pressure to provide a baseline value for computing altitude from the radiosonde data. This baseline value is used to compute any offsets that are needed for the sonde's pressure measurements. A good quality barometer that is regularly calibrated and audited should be used to make this measurement. Other baseline readings that should be taken include temperature and moisture (wet bulb or relative humidity), and surface winds, although these data are typically not used to offset the sonde measurements.

High quality tracking information is necessary for obtaining high quality wind data within the atmospheric boundary layer. For monitoring programs with a strong emphasis on characterizing low-level boundary layer winds, it is important that the radio theodolite operator get the theodolite to “lock on” to the radiosonde transmission right from the moment of launch. Otherwise, a few minutes of wind data may be lost while the system acquires the signal and begins tracking the radiosonde automatically. Due to this type of delay, for example, typical National Weather Service (NWS) data collection procedures result in a smoothing of the winds within approximately the lowest 300 m. With NAVAID systems, it is important to ensure that position information is being acquired prior to release of the balloon. At some sites, high terrain or other obstacles may block the NAVAID radio signals, so that the balloon must be airborne for a few minutes before accurate position information is available. This, too, can cause a few minutes of wind data to be lost at the beginning of a sounding. Normally autonomous (single receiver) GPS position data are only accurate to about 100 meters due to the use of selective availability by the military to introduce an “uncertainty” into the signal. To compensate for this error, the meteorological sounding systems use the base (receiving) station as a differential GPS location which can increase GPS accuracy to better than 1 meter. The horizontal drift of the radiosonde from the release location may also result in the incomplete characterization of the vertical structure of small (spatial and or temporal) scale features.

Generally speaking, radiosonde soundings made for boundary layer air quality studies do not need to achieve the kind of high altitude coverage required for soundings made by the NWS, where data to the tropopause and to stratospheric levels are needed for weather forecasting. For most air quality studies, the vertical range for radiosonde data will not need to exceed 10,000 m msl (approximately 300 mb), and data coverage to 5000 m msl (approximately 500 mb) will be sufficient. In this case, a smaller weather balloon than that used by the NWS, e.g., a 100-gram balloon as opposed to a 300- to 600-gram balloon, is adequate. Balloon size is stated as weight rather than diameter because the weight relates directly to the amount of free lift needed to achieve the desired ascent rate during a sounding, which in turn influences how much helium must be used and, therefore, the cost per sounding.

In a compromise between adequate ventilation of the temperature and moisture sensors on the sonde and good vertical resolution in the boundary layer, ascent rates used for soundings made during air quality studies (2 to 3 ms^{-1}) are also typically less than that used by the NWS (5 to 6 ms^{-1}). As noted earlier, these ascent rates are consistent with an elapsed time of approximately one hour. Thus, the vertical resolution of the thermodynamic data is usually 5 to 10 m, depending on the interval at which the data acquisition system samples the signals from the radiosonde and the time response of the sensor. The vertical resolution of the wind data ranges from approximately 45 to 200 m, depending on the type of sounding system used. The data averaging interval for radiosondes is 1 to 2 minutes in the lower part of a sounding (e.g., lowest 3000 m) and approximately 3 to 4 minutes in the upper part of a sounding.

9.1.3 Doppler Sodar

Commercial sodars operated for the purpose of collecting upper-air wind measurements consist of antennas that transmit and receive acoustic signals. A mono-static system uses the same antenna for transmitting and receiving, while a bi-static system uses separate antennas. The difference between the two antenna systems determines whether atmospheric scattering by temperature fluctuations (in mono-static systems), or by both temperature and wind velocity fluctuations (in bi-static systems) is the basis of the measurement. The vast majority of sodars in use are of the mono-static variety due to their more compact antenna size, simpler operation, and generally greater altitude coverage. Figure 9-2 shows the beam configurations of mono-static and bi-static systems.

Mono-static antenna systems can be divided into two categories: those using multiple axis, individual antennas and those using a single phased-array antenna. The multiple-axis systems generally use three individual antennas aimed in specific directions to steer the acoustic beam. One antenna is generally aimed vertically, and the other two are tilted slightly from the vertical at an orthogonal angle. Each of the individual antennas may use a single transducer focused into a parabolic dish, or an array of speaker drivers and horns (transducers) all transmitting in-phase to form a single beam. Both the tilt angle from the vertical and the azimuth angle of each antenna need to be measured when the system is set up. Phased-array antenna systems use a single array of speaker drivers and horns (transducers), and the beams are electronically steered by phasing the transducers appropriately. To set up a phased-array antenna, one needs to measure the pointing direction of the array and ensure that the antenna is either level or oriented as specified by the manufacturer.

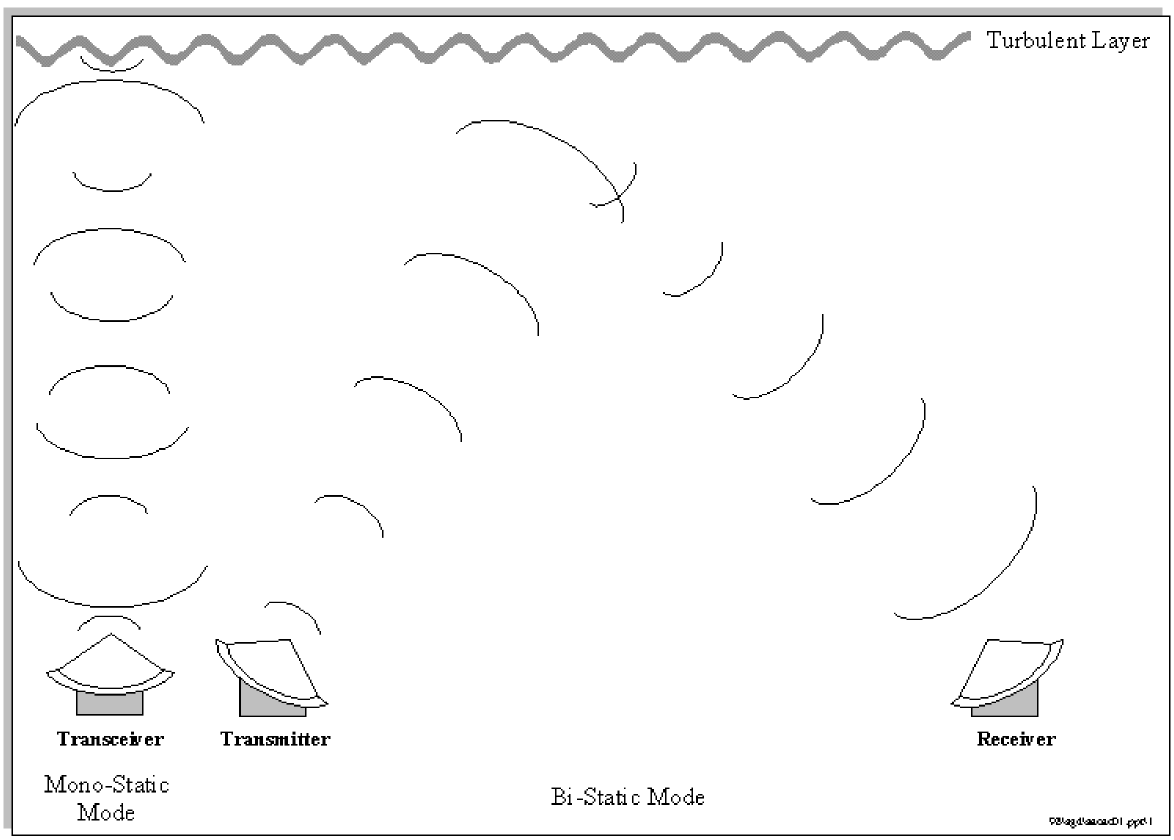

Figure 9-2 Simple depiction of a monostatic and bistatic sodar.

The horizontal components of the wind velocity are calculated from the radially measured Doppler shifts and the specified tilt angle from the vertical. The tilt angle, or zenith angle, is generally 15° to 30°, and the horizontal beams are typically oriented at right angles to one another. Since the Doppler shift of the radial components along the tilted beams includes the influence of both the horizontal and vertical components of the wind, a correction for the vertical velocity should be applied in systems with zenith angles less than 20°. In addition, if the system is located in a region where expected vertical velocities may be greater than about 0.2 ms^{-1}, corrections for the vertical velocity should be made regardless of the beam's zenith angle.

The vertical range of sodars is approximately 0.2 to 2 kilometers (km) and is a function of frequency, power output, atmospheric stability, turbulence, and, most importantly, the noise environment in which a sodar is operated. Operating frequencies range from less than 1000 Hz to over 4000 Hz, with power levels up to several hundred watts. Due to the attenuation characteristics of the atmosphere, high power, lower frequency sodars will generally produce greater height coverage. Some sodars can be operated in different modes to better match vertical resolution and range to the application. This is accomplished through a relaxation between pulse length and maximum altitude, as explained in Section 9.1.4 for radar wind profilers.

Sodar systems should include available options for maximizing the intended capabilities (e.g., altitude range, sampling resolution, averaging time) of the system and for processing and validating the data. The selection of installation site(s) should be made in consultation with the manufacturer and should consider issues associated with the operation of the sodar instrument. Training should be obtained from the manufacturer on the installation, operation, maintenance, and data validation. Additional information on these issues is provided in Section 9.5 of this document.

9.1.4 Radar Wind Profiler

Operating characteristics of three common types of radar wind profilers are given in Table 9-3. The categories included in the table are: 1) very high frequency (VHF) profilers that operate at frequencies near 50 MHZ; 2) ultra-high frequency (UHF) tropospheric profilers that operate at frequencies near 400 MHZ; and 3) UHF lower tropospheric profilers that operate at frequencies near 1000 MHZ. The guidance provided herein is intended for radar wind profilers that fall into the third category; i.e., UHF lower tropospheric profilers (also called boundary layer radar wind profilers).

Doppler radar wind profilers operate using principles similar to those used by Doppler sodars, except that electromagnetic (EM) signals are used rather than acoustic signals to remotely sense winds aloft. Figure 9-3 shows an example of the geometry of a UHF radar wind profiler equipped with a RASS unit (see Section 9.1.5). In this illustration, the radar can sample along each of five beams: one is aimed vertically to measure vertical velocity, and four are tilted off vertical and oriented orthogonal to one another to measure the horizontal components of the air's motion. A UHF profiler includes subsystems to control the radar's transmitter, receiver, signal processing, and RASS (if provided), as well as data telemetry and remote control.

Detailed information on profiler operation can be found in references **[73]** and **[74]**; a brief summary of the fundamentals is provided in the following. The radar transmits an electromagnetic pulse along each of the antenna's pointing directions. The duration of the transmission determines the length of the pulse emitted by the antenna, which in turn corresponds to the volume of air illuminated (in electrical terms) by the radar beam. Small amounts of the transmitted energy are scattered back (referred to as backscattering) toward and received by the radar. Delays of fixed intervals are built into the data processing system so that the radar receives scattered energy from discrete altitudes, referred to as range gates. The Doppler frequency shift of the backscattered energy is determined, and then used to calculate the velocity of the air toward or away from the radar along each beam as a function of altitude. The source of the backscattered energy (radar "targets") is small-scale turbulent fluctuations that induce irregularities in the radio refractive index of the atmosphere. The radar is most sensitive to scattering by turbulent eddies whose spatial scale is ½ the wavelength of the radar, or approximately 16 centimeters (cm) for a UHF profiler.

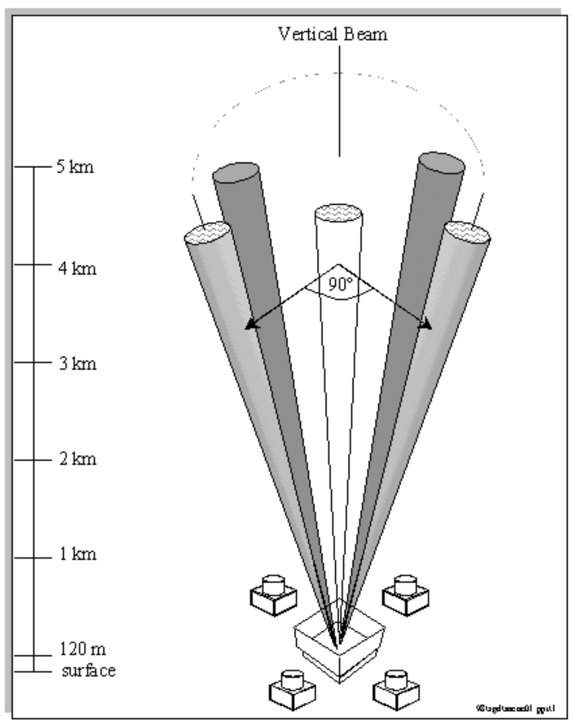

Figure 9-3 Schematic of sampling geometry for a radar wind profiler with RASS.

Table 9-3

Characteristics of radar wind profilers

Frequency Class	Antenna Size (m^2)	Peak Power (kw)	Range (km)	Resolution (m)	Alias and Prototypes
50 MHZ	10,000	250	2-20	150-1000	Alias: VHF radar wind profiler Prototype: 50 MHZ (600 cm) profiler used in the Colorado Wind Profiler Network in 1983.
400 MHZ	120	40	0.2-14	250	Alias: UHF (tropospheric) radar wind profiler Prototypes: 404 MHZ (74 cm) profiler developed for the Wind Profiler Demonstration Network (WPDN) in 1988. 449 MHZ (67 cm) profiler operates at the approved frequency for UHF profilers and will eventually replace the 404 MHZ units. 482 MHZ (62 cm) profiler used by the German Weather Service.
1000 MHZ	3-6	0.5	0.1-5	60-100	Alias: UHF lower-tropospheric radar wind profiler Boundary layer radar wind profiler Lower-atmospheric radar wind profiler Prototypes: 915 MHZ (33 cm) profiler used in the Colorado Wind Profiler Network in 1983. 1290 MHZ (23 cm) boundary layer profiler used by the German Weather Service.

A profiler's (and sodar's) ability to measure winds is based on the assumption that the turbulent eddies that induce scattering are carried along by the mean wind. The energy scattered by these eddies and received by the profiler is orders of magnitude smaller than the energy transmitted. However, if sufficient samples can be obtained, then the amplitude of the energy scattered by these eddies can be clearly identified above the background noise level, then the mean wind speed and direction within the volume being sampled can be determined.

The radial components measured by the tilted beams are the vector sum of the horizontal motion of the air toward or away from the radar and any vertical motion present in the beam. Using appropriate trigonometry, the three-dimensional meteorological velocity components (u,v,w) and wind speed and wind direction are calculated from the radial velocities with corrections for vertical motions. A boundary-layer radar wind profiler can be configured to compute averaged wind profiles for periods ranging from a few minutes to an hour.

Boundary-layer radar wind profilers are often configured to sample in more than one mode. For example, in a "low mode," the pulse of energy transmitted by the profiler may be 60 m in length. The pulse length determines the depth of the column of air being sampled and thus the vertical resolution of the data. In a "high mode," the pulse length is increased, usually to 100 m or greater. The longer pulse length means that more energy is being transmitted for each sample, which improves the signal-to-noise ratio (SNR) of the data. Using a longer pulse length increases the depth of the sample volume and thus decreases the vertical resolution in the data. The greater energy output of the high mode increases the maximum altitude to which the radar wind profiler can sample, but at the expense of coarser vertical resolution and an increase in the altitude at which the first winds are measured. When radar wind profilers are operated in multiple modes, the data are often combined into a single overlapping data set to simplify post-processing and data validation procedures.

9.1.5 RASS

The principle of operation behind RASS is as follows: Bragg scattering occurs when acoustic energy (i.e., sound) is transmitted into the vertical beam of a radar such that the wavelength of the acoustic signal matches the half-wavelength of the radar. As the frequency of the acoustic signal is varied, strongly enhanced scattering of the radar signal occurs when the Bragg match takes place. When this occurs, the Doppler shift of the radar signal produced by the Bragg scattering can be determined, as well as the atmospheric vertical velocity. Thus, the speed of sound as a function of altitude can be measured, from which virtual temperature (T_v) profiles can be calculated with appropriate corrections for vertical air motion. The virtual temperature of an air parcel is the temperature that dry air would have if its pressure and density were equal to those of a sample of moist air. As a rule of thumb, an atmospheric vertical velocity of 1 ms^{-1} can alter a T_v observation by 1.6°C.

RASS can be added to a radar wind profiler or to a sodar system. In the former case, the necessary acoustic subsystems must be added to the radar wind profiler to generate the sound signals and to perform signal processing. When RASS is added to a radar profiler, three or four vertically pointing acoustic sources (equivalent to high quality stereo loud speakers) are placed around the radar wind profiler's antenna, and electronic subsystems are added that include the acoustic power amplifier and the signal generating circuit boards. The acoustic sources are used only to transmit sound into the vertical beam of the radar, and are usually encased in noise suppression enclosures to minimize nuisance effects that may bother nearby neighbors or others in the vicinity of the instrument.

When RASS is added to a sodar, the necessary radar subsystems are added to transmit and receive the radar signals and to process the radar reflectivity information. Since the wind data are obtained by the sodar, the radar only needs to sample along the vertical axis. The sodar transducers are used to transmit the acoustic signals that produce the Bragg scattering of the radar signals, which allows the speed of sound to be measured by the radar.

The vertical resolution of RASS data is determined by the pulse length(s) used by the radar. RASS sampling is usually performed with a 60- to 100-m pulse length. Because of atmospheric attenuation of the acoustic signals at the RASS frequencies used by boundary layer radar wind profilers, the altitude range that can be sampled is usually 0.1 to 1.5 km, depending on atmospheric conditions (e.g., high wind velocities tend to limit RASS altitude coverage to a few hundred meters because the acoustic signals are blown out of the radar beam).

9.2 Performance Characteristics

The following references provide documentation of performance characteristics for the upper-air measurement platforms covered in this guidance (lidar is included for completeness):

- Rawinsonde **[9] [75] [76] [77] [78] [79] [80] [81]**
- Sodar **[82] [83] [84] [85] [86] [87] [88]**
- Radar wind profiler **[89] [90] [91] [92]**
- RASS **[93] [94] [95] [96]**
- Lidar **[83] [97] [98] [99]**

9.2.1 Definition of Performance Specifications

Accuracy is defined as the degree of agreement of a measurement with an accepted reference or true value **[2]**. Determining the absolute accuracy of an upper-air instrument through an inter-comparison study is difficult because there is no “reference” instrument that can provide a known or true value of the atmospheric conditions. This is due in part to system uncertainties and inherent uncertainties caused by meteorological variability, spatial and temporal separation of the measurements, external and internal interference, and random noise. The only absolute accuracy check that can be performed is on the system electronics, by processing a simulated signal. Similarly, a true precision, or the standard deviation of a series of measured values about a mean measured reference value, can only be calculated using the system responses to repeated inputs of the same simulated signal.

The performance specifications provided by manufacturers for accuracy, precision, and other data quality objectives are derived in a number of ways, and it is prudent to understand the basis behind the published specifications. Manufacturers' specifications may be derived from the results of inter-comparison studies, from what the instrument system can resolve through the system electronics and processing algorithms, or a combination of these methods. It may not be practical for a user to verify the exact specifications claimed by the manufacturers. What is needed, however, is a means of verifying that the data obtained from an upper-air system compare reasonably to observations obtained from another measurement system. Guidance for system acceptance testing, field testing, auditing, and data comparison is provided in Section 9.6.

To quantify the reasonableness of the data, one compares observations from the upper-air system being evaluated to data provided by another sensor that is known to be operating properly. In assessing how well the sensors compare, two measures are commonly used. The first involves calculating the "systematic difference" between the observed variables measured by the two methods. The second involves calculating a measure of the uncertainty between the measurements, which is referred to as the "operational comparability" (or simply "comparability"), as described in reference **[100]**. Comparability, for these purposes, is the root-mean-square (rms) of a series of differences between two instruments measuring nearly the same population. The comparability statistic provides a combined measure of both precision and bias, and will express how well the two systems agree.

Using the ASTM notation **[100]**, the systematic difference (or bias) is defined as:

$$d = \frac{1}{n}\sum(\chi_{a,i} - \chi_{b,i}) \qquad \textbf{(9-1)}$$

where

n	=	number of observations
$x_{a,i}$	=	ith observation of the sensor being evaluated
$x_{b,i}$	=	ith observation of the "reference" instrument

Operational comparability (or root-mean-square error) is defined as

$$c = \sqrt{\frac{1}{n}\sum(\chi_{a,i} - \chi_{b,i})^2} \qquad \textbf{(9-2)}$$

Many of the inter-comparison programs discussed in the next section have evaluated instrument performance using the systematic difference and comparability statistics described here. Other statistical measures that can be used include, for example, correlation coefficients and linear regression.

Another important performance specification for upper-air instrument systems is data recovery rate. Data recovery is usually calculated as the ratio of the number of observations actually reported at a sampling height to the total number of observations that could have been reported so long as the instrument was operating (i.e., downtime is usually not included in data recovery statistics but is treated separately). Data recovery is usually expressed as percent as a function of altitude. Altitude coverage for upper-air data is often characterized in terms of the height up to which data are reported 80 percent of the time, 50 percent of the time, etc.

9.2.2 Performance Characteristics of Radiosonde Sounding Systems

Radiosonde sounding systems are the most widely used upper-air instruments. The wind and thermodynamic data provided by these systems are critical to the numerical weather prediction (NWP) and forecasting programs conducted by all countries that provide such services. Thus, the performance characteristics of radiosondes and the relative accuracy of radiosonde winds have been the subject of a great deal of scrutiny over the last few decades. The World Meteorological Organization (WMO) and national weather agencies such as the U.S. NWS and British Meteorological Office have all sanctioned a number of inter-comparison studies to determine the performance characteristics of radiosonde systems (references **[9]**, **[75]**, and **[77]**). Inter-comparison and performance evaluation studies have also been conducted by independent researchers who have been interested in determining the accuracy of radiosonde wind and/or thermodynamic measurements for meeting specific research objectives (see reference**[81]** for a recent summary of some of these studies, especially those related to boundary-layer measurements). Some references are also provided in Table 9-4. Radiosonde systems will continue to be an important source of upper-air data for the foreseeable future, and efforts to characterize and improve radiosonde sounding system performance specifications continues **[79]**.

Performance tests of radiosonde systems have involved “flying” multiple radiosondes on the same balloon, and/or obtaining independent tracking information using high-precision tracking radars **[79]**. Such tests do not provide information on absolute accuracy of either the radiosondes or the tracking systems. Rather, they provide measures of the relative differences between comparable instrument systems, e.g., of temperature or relative humidity measured by different radiosondes flown at the same time and winds measured by radio theodolites or NAVAID systems. The NWS and WMO perform such tests to quantify the functional precision of the instruments, which is defined as the rms of the differences between the measurements, that is, if the differences have a Gaussian distribution then 67 percent of the differences would lie within the range specified by the functional precision. The functional precision is thus similar to the comparability statistic defined by Equation 9-2. Performance specifications for radiosonde systems are summarized in Table 9-1, the performance specifications are based on manufacturer's specifications and inter-comparison tests described in references **[77]** and **[79]**.

Errors and uncertainties encountered in radiosonde measurements, particularly errors in temperature and moisture, can occur at higher altitudes (e.g., beginning in the upper-troposphere), and are caused by factors such as exposure to solar radiation, sensor heating, and time lag. Data collected at lower altitudes (e.g., below about 10 km) do not tend to display such errors. Likewise, the relative accuracy of upper-air winds measured by radiosondes tends to decrease with increasing altitude. This is due in part to many weather services using radio theodolite sounding systems, where errors in tracking angles (especially elevation) become more troublesome as the balloon approaches the horizon and the antenna reaches its tracking limit.

At altitudes below about 10 km, radiosonde winds tend to show good agreement with other independent upper-air measurements **[79]**. As noted earlier in this document, there are circumstances under which data resolution within the lowest few hundred meters can be compromised.

9.2.3 Performance Characteristics of Remote Sensing Systems

Many of the studies that have been performed to estimate the accuracy and precision of remote sensors were based on inter-comparisons to tower-based measurements. These comparisons have generally assumed that the tower measurements provide the known standard and are representative of the same environment measured by the remote sensors. However, differences between point measurements from *in situ* sensors located on the tower and volume-averaged measurements from the remote sensors located near the tower are expected to lead to differences in the results, even though conditions for these inter-comparisons are likely as close to "ideal" as one could expect. The performance of remote profiling instrumentation is greatly influenced by individual site characteristics, instrument condition, and operating parameters established for the equipment.

Table 9-1 includes estimates of expected performance characteristics for remote sensing systems that are installed and working properly. These results should be used for establishing data quality objectives for upper-air programs and as a basis for interpreting results from inter-comparison programs or performance audits of upper-air equipment (see Section 9.6). To avoid ambiguities in wind direction associated with light and variable winds, it is recommended that the wind direction comparability calculations be made only when actual wind speeds are greater than approximately 2 ms^{-1}.

9.3 Monitoring Objectives and Goals

When the primary use of upper-air data is for the analysis and modeling of meteorological and air quality conditions in the boundary layer and lower troposphere, the focus of the upper air program should be to maximize the temporal and spatial resolution of the data collected in this portion of the atmosphere, i.e. the first one to three km. Each modeling and analysis application will have its own unique objectives and scales of interest. However there are certain characteristics that have a large bearing on the type of upper-air measurement system chosen, the manner in which it is operated, and data processing and archival procedures. These characteristics include the duration of the measurement program, that is whether the measurements are part of a long-term monitoring program of seasonal to yearly extent, or a shorter-term intensive field campaign characterized by a greater number of measurements. The types of measured and derived meteorological variables required for the modeling/analysis, including the required spatial and temporal resolution, will also affect the choice of measurement system, as will the need, in many cases, to make comparable measurements with surface-based meteorological systems.

The choice of upper-air measurement technologies is considerably greater now than at any time in the last two decades. With that choice comes the need to carefully consider the requirements of the application and to choose and configure the appropriate systems. Considerable field experience has been gained in the use of the various measurement technologies, especially since 1990. The following discussion for each class of upper-air measurement system is meant to stimulate thinking regarding the best match of the system to the specific application.

9.3.1 Data Quality Objectives

Inherent in any measurement program is the need to establish data quality objectives. These relate the quality of measurements obtained to the level of uncertainty that decision makers are willing to accept in the data and results derived from the data **[65]**. Data quality objectives state how "good" the data need to be to satisfy the program objectives. The stated objectives generally include completeness, systematic difference, and comparability. Operators of the instruments should let the data quality objectives be determined based on instrument performance specifications and modeling and analysis needs. Data quality objectives should be specified for all of the primary variables measured by the instrument.

To check whether or not the data meet the data quality objectives from an instrument performance perspective, a comparison to another sensor that is known to be operating properly is recommended (see Section 9.5). In assessing how well the sensors compare, the systematic difference and the operational comparability can be computed and compared to the data quality objectives that are presented in Table 9-4.

In evaluating the sodar and radar wind profiler data, the primary criteria for comparison are the component data; the vector wind speed and wind direction are secondary. The indicated values for u and v for the sodar and radar wind profiler in Table 9-4 refer to the components along the antenna axes, and for these instruments, the component comparisons should be performed using calculated values along the antenna axes. Values along the meteorological axes (north/south and east/west) should only be used if evaluating a radiosonde. For the sodar and radar wind profiler, the data quality objective for the vector wind speed and wind direction comparisons should be applied when winds are greater than 2 to 3 ms^{-1}. Note that the values presented in Table 9-5 are based on a number of studies and were reviewed by several measurement experts participating in an EPA-sponsored workshop on upper-air measurement systems.

Table 9-4.

Suggested data quality objectives for upper-air measurement systems.

Measurement Method	Systematic Difference	Comparability
Radiosonde	p:± 0.5 mb T: ± 0.2°C RH: ± 10% u,v: ± 0.5 to 1 ms^{-1}	P (as height):± 24 m T: ± 0.6°C T_d: ± 3.3°C WS: ± 3.1 ms^{-1} WD: ± 18° to ± 5°[a]
Sodar[b]	u,v: ± 1 ms^{-1} WS: ± 1 ms^{-1} WD: ± 10°	u,v: ± 2 ms^{-1} WS: ± 2 ms^{-1} WD: ± 30°
Radar wind profiler[b]	u,v: ± 1 ms^{-1} WS: ± 1 ms^{-1} WD: ± 10°	u,v: ± 2 ms^{-1} WS: ± 2 ms^{-1} WD: ± 30°
RASS	±1°C	±1.5°C

[a] Over a WS range from 3 to 21 ms^{-1}.

[b] For wind speeds greater than approximately 2 ms^{-1}.

Comparison results in excess of the data quality objectives do not necessarily mean that the data are invalid. In making this assessment, it is important to understand the reasons for the differences. Reasons may include unusual meteorological conditions, differences due to problems in one or both instruments, or differences due to sampling techniques and data reduction protocols. Both the reasons for and the magnitude of the differences, as well as the anticipated uses of the data, should be considered in determining whether the data quality objectives are met. This assessment should be part of the QA protocol.

Data completeness for radiosonde sounding systems is usually not significantly affected by outside environmental conditions such as high winds, precipitation, or atmospheric stability. However, environmental factors can have a significant effect on the rate of data capture for remote sensing systems.

9.4 Siting and Exposure

Siting and exposure issues related to radiosonde sounding systems, sodar, radar wind profiler, and RASS meteorological measurement systems are addressed in this section.

Careful planning should accompany the siting of upper-air measurement systems, since siting and exposure directly affect the quality of the data. The complexities of ground based remote sensing devices provide a challenge for the user to balance the conditions favorable for the technology with the availability of sites and the overall data collection goals of the program. Site selection may benefit from the experience of vendors or users of the type of instrument to be installed. Additional information on siting can be found in reference **[2]**. Listed below are some key issues to consider in siting upper-air systems.

- **Representative location.** Sites should be located where upper-air data are needed to characterize the meteorological features important to meeting the program objectives. Panoramic photographs should be taken of the site to aid in the evaluation of the data and preparation of the monitoring plan. Data collected at sites in regions with local geographic features such as canyons, deep valleys, etc., may be unrepresentative of the surrounding area and should be avoided, unless such data are needed to resolve the local meteorological conditions. Measurements made in complex terrain may be representative of a much smaller geographical area than those made in simple homogeneous terrain. See reference **[101]** for a discussion of the influence of terrain on siting and exposure of meteorological instrumentation.

- **Site logistics.**
  - Adequate power should be available for the instrument system as well as an environmentally controlled shelter that houses system electronics, and data storage and communication devices.
  - The site should be in a safe, well lit, secure area with level terrain, sufficient drainage, and clear of obstacles. The site should allow adequate room for additional equipment that may be required for calibrations, audits, or supplementary measurements.
  - A fence should be installed around the equipment and shelter to provide security, and appropriate warning signs should be posted as needed to alert people to the presence of the equipment.
  - A remote data communications link (e.g., dedicated leased line, standard dial-up modem line, or a cellular telephone link) should be installed at the monitoring site. It is recommended that a 9600 baud or higher line be established to facilitate rapid data transfer and uploading and downloading of information. A site in a remote location with no communication capabilities may collect valid data, but if the system goes down it may not be discovered until the next time the site is visited.

- **Collocation with surface meteorological measurements.** Several advantages can be gained by locating an upper-air site with or near an existing meteorological monitoring station. For instance, collocated data can be used for data validation purposes and for performing reasonableness checks (e.g., do surface winds roughly agree with near-surface upper-air winds, surface temperatures with near-surface RASS measurements). Existing shelter, power, and personnel could also be used for operating the upper-air instrument. Additional surface meteorological measurements of wind speed, wind direction, temperature and humidity are recommended. The height of the wind sensors will depend on the terrain. In homogeneous terrain, wind data collected at a height of 10 m may be sufficient.

- **Instrument noise.** Sodar and RASS generate noise that can disturb nearby neighbors. Depending on the type of sodar or RASS instrument, power level, frequency, acoustic shielding around the system, and atmospheric conditions, the transmitted pulse can be heard from tens of meters up to a kilometer away. An optimum site is one that is isolated from acoustically sensitive receptors **[102]**.
- **Passive interference/noise sources**. Objects such as stands of trees, buildings or tall stacks, power lines, towers, guy wires, vehicles, birds, or aircraft can reflect sodar or radar transmit pulses and contaminate the data. Not all sites can be free of such objects, but an optimum site should be selected to minimize the effects of such obstacles. If potential reflective "targets" are present at an otherwise acceptable site, the beams of the instrument should be aimed away from the reflective objects. In the case of sodars, locating the antennas so that there are no direct reflections from objects will help minimize potential contamination. In the case of the radar profiler, it is best to aim the antennas away from the object and orient a phased array antenna's corners so they are pointing toward the objects. As a rule of thumb, sites with numerous objects taller than about 15° above the horizon should be avoided. The manufacturers of the remote sensing equipment should be contacted regarding software that may be available to identify and minimize the effects of these passive noise sources.
- **Active interference/noise sources.** For sodars, noise sources such as air conditioners, roadways, industrial facilities, animals, and insects will degrade the performance of sodar systems **[102]**. If proximity to such sources cannot be avoided, then additional acoustic shielding may help minimize the potentially adverse effects on the data. In general, noise levels below 50 decibels (dBA) are considered to be representative of a quiet site, while levels above 60 dBA are characteristic of a noisy site. For radar wind profilers and RASS, radio frequency (RF) sources such as radio communications equipment and cellular telephones may have an adverse effect on performance.
- **Licenses and Ordinances**. Before operating a remote sensor it is recommended that all applicable requirements for operation of equipment be addressed. For example, to operate a radar wind profiler or a RASS, a Federal Communications Commission (FCC) license is required. For radiosonde sounding systems (or other balloon-borne systems), a Federal Aviation Administration (FAA) waiver may be required. Local noise ordinances may limit the operation of sodar or RASS instruments. Some of these requirements may take several months to address and complete.
- **Surveying Candidate Locations.** Prior to final site selection, a survey is recommended to identify audio sources **[103]** and RF sources that may degrade system performance. Additionally, panoramic photographs should be taken to aid in the evaluation of the candidate site and for the preparation of the monitoring plan. As part of the survey, appropriate topographic and other maps should be used to identify other potential sources of interference, such as roadways and airports.

9.5 Installation and Acceptance Testing

This section provides guidance for the installation and acceptance testing of upper-air monitoring systems; similar guidance for in situ sensors is provided in Section 8.2.

The installation period is the optimal time to receive appropriate training in instrument principles, operations, maintenance, and troubleshooting, as well as data interpretation and validation. Meteorological consultants as well as some manufacturers and vendors of meteorological instruments provide these services.

Installation procedures specific to upper-air monitoring systems include the following:

- The latitude, longitude, and elevation of the site should be determined using U.S. Geological Survey (USGS) topographical maps, other detailed maps, or a GPS instrument.
- The orientation of antennas of the sodar, radar profiler, or radio theodolite systems should be defined with respect to true north. One recommended method is to use the solar siting technique **[2]** . This technique enables determination of true north at any location using a compass (or other pointing device suitable for measuring the azimuth angle to the sun), a computer program, the site latitude and longitude, and accurate local time.
- The site should be documented as follows:
    - Photographs in sufficient increments to create a documented 360° panorama around the antennas should be taken. Additionally, pictures of the antenna installation, shelter and any obstacles that could influence the data should be obtained.
    - Photographs of the instrument, site, shelter, and equipment and computers inside the shelter should be obtained.
    - A detailed site layout diagram that identifies true north and includes the locations of the instrument, shelter, other equipment, etc. should be prepared. An example of such a diagram is shown in Figure 9-4. Additionally, it is recommended that the site layout diagram include the electrical and signal cable layout, and the beam directions of any remote sensor.
    - A vista table that documents the surroundings of the site in 30° increments should be prepared. Vistas for the beam directions, if they are not represented by the 30° views (±5°), should be included. The table should identify any potential passive and active noise sources in each direction, and the approximate distance and elevation angle above the horizon to the objects. An example is shown in Table 9-5.

An acceptance test is used to determine if an instrument performs according to the manufacturer's specifications **[2]**. Manufacturer's procedures for unpacking, inspection, installation, and system diagnostics should be followed to assure that all components are functioning appropriately. All acceptance-testing activities should be documented in the station log.

Once the system is installed, a final field check is needed to assure that the data are reasonable. This is best performed using collocated meteorological information from towers or other upper-air sensors. In the absence of these data sources, nearby upper-air data from the NWS radiosonde network, the NOAA profiler network, aircraft reports, National Center for Environmental Prediction (NCEP) high resolution mesoscale analyses, or other upper-air data can be used. It is important to have an individual trained in the interpretation of the data perform a thorough review of at least several days of data. This check is not meant to evaluate whether or not the data meet the manufacturer's data specifications, but is intended to identify problems such as:

- Component failures
- Incorrect or improper operating/sampling parameters
- Antenna azimuth angles specified improperly or incorrectly measured
- Siting problems (active and passive interfering noise sources)

Shortly after the installation and startup of an instrument, a system and performance audit should be performed. These audits will provide information for the qualitative and quantitative assessment of the performance of the system, as well as the adequacy of the standard operating procedures used for collection, processing, and validation of the data. To best assure that the data collected is of known quality, and that potential problems are identified early, it is recommended the initial audit be performed within 30 days of the start-up date.

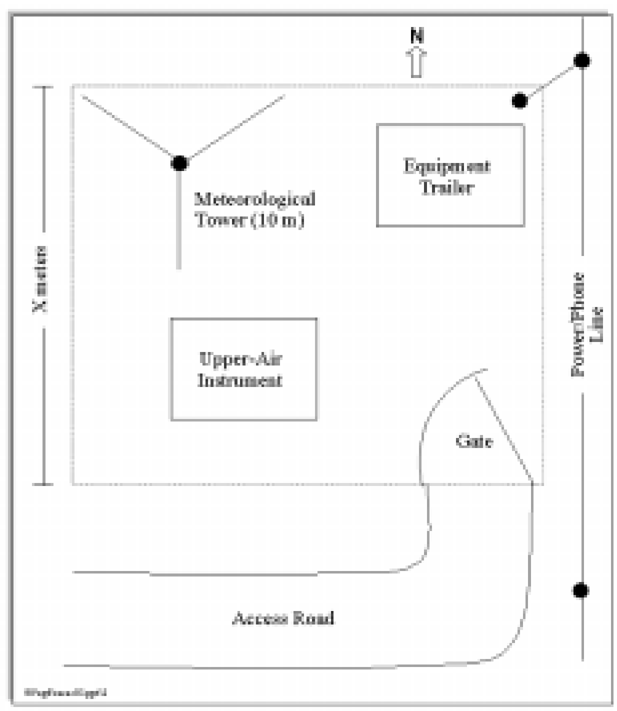

Figure 9-4 Example site layout diagram.

9.6 Quality Assurance and Quality Control

This section provides information on QAQC procedures unique to upper-air measurement systems. Generic material on QAQC procedures for meteorological systems and definitions of terms used in QAQC is presented in Section 8.

With some exceptions (e.g., rawinsonde measurements of pressure, temperature, and humidity) upper-air monitoring systems provide indirect measurements of the meteorological variables used in dispersion modeling. This presents a unique challenge to the quality assurance and quality control (QAQC) of these systems; for example, there is no upper-air counterpart to the bench top calibration of a wind vane. The alternative to the bench-top calibration is a calibration using a collocated transfer standard; this involves locating an identical instrument as close as practical to the instrument being calibrated (see Section 8.3) - again, as with the bench-top procedure, there is no upper-air counterpart to the collocated transfer standard for a wind vane. Similarly, there is no upper-air counter part to the performance audit of a wind vane (as explained in Section 8, calibrations and audits are one and the same as far as "what" takes place; the difference has to do with the independence of the person conducting the audit). Given the inability to conduct a true performance audit, the onus for claims of data validity for most upper-air measurements falls on the systems audit - this, as explained in Section 8.4, is essentially a challenge to the QAPP and provides an overall assessment of the commitment to data validity.

Alternative procedures for calibrations and performance audits of upper-air measurement systems are based on inter-comparisons with other measurement systems - these alternatives are discussed in Sections 9.6.1 (Calibration Methods) and 9.6.2 (Systems and Performance Audits).

Before discussing quality assurance programs, it is useful to explain the difference between quality control (QC) and quality assurance (QA). For the purposes of this document, QC refers to the operational procedures used to ensure that a measurement process is working properly. QC procedures include periodic instrument calibrations, site checks, data examination for reasonableness, and data validation. QC procedures produce quantitative documentation upon which claims of accuracy can be based. QA refers to all the planned or systematic actions necessary to provide adequate confidence that the entire measurement process is producing data that meets the data quality objectives established for a monitoring program. These actions include routine evaluation of how the QC procedures are implemented (system audits) and assessments of instrument performance (performance audits). Summarized below are details on the preparation of a Quality Assurance Project Plan (QAPP) and key elements that are unique to upper-air measurement methods.

Table 9-5

Example site vista table

VISTA, ORIENTATION, AND LEVEL AUDIT RECORD			
Date:	January 3, 1996	Site Name:	Site 5
Key Person:	John Sitetech	Project:	ABC
Instrument:	Radar Wind Profiler	Latitude:	31°10'25"
Model Number:	GEN-1500	Longitude:	91°15'33"
Serial Number:	1234	Elevation:	172 m
Software version:	3.95		
Rotation angle		Direction	
System:	147°true	Beam 1:	146°
Measured:	146°true	Beam 2:	236°
Difference:	1°		
		Firing order:	W, beam 1, beam 2
Array Level:	< 0.5°	Declination:	11° east (solar verification)
Azimuth Angle (deg.)			
Magnetic	True	Terrain Elevation Angle (deg.)	Features/Distance
--	0	12	Buildings and power lines at ~ 300 m.
--	30	19	Stack at 150-200 m.
--	60	22	Power pole at 10 m, < 5° beyond.
--	90	4	Low trees and bushes at 10 m.
--	120	15	Power lines at 200-300 m
--	150	4	Trees at 30-40 m.
----	180	0	Looking out over the lake.
--	240	< 2	Looking out over the lake, can see land.
--	270	< 2	Looking out over the lake, can see land.
--	300	3	Trees and telephone pole at 100 m.
--	330	14	Light pole at 25 m. Buildings at ~250 m.

9.6.1 Calibration Methods

A calibration involves measuring the conformance to or discrepancy from a specification for an instrument and an adjustment of the instrument to conform to the specification. In this sense, other than directional alignment checks, a true calibration of the upper-air instruments described in this document is difficult. Due to differences in measurement techniques and sources of meteorological variability, direct comparison with data from other measurement platforms is not adequate for a calibration. Instead, a calibration of these sensors consists of test signals and diagnostic checks that are used to verify that the electronics and individual components of a system are working properly. Results from these calibrations should not be used to adjust any data. All calibrations should be documented in the station log.

System calibration and diagnostic checks be performed at six month intervals, or in accordance with the manufacturer's recommendations, whichever is more frequent. The alignment of remote sensing antennas, referenced to true north, should be verified at six month intervals. Generic guidance and definitions of terms related to calibrations is provided in Section 8.3.

Radiosonde Sounding Systems For radiosonde sounding systems, the primary calibration that is required is to obtain an accurate surface pressure reading using a barometer that is regularly calibrated and periodically audited. This pressure reading is used to determine if an offset needs to be applied to the radiosonde pressure data. If an offset is needed, the data systems of the commercially available instruments will make the adjustment automatically. It is also useful to obtain surface readings of temperature and atmospheric moisture using a psychrometer or similar instrument. These data can be used to provide a reality check on the radiosonde measurements. This check can be performed using data from a nearby tower. A more robust check can be made by placing the sonde in a ventilated chamber and taking readings that are then compared to temperature and moisture measurements made in the chamber using independent sensors. The alignment of the theodolite should be validated against the reference marker that was installed at the time of system setup.

Sodar Recent advances in instrumentation for auditing of sodar instruments **[104]** have led to the development of a transponder that can simulate a variety of acoustic Doppler shifted signals on certain sodars. This instrument can be used to verify the calibration of the sodar's total system electronics and, in turn, validate the overall system operation in terms of wind speed and altitude calculations. However, such a check should not be considered a “true” calibration of the system since it does not consider other factors that can affect data recovery. These factors include the system signal-to-noise ratio, receiver amplification levels, antenna speaker element performance, beam steering and beam forming for phased-array systems, and overall system electronic noise.

Radar Wind Profilers and RASS A transponding system for radar does not yet exist, but the feasibility of such a system is being explored. Therefore, there is no simple means at present of verifying the accuracy of the Doppler shifted signals in the field other than to perform a comparison with some other measurement system, as described later in this section. Instead, calibrations of radar wind profiler and RASS systems are performed and checked at the system component level. These checks should be performed in accordance with the manufacturer's recommendations. Like some sodar systems, the radar systems use both software and hardware diagnostics to check the system components.

9.6.2 System and Performance Audits

Audits of upper-air instrumentation to verify their proper operation pose some interesting challenges. While system audits can be performed using traditional system checks and alignment and orientation techniques, performance audits of some instruments require unique, and sometimes expensive procedures. In particular, unlike surface meteorological instrumentation, the upper-air systems cannot be challenged using known inputs such as rates of rotation, orientation directions, or temperature baths. Recommended techniques for both system and performance audits of the upper-air instruments are described below. These techniques have been categorized into system audit checks and performance audit procedures for radiosonde sounding systems, radar wind profilers, sodars, and RASS.

9.6.2.1 Systems Audit

System audits of an upper-air station should include a complete review of the QAPP, any monitoring plan for the station, and the station's standard operating procedures. The system audit will determine if the procedures identified in these plans are followed during station operation. Deviations from the plans should be noted and an assessment made as to what effect the deviation may have on data quality. To ensure consistency in the system audits, a checklist should be used. System audits should be conducted at the beginning of the monitoring program and annually thereafter.

<u>Radiosonde Sounding Systems</u> For radiosonde sounding systems, an entire launch cycle should be observed to ensure that the site technician is following the appropriate procedures. The cycle begins with the arrival of the operator at the site and ends with completion of the sounding and securing of the station. The following items should be checked:

- Ground station initialization procedures should be reviewed to ensure proper setup.
- Sonde initialization procedures should be reviewed to verify that the sonde has been properly calibrated.
- Balloon inflation should be checked to ensure an appropriate ascent rate.
- Proper and secure attachment of sonde to balloon should be verified.
- Orientation of the radio theodolite antenna should be checked, using solar sitings when possible. The antenna alignment should be maintained within ±2°.
- The vertical angle of the radio theodolite antenna should be checked and should be within ±0.5°.
- Data acquisition procedures should be reviewed and a sample of the acquired data should be inspected.
- Data archiving and backup procedures should be reviewed.

- Flight termination and system shutdown procedures should be reviewed.
- Preventive maintenance procedures should be reviewed and their implementation should be checked.
- Data processing and validation procedures should be reviewed to ensure that questionable data are appropriately flagged and that processing algorithms do not excessively smooth the data.
- Data from several representative launches should be reviewed for reasonableness and consistency.
- Station logbooks, checklists, and calibration forms should be reviewed for completeness and content to assure that the entries are commensurate with the expectations in the procedures for the site.

Remote Sensing Instrumentation

A routine check of the monitoring station should be performed to ensure that the local technician is following all standard operating procedures (SOPs). In addition, the following items should be checked:

- The antenna and controller interface cables should be inspected for proper connection. If multi-axis antennas are used, this includes checking for the proper connection between the controller and individual antennas.
- Orientation checks should be performed on the individual antennas, or phased-array antenna. The checks should be verified using solar sitings when possible. The measured orientation of the antennas should be compared with the system software settings. The antenna alignment should be maintained within ±2°.
- For multi-axis antennas, the inclination angle, or zenith angle from the vertical, should be verified against the software settings and the manufacturer's recommendations. The measured zenith angle should be within ±0.5° of the software setting in the data system.
- For phased-array antennas, the array should be level within ±0.5° of the horizontal.
- For multi-axis sodar systems, a separate distinct pulse, or pulse train in the case of frequency-coded pulse systems, should be heard from each of the antennas. In a frequency-coded pulse system there may be a sound pattern that can be verified. The instrument manual should be referenced to determined whether there is such a pattern.
- For sodar systems, general noise levels should be measured, in dBA, to assess the ambient conditions and their potential influence on the performance of the sodar.
- The vista table for the site (see Section 9.5) should be reviewed. If a table is not available then one should be prepared.
- The electronic systems and data acquisition software should be checked to ensure that the instruments are operating in the proper mode and that the data being collected are those specified by the SOPs.

- Station logbooks, checklists, and calibration forms should be reviewed for completeness and content to assure that the entries are commensurate with the expectations in the procedures for the site.
- The site operator should be interviewed to determine his/her knowledge of system operation, maintenance, and proficiency in the performance of quality control checks.
- The antenna enclosures should be inspected for structural integrity that may cause failures as well as for any signs of debris that may cause drainage problems in the event of rain or snow.
- Preventive maintenance procedures should be reviewed for adequacy and implementation.
- The time clocks on the data acquisition systems should be checked and compared to a standard of ±2 minutes.
- The data processing procedures and the methods for processing the data from sub-hourly to hourly intervals should be reviewed for appropriateness.
- Data collected over a multi-day period (e.g., 2-3 days) should be reviewed for reasonableness and consistency. The review should include vertical consistency within given profiles and temporal consistency from period to period. For radar wind profilers and sodar, special attention should be given to the possibility of contamination of the data by passive or active noise sources.

9.6.2.2 Performance Audit and Comparison Procedures

Performance audits should be conducted at the beginning of the monitoring program and annually thereafter. A final audit should be conducted at the conclusion of the monitoring program. An overview of the recommended procedures for performance auditing is provided below.

Radiosondes Performance auditing of radiosonde sounding systems presents a unique challenge in that the instrument is used only once and is rarely recovered. Therefore, a performance audit of a single sonde provides little value in assessing overall system performance. The recommended approach is to audit only the instruments that are used to provide ground truth data for the radiosondes prior to launch (thermometer, relative humidity sensor, psychrometer, barometer, etc.). The reference instruments used to audit the site instruments should be traceable to a known standard. Details on these audit methods can be found in reference **[2]**.

In addition, a qualitative assessment of the direction and speed of balloon travel should be made during an observed launch for comparison with the computed wind measurements. An alternative approach is to attach a second sonde package to the balloon, track it from an independent ground station, and compare the results of the two systems. An optical tracking system is adequate for this type of comparison.

Remote Sensing Instrumentation Methods for performance audits and data comparisons of remote sensing instrumentation have been under development for a number of years. Only recently has interim guidance reference **[2]** been released to help standardize performance audit methods. Even with the release of that guidance, there are still a number of areas undergoing development. Recommended procedures for performance audits and data comparisons of remote sensors which are presented below typically incorporate inter-comparison checks. If inter-comparison checks are used, a quick review of the datasets should be performed before dismantling the comparison system.

Sodar. The performance audit is used to establish confidence in the ability of the sodar to accurately measure winds. A performance audit of a system typically introduces a known value into the sensor and evaluates the sensor response. It may not be possible to perform this type of audit for all types of sodar instruments. In this case, a comparison between the sodar and another measurement system of known accuracy should be performed to establish the reasonableness of the sodar data. With any of the audit or comparison methods, the evaluation of the data should be performed on a component specific basis that corresponds to the sodar beam directions. Any of the following approaches may be considered in the sodar performance evaluation.

- Comparison with data from an adjacent tall tower. Using this approach, conventional surface meteorological measurements from sensors mounted on tall towers (at elevations within the operating range of the sodar) are compared with the sodar data. This method should only be used if the tall tower is an existing part of a monitoring program and its measurements are valid and representative of the sodar location. At least 24 hours of data should be compared. The tower data should be time averaged to correspond to the sodar averaging interval and the comparisons should be made on a component basis. This comparison will provide an overall evaluation of the sodar performance as well as a means for detecting potential active and passive noise sources.
- Comparison with data from another sodar. This comparison uses two sodars operating on different frequencies. The comparison sodar should be located in an area that will allow it to collect data that is representative of the site sodar measurements. At least 24 hours of data should be collected for the comparison. If the measurement levels of the two sodars differ, the comparison sodar data should be volume averaged to correspond with the site sodar. Additionally, the comparison sodar time averaging should correspond to the site sodar. As with the adjacent tall tower, the comparison should be performed on a component basis. This comparison will provide an overall evaluation of the sodar performance as well as a means for detecting potential active and passive noise sources.
- Comparison with radiosonde data. This comparison uses data obtained from a radiosonde carried aloft by a free-flight, slow-rise balloon. The balloon should be inflated so the ascent rate is about 2 ms^{-1}. This will provide the appropriate resolution for the comparison data, within the boundary layer. The wind data should be volume averaged to correspond with the sodar data and the comparisons should be made on a component as well as a total vector basis. The launch times should be selected to avoid periods of changing meteorological conditions. For example, evaluation of the comparison data should recognize the potential differences due to differences in both the spatial and temporal resolution of the measurements (i.e., the instantaneous data collected by the radiosonde as compared with the time averaged data collected by the sodar). This comparison will provide an overall evaluation of the sodar performance as well as a means for detecting potential active and passive noise sources.
- Comparison with tethersonde data. The tethersonde comparison is performed using single or multi-sonde systems. Using this approach, a tethered balloon is used to lift the

sonde(s) to altitude(s) corresponding with the sodar measurement levels. This method should collect data at one or more layers appropriate to the program objectives. At a minimum, data corresponding to the equivalent of five sodar averaging periods should be collected at each altitude. Multiple altitudes can be collected simultaneously using a multi-sonde system with two or more sondes. The individual sonde readings should be processed into components that correspond to the sodar beam directions and then time averaged to correspond to the sodar averaging period. This comparison will provide an overall evaluation of the sodar performance as well as a means for detecting potential active and passive noise sources.

- Comparison with data from an anemometer kite. This measurement system is suitable in relatively high wind speed conditions that would preclude the use of a tethersonde. The kite anemometer consists of a small sled type kite attached to a calibrated spring gauge. Horizontal wind speeds are determined from the pull of the kite on the spring gauge. The altitude of the kite (i.e. the height of the measured wind) is determined from the elevation angle and the distance to the kite. The wind direction is determined by measuring the azimuth angle to the kite. At a minimum, data corresponding to the equivalent of five sodar averaging periods should be collected at a level appropriate to the monitoring program objectives. The wind speed and kite azimuth and elevation readings should be taken every minute. The individual readings should be processed into components that correspond to the sodar beam directions and then time averaged to correspond to the sodar averaging period. This comparison will provide an overall evaluation of the sodar performance as well as a means for detecting potential active and passive noise sources.

- Use of a pulse transponding system. A pulse transponding system provides a means of testing the sodar system processing electronics for accuracy through the interpretation of simulated Doppler shifted signals at known time intervals **[104]**. This method can be considered an audit rather than a comparison because it provides a signal input equivalent to a known wind speed, wind direction and altitude to test the response of a sodar system. At least three averaging periods of transponder data should be collected with the sodar in its normal operating mode. Depending on the sodar configuration, this method along with an evaluation of the internal consistency of the sodar data to identify potential passive and active noise sources, may serve as the performance audit without the need of further comparisons. In the case of phased array sodars, an additional comparison is needed to verify proper beam steering. This comparison may be performed using any of the methods above. For this check, three sodar averaging periods at a single level are sufficient. It should be noted that current transponder technology is limited to sodars with three beams.

<u>Radar Wind Profilers</u>. At present, the performance of radar wind profilers can only be evaluated by comparison to collocated or nearby upper-air measurements. Various types of comparison instruments can be used including tall towers, sodar, radiosonde sounding systems, and tethersondes. A tethersonde may be used, but care should be taken to ensure that it does not interfere with the radar operation. Since it is important to have confidence in the reference instrument, an independent verification of operation of the reference instrument should also be obtained. If using a sodar or a radiosonde sounding system, the procedures outlined above should be followed to ensure acceptable operation of the system. If data from an adjacent tower are used, then it is recommended that the quality of the tower-based data be established. The

comparison methods should follow those described for sodars above. Where RASS acoustic sources may interfere with the comparison sodar operation, care should be taken to identify potentially contaminated data.

RASS. Like the radar wind profiler, the evaluation of a RASS relies on a comparison to a reference instrument. The recommended method is to use a radiosonde sounding system to measure the variables needed to calculate virtual temperature (i.e., pressure, temperature, and humidity). Sufficient soundings should be made for comparisons during different times of the day to evaluate the performance of the system under different meteorological conditions. Data collected from the sonde should be volume averaged into intervals consistent with the RASS averaging volumes, and the values should be compared on a level-by-level and overall basis.

9.6.3 Standard Operating Procedures

Standard operating procedures (SOPs) should be developed that are specific to the operations at a given site. The purpose of an SOP is to spell out operating and QC procedures with the ultimate goal of maximizing data quality and data capture rates. Operations should be performed according to a set of well defined, written SOPs with all actions documented in logs and on prepared forms. SOPs should be written in such a way that if problems are encountered, instructions are provided on actions to be taken. At a minimum, SOPs should address the following issues:

- Installation, setup, and checkout
- Site operations and calibrations
- Operational checks and preventive maintenance
- Data collection protocols
- Data validation steps
- Data archiving

9.6.4 Operational Checks and Preventive Maintenance

Like all monitoring equipment, upper-air instruments require various operational checks and routine preventive maintenance. The instrument maintenance manuals should be consulted to determine which checks to perform and their recommended frequency. The quality and quantity of data obtained will be directly proportional to the care taken in ensuring that the system is routinely and adequately maintained. The site technicians who will perform preventive and emergency maintenance should be identified. The site technicians serve a crucial role in producing high quality data and thus should receive sufficient training and instruction on how to maintain the equipment. Some general issues related to operational checks and preventive maintenance should be addressed in the QAPP, including:

- Identification of the components to be checked and replaced
- Development of procedures and checklists to conduct preventive maintenance
- Establishment of a schedule for checks and preventive maintenance

- Identification of persons (and alternates) who will perform the checks and maintenance
- Development of procedures for maintaining spare components that need frequent replacement

Listed below are some key items to be included in the operational checklists for each of the different types of instrumentation. The list is by no means complete, but should serve as a starting point for developing a more thorough set of instrumentation checks.

- Safety equipment (first aid kit, fire extinguisher) should be inventoried and checked.
- After severe or inclement weather, the site should be visited and the shelter and equipment should be inspected.
- Computers should be routinely monitored to assure adequate disk space is available, and diagnosed to ensure integrity of the disk.
- A visual inspection of the site, shelter, instrument and its components should be made.
- Data should be backed up on a routine basis.
- If the remote sensors are operated during the winter, procedures for snow and ice removal should be developed and implemented, as needed.
- The clock time of the instruments should be monitored, and a schedule for updating the clocks established based on the timekeeping ability of the instrument.
- The antenna level and orientation of sodar, radar, RASS, and radio theodolite radiosonde systems should be verified periodically.
- The inside of the antennas/enclosures of the sodar, radar and RASS systems should be inspected and any leaves, dust, animals, insects, snow, ice, or other materials removed. Since the antennas are open to precipitation, drain holes are provided to allow water to pass through the bottom of the antennas. These holes should be periodically inspected and cleaned.
- Cables and guy wires securing the equipment should be checked to ensure that they are tight and in good condition.
- Antenna cables and connections should be inspected for signs of damage due to normal wear, moisture, or animal activities.
- For sodar systems, the site technician(s) should listen to assure that the system is transmitting on all axes and in the correct firing sequence. For three-axis systems, this is accomplished by listening to each antenna. For phased-array systems, this can be accomplished by standing away from the antenna in the direction of each beam and listening for relatively stronger pulses.
- The integrity of any acoustic enclosures and acoustic-absorbing materials should be inspected. Weathering of these items will degrade the acoustic sealing properties of the enclosure and reduce the performance.
- For a radar profiler with RASS, acoustic levels from the sound sources should be measured using a sound meter (ear protection is required) and readings should be compared with manufacturer's guidelines.

All operational checks and preventive maintenance activities should be recorded in logs and/or on appropriate checklists, (electronic and/or paper) which will become part of the documentation that describes and defends the overall quality of the data produced.

9.6.5 Corrective Action and Reporting

A corrective action program must have the capability to discern errors or defects at any point in an upper-air monitoring program. It is an essential management tool for coordination, QC, and QA activities. A workable corrective action program must enable identification of problems, and establish procedures for reporting problems to the responsible parties, tracing the problems to the source, planning and implementing measures to correct the problems, maintaining documentation of the results of the corrective process, and resolution of each problem. The overall documentation associated with the corrective action and reporting process will become part of the documentation that describes and defends the overall quality of the data produced. A sample correction form can be found in reference **[65]**.

9.6.6 Common Problems Encountered in Upper-Air Data Collection

Studies performed to date have indicated that the upper-air measurement systems described in this document can reliably and routinely provide high quality meteorological data. However, these are complicated systems, and like all such systems are subject to sources of interference and other problems that can affect data quality. Users should read the instrument manuals to obtain an understanding of potential shortcomings and limitations of these instruments. If any persistent or recurring problems are experienced, the manufacturer or someone knowledgeable about instrument operations should be consulted.

Radiosonde data are susceptible to several problems, including the following:

- **Poor ventilation.** Prior to launch, lack of ventilation of the sonde may result in unrepresentative readings of temperature and relative humidity (and thus dew-point temperature) at or near the surface.
- **Radio frequency (RF) interference.** RF interference may occasionally produce erroneous temperature, dew-point temperature, and relative humidity measurements, which appear as spikes in the data when plotted in a time series or profile plot.
- **Uncertainties in the tracking mechanism.** Uncertainties in a radio theodolite's tracking mechanism may produce unrealistic changes in the wind speed and direction, especially when the antenna's elevation angle is less than about 10°.
- **Tracking problems.** Tracking of radiosondes can be problematic within rainshafts or updrafts/downdrafts associated with thunderstorms.
- **Icing.** When a balloon encounters clouds and precipitation zones where the temperature is below freezing, ice can form on the balloon and cause it to descend. Once the balloon descends below the freezing level, the ice melts and the balloon re-ascends. This causes the balloon to fluctuate up and down around the freezing level, and produces unrepresentative wind and thermodynamic data.

- **Poor radio navigation reception.** Not all sites have good radio navigation reception. If this technique is used to track the radiosonde, poor reception can produce uncertainties in the wind data. Poor reception will not affect the thermodynamic data.
- **Low-level wind problems.** Often the first few data points in a radiosonde wind profile tend to have more uncertainty due to initial tracking procedures or difficulties (see Section 9.1 for more details).

Sodar data can be rendered problematic by the following:

- **Passive noise sources (also called fixed echo reflections).** Passive noise occurs when nearby obstacles reflect the sodar's transmitted pulse. Depending on atmospheric conditions, wind speed, background noise, and signal processing techniques, the fixed echoes may reduce the velocity measured along a beam(s) or result in a velocity of zero. This problem is generally seen in the resultant winds as a rotation in direction and/or a decrease in speed at the affected altitude. Some manufacturers offer systems that have software designed to detect fixed echoes and effectively reject their influence. To further decrease the effect of the fixed echoes, additional acoustic shielding can be added to the system antenna.
- **Active noise sources (ambient noise interference).** Ambient noise can come from road traffic, fans or air conditioners, animals, insects, strong winds, etc. Loud broad-spectrum noise will decrease the SNR of the sodar and decrease the performance of the system. Careful siting of the instrument will help minimize this problem.
- **Unusually consistent winds at higher altitudes**. Barring meteorological explanations for this phenomenon, the most common cause is a local noise source that is incorrectly interpreted as a “real” Doppler shift. These winds typically occur near the top of the operating range of the sodar. A good means of identifying this problem is to allow the sodar to operate in a listen-only mode, without a transmit pulse, to see if winds are still reported. In some cases it may be necessary to make noise measurements in the specific operating range of the sodar to identify the noise source.
- **Reduced altitude coverage due to debris in the antenna.** In some instances, particularly after a precipitation event, the altitude coverage of the sodar may be significantly reduced due to debris in the antennas. In three axis systems, drain holes may become plugged with leaves or dirt and water, snow, or ice may accumulate in the antenna dishes. Similarly, some of the phased-array antenna systems have the transducers oriented vertically and are open to the environment. Blocked drain holes in the bottom of the transducers may prevent water from draining. Regular maintenance can prevent this type of problem.
- **Precipitation interference.** Precipitation, mostly rain, may affect the data collected by sodars. During rainfall events, the sodar may measure the fall speed of drops, which will produce unrealistic winds. In addition, the sound of the droplets hitting the antenna can increase the ambient noise levels and reduce the altitude coverage.
- **Low signal to noise ratio (SNR).** Conditions that produce low SNR can degrade the performance of a sodar. These conditions can be produced by high background noise, low turbulence and near neutral lapse rate conditions.

Data from radar wind profiler systems can be affected by several problems, including the following:

- **Interference from migrating birds.** Migrating birds can contaminate radar wind profiler signals and produce biases in the wind speed and direction measurements **[105]**. Birds act as large radar "targets," so that signals from birds overwhelm the weaker atmospheric signals. Consequently, the radar wind profiler measures bird motion instead of, or in addition to, atmospheric motion. Migrating birds have no effect on RASS. Birds generally migrate year-round along preferred flyways, with the peak migrations occurring at night during the spring and fall months **[106]**.

- **Precipitation interference.** Precipitation can affect the data collected by radar profilers operating at 915 MHZ and higher frequencies. During precipitation, the radar profiler measures the fall speed of rain drops or snow flakes. If the fall speeds are highly variable during the averaging period (e.g., convective rainfall), a vertical velocity correction can produce erroneous data.

- **Passive noise sources (ground clutter).** Passive noise interference is produced when a transmitted signal is reflected off an object instead of the atmosphere. The types of objects that reflect radar signals are trees, elevated overpasses, cars, buildings, airplanes, etc. Careful siting of the instrument can minimize the effects of ground clutter on the data. Both software and hardware techniques are also used to reduce the effects of ground clutter. However, under some atmospheric conditions (e.g., strong winds) and at some site locations, ground clutter can produce erroneous data. Data contaminated by ground clutter can be detected as a wind shift or a decrease in wind speed at affected altitudes. Additional information is provided in references **[107]** and **[108]**.

- **Velocity folding or aliasing.** Velocity folding occurs when the magnitude of the radial component of the true air velocity exceeds the maximum velocity that the instrument is capable of measuring, which is a function of sampling parameters **[109]**. Folding occurs during very strong winds (>20 m/s) and can be easily identified and flagged by automatic screening checks or during the manual review.

RASS systems are susceptible to several common problems including the following:

- **Vertical velocity correction.** Vertical motions can affect the RASS virtual temperature measurements. As discussed in Section 9.1, virtual temperature is determined by measuring the vertical speed of an upward-propagating sound pulse, which is a combination of the acoustic velocity and the atmospheric vertical velocity. If the atmospheric vertical velocity is non-zero and no correction is made for the vertical motion, it will bias the temperature measurement. As a rule of thumb, a vertical velocity of 1 ms^{-1} can alter a virtual temperature observation by 1.6°C.

- **Potential cold bias.** Recent inter-comparisons between RASS systems and radiosonde sounding systems have shown a bias in the lower sampling altitudes **[110]**. The RASS virtual temperatures are often slightly cooler (-0.5 to -1.0°C) than the reference radiosonde data. Work is currently underway to address this issue.

9.7 Data Processing and Management (DP&M)

An important component of any upper-air meteorological monitoring program is the processing, QA, management, and archival of the data. Each of these components is briefly discussed in this section and some general recommendations for data processing and management are provided. Additional guidance on data issues is provided in Chapter 8 of this guidance document.

9.7.1 Overview of Data Products

For radiosonde systems, the final data products typically consist of one or more ASCII files that contain the reduced thermodynamic data (pressure, temperature, relative humidity, dewpoint, etc.) and wind speed and wind direction as a function of altitude. Some radiosonde data systems store the thermodynamic information in one data file and the wind information in another, whereas other systems combine the observations into a single data file. Regardless of the approach used, the files containing the reduced wind and thermodynamic observations should be considered the final data products produced by the radiosonde sounding systems. Depending on the type of equipment, additional files may be created that include data reported in formats specifically intended for use by the NWS or other organizations, information on site location, sampling parameters, balloon position, etc. Typically, one set of files is created per sounding, that is, data from multiple soundings are not merged together.

For the remote sensing systems (sodar, radar wind profilers, RASS), the final data products usually consist of one or more ASCII files containing the averaged profiles of winds or virtual temperatures as a function of altitude. Supporting information provided with the reduced data products may include other variables such as horizontal and vertical meteorological velocity components (u, v, w), averaged return power, SNR or some other measure of signal strength, estimates of turbulence parameters (σ_w, σ_θ), mixing depth, etc. Typically one set of files is produced per 24-hour sampling period. These data files should be considered the final data products produced by this class of upper-air monitoring system. Other (lower-level) information generated by these systems may include, for example, the Doppler moment data and raw Doppler spectra. The quantity of information produced by the remote sensing systems usually requires that the lower-level data be stored in a binary format to conserve disk space. These data should be archived for backup purposes and to support post-processing or additional analyses of periods of interest.

9.7.2 Steps in DP&M

Data processing, validation, and management procedures for an upper-air meteorological monitoring program would typically include the following steps, which should be described in the QAPP:

- Collection and storage on-site (as appropriate) of the “raw” signals from the upper-air sensors, followed by real-time processing of the “raw” data by the data acquisition system to produce reduced, averaged profiles of the meteorological variables. The reduced data are stored on the data acquisition system's computer, usually in one or more ASCII files.

- Transfer of the reduced data to a central data processing facility at regular intervals (e.g., daily). Once the data are received at the central facility, they should be reviewed by an experienced data technician as soon as possible to verify the operational readiness of the upper-air site. Backup electronic copies of the data should be prepared and maintained on-site and off-site.

Data collected by the remote sensing systems can usually be obtained by polling the data system at a site from the central facility using a personal computer, modem, and standard telecommunications software. Other options that are available for communications with a remote upper-air site include leased-line telephone service, local or wide area network (LAN, WAN) connections, Internet access, and satellite telemetry. For immediate turnaround of radiosonde data, the upper-air operator can transfer the sounding data to the central facility using a personal computer equipped with a modem and communications software. There must be a bulletin board system (BBS) operating at the central facility, or some other means provided to receive the data (e.g., via an Internet access). Alternatively, if a one- or two-day delay is acceptable, the operator can mail the sounding data to the data center.

Please note that the initial review of the data is not very time consuming, but it is an extremely important component of a successful upper-air program. It is at this stage that most problems affecting data quality or data recovery will be detected. If the upper-air data are not reviewed at regular, frequent intervals, the risk of losing valuable information increases. If the data are reviewed frequently, then problems can be detected and corrected quickly, often the same day, thereby minimizing data losses. At a minimum, the operational readiness of an upper-air monitoring site should be checked regularly. Likewise, maintaining backup copies of the data at each stage of processing is extremely important. Backup copies should be kept at the central data processing facility and at a separate, off-site location(s) to ensure that no data are damaged or lost.

- Additional post-processing is performed as required (e.g., reformatting the data using a different database format than that produced by the data acquisition system) to produce the version of the data that will be subjected to final quality control validation.
- At this stage, the data are usually said to be at “Level 0” quality control validation, meaning that they are ready for quality control screening and final validation.
- Quantitative screening of the data can be performed using quality control software to identify outliers or other observations that are possibly in error or otherwise appear questionable.
- A final review of the data should be performed by an experienced meteorologist who understands the methods used to collect the data and who is knowledgeable about the kinds of meteorological conditions expected to be revealed in the data.

This is the process that brings the data to what is usually referred to as “Level 1” quality control validation, meaning that the data have been subjected to a qualitative (and often quantitative) review by experts to assess the accuracy, completeness, and internal consistency of the data. At this stage, data that have been determined to be in error are usually removed from the database, and quality control flags are assigned to the data values to indicate their validity. It is also at this stage that final calibrations should be applied to the data as necessary, as well as any changes required as the result of the system audits. Additional screening of the data based on comparisons to other independent data sets may be performed, which is part of the process to bring the data to "Level 2" quality control.

- Some final processing may be necessary to convert the data to the format that will be used to submit the information to the final data archive.

Final documentation should be prepared that summarizes sampling strategies and conditions; describes the results of audits and any actions taken to address issues raised by the audits; identifies any problems that adversely affected data quality and/or completeness; and describes the contents and formats of the database. Typically, a copy (electronic and/or paper) of this documentation accompanies the submittal of the data to the final data archive. Once the above steps are completed, the data are ready to be submitted to the upper-air archive. Several options for creating an archive are available, ranging from a simple repository to complex database management systems (DBMS).

9.7.3 Data Archiving

Maintaining a complete and reliable data archive is an important component of a QAPP. Upper-air instruments, especially remote sensors, produce a large amount of data consisting of raw and reduced data. The amount of data from these upper-air sensors can require in excess of several gigabytes of computer storage space per site per year. A protocol for routinely archiving the data should be established.

Raw data are the most basic data elements from which the final data are produced. Archiving these data is important because at a later date the raw data may need to be reprocessed to account for problems, errors, or calibrations. In addition, future processing algorithms may become available to extract more information from the raw data. Raw data are generally stored on-site and should be archived as part of the operational checks. Data should be stored on convenient and reliable archive media such as diskette, tape, or optical disk. The primary archive should be stored in a central repository at the agency responsible for collecting the data. A second backup of the raw data should be made and stored off-site to ensure a backup if the primary data archive becomes corrupted or destroyed.

Reduced data, which are created from the raw data by averaging, interpolating, or other processing methods, should also be archived. Reduced data include hourly averaged winds and temperatures from remote sensors, and vertically averaged winds and thermodynamic data from radiosonde sounding systems. Data validation is performed on the reduced data to identify and flag erroneous and questionable data. Both the reduced and validated data should be routinely (e.g., weekly or monthly) archived onto digital media, with one copy stored onsite and a second copy stored offsite.

Other supporting information should be archived along with the data such as:

- Site and maintenance logs
- Audit and calibration reports
- Site information
- Log of changes made to the data and the data quality control codes

- Information that future users would need to decode, understand, and use the data
- Surface measurements and other relevant weather data

Data should be retained indefinitely because they are often used for modeling and analysis many years following their collection. Periodically, the integrity of the archive media should be checked to ensure that data will be readable and have not become corrupted. Data should be recycled by transfer from old to new media approximately every 5 to 10 years. If an archive is scheduled to be eliminated, potential users should be notified beforehand so that any important or useful information can be extracted or saved.

9.8 Recommendations for Upper-Air Data Collection

- *Suggested Data Quality Objectives (DOQs) for upper-air measurement systems are given in Table 9-5. DOQs for accuracy should be based on systematic differences; DOQs for precision should be based on the "comparability" statistic; DOQs for completeness should be based on percent data recovery.*
- *Site selection for upper-air measurement systems is best accomplished in consultation with vendors or users with expertise in such systems. Operators and site technicians of upper-air monitoring systems should receive appropriate training prior to or during system shake-down. Training should include instruction in instrument principles, operations, maintenance, troubleshooting, data interpretation and validation.*
- *System calibration and diagnostic checks of upper-air measurement systems should be performed at six month intervals, or in accordance with the manufacturer's recommendations, whichever is more frequent.*
- *Data capture for wind direction and wind speed from a sodar or radar wind profiler is defined somewhat differently than for more conventional instruments. The following definitions and requirements apply to databases generated by these instruments:*

  - An averaging period (e.g., hourly) is considered valid if there are at least three valid levels of data for the period (independent of height).

  - If hourly average data are generated from sub-hourly intervals, the hourly values are considered valid if they consist for at least 30 minutes of valid sub- hourly data.

  - A valid level consists of all of the components needed to generate the horizontal wind vector.
- *Remote sensing data should be reviewed at least weekly and preferably daily to assess the operational status of the system and to ensure that data are valid and reasonable.*

General recommendations for the processing, management, and archival of upper-air meteorological data include:

- *A consistent/standardized database format should be established and maintained, at a minimum for each individual monitoring program..*

- *The data archive should include raw, reduced, and validated data as well as other (low-level) data products, as appropriate (e.g., Doppler spectral moments data).*
- *The upper-air data should be validated to Level 1 before distribution.*
- *The data archive should be routinely backed up and checked for integrity.*
- *A secondary backup of the data should be kept at an alternate location, routinely checked for integrity, and periodically recycled onto new storage media.*

Table 9-1

Operating characteristics of upper-air meteorological monitoring systems.

VARIABLES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Measured	• p, T, RH • Vector winds (WS, WD)	• Vector winds (WS, WD) • u,v,w wind components	• Vector winds (WS, WD) • u,v,w wind components	• Virtual temperature (T_v) • w wind component
Derived	• Altitude • Moisture variables (dewpoint, mixing ratio, vapor pressure, etc.) • Potential temperature • Inversion base, top • Mixing depth	• Mixing depth • Dispersion statistics (σ_θ, σ_w)	• Mixing depth	• Inversion base, top • Mixing depth

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

PERFORMANCE CHARACTERISTICS	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Minimum Altitude	10-150 m	10-30 m	90-120 m	90-120 m
Maximum Altitude	5-15 km	0.2-2 km	1.5-4 km	0.5-1.5 km
Vertical Resolution	5-10 m (p, T, RH) 50-100 m (winds)	5-100 m	60-100 m	60-100 m
Temporal Resolution	Integration time 5 sec.-2 min. Resolution: intermittent (time between soundings 1.5-12 hr.)	Integration time: 11-60 min. Resolution: continuous	Integration time 15-60 min. Resolution: continuous	Integration time 5-10 min. Resolution: intermittent (time between profiles 5 min-1 hr.)

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

PERFORMANCE CHARACTERISTICS	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Systematic Difference	p: ± 0.5 mb T: ± 0.2°C RH: ± 10% U.V.: ± 0.5 to 1.0 ms^{-1}	WS: ± 0.2 to 1.0 ms^{-1} WD: ± 3-10°	WS: ± 1 ms^{-1} WD: ± 3-10°	± 1°C
Comparability	p (as height): ± 24 m T: ± 0.6°C T_d: ± 3.3°C WS: ± 3.1 ms^{-1} WD: ± 5-18°	WS: ± 0.5 to 2.0 ms^{-1} WD: ± 5-30°	WS: ± 2 ms^{-1} WD: ± 30°	± 1.5°C

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Siting Requirements	• Requires relatively flat area approx. 30x30 m (allow sufficient space to launch balloon). • Absence of tall objects (trees, power lines, towers) that could snag weather balloon.	• Requires relatively flat area approx. 20x20 m (allow space for audit equipment, met tower). • Absence of active noise sources. • Absence of passive noise (clutter) targets. • No neighbors within about 100-500 m (depending on the sodar) who would be bothered by noise.	• Requires relatively flat area approx. 20x20 m (allow space for audit equipment, met tower). • Lack of radar clutter targets extending more than 5° above the horizon in antenna pointing directions; 15° otherwise.	• No neighbors within about 1000 m who would be bothered by noise.

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Siting Logistics	• Balloon inflation shelter (e.g., small shed, tent, etc.) • Small (e.g., 8x12 ft.) equipment shelter, tied down, lightning protection • Security fence • 110/220v, 30 amp power service (usually required for air conditioning) • Communications service for data telemetry, voice. • May require FAA approval for operations at airports. • Instrument set-up can be completed in less than a day.	• Small (e.g., 8x12 ft.) equipment shelter, tied down, lightning protection • Security fence • 110/220v, 30 amp power service (usually required for air conditioning) • Communications service for data telemetry, voice. • Site will require 1-2 days to establish once trailer, power, etc. installed.	• Small (e.g., 8x12 ft.) equipment shelter, tied down, lightning protection. • Security fence • 110/220v, 30 amp power service (usually required for air conditioning) • Communications service for data telemetry, voice. • Site will require 2-3 days to establish once trailer, power, etc. installed.	• Add-on to radar profiler or sodar. No special additional logistical requirements. • Approx. 0.5-1 day needed to install and get operational.
Licensing	N/A	N/A	FCC license required	FCC license required

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Routine Operations	• Intermittent sampling; number of soundings varies with measurement objectives. Typically, one sounding per day near sunrise is a minimum sampling frequency; this will characterize the early morning stable boundary layer. Additional soundings are useful at mid-morning (ABL development), mid-to-late afternoon (full extent of daytime ABL), and at night (nocturnal ABL). • Requires expendables for each sounding (radiosonde, balloon, helium, parachute, light for night operations). • Manned operations; requires an operator for each sounding.	• Continuous sampling • Automated, unmanned • Daily checks of operational status via remote polling.	• Continuous sampling • Automated, unmanned • Daily checks of operational status via remote polling.	• Intermittent sampling every hour, or more often as needed. • Automated, unmanned • Daily checks of operational status via remote polling.

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Maintenance	• Bi-weekly barometer calibration checks • Daily back-ups • Back-up tracking device (e.g., optical theodolite) useful in case primary tracking system fails.	• Routine bi-weekly site inspections, servicing • Monthly on-site backups • Snow, ice removal in winter • Manufacturer-recommended spare parts	• Routine bi-weekly site inspections, servicing • Monthly on-site backups • Snow, ice removal in winter • Manufacturer-recommended spare parts	• Routine bi-weekly site inspections, servicing (follow SOP) • Monthly on-site backups • Snow, ice removal in winter • Manufacturer-recommended spare parts
Ground Truth	• Barometric pressure • T, RH • Radio theodolite oriented to true north, level	• Antenna orientation relative to true north • Antenna level	• Antenna orientation relative to true north • Antenna level	• Acoustic sources level • Antenna level

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
QA	• Acceptance test • Standard operating procedure (SOP) • Routine comparison with 10 m tower data • Annual system audit • Annual performance audit of ground truth instruments (e.g., barometer).	• Acceptance test • Standard operating procedure (SOP) • Routine comparison with 10 m tower data • Annual system audit • Annual intercomparison using complementary upper-air system.	• Acceptance test • Standard operating procedure (SOP) • Routine comparison with 10 m tower data • Annual system audit • Annual intercomparison using complementary upper-air system.	• Acceptance test • Standard operating procedure (SOP) • Routine comparison with 10 m tower data • Annual system audit • Annual intercomparison using complementary upper-air system.
Training	• Operators trained to perform soundings; usually requires a few days of classroom and on-site training. • Final data review should be performed by a meteorologist familiar with the instrument systems used.	• Site technicians trained to service equipment; usually requires 1-2 days of on-site training. • Data processing technician trained to poll site, retrieve data, review operational status, troubleshoot problems. • Final data review should be performed by a meteorologist familiar with the instrument systems used.	• Site technicians trained to service equipment; usually requires 1-2 days of on-site training. • Data processing technician trained to poll site, retrieve data, review operational status, troubleshoot problems. • Final data review should be performed by a meteorologist familiar with the instrument systems used.	• Site technicians trained to service equipment; usually requires 1-2 days of on-site training. • Data processing technician trained to poll site, retrieve data, review operational status, troubleshoot problems. • Final data review should be performed by a meteorologist familiar with the instrument systems used.

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

OPERATIONAL ISSUES	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
Data Processing	• Reduce data on-site, ensure proper operations. • Bring final data to at least Level 1 QC validation (see text). • 100 Kb - 1 Mb/sounding	• Use vertical velocity correction (see text). • Bring final data to at least Level 1 QC validation (see text). • 100 Kb/day	• Use vertical velocity correction (see text). • Bring final data to at least Level 1 QC validation (see text). • 150 Kb-1 Mb /day	• Use vertical velocity correction (see text). • Bring final data to at least Level 1 QC validation (see text). • 20 Kb/day

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

STRENGTHS	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
	• *In situ* measurements • Deep profiles, high data recovery rates to extended altitudes. • Measures atmospheric moisture • Data compatible with global upper-air network.	• Samples lower parts of ABL • Continuous • Smaller sample volumes (finer vertical resolution). • Fixed reference frame • Useful in complex terrain to measure winds at plume heights.	• Samples through full extent of ABL • Continuous • Data recovery not affected by high wind speeds. • Performance improves with increasing RH. • Fixed reference frame	• Provides high time resolution of temperature profiles in ABL. • Measures T_v • Fixed reference frame

Table 9-1 (continued)

Operating characteristics of upper-air meteorological monitoring systems.

LIMITATIONS	RADIOSONDE	DOPPLER SODAR	BOUNDARY LAYER RADAR WIND PROFILER	RASS
	• Not continuous • Manned operations • Lowest altitude at which good winds are reported can be 200-300 m above ground level depending on tracking system, signal strength, operator training. • Balloon drifts with wind, producing moving reference frame for measurements. • Wet bulb not as reliable as carbon hygristor for measuring frost point. • Launching problematic during thunderstorms. • Subject to icing. • LORAN radio navigation system being discontinued.	• Altitude coverage may not extend through full depth of daytime ABL. • Altitude coverage may be limited at night due to nocturnal inversion. • Interference from active noise sources. • Interference from precipitation. • High wind speeds reduce altitude coverage. • Performance degrades (lower altitude coverage) with low RH. • Nuisance effects from transmitted noise. • Multiple component statistics such as σ_θ not reliable.	• Interference from precipitation. • Interference from migrating birds. • Lowest altitude sampled ~100 m above ground level. • May be subject to ground clutter. • Larger sample volumes (coarser vertical resolution). • Performance degrades (lower altitude coverage) at low RH.	• T_v may need to be converted to T. • Nuisance effects from transmitted noise. • Altitude coverage may not extend through full depth of daytime ABL. • Error sources exist that can produce biases on the order of 0.5-1° C, which may be corrected during post-processing.

10. REFERENCES

1. Code of Federal Regulations, Title 40 (Protection of the Environment) Appendix W to Part 51 - Guideline on Air Quality Models.

2. EPA, 1995. Quality assurance handbook for air pollution measurement systems. Vol. IV, Meteorological Measurements. EPA/600/R-94/038d, U.S. Environmental Protection Agency, Research Triangle Park, NC.

3. Hoffnagle, G.F., M.E. Smith, T.V. Crawford, and T.J. Lockhart, 1981. On-Site Meteorological Instrumentation Requirements to Characterize Diffusion from Point Sources -A Workshop, 15-17 January 1980, Raleigh, NC. Bull Amer. Meteor. Soc., Vol.62, No. 2, pp255-261.

4. ANS, 1984. Standard for Determining Meteorological Information at Nuclear Power Sites. ANSI/ANS-2.5-1984. American Nuclear Society, La Grange Park, IL.

5. Mason, C. J. and H. Moses, 1984. Meteorological Instrumentation. In: Atmospheric Science and Power Production, D. Randerson (ed.). DOE/TIC27601. U. S. Department of Energy, Oak Ridge, TN.

6. HMSO, 1956. Handbook of Meteorological Instruments, Part I. Great Britain Meteorological Office, Her Majesty's Stationery Office, London, England

7. Middleton, W. E. K. and A. F. Spilhaus, 1953. Meteorological Instruments, 3rd ed. University of Toronto Press, Toronto, Canada.

8. Wang, J. Y. and C. M. M. Felton, 1983. Instruments for Physical Environmental Measurements, 2nd ed. Kendall/Hunt Publishing Company, Dubuque, IA.

9. WMO, 1983. Guide to Meteorological Instruments and Methods of Observation (Fifth Edition) WMO No. 8., Secretariat of the World Meteorological Organization, Geneva, Switzerland.

10. Nappo, C. J. et al, 1982. The Workshop on the Representativeness of Meteorological Observations, June 1981, Boulder, CO. Bull. Amer. Meteor. Soc., Vol. 63, No. 7, pp.761-764. American Meteorological Society, Boston, MA.

11. Stauffer, D.R. and Seaman, N.L., 1990. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Monthly Weather Review*, 118: 1250-1277.

12. Stauffer, D.R., Seaman, N.L., and Binkowski, F.S., 1991. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part II: Effect of data assimilation within the planetary boundary layer. *Monthly Weather Review*, 119: 734-754.

13. EPA, 1985. Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations) - Revised. EPA 450/4-80-023R. U. S. Environmental Protection Agency, Research Triangle Park, NC.

14. Hanna, S. R., G. A. Briggs, and R. P. Hosker, 1982. Handbook on Atmospheric Diffusion. DOE/TIC-11223. U. S. Department of Energy, Oak Ridge, TN.

15. DOC, 1972. National Weather Service Observing Handbook No.2, Substation Observations. U.S. Department of Commerce, Environmental Science Services, Office of Meteorological Operations, Silver Springs, MD.

16. Raynor, G. S, P. Michael, and S. SethuRaman, 1979. Recommendations for Meteorological Measurement Programs and Atmospheric Diffusion Prediction Methods for Use at Coastal Nuclear Reactor Sites. NUREG/CR-0936. U.S. Nuclear Regulatory Commission, Washington, DC.

17. Brooks, C. E. P. and N. Carruthers, 1953. Handbook of Statistical Methods in Meteorology, M.O.538. Her Majesty's Stationery Office, London, England.

18. Mazzarella, D. A., 1972. An Inventory of Specifications for Wind Measuring Instruments. Bull. Amer. Meteor. Soc., Vol. 53, No. 9. pp.860-871, American Meteorological Society, Boston, MA

19. Gill, G. C., 1967. On the Dynamic Response of Meteorological Sensors and Recorders. Proceedings of the First Canadian Conference on Micro meteorology, Part I, Meteorological Service of Canada, Toronto, Canada.

20. American Society for Testing and Materials, 1985. Standard Method for Measuring Surface Wind by Means of Wind Vanes and Rotating Anemometers. ASTM D4480-85, American Society for Testing and Materials, Philadelphia, PA.

21. Mazzarella, D. A., 1978. Meteorological Instruments for Use Near the Ground: Their Selection and Use in Air Pollution Studies. In: Air Quality Meteorology and Atmospheric Ozone, Morris and Barris (eds.), American Society for Testing and Materials, Philadelphia, PA.

22. Snow, J. T., 1985. Meeting of ASTM Subcommittee D-22.1l: Meteorology. Bull. Amer. Meteor.. Soc., Vol. 66, No. ll, p.1432, American Meteorological Society, Boston, MA.

23. Mori, Y., 1986. Evaluation of Several Single-Pass Estimators of the Mean and the Standard Deviation of Wind Direction. J Climate Appl. Metro., 25, 1387-1397.

24. Mardia, K. V., 1972. Statistics of Directional Data. Academic Press, New York, NY.

25. Turner, D. B., 1986. Comparison of Three Methods for Calculating the Standard Deviation of the Wind Direction. J. Climate Appl. Meteor., Vol. 25, pp 703-707.

26. Yamartino, R. J., 1984. A Comparison of Several "Single-pass" Estimators of the Standard Deviation of Wind Direction. J. Climate Appl. Meteor., Vol. 23, pp.1362-l366.

27. Scire, J.S., D.G. Strimaitis, and R.J. Yamartino, 1990. Model formulation and user's guide for the CALPUFF dispersion model. Sigma Research Corp., Concord, MA.

28. Scire, J.S., E.M. Insley, and R.J. Yamartino, 1990. Model formulation and user's guide for the CALMET meteorological model. Sigma Research Corp., Concord, MA.

29. EPA, 1984. Calms Processor (CALMPRO) User's Guide. EPA-901/9-84-001. U. S. Environmental Protection Agency, Region I, Boston, MA.

30. Weber, A., J. S. Irwin, J. P. Kahler, and W. B. Petersen, 1975. Atmospheric Turbulence Properties in the Lowest 300 Meters. EPA 600/4-75-004. Environmental Protection Agency, Research Triangle, Park, NC.

31. Deihl, B. J., 1984. Vertical Wind Direction Standard Deviation (σ_ϕ); Variation With Height and Comparison of Measurement Systems. Public Service Company of New Mexico, Albuquerque, NM.

32. Irwin, J.S., 1979. A Theoretical Variation of the Wind Profile Power Law Exponent as a Function of Surface Roughness and Stability. Atmos. Env., Vol. 13, pp. 191-194

33. Pasquill, F., 1961. The estimation of the dispersion of windborne material, Meteorol. Mag., Vol. 90, pp. 33-49.

34. Turner, D.B., 1964. A diffusion model for an urban area. J. Appl. Meteor., Vol. 3. pp. 83-91.

35. Irwin, J.S., 1980. Dispersion estimate suggestion No. 8. U.S. Environmental Protection Agency, Research Triangle Park, NC.

36. List, R. J. 1966. Smithsonian Meteorological Tables, Sixth Revised Edition (Third Reprint). Smithsonian Institution, Washington, D. C.

37. Bowen, B.M., J.M. Dewart, and A.I. Chen, 1983. Stability Class Determination: A Comparison for one site. Proceedings Sixth Symposium on Turbulence and Diffusion, American Meteorological Society, Boston, MA, pp. 211-214.

38. EPA, 1994. An Evaluation of a Solar Radiation Delta-T Method for Estimating Pasquill-Gifford (P-G) Stability Categories, EPA-454/R-93-055, U.S. Environmental Protection Agency, Research Triangle Park, NC.

39. Mitchell, Jr. A.E. and K.O. Timbre, 1979. Atmospheric Stability Class from Horizontal Wind Fluctuation. Presented at 72nd Annual Meeting of Air Pollution Control Association, Cincinnati, OH; June 24-29, 1979. (Docket No. A-80-46, II-P-9).

40. NRC, 1972. Meteorological Programs in Support of Nuclear Power Plants. Regulatory Guide 1.23, U.S. Nuclear Regulatory Commission, Office of Standards Development, Washington, DC. (Docket No. A-80-46, II-P-11).

41. Hogstrom, A. and V. Hogstrom, 1978. A Practical Method for Determining Wind Frequency Distributions for the Lowest 200 m from Routine Meteorological Data. Journal of Applied Meteorology, 17(7):942-954.

42. Smith T.B. and S.M. Howard, 1972. Methodology for Treating Diffusivity. MRI 72 FR-1030. Meteorology Research Inc., Altadena, CA. (Docket No. A-80-46, II-P-8).

43. Beyrich, F. 1997. Mixing height estimation from sodar data--a critical discussion. *Atmos. Environ.*, **31**, 3941-3953.

44. Holzworth, G. C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. AP-101. U.S. Environmental Protection Agency, Research Triangle Park, NC.

45. Weil, J.C., and Brower, R.P., 1983. Estimating convective boundary layer parameters for diffusion applications. Environmental Center, Martin Marietta Corp. PPSP-MP-48, Baltimore, Maryland, 45pp.

46. Paine, R.J., 1987. User's Guide to the CTDM Meteorological Preprocessor (METPRO) Program, U.S. Environmental Protection Agency EPA/600/8-88/004 (NTIS 8-162102), RTP, NC, 160pp.

47. EPA, 1985. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume II Description of Model Algorithms. EPA-454/B-95-003b. U.S. Environmental Protection Agency, Research Triangle Park, NC.

48. Golder, D., 1972. Relations among stability parameters in the surface layer. Boundary Layer Meteor., 3, 47-58.

49. Nieuwstadt, R. T. M., 1978. The computation of the friction velocity u* and the temperature scale T* from temperature and wind velocity profiles by least-square methods. Bound.-Layer Meteorol., Vol. 14, pp.235-246.

50. Wang, I.T., 1981. The determination of surface-layer stability and eddy fluxes using wind speed and vertical temperature gradient measurements. J. Appl. Met. 20, 1241-1248.

51. Irwin, J. S. and F. S. Binkowski, 1981. Estimation of the Monin-Obukhov scaling length using on-site instrumentation. Atmos. Environ., Vol. 15, pp.1091-1094. (Erratum, 1982, Atmos. Environ., 16, 887).

52. Berkowicz, R. And L.P. Prahm, 1982. Evaluation of the profile method for estimation of the surface fluxes of momentum and heat. Atmospheric Environment, 16, 2809-2819.

53. Holtslag A.A.M. and A.P. van Ulden, 1983: A simple scheme for daytime estimates of the surface fluxes from routine weather data. *J. Clim. and Appl. Meteor.*, **22**, 517-529.

54. Holtslag, A. A. M., 1984. Estimates of diabatic wind speed profiles from near surface weather observations. Bound-Layer Meteor., Vol. 29, pp.225-250.

55. Van Ulden, A.P., and A.A.M. Holtslag, 1985. Estimation of atmospheric boundary layer parameters for diffusion applications. J. Clim. And Appl. Meteor., 24, 1196-1207.

56. Holtslag, A.A.M. and F.T.M. Nieuwstadt, 1986. Scaling the atmospheric boundary layer. Bound-Layer Meteor., 36, 201-209.

57. Gryning, S.E., A.A.M. Holtslag, J.S. Irwin, and B. Sivertsen, 1987. Applied dispersion modeling based on meteorological scaling parameters. Atmospheric Environment, 21, 79-89.

58. Byun, W.B., 1990. On the analytical solution of flux-profile relationships for the atmospheric surface layer. *J. Appl. Meteor., 29(7): 652-657.*

59. Irwin, J.S., and J.O. Paumier, 1990. Characterizing the dispersive state of convective boundary layers for applied dispersion modeling. Bound-Layer Meteor., 53, 267-296.

60. Wieringa, J., 1993. Representative roughness parameters for homogeneous terrain. Bound-Layer Meteor., 63, 323-363.

61. Irwin, J.S., T.M. Asbury and W.B. Petersen (1986): Description of the Savanna River Laboratory meteorological data base for 1975 to 1979. EPA/600/3-86-017. Atmospheric Sciences Research Laboratory, RPT, NC, 121 pp. (NTIS Accession Number PB 86-166287).

62. NWS, 1995. Federal Meteorological Handbook No. 1 (FMH-1) Surface Weather Observations and Reports, fifth edition, Washington, D.C.

63. Lockhart, T. J., 1985. Quality Assurance of Meteorological Measurements. In: Quality Assurance for Environmental Measurements, ASTM STP 867. J. K. Taylor and T. W. Stanley (eds). American Society for Testing and Materials, Philadelphia, PA.

64. Weiss, L. L., 1961. Relative Catches of Snow in Shielded and Unshielded Gauges at Different Wind Speeds. Monthly Weather Review, Vol. 89.

65. EPA 1994. Quality assurance handbook for air pollution measurement systems. Vol. I, a field guide to environmental quality assurance. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/R-94/038a.

66. Mueller P.K. and Watson J.G. (1982) Eastern regional air quality measurements. Vol. 1, Section 7. Report prepared by Electric Power Research Institute, Palo Alto, CA, Report No. EA-1914.

67. Watson J.G., Lioy P.J., and Mueller P.K. (1989) The measurement process: precision, accuracy, and validity. In *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*, 7th Edition, Hering S.V., ed., American Conference of Governmental Industrial Hygienists, Cincinnati, OH, pp. 51-57.

68. Atkinson B.W. 1981. *Meso-Scale Atmospheric Circulations*. Academic Press, Inc., London.

69. Stull R.B. 1988. *An Introduction to Boundary Layer Meteorology*. Kluwer Academic Publishers, Norwell, MA, 666 pp.

70. Neff, W.D. 1998. Advances in meteorological measurement methods for application to air quality research and monitoring. *Atmos. Environ.*, submitted.

71. Dye T.S., C.G. Lindsey, and J.A. Anderson. 1995. Estimates of mixing depths from "boundary layer" radar profilers. In *Preprints of the 9th Symposium on Meteorological Observations and Instrumentation*, Charlotte, NC, March 27-31, *Amer. Meteor. Soc.*, 156-160.

72. Gaynor, J.E. 1994. Accuracy of sodar wind variance measurements. *Int. J. Remote Sens.*, 15, 313-324.

73. van de Kamp D.W. 1988. Profiler training manual #2: quality control of wind profiler data. Report prepared for the National Weather Service Office of Meteorology by NOAA/WPL, Boulder, CO.

74. Ecklund W.L., Carter D.A., and Balsley B.B. 1987. A UHF wind profiler for the boundary layer: brief description and initial results. *J. Atmos. Ocean. Technol.*, **5**, 432-441.

75. Hooper A.H. 1975. Upper-air sounding studies. Vol. 1: studies on radiosonde performance. World Meteorological Organization, Tech. Note No. 140, WMO No. 394, 109 pp.

76. Yako, S., W. Yagihashi, and S. Chubachi. 1977. Comparison of temperature, humidity, and wind data between conventional rawinsonde and tethered balloon. *J. Meteor. Res.*, **29**, 153-157.

77. Hoehne W.E. 1980. Precision of National Weather Service upper air measurements. Technical memo prepared by Office of Systems Development, Test and Evaluation Division, National Oceanic and Atmospheric Administration, Sterling, VA, NOAA No. NWS T&ED-016, 23 pp.

78. Richner, H., and P.D. Phillips. 1981. Reproducibility of VIZ radiosonde data and some sources of error. *J. Appl. Meteor.*, **20**, 954-963.

79. Finger F.G. and Schmidlin F.J. 1991. Upper-air measurements and instrumentation workshop. *Bull. Am. Meteorol. Soc.*, **72**, 50-55.

80. Wade, C.G. 1994. An evaluation of problems affecting the measurement of low relative humidity on the United States radiosonde. *J. Atmos. Oceanic Technol.*, **11**, 687-700.

81. Connell B.H. and Miller D.R. 1995. An interpretation of radiosonde errors in the atmospheric boundary layer. J. Appl. Meteorol., **34**, 1070-1081.

82. Finkelstein, P. L., J. C. Kaimal, J. E. Gaynor, M. E. Graves, and T. J. Lockhart. 1986. Comparison of wind monitoring systems. Part II: Doppler sodars. *J. Atmos. Oceanic Technol.*, **3**, 594-604.

83. Chintawongvanich, P., R. Olsen, and C.A. Biltoft. 1989. Intercomparison of wind measurements from two acoustic Doppler sodars, a laser Doppler lidar, and *in situ* sensors. *J. Atmos. Oceanic Technol.*, **6**, 785-797.

84. Gaynor, J.E., C.B. Baker, and J.C. Kaimal. 1990. The international sodar intercomparison experiment. Proc., *5th International Symposium on Acoustic Remote Sensing*, New Delhi, India, Int. Soc. Acoust. Remote Sens., 67-74.

85. Gaynor, J.E., C.B. Baker, and B. Templeman. 1991. Fine time-scale comparisons between Doppler sodar and sonic anemometer-derived winds. Preprint, *Seventh Symposium on Meteorological Observations and Instrumentation*, New Orleans, LA, Amer. Meteor. Soc., 401-404.

86. Thomas, P., and S. Vogt. 1993. Intercomparison of turbulence data measured by sodar and sonic anemometers. *Bound.-Layer Meteor.*, **62**, 353-359.

87. Kurzeja, R.J. 1994. Comparison of a Doppler sodar with bivanes and cup anemometers. *J. Atmos. Oceanic Technol.*, **11**, 192-199.

88. Crescenti, G.H. 1997. A look back on two decades of Doppler sodar comparison studies: a review. Bull. Amer. Meteor. Soc., **78**, 651-673.

89. Gage, K.S., J.R. McAfee, W.G. Collins, D. Söderman, H. Böttger, A. Radford, and B. Balsley. 1988. A comparison of winds observed at Christmas Island using a wind-profiling Doppler radar with NMC and ECMWF analyses. *Bull. Amer. Meteor. Soc.*, **69**, 1041-1046.

90. Weber, B.L., and D.B. Wuertz. 1990. Comparison of rawinsonde and wind profiler radar measurements. *J. Atmos. Oceanic Technol.*, **7**, 157-174.

91. Angevine, W.M., and J.I. MacPherson. 1995. Comparison of wind profiler and aircraft wind measurements at Chebogue Point, Nova Scotia. *J. Atmos. Oceanic Technol.*, **12**, 421-426.

92. Dobos, P.H., R.J. Lind, and R.L. Elsberry. 1995. Surface wind comparisons with radar wind profiler observations near tropical cyclones. *Wea. Forecasting*, **10**, 564-575.

93. Schroeder, J.A. 1990. A comparison of temperature soundings obtained from simultaneous radiometric, radio-acoustic, and rawinsonde measurements. *J. Atmos. Oceanic Technol.*, **7**, 495-503.

94. Schroeder, J.A., E.R. Westwater, P.T. May, and L.M. McMillin. 1991. Prospects for temperature sounding with satellite and ground-based RASS measurements. *J. Atmos. Oceanic Technol.*, **8**, 506-513.

95. Martner, B.E., D.B. Wuertz, B.B. Stankov, R.G. Strauch, E.R. Westwater, K.S. Gage, W.L. Ecklund, C.L. Martin, and W.F. Dabberdt. 1993. An evaluation of wind profiler, RASS, and microwave radiometer performance. *Bull. Amer. Meteor. Soc.*, **74**, 599-613.

96. Engelbart, D., H. Steinhagen, U. Gorsdorf, J. Lippmann, and J. Neisser. 1995. A 1290 MHZ profiler with RASS for monitoring wind and temperature in the boundary layer. *Contributions to Atmospheric Physics*, **69**, 63-80.

97. Congeduti, F., G. Fiocco, A. Adriani, and C. Guarrella. 1981. Vertical wind velocity measurements by a Doppler lidar and comparisons with a Doppler sodar. *Appl. Opt.*, **20**, 2048-2054.

98. Devara, P.C.S., P.E. Raj, B.S. Murthy, G. Pandithurai, S. Sharma, and K.G. Vernekar. 1995. Intercomparison of nocturnal lower-atmospheric structure observed with lidar and sodar techniques at Pune, India. *J. Appl. Meteor.*, **34**, 1375-1383.

99. Casadio, S., A. Di Sarra, G. Fiocco, D. Fuà, F. Lena, and M.P. Rao. 1996. Convective characteristics of the nocturnal urban boundary layer as observed with Doppler sodar and Raman lidar. *Bound.-Layer Meteor.*, **79**, 375-391.

100. ASTM, 1984. Standard practice for determining the operational comparability of meteorological measurements., American Society for Testing and Materials, Philadelphia, PA, No. D 4430-84.

101. Thuillier, R.H. 1995. The influence of instrumentation, siting, exposure height, and temporal averaging methodology on meteorological measurements from SJVAQS/AUSPEX. *J. Appl. Meteor.*, **34**, 1815-1823.

102. Crescenti, G. H. 1998. The degradation of Doppler sodar performance due to noise: a review. *Atmos. Environ.*, **32**, 1499-1509.

103. Crescenti, G.H., and R.A. Baxter. 1998. Examples of noise interference on Doppler sodar performance. Preprint, *Tenth Symposium on Meteorological Observations and Instrumentation*, Phoenix, AZ, Jan. 11-16, Amer. Meteor. Soc., 228-232.

104. Baxter R.A. 1994. Development of a universal acoustic pulse transponding system for performance auditing of sodars. In *Proceedings from the 7th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans*, Boulder, CO, October, pp. 3-35-3-40.

105. Wilczak, J.M., R.G. Strauch, F.M. Ralph, B.L. Weber, D.A. Merritt, J.R. Jordan, D.E. Wolfe, L.K. Lewis, D.B. Wuertz, J.E. Gaynor, S.A. McLaughlin, R.R. Rogers, A.C. Riddle, and T.S. Dye. 1995. Contamination of wind profiler data by migrating birds: characteristics of corrupted data and potential solutions. *J. Atmos. Oceanic Technol.*, **12**, 449-467.

106. Gauthreaux Jr., S.A. (1991) The flight behavior of migrating birds in changing wind fields: radar and visual analyses. *Amer. Zool.*, **31**, 187-204.

107. Brewster, K.A. 1989. Profiler training manual #2: quality control of wind profiler data. Report prepared for Office of Meteorology, National Weather Service by NOAA/ERL/FSL, Boulder, CO, August.

108. Gaynor, J.E. 1994. Siting guidance for boundary layer meteorological profiles. *Proceedings, International Symposium on the Measurement of Toxic and Related Pollutants*, Durham, NC, May 3-6, AWMA, 263-269.

109. Miller P.A., T.W. Schlatter, D.W. van de Kamp, M.F. Barth, and B.L Weber. 1994. An unfolding algorithm for profiler winds. *J. Atmos. Ocean. Technol.* **11**, 32-41.

110. Riddle A.C., W.M. Angevine, W.L. Ecklund, E.R. Miller, D.B. Parsons, D.A. Carter, and K.S. Gage. 1995. Wind-profiler performance and balloon observations compared at ISS sites during TOGA COARE. *Contrib. Atmos. Phy.*, (accepted for publication).

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. EPA-454/R-99-005	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Meteorological Monitoring Guidance for Regulatory Modeling Applications		5. REPORT DATE February 2000 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Desmond T. Bailey		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This document provides EPA's guidance for the collection and processing of meteorological data for use in regulatory dispersion modeling and is the basis for the regulatory review of proposed meteorological monitoring plans by the EPA Regions and the States. The document contains comprehensive and detailed guidance for meteorological measurement programs, covering the initial design and siting of a system, through data recording and processing.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Atmospheric Dispersion Modeling Meteorological Processors Meteorological Monitoring Meteorology		
18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 168
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

Subject: RE: Illinois EPA Modeling Guidance
From: "Will, Matt" <Matt.Will@Illinois.gov>
Date: 9/12/2013 3:28 PM
To: Steven Klafka <sklafka@wingraengineering.com>

9-12-2013

Hi Steve,

I was able to resolve the surface roughness issues with Evansville, so for your modeling at Newton, please use Evansville surface met data. I have attached the AERMET stage 3 inputs for processing AERMOD ready met data for Evansville. I can also answer any further questions that you may have regarding your modeling.

Regards,

Matt

-----Original Message-----
From: Steven Klafka [mailto:sklafka@wingraengineering.com]
Sent: Thursday, September 12, 2013 2:46 PM
To: Will, Matt
Subject: Re: Illinois EPA Modeling Guidance

Matt,

Thought I'd check back with you on the use of the Mattoon met data for modeling sources in Newton. I normally wouldn't badger but the modeling results are due by Monday if possible.

Steve Klafka

Will, Matt wrote:

> Hi Steve,
>
> The rationale surface data characteristics for different years involves taking into account what seasons of what years were wet, dry, or normal as well as percentages of snow cover for winter seasons.
>
> The acceptability met data from Mattoon is still under consideration but hopefully, will get resolved shortly.
>
> Regards,
>
> Matt
>
> -----Original Message-----
> From: Steven Klafka [mailto:sklafka@wingraengineering.com]
> Sent: Tuesday, September 10, 2013 10:58 AM
> To: Will, Matt
> Subject: Re: Illinois EPA Modeling Guidance
>
> Matt,
>
> Thought I would check and see if you've considered the acceptability of using met data from the Coles County Memorial Airport in Mattoon for sources in Newton.
>
> Reviewing the surface characteristics for Paducah, how did processing of each year differ? I would assume the land use would be the same, but did the Site Surface Moisture or Continuous Snow Cover vary from year to year?

Thanks.

Steve Klafka

Steven Klafka wrote:

> Thanks. Have good weekend as well.
>
> Will, Matt wrote:
>
>> Hi Steve,
>>
>> I have attached the Paducah, Kentucky and Evansville, Indiana, surface data characteristics if we decide to go with Evansville. Have a good weekend.
>>
>> Regards,
>>
>> Matt
>>
>> Matthew L. Will
>> Modeling Unit/Air Quality Planning Section, MS39 Bureau of Air
>> Illinois EPA
>> 1021 North Grand Avenue East
>> P.O. Box 19276
>> Springfield, Illinois 62794-9276
>> Phone: 217/524-4789
>> FAX: 217/524-4710
>> Email: matt.will@illinois.gov
>> Web Site: http://www.epa.state.il.us/
>>
>> -----Original Message-----
>> From: Steven Klafka [mailto:sklafka@wingraengineering.com]
>> Sent: Friday, September 06, 2013 11:33 AM
>> To: Will, Matt
>> Subject: Re: Illinois EPA Modeling Guidance
>>
>> My bad. Yes, I see Paducah would be a better choice for proximity and land use.
>>
>> Will, Matt wrote:
>>
>>> Hi Steve,
>>>
>>> The airport was Paducah, Kentucky not Cahokia, Illinois.
>>>
>>> Regards,
>>>
>>> Matt
>>>
>>> -----Original Message-----
>>> From: Steven Klafka [mailto:sklafka@wingraengineering.com]
>>> Sent: Friday, September 06, 2013 11:24 AM
>>> To: Will, Matt
>>> Subject: Re: Illinois EPA Modeling Guidance
>>>
>>> Matt,
>>>
>>> For the Joppa site, I initially processed met data from the Southern Illinois Airport in Carbondale. I believe you suggested met data from the Cahokia airport. I thought Carbondale was a good fit for Joppa due to its proximity, similar land use and after processing one minute winds had 1.85% calms.

For your review, attached are the .sfc and .pfl files created by AERMET for Southern Illinois, a wind rose and aerial photo comparison of Joppa, Southern Illinois Airport and Cahokia.

Let me know if either the airport at Carbondale or Cahokia would be more appropriate for modeling sources in Joppa.

Thanks.

Steve Klafka

Steven Klafka wrote:

> Matt,
>
> As discussed this morning, please send the Stage 3 AERMET files for met stations you recommend for modeling sources in Joppa and Newton.
>
> For Newton, I had considered the use of met data from the Coles County Memorial Airport in Mattoon. It is closer than Evansville, has similar land use as Newton and only had 0.74% calms after using one winds for processing in AERMET. For you information, I have attached the final .sfc and .pfl files, a wind rose and aerial photo comparison. Please let me know if you think Coles County or Evansville met data would be a better fit for Newton.
>
> Thanks for your assistance.
>
> Steve Klafka
>
> Steven Klafka wrote:
>
>> Matt,
>>
>> Thank you for returning my call.
>>
>> I was interesting in receiving Illinois EPA dispersion modeling guidance which explains acceptable modeling procedures. It would be appreciated if you sent a copy of your current guidance.
>>
>> You mentioned that EPA does not provide met data for modeling analyses. However, please provide any guidance regarding the selection and processing of met data.
>>
>> Should have any questions, don't hesitate to call.
>>
>> Steve Klafka

--
Steven Klafka, P.E., BCEE
Environmental Engineer
Wingra Engineering, S.C.
303 South Paterson Street
Madison, WI 53703
(608) 255-5030
www.wingraengineering.com
Since 1991

evv2012_adjusted.txt

```
** EVV 2012
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Fall, Dry Winter Spring Summer, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**          Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.20     1.95     0.023
   SITE_CHAR    1       2     0.20     1.95     0.015
   SITE_CHAR    1       3     0.20     1.95     0.023
   SITE_CHAR    1       4     0.20     1.95     0.025
   SITE_CHAR    1       5     0.20     1.95     0.022
   SITE_CHAR    1       6     0.20     1.95     0.109
   SITE_CHAR    1       7     0.20     1.95     0.015
   SITE_CHAR    1       8     0.20     1.95     0.033
   SITE_CHAR    1       9     0.20     1.95     0.025
   SITE_CHAR    1      10     0.20     1.95     0.019
   SITE_CHAR    1      11     0.20     1.95     0.017
   SITE_CHAR    1      12     0.20     1.95     0.030
   SITE_CHAR    2       1     0.15     1.20     0.031
   SITE_CHAR    2       2     0.15     1.20     0.023
   SITE_CHAR    2       3     0.15     1.20     0.035
   SITE_CHAR    2       4     0.15     1.20     0.039
   SITE_CHAR    2       5     0.15     1.20     0.034
   SITE_CHAR    2       6     0.15     1.20     0.144
   SITE_CHAR    2       7     0.15     1.20     0.024
   SITE_CHAR    2       8     0.15     1.20     0.040
   SITE_CHAR    2       9     0.15     1.20     0.032
   SITE_CHAR    2      10     0.15     1.20     0.025
   SITE_CHAR    2      11     0.15     1.20     0.024
   SITE_CHAR    2      12     0.15     1.20     0.042
   SITE_CHAR    3       1     0.19     1.43     0.051
   SITE_CHAR    3       2     0.19     1.43     0.049
   SITE_CHAR    3       3     0.19     1.43     0.104
   SITE_CHAR    3       4     0.19     1.43     0.133
```

```
   SITE_CHAR    3       5     0.19     1.43     0.119
   SITE_CHAR    3       6     0.19     1.43     0.189
   SITE_CHAR    3       7     0.19     1.43     0.050
   SITE_CHAR    3       8     0.19     1.43     0.049
   SITE_CHAR    3       9     0.19     1.43     0.043
   SITE_CHAR    3      10     0.19     1.43     0.033
   SITE_CHAR    3      11     0.19     1.43     0.041
   SITE_CHAR    3      12     0.19     1.43     0.077
   SITE_CHAR    4       1     0.19     0.79     0.045
   SITE_CHAR    4       2     0.19     0.79     0.042
   SITE_CHAR    4       3     0.19     0.79     0.097
   SITE_CHAR    4       4     0.19     0.79     0.127
   SITE_CHAR    4       5     0.19     0.79     0.112
   SITE_CHAR    4       6     0.19     0.79     0.161
   SITE_CHAR    4       7     0.19     0.79     0.042
   SITE_CHAR    4       8     0.19     0.79     0.044
   SITE_CHAR    4       9     0.19     0.79     0.038
   SITE_CHAR    4      10     0.19     0.79     0.028
   SITE_CHAR    4      11     0.19     0.79     0.035
   SITE_CHAR    4      12     0.19     0.79     0.070
```

evv2011_adjusted.txt

```
** EVV 2011
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Wet All Seasons, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**          Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.20     0.77     0.022
   SITE_CHAR    1       2     0.20     0.77     0.015
   SITE_CHAR    1       3     0.20     0.77     0.022
   SITE_CHAR    1       4     0.20     0.77     0.025
   SITE_CHAR    1       5     0.20     0.77     0.022
   SITE_CHAR    1       6     0.20     0.77     0.109
```

```
SITE_CHAR    1     7     0.20     0.77     0.015
SITE_CHAR    1     8     0.20     0.77     0.033
SITE_CHAR    1     9     0.20     0.77     0.025
SITE_CHAR    1    10     0.20     0.77     0.019
SITE_CHAR    1    11     0.20     0.77     0.017
SITE_CHAR    1    12     0.20     0.77     0.030
SITE_CHAR    2     1     0.15     0.26     0.031
SITE_CHAR    2     2     0.15     0.26     0.023
SITE_CHAR    2     3     0.15     0.26     0.035
SITE_CHAR    2     4     0.15     0.26     0.039
SITE_CHAR    2     5     0.15     0.26     0.034
SITE_CHAR    2     6     0.15     0.26     0.144
SITE_CHAR    2     7     0.15     0.26     0.024
SITE_CHAR    2     8     0.15     0.26     0.040
SITE_CHAR    2     9     0.15     0.26     0.032
SITE_CHAR    2    10     0.15     0.26     0.025
SITE_CHAR    2    11     0.15     0.26     0.024
SITE_CHAR    2    12     0.15     0.26     0.042
SITE_CHAR    3     1     0.19     0.33     0.051
SITE_CHAR    3     2     0.19     0.33     0.049
SITE_CHAR    3     3     0.19     0.33     0.104
SITE_CHAR    3     4     0.19     0.33     0.133
SITE_CHAR    3     5     0.19     0.33     0.119
SITE_CHAR    3     6     0.19     0.33     0.189
SITE_CHAR    3     7     0.19     0.33     0.050
SITE_CHAR    3     8     0.19     0.33     0.049
SITE_CHAR    3     9     0.19     0.33     0.043
SITE_CHAR    3    10     0.19     0.33     0.033
SITE_CHAR    3    11     0.19     0.33     0.041
SITE_CHAR    3    12     0.19     0.33     0.077
SITE_CHAR    4     1     0.19     0.44     0.045
SITE_CHAR    4     2     0.19     0.44     0.042
SITE_CHAR    4     3     0.19     0.44     0.097
SITE_CHAR    4     4     0.19     0.44     0.127
SITE_CHAR    4     5     0.19     0.44     0.112
SITE_CHAR    4     6     0.19     0.44     0.161
SITE_CHAR    4     7     0.19     0.44     0.042
SITE_CHAR    4     8     0.19     0.44     0.044
SITE_CHAR    4     9     0.19     0.44     0.038
SITE_CHAR    4    10     0.19     0.44     0.028
SITE_CHAR    4    11     0.19     0.44     0.035
SITE_CHAR    4    12     0.19     0.44     0.070
```

evv2010_adjusted.txt

```
** EVV 2010
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average All Seasons, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11
```

```
   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**          Season   Sect    Alb      Bo       Zo
   SITE_CHAR    1       1    0.26     0.72     0.021
   SITE_CHAR    1       2    0.26     0.72     0.013
   SITE_CHAR    1       3    0.26     0.72     0.022
   SITE_CHAR    1       4    0.26     0.72     0.023
   SITE_CHAR    1       5    0.26     0.72     0.021
   SITE_CHAR    1       6    0.26     0.72     0.098
   SITE_CHAR    1       7    0.26     0.72     0.014
   SITE_CHAR    1       8    0.26     0.72     0.032
   SITE_CHAR    1       9    0.26     0.72     0.024
   SITE_CHAR    1      10    0.26     0.72     0.017
   SITE_CHAR    1      11    0.26     0.72     0.015
   SITE_CHAR    1      12    0.26     0.72     0.029
   SITE_CHAR    2       1    0.15     0.41     0.031
   SITE_CHAR    2       2    0.15     0.41     0.023
   SITE_CHAR    2       3    0.15     0.41     0.035
   SITE_CHAR    2       4    0.15     0.41     0.039
   SITE_CHAR    2       5    0.15     0.41     0.034
   SITE_CHAR    2       6    0.15     0.41     0.144
   SITE_CHAR    2       7    0.15     0.41     0.024
   SITE_CHAR    2       8    0.15     0.41     0.040
   SITE_CHAR    2       9    0.15     0.41     0.032
   SITE_CHAR    2      10    0.15     0.41     0.025
   SITE_CHAR    2      11    0.15     0.41     0.024
   SITE_CHAR    2      12    0.15     0.41     0.042
   SITE_CHAR    3       1    0.19     0.53     0.051
   SITE_CHAR    3       2    0.19     0.53     0.049
   SITE_CHAR    3       3    0.19     0.53     0.104
   SITE_CHAR    3       4    0.19     0.53     0.133
   SITE_CHAR    3       5    0.19     0.53     0.119
   SITE_CHAR    3       6    0.19     0.53     0.189
   SITE_CHAR    3       7    0.19     0.53     0.050
   SITE_CHAR    3       8    0.19     0.53     0.049
   SITE_CHAR    3       9    0.19     0.53     0.043
   SITE_CHAR    3      10    0.19     0.53     0.033
   SITE_CHAR    3      11    0.19     0.53     0.041
   SITE_CHAR    3      12    0.19     0.53     0.077
   SITE_CHAR    4       1    0.19     0.79     0.045
   SITE_CHAR    4       2    0.19     0.79     0.042
   SITE_CHAR    4       3    0.19     0.79     0.097
   SITE_CHAR    4       4    0.19     0.79     0.127
   SITE_CHAR    4       5    0.19     0.79     0.112
   SITE_CHAR    4       6    0.19     0.79     0.161
   SITE_CHAR    4       7    0.19     0.79     0.042
   SITE_CHAR    4       8    0.19     0.79     0.044
   SITE_CHAR    4       9    0.19     0.79     0.038
   SITE_CHAR    4      10    0.19     0.79     0.028
```

```
   SITE_CHAR    4      11     0.19     0.79     0.035
   SITE_CHAR    4      12     0.19     0.79     0.070
```

evv2009_adjusted.txt

```
** EVV 2009
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Winter Spring Summer, Wet Fall, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.20     0.78     0.023
   SITE_CHAR    1       2     0.20     0.78     0.015
   SITE_CHAR    1       3     0.20     0.78     0.024
   SITE_CHAR    1       4     0.20     0.78     0.025
   SITE_CHAR    1       5     0.20     0.78     0.023
   SITE_CHAR    1       6     0.20     0.78     0.109
   SITE_CHAR    1       7     0.20     0.78     0.016
   SITE_CHAR    1       8     0.20     0.78     0.034
   SITE_CHAR    1       9     0.20     0.78     0.026
   SITE_CHAR    1      10     0.20     0.78     0.019
   SITE_CHAR    1      11     0.20     0.78     0.017
   SITE_CHAR    1      12     0.20     0.78     0.031
   SITE_CHAR    2       1     0.15     0.41     0.031
   SITE_CHAR    2       2     0.15     0.41     0.023
   SITE_CHAR    2       3     0.15     0.41     0.035
   SITE_CHAR    2       4     0.15     0.41     0.039
   SITE_CHAR    2       5     0.15     0.41     0.034
   SITE_CHAR    2       6     0.15     0.41     0.144
   SITE_CHAR    2       7     0.15     0.41     0.024
   SITE_CHAR    2       8     0.15     0.41     0.040
   SITE_CHAR    2       9     0.15     0.41     0.032
   SITE_CHAR    2      10     0.15     0.41     0.025
   SITE_CHAR    2      11     0.15     0.41     0.024
   SITE_CHAR    2      12     0.15     0.41     0.042
```

```
   SITE_CHAR    3       1     0.19     0.53     0.051
   SITE_CHAR    3       2     0.19     0.53     0.049
   SITE_CHAR    3       3     0.19     0.53     0.104
   SITE_CHAR    3       4     0.19     0.53     0.133
   SITE_CHAR    3       5     0.19     0.53     0.119
   SITE_CHAR    3       6     0.19     0.53     0.189
   SITE_CHAR    3       7     0.19     0.53     0.050
   SITE_CHAR    3       8     0.19     0.53     0.049
   SITE_CHAR    3       9     0.19     0.53     0.043
   SITE_CHAR    3      10     0.19     0.53     0.033
   SITE_CHAR    3      11     0.19     0.53     0.041
   SITE_CHAR    3      12     0.19     0.53     0.077
   SITE_CHAR    4       1     0.19     0.44     0.045
   SITE_CHAR    4       2     0.19     0.44     0.042
   SITE_CHAR    4       3     0.19     0.44     0.097
   SITE_CHAR    4       4     0.19     0.44     0.127
   SITE_CHAR    4       5     0.19     0.44     0.112
   SITE_CHAR    4       6     0.19     0.44     0.161
   SITE_CHAR    4       7     0.19     0.44     0.042
   SITE_CHAR    4       8     0.19     0.44     0.044
   SITE_CHAR    4       9     0.19     0.44     0.038
   SITE_CHAR    4      10     0.19     0.44     0.028
   SITE_CHAR    4      11     0.19     0.44     0.035
   SITE_CHAR    4      12     0.19     0.44     0.070
```

evv2008_adjusted.txt

```
** EVV 2008
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Summer Fall, Wet Winter Spring, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**          Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.19     0.44     0.023
   SITE_CHAR    1       2     0.19     0.44     0.015
```

SITE_CHAR	1	3	0.19	0.44	0.024
SITE_CHAR	1	4	0.19	0.44	0.026
SITE_CHAR	1	5	0.19	0.44	0.023
SITE_CHAR	1	6	0.19	0.44	0.109
SITE_CHAR	1	7	0.19	0.44	0.016
SITE_CHAR	1	8	0.19	0.44	0.034
SITE_CHAR	1	9	0.19	0.44	0.026
SITE_CHAR	1	10	0.19	0.44	0.019
SITE_CHAR	1	11	0.19	0.44	0.017
SITE_CHAR	1	12	0.19	0.44	0.031
SITE_CHAR	2	1	0.15	0.26	0.031
SITE_CHAR	2	2	0.15	0.26	0.023
SITE_CHAR	2	3	0.15	0.26	0.035
SITE_CHAR	2	4	0.15	0.26	0.039
SITE_CHAR	2	5	0.15	0.26	0.034
SITE_CHAR	2	6	0.15	0.26	0.144
SITE_CHAR	2	7	0.15	0.26	0.024
SITE_CHAR	2	8	0.15	0.26	0.040
SITE_CHAR	2	9	0.15	0.26	0.032
SITE_CHAR	2	10	0.15	0.26	0.025
SITE_CHAR	2	11	0.15	0.26	0.024
SITE_CHAR	2	12	0.15	0.26	0.042
SITE_CHAR	3	1	0.19	0.53	0.051
SITE_CHAR	3	2	0.19	0.53	0.049
SITE_CHAR	3	3	0.19	0.53	0.104
SITE_CHAR	3	4	0.19	0.53	0.133
SITE_CHAR	3	5	0.19	0.53	0.119
SITE_CHAR	3	6	0.19	0.53	0.189
SITE_CHAR	3	7	0.19	0.53	0.050
SITE_CHAR	3	8	0.19	0.53	0.049
SITE_CHAR	3	9	0.19	0.53	0.043
SITE_CHAR	3	10	0.19	0.53	0.033
SITE_CHAR	3	11	0.19	0.53	0.041
SITE_CHAR	3	12	0.19	0.53	0.077
SITE_CHAR	4	1	0.19	0.79	0.045
SITE_CHAR	4	2	0.19	0.79	0.042
SITE_CHAR	4	3	0.19	0.79	0.097
SITE_CHAR	4	4	0.19	0.79	0.127
SITE_CHAR	4	5	0.19	0.79	0.112
SITE_CHAR	4	6	0.19	0.79	0.161
SITE_CHAR	4	7	0.19	0.79	0.042
SITE_CHAR	4	8	0.19	0.79	0.044
SITE_CHAR	4	9	0.19	0.79	0.038
SITE_CHAR	4	10	0.19	0.79	0.028
SITE_CHAR	4	11	0.19	0.79	0.035
SITE_CHAR	4	12	0.19	0.79	0.070

Attachments:

evv2012_adjusted.txt	3.6 KB
evv2011_adjusted.txt	3.6 KB
evv2010_adjusted.txt	3.6 KB
evv2009_adjusted.txt	3.6 KB
evv2008_adjusted.txt	3.6 KB

Subject: RE: Illinois EPA Modeling Guidance
From: "Will, Matt" <Matt.Will@Illinois.gov>
Date: 9/6/2013 4:48 PM
To: Steven Klafka <sklafka@wingraengineering.com>

Hi Steve,

I have attached the Paducah, Kentucky and Evansville, Indiana, surface data characteristics if we decide to go with Evansville. Have a good weekend.

Regards,

Matt

Matthew L. Will
Modeling Unit/Air Quality Planning Section, MS39
Bureau of Air
Illinois EPA
1021 North Grand Avenue East
P.O. Box 19276
Springfield, Illinois 62794-9276
Phone: 217/524-4789
FAX: 217/524-4710
Email: matt.will@illinois.gov
Web Site: http://www.epa.state.il.us/

-----Original Message-----
From: Steven Klafka [mailto:sklafka@wingraengineering.com]
Sent: Friday, September 06, 2013 11:33 AM
To: Will, Matt
Subject: Re: Illinois EPA Modeling Guidance

My bad. Yes, I see Paducah would be a better choice for proximity and land use.

Will, Matt wrote:

> Hi Steve,
>
> The airport was Paducah, Kentucky not Cahokia, Illinois.
>
> Regards,
>
> Matt
>
> -----Original Message-----
> From: Steven Klafka [mailto:sklafka@wingraengineering.com]
> Sent: Friday, September 06, 2013 11:24 AM
> To: Will, Matt
> Subject: Re: Illinois EPA Modeling Guidance
>
> Matt,
>
> For the Joppa site, I initially processed met data from the Southern Illinois Airport in Carbondale. I believe you suggested met data from the Cahokia airport. I thought Carbondale was a good fit for Joppa due to its proximity, similar land use and after processing one minute winds had 1.85% calms.
>
> For your review, attached are the .sfc and .pfl files created by AERMET for Southern Illinois, a wind rose and aerial photo comparison of Joppa, Southern Illinois Airport and Cahokia.

> Let me know if either the airport at Carbondale or Cahokia would be more appropriate for modeling sources in Joppa.
>
> Thanks.
>
> Steve Klafka
>
> Steven Klafka wrote:
>> Matt,
>>
>> As discussed this morning, please send the Stage 3 AERMET files for met stations you recommend for modeling sources in Joppa and Newton.
>>
>> For Newton, I had considered the use of met data from the Coles County Memorial Airport in Mattoon. It is closer than Evansville, has similar land use as Newton and only had 0.74% calms after using one winds for processing in AERMET. For you information, I have attached the final .sfc and .pfl files, a wind rose and aerial photo comparison. Please let me know if you think Coles County or Evansville met data would be a better fit for Newton.
>>
>> Thanks for your assistance.
>>
>> Steve Klafka
>>
>> Steven Klafka wrote:
>>> Matt,
>>>
>>> Thank you for returning my call.
>>>
>>> I was interesting in receiving Illinois EPA dispersion modeling guidance which explains acceptable modeling procedures. It would be appreciated if you sent a copy of your current guidance.
>>>
>>> You mentioned that EPA does not provide met data for modeling analyses. However, please provide any guidance regarding the selection and processing of met data.
>>>
>>> Should have any questions, don't hesitate to call.
>>>
>>> Steve Klafka

--
Steven Klafka, P.E., BCEE
Environmental Engineer
Wingra Engineering, S.C.
303 South Paterson Street
Madison, WI 53703
(608) 255-5030
www.wingraengineering.com
Since 1991

pah2012.txt

```
** PAH 2012
** Generated by AERSURFACE, dated 13016
```

```
** Generated from "kentucky.nlcd.tif"
** Center Latitude (decimal degrees):     37.056364
** Center Longitude (decimal degrees):   -88.774246
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Winter Fall, Dry Spring Summer, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**          Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.19     0.70     0.018
   SITE_CHAR    1       2     0.19     0.70     0.023
   SITE_CHAR    1       3     0.19     0.70     0.019
   SITE_CHAR    1       4     0.19     0.70     0.019
   SITE_CHAR    1       5     0.19     0.70     0.021
   SITE_CHAR    1       6     0.19     0.70     0.026
   SITE_CHAR    1       7     0.19     0.70     0.044
   SITE_CHAR    1       8     0.19     0.70     0.020
   SITE_CHAR    1       9     0.19     0.70     0.019
   SITE_CHAR    1      10     0.19     0.70     0.024
   SITE_CHAR    1      11     0.19     0.70     0.022
   SITE_CHAR    1      12     0.19     0.70     0.018
   SITE_CHAR    2       1     0.14     1.03     0.024
   SITE_CHAR    2       2     0.14     1.03     0.031
   SITE_CHAR    2       3     0.14     1.03     0.028
   SITE_CHAR    2       4     0.14     1.03     0.031
   SITE_CHAR    2       5     0.14     1.03     0.033
   SITE_CHAR    2       6     0.14     1.03     0.041
   SITE_CHAR    2       7     0.14     1.03     0.068
   SITE_CHAR    2       8     0.14     1.03     0.031
   SITE_CHAR    2       9     0.14     1.03     0.027
   SITE_CHAR    2      10     0.14     1.03     0.034
   SITE_CHAR    2      11     0.14     1.03     0.032
   SITE_CHAR    2      12     0.14     1.03     0.024
   SITE_CHAR    3       1     0.19     1.18     0.032
   SITE_CHAR    3       2     0.19     1.18     0.055
   SITE_CHAR    3       3     0.19     1.18     0.085
   SITE_CHAR    3       4     0.19     1.18     0.167
   SITE_CHAR    3       5     0.19     1.18     0.164
   SITE_CHAR    3       6     0.19     1.18     0.203
   SITE_CHAR    3       7     0.19     1.18     0.263
   SITE_CHAR    3       8     0.19     1.18     0.114
   SITE_CHAR    3       9     0.19     1.18     0.056
```

```
   SITE_CHAR    3      10     0.19     1.18     0.097
   SITE_CHAR    3      11     0.19     1.18     0.088
   SITE_CHAR    3      12     0.19     1.18     0.032
   SITE_CHAR    4       1     0.19     0.71     0.026
   SITE_CHAR    4       2     0.19     0.71     0.048
   SITE_CHAR    4       3     0.19     0.71     0.077
   SITE_CHAR    4       4     0.19     0.71     0.166
   SITE_CHAR    4       5     0.19     0.71     0.164
   SITE_CHAR    4       6     0.19     0.71     0.203
   SITE_CHAR    4       7     0.19     0.71     0.263
   SITE_CHAR    4       8     0.19     0.71     0.108
   SITE_CHAR    4       9     0.19     0.71     0.048
   SITE_CHAR    4      10     0.19     0.71     0.092
   SITE_CHAR    4      11     0.19     0.71     0.082
   SITE_CHAR    4      12     0.19     0.71     0.026
```

pah2011.txt

```
** PAH 2011
** Generated by AERSURFACE, dated 13016
** Generated from "kentucky.nlcd.tif"
** Center Latitude (decimal degrees):     37.056364
** Center Longitude (decimal degrees):   -88.774246
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Summer, Wet Winter Spring Fall, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**            Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.20     1.72     0.017
   SITE_CHAR    1       2     0.20     1.72     0.022
   SITE_CHAR    1       3     0.20     1.72     0.018
   SITE_CHAR    1       4     0.20     1.72     0.019
   SITE_CHAR    1       5     0.20     1.72     0.021
   SITE_CHAR    1       6     0.20     1.72     0.026
   SITE_CHAR    1       7     0.20     1.72     0.043
   SITE_CHAR    1       8     0.20     1.72     0.020
   SITE_CHAR    1       9     0.20     1.72     0.018
   SITE_CHAR    1      10     0.20     1.72     0.024
   SITE_CHAR    1      11     0.20     1.72     0.022
```

```
   SITE_CHAR    1      12     0.20     1.72     0.017
   SITE_CHAR    2       1     0.14     0.22     0.024
   SITE_CHAR    2       2     0.14     0.22     0.031
   SITE_CHAR    2       3     0.14     0.22     0.028
   SITE_CHAR    2       4     0.14     0.22     0.031
   SITE_CHAR    2       5     0.14     0.22     0.033
   SITE_CHAR    2       6     0.14     0.22     0.041
   SITE_CHAR    2       7     0.14     0.22     0.068
   SITE_CHAR    2       8     0.14     0.22     0.031
   SITE_CHAR    2       9     0.14     0.22     0.027
   SITE_CHAR    2      10     0.14     0.22     0.034
   SITE_CHAR    2      11     0.14     0.22     0.032
   SITE_CHAR    2      12     0.14     0.22     0.024
   SITE_CHAR    3       1     0.19     0.44     0.032
   SITE_CHAR    3       2     0.19     0.44     0.055
   SITE_CHAR    3       3     0.19     0.44     0.085
   SITE_CHAR    3       4     0.19     0.44     0.167
   SITE_CHAR    3       5     0.19     0.44     0.164
   SITE_CHAR    3       6     0.19     0.44     0.203
   SITE_CHAR    3       7     0.19     0.44     0.263
   SITE_CHAR    3       8     0.19     0.44     0.114
   SITE_CHAR    3       9     0.19     0.44     0.056
   SITE_CHAR    3      10     0.19     0.44     0.097
   SITE_CHAR    3      11     0.19     0.44     0.088
   SITE_CHAR    3      12     0.19     0.44     0.032
   SITE_CHAR    4       1     0.19     0.38     0.026
   SITE_CHAR    4       2     0.19     0.38     0.048
   SITE_CHAR    4       3     0.19     0.38     0.077
   SITE_CHAR    4       4     0.19     0.38     0.166
   SITE_CHAR    4       5     0.19     0.38     0.164
   SITE_CHAR    4       6     0.19     0.38     0.203
   SITE_CHAR    4       7     0.19     0.38     0.263
   SITE_CHAR    4       8     0.19     0.38     0.108
   SITE_CHAR    4       9     0.19     0.38     0.048
   SITE_CHAR    4      10     0.19     0.38     0.092
   SITE_CHAR    4      11     0.19     0.38     0.082
   SITE_CHAR    4      12     0.19     0.38     0.026
```

pah2010.txt

```
** PAH 2010
** Generated by AERSURFACE, dated 13016
** Generated from "kentucky.nlcd.tif"
** Center Latitude (decimal degrees):     37.056364
** Center Longitude (decimal degrees):   -88.774246
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Spring Summer Fall, Dry Winter, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
```

```
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.23     1.62      0.017
   SITE_CHAR    1       2     0.23     1.62      0.022
   SITE_CHAR    1       3     0.23     1.62      0.018
   SITE_CHAR    1       4     0.23     1.62      0.018
   SITE_CHAR    1       5     0.23     1.62      0.020
   SITE_CHAR    1       6     0.23     1.62      0.025
   SITE_CHAR    1       7     0.23     1.62      0.042
   SITE_CHAR    1       8     0.23     1.62      0.019
   SITE_CHAR    1       9     0.23     1.62      0.018
   SITE_CHAR    1      10     0.23     1.62      0.023
   SITE_CHAR    1      11     0.23     1.62      0.021
   SITE_CHAR    1      12     0.23     1.62      0.017
   SITE_CHAR    2       1     0.14     0.35      0.024
   SITE_CHAR    2       2     0.14     0.35      0.031
   SITE_CHAR    2       3     0.14     0.35      0.028
   SITE_CHAR    2       4     0.14     0.35      0.031
   SITE_CHAR    2       5     0.14     0.35      0.033
   SITE_CHAR    2       6     0.14     0.35      0.041
   SITE_CHAR    2       7     0.14     0.35      0.068
   SITE_CHAR    2       8     0.14     0.35      0.031
   SITE_CHAR    2       9     0.14     0.35      0.027
   SITE_CHAR    2      10     0.14     0.35      0.034
   SITE_CHAR    2      11     0.14     0.35      0.032
   SITE_CHAR    2      12     0.14     0.35      0.024
   SITE_CHAR    3       1     0.19     0.44      0.032
   SITE_CHAR    3       2     0.19     0.44      0.055
   SITE_CHAR    3       3     0.19     0.44      0.085
   SITE_CHAR    3       4     0.19     0.44      0.167
   SITE_CHAR    3       5     0.19     0.44      0.164
   SITE_CHAR    3       6     0.19     0.44      0.203
   SITE_CHAR    3       7     0.19     0.44      0.263
   SITE_CHAR    3       8     0.19     0.44      0.114
   SITE_CHAR    3       9     0.19     0.44      0.056
   SITE_CHAR    3      10     0.19     0.44      0.097
   SITE_CHAR    3      11     0.19     0.44      0.088
   SITE_CHAR    3      12     0.19     0.44      0.032
   SITE_CHAR    4       1     0.19     0.71      0.026
   SITE_CHAR    4       2     0.19     0.71      0.048
   SITE_CHAR    4       3     0.19     0.71      0.077
   SITE_CHAR    4       4     0.19     0.71      0.166
   SITE_CHAR    4       5     0.19     0.71      0.164
   SITE_CHAR    4       6     0.19     0.71      0.203
   SITE_CHAR    4       7     0.19     0.71      0.263
   SITE_CHAR    4       8     0.19     0.71      0.108
   SITE_CHAR    4       9     0.19     0.71      0.048
   SITE_CHAR    4      10     0.19     0.71      0.092
   SITE_CHAR    4      11     0.19     0.71      0.082
   SITE_CHAR    4      12     0.19     0.71      0.026
```

pah2009.txt

```
** PAH 2009
** Generated by AERSURFACE, dated 13016
** Generated from "kentucky.nlcd.tif"
** Center Latitude (decimal degrees):     37.056364
** Center Longitude (decimal degrees):   -88.774246
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Winter Spring, Wet Summer Fall, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**            Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.18     0.71     0.018
   SITE_CHAR    1       2     0.18     0.71     0.023
   SITE_CHAR    1       3     0.18     0.71     0.019
   SITE_CHAR    1       4     0.18     0.71     0.020
   SITE_CHAR    1       5     0.18     0.71     0.022
   SITE_CHAR    1       6     0.18     0.71     0.027
   SITE_CHAR    1       7     0.18     0.71     0.044
   SITE_CHAR    1       8     0.18     0.71     0.021
   SITE_CHAR    1       9     0.18     0.71     0.019
   SITE_CHAR    1      10     0.18     0.71     0.025
   SITE_CHAR    1      11     0.18     0.71     0.023
   SITE_CHAR    1      12     0.18     0.71     0.018
   SITE_CHAR    2       1     0.14     0.35     0.024
   SITE_CHAR    2       2     0.14     0.35     0.031
   SITE_CHAR    2       3     0.14     0.35     0.028
   SITE_CHAR    2       4     0.14     0.35     0.031
   SITE_CHAR    2       5     0.14     0.35     0.033
   SITE_CHAR    2       6     0.14     0.35     0.041
   SITE_CHAR    2       7     0.14     0.35     0.068
   SITE_CHAR    2       8     0.14     0.35     0.031
   SITE_CHAR    2       9     0.14     0.35     0.027
   SITE_CHAR    2      10     0.14     0.35     0.034
   SITE_CHAR    2      11     0.14     0.35     0.032
   SITE_CHAR    2      12     0.14     0.35     0.024
   SITE_CHAR    3       1     0.19     0.27     0.032
   SITE_CHAR    3       2     0.19     0.27     0.055
   SITE_CHAR    3       3     0.19     0.27     0.085
   SITE_CHAR    3       4     0.19     0.27     0.167
   SITE_CHAR    3       5     0.19     0.27     0.164
   SITE_CHAR    3       6     0.19     0.27     0.203
```

```
   SITE_CHAR    3       7      0.19     0.27     0.263
   SITE_CHAR    3       8      0.19     0.27     0.114
   SITE_CHAR    3       9      0.19     0.27     0.056
   SITE_CHAR    3      10      0.19     0.27     0.097
   SITE_CHAR    3      11      0.19     0.27     0.088
   SITE_CHAR    3      12      0.19     0.27     0.032
   SITE_CHAR    4       1      0.19     0.38     0.026
   SITE_CHAR    4       2      0.19     0.38     0.048
   SITE_CHAR    4       3      0.19     0.38     0.077
   SITE_CHAR    4       4      0.19     0.38     0.166
   SITE_CHAR    4       5      0.19     0.38     0.164
   SITE_CHAR    4       6      0.19     0.38     0.203
   SITE_CHAR    4       7      0.19     0.38     0.263
   SITE_CHAR    4       8      0.19     0.38     0.108
   SITE_CHAR    4       9      0.19     0.38     0.048
   SITE_CHAR    4      10      0.19     0.38     0.092
   SITE_CHAR    4      11      0.19     0.38     0.082
   SITE_CHAR    4      12      0.19     0.38     0.026
```

pah2008.txt

```
** PAH 2008
** Generated by AERSURFACE, dated 13016
** Generated from "kentucky.nlcd.tif"
** Center Latitude (decimal degrees):     37.056364
** Center Longitude (decimal degrees):   -88.774246
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Winter Summer, Wet Spring, Dry Fall, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect     Alb      Bo        Zo
   SITE_CHAR    1       1      0.17     0.72     0.018
   SITE_CHAR    1       2      0.17     0.72     0.023
   SITE_CHAR    1       3      0.17     0.72     0.019
   SITE_CHAR    1       4      0.17     0.72     0.020
   SITE_CHAR    1       5      0.17     0.72     0.022
   SITE_CHAR    1       6      0.17     0.72     0.027
   SITE_CHAR    1       7      0.17     0.72     0.045
   SITE_CHAR    1       8      0.17     0.72     0.021
```

```
SITE_CHAR    1     9    0.17    0.72    0.019
SITE_CHAR    1    10    0.17    0.72    0.025
SITE_CHAR    1    11    0.17    0.72    0.023
SITE_CHAR    1    12    0.17    0.72    0.018
SITE_CHAR    2     1    0.14    0.22    0.024
SITE_CHAR    2     2    0.14    0.22    0.031
SITE_CHAR    2     3    0.14    0.22    0.028
SITE_CHAR    2     4    0.14    0.22    0.031
SITE_CHAR    2     5    0.14    0.22    0.033
SITE_CHAR    2     6    0.14    0.22    0.041
SITE_CHAR    2     7    0.14    0.22    0.068
SITE_CHAR    2     8    0.14    0.22    0.031
SITE_CHAR    2     9    0.14    0.22    0.027
SITE_CHAR    2    10    0.14    0.22    0.034
SITE_CHAR    2    11    0.14    0.22    0.032
SITE_CHAR    2    12    0.14    0.22    0.024
SITE_CHAR    3     1    0.19    0.44    0.032
SITE_CHAR    3     2    0.19    0.44    0.055
SITE_CHAR    3     3    0.19    0.44    0.085
SITE_CHAR    3     4    0.19    0.44    0.167
SITE_CHAR    3     5    0.19    0.44    0.164
SITE_CHAR    3     6    0.19    0.44    0.203
SITE_CHAR    3     7    0.19    0.44    0.263
SITE_CHAR    3     8    0.19    0.44    0.114
SITE_CHAR    3     9    0.19    0.44    0.056
SITE_CHAR    3    10    0.19    0.44    0.097
SITE_CHAR    3    11    0.19    0.44    0.088
SITE_CHAR    3    12    0.19    0.44    0.032
SITE_CHAR    4     1    0.19    1.83    0.026
SITE_CHAR    4     2    0.19    1.83    0.048
SITE_CHAR    4     3    0.19    1.83    0.077
SITE_CHAR    4     4    0.19    1.83    0.166
SITE_CHAR    4     5    0.19    1.83    0.164
SITE_CHAR    4     6    0.19    1.83    0.203
SITE_CHAR    4     7    0.19    1.83    0.263
SITE_CHAR    4     8    0.19    1.83    0.108
SITE_CHAR    4     9    0.19    1.83    0.048
SITE_CHAR    4    10    0.19    1.83    0.092
SITE_CHAR    4    11    0.19    1.83    0.082
SITE_CHAR    4    12    0.19    1.83    0.026
```

evv2012.txt

```
** EVV 2012
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Fall, Dry Winter Spring Summer, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11
```

```
   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.20     1.95     0.023
   SITE_CHAR    1       2     0.20     1.95     0.015
   SITE_CHAR    1       3     0.20     1.95     0.023
   SITE_CHAR    1       4     0.20     1.95     0.025
   SITE_CHAR    1       5     0.20     1.95     0.022
   SITE_CHAR    1       6     0.20     1.95     0.018
   SITE_CHAR    1       7     0.20     1.95     0.015
   SITE_CHAR    1       8     0.20     1.95     0.033
   SITE_CHAR    1       9     0.20     1.95     0.025
   SITE_CHAR    1      10     0.20     1.95     0.019
   SITE_CHAR    1      11     0.20     1.95     0.017
   SITE_CHAR    1      12     0.20     1.95     0.030
   SITE_CHAR    2       1     0.15     1.20     0.031
   SITE_CHAR    2       2     0.15     1.20     0.023
   SITE_CHAR    2       3     0.15     1.20     0.035
   SITE_CHAR    2       4     0.15     1.20     0.039
   SITE_CHAR    2       5     0.15     1.20     0.034
   SITE_CHAR    2       6     0.15     1.20     0.028
   SITE_CHAR    2       7     0.15     1.20     0.024
   SITE_CHAR    2       8     0.15     1.20     0.040
   SITE_CHAR    2       9     0.15     1.20     0.032
   SITE_CHAR    2      10     0.15     1.20     0.025
   SITE_CHAR    2      11     0.15     1.20     0.024
   SITE_CHAR    2      12     0.15     1.20     0.042
   SITE_CHAR    3       1     0.19     1.43     0.051
   SITE_CHAR    3       2     0.19     1.43     0.049
   SITE_CHAR    3       3     0.19     1.43     0.104
   SITE_CHAR    3       4     0.19     1.43     0.133
   SITE_CHAR    3       5     0.19     1.43     0.119
   SITE_CHAR    3       6     0.19     1.43     0.080
   SITE_CHAR    3       7     0.19     1.43     0.050
   SITE_CHAR    3       8     0.19     1.43     0.049
   SITE_CHAR    3       9     0.19     1.43     0.043
   SITE_CHAR    3      10     0.19     1.43     0.033
   SITE_CHAR    3      11     0.19     1.43     0.041
   SITE_CHAR    3      12     0.19     1.43     0.077
   SITE_CHAR    4       1     0.19     0.79     0.045
   SITE_CHAR    4       2     0.19     0.79     0.042
   SITE_CHAR    4       3     0.19     0.79     0.097
   SITE_CHAR    4       4     0.19     0.79     0.127
   SITE_CHAR    4       5     0.19     0.79     0.112
   SITE_CHAR    4       6     0.19     0.79     0.071
   SITE_CHAR    4       7     0.19     0.79     0.042
   SITE_CHAR    4       8     0.19     0.79     0.044
   SITE_CHAR    4       9     0.19     0.79     0.038
   SITE_CHAR    4      10     0.19     0.79     0.028
   SITE_CHAR    4      11     0.19     0.79     0.035
   SITE_CHAR    4      12     0.19     0.79     0.070
```

evv2011.txt

```
** EVV 2011
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Wet All Seasons, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect    Alb      Bo       Zo
   SITE_CHAR    1       1     0.20     0.77     0.022
   SITE_CHAR    1       2     0.20     0.77     0.015
   SITE_CHAR    1       3     0.20     0.77     0.022
   SITE_CHAR    1       4     0.20     0.77     0.025
   SITE_CHAR    1       5     0.20     0.77     0.022
   SITE_CHAR    1       6     0.20     0.77     0.018
   SITE_CHAR    1       7     0.20     0.77     0.015
   SITE_CHAR    1       8     0.20     0.77     0.033
   SITE_CHAR    1       9     0.20     0.77     0.025
   SITE_CHAR    1      10     0.20     0.77     0.019
   SITE_CHAR    1      11     0.20     0.77     0.017
   SITE_CHAR    1      12     0.20     0.77     0.030
   SITE_CHAR    2       1     0.15     0.26     0.031
   SITE_CHAR    2       2     0.15     0.26     0.023
   SITE_CHAR    2       3     0.15     0.26     0.035
   SITE_CHAR    2       4     0.15     0.26     0.039
   SITE_CHAR    2       5     0.15     0.26     0.034
   SITE_CHAR    2       6     0.15     0.26     0.028
   SITE_CHAR    2       7     0.15     0.26     0.024
   SITE_CHAR    2       8     0.15     0.26     0.040
   SITE_CHAR    2       9     0.15     0.26     0.032
   SITE_CHAR    2      10     0.15     0.26     0.025
   SITE_CHAR    2      11     0.15     0.26     0.024
   SITE_CHAR    2      12     0.15     0.26     0.042
   SITE_CHAR    3       1     0.19     0.33     0.051
   SITE_CHAR    3       2     0.19     0.33     0.049
```

```
   SITE_CHAR    3       3     0.19     0.33     0.104
   SITE_CHAR    3       4     0.19     0.33     0.133
   SITE_CHAR    3       5     0.19     0.33     0.119
   SITE_CHAR    3       6     0.19     0.33     0.080
   SITE_CHAR    3       7     0.19     0.33     0.050
   SITE_CHAR    3       8     0.19     0.33     0.049
   SITE_CHAR    3       9     0.19     0.33     0.043
   SITE_CHAR    3      10     0.19     0.33     0.033
   SITE_CHAR    3      11     0.19     0.33     0.041
   SITE_CHAR    3      12     0.19     0.33     0.077
   SITE_CHAR    4       1     0.19     0.44     0.045
   SITE_CHAR    4       2     0.19     0.44     0.042
   SITE_CHAR    4       3     0.19     0.44     0.097
   SITE_CHAR    4       4     0.19     0.44     0.127
   SITE_CHAR    4       5     0.19     0.44     0.112
   SITE_CHAR    4       6     0.19     0.44     0.071
   SITE_CHAR    4       7     0.19     0.44     0.042
   SITE_CHAR    4       8     0.19     0.44     0.044
   SITE_CHAR    4       9     0.19     0.44     0.038
   SITE_CHAR    4      10     0.19     0.44     0.028
   SITE_CHAR    4      11     0.19     0.44     0.035
   SITE_CHAR    4      12     0.19     0.44     0.070
```

evv2010.txt

```
** EVV 2010
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average All Seasons, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**            Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.26     0.72     0.021
   SITE_CHAR    1       2     0.26     0.72     0.013
   SITE_CHAR    1       3     0.26     0.72     0.022
   SITE_CHAR    1       4     0.26     0.72     0.023
```

```
   SITE_CHAR    1       5     0.26     0.72     0.021
   SITE_CHAR    1       6     0.26     0.72     0.017
   SITE_CHAR    1       7     0.26     0.72     0.014
   SITE_CHAR    1       8     0.26     0.72     0.032
   SITE_CHAR    1       9     0.26     0.72     0.024
   SITE_CHAR    1      10     0.26     0.72     0.017
   SITE_CHAR    1      11     0.26     0.72     0.015
   SITE_CHAR    1      12     0.26     0.72     0.029
   SITE_CHAR    2       1     0.15     0.41     0.031
   SITE_CHAR    2       2     0.15     0.41     0.023
   SITE_CHAR    2       3     0.15     0.41     0.035
   SITE_CHAR    2       4     0.15     0.41     0.039
   SITE_CHAR    2       5     0.15     0.41     0.034
   SITE_CHAR    2       6     0.15     0.41     0.028
   SITE_CHAR    2       7     0.15     0.41     0.024
   SITE_CHAR    2       8     0.15     0.41     0.040
   SITE_CHAR    2       9     0.15     0.41     0.032
   SITE_CHAR    2      10     0.15     0.41     0.025
   SITE_CHAR    2      11     0.15     0.41     0.024
   SITE_CHAR    2      12     0.15     0.41     0.042
   SITE_CHAR    3       1     0.19     0.53     0.051
   SITE_CHAR    3       2     0.19     0.53     0.049
   SITE_CHAR    3       3     0.19     0.53     0.104
   SITE_CHAR    3       4     0.19     0.53     0.133
   SITE_CHAR    3       5     0.19     0.53     0.119
   SITE_CHAR    3       6     0.19     0.53     0.080
   SITE_CHAR    3       7     0.19     0.53     0.050
   SITE_CHAR    3       8     0.19     0.53     0.049
   SITE_CHAR    3       9     0.19     0.53     0.043
   SITE_CHAR    3      10     0.19     0.53     0.033
   SITE_CHAR    3      11     0.19     0.53     0.041
   SITE_CHAR    3      12     0.19     0.53     0.077
   SITE_CHAR    4       1     0.19     0.79     0.045
   SITE_CHAR    4       2     0.19     0.79     0.042
   SITE_CHAR    4       3     0.19     0.79     0.097
   SITE_CHAR    4       4     0.19     0.79     0.127
   SITE_CHAR    4       5     0.19     0.79     0.112
   SITE_CHAR    4       6     0.19     0.79     0.071
   SITE_CHAR    4       7     0.19     0.79     0.042
   SITE_CHAR    4       8     0.19     0.79     0.044
   SITE_CHAR    4       9     0.19     0.79     0.038
   SITE_CHAR    4      10     0.19     0.79     0.028
   SITE_CHAR    4      11     0.19     0.79     0.035
   SITE_CHAR    4      12     0.19     0.79     0.070
```

evv2009.txt

```
** EVV 2009
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Winter Spring Summer, Wet Fall, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
```



```
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**            Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1        1     0.20     0.78     0.023
   SITE_CHAR    1        2     0.20     0.78     0.015
   SITE_CHAR    1        3     0.20     0.78     0.024
   SITE_CHAR    1        4     0.20     0.78     0.025
   SITE_CHAR    1        5     0.20     0.78     0.023
   SITE_CHAR    1        6     0.20     0.78     0.019
   SITE_CHAR    1        7     0.20     0.78     0.016
   SITE_CHAR    1        8     0.20     0.78     0.034
   SITE_CHAR    1        9     0.20     0.78     0.026
   SITE_CHAR    1       10     0.20     0.78     0.019
   SITE_CHAR    1       11     0.20     0.78     0.017
   SITE_CHAR    1       12     0.20     0.78     0.031
   SITE_CHAR    2        1     0.15     0.41     0.031
   SITE_CHAR    2        2     0.15     0.41     0.023
   SITE_CHAR    2        3     0.15     0.41     0.035
   SITE_CHAR    2        4     0.15     0.41     0.039
   SITE_CHAR    2        5     0.15     0.41     0.034
   SITE_CHAR    2        6     0.15     0.41     0.028
   SITE_CHAR    2        7     0.15     0.41     0.024
   SITE_CHAR    2        8     0.15     0.41     0.040
   SITE_CHAR    2        9     0.15     0.41     0.032
   SITE_CHAR    2       10     0.15     0.41     0.025
   SITE_CHAR    2       11     0.15     0.41     0.024
   SITE_CHAR    2       12     0.15     0.41     0.042
   SITE_CHAR    3        1     0.19     0.53     0.051
   SITE_CHAR    3        2     0.19     0.53     0.049
   SITE_CHAR    3        3     0.19     0.53     0.104
   SITE_CHAR    3        4     0.19     0.53     0.133
   SITE_CHAR    3        5     0.19     0.53     0.119
   SITE_CHAR    3        6     0.19     0.53     0.080
   SITE_CHAR    3        7     0.19     0.53     0.050
   SITE_CHAR    3        8     0.19     0.53     0.049
   SITE_CHAR    3        9     0.19     0.53     0.043
   SITE_CHAR    3       10     0.19     0.53     0.033
   SITE_CHAR    3       11     0.19     0.53     0.041
   SITE_CHAR    3       12     0.19     0.53     0.077
   SITE_CHAR    4        1     0.19     0.44     0.045
   SITE_CHAR    4        2     0.19     0.44     0.042
   SITE_CHAR    4        3     0.19     0.44     0.097
   SITE_CHAR    4        4     0.19     0.44     0.127
   SITE_CHAR    4        5     0.19     0.44     0.112
   SITE_CHAR    4        6     0.19     0.44     0.071
   SITE_CHAR    4        7     0.19     0.44     0.042
   SITE_CHAR    4        8     0.19     0.44     0.044
```



```
   SITE_CHAR    4       9     0.19     0.44     0.038
   SITE_CHAR    4      10     0.19     0.44     0.028
   SITE_CHAR    4      11     0.19     0.44     0.035
   SITE_CHAR    4      12     0.19     0.44     0.070
```

evv2008.txt

```
** EVV 2008
** Generated by AERSURFACE, dated 13016
** Generated from "indiana.nlcd.tif"
** Center Latitude (decimal degrees):     38.044148
** Center Longitude (decimal degrees):   -87.520737
** Datum: NAD83
** Study radius (km) for surface roughness:   1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average Summer Fall, Wet Winter Spring, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11


   FREQ_SECT  SEASONAL 12
   SECTOR   1    0   30
   SECTOR   2   30   60
   SECTOR   3   60   90
   SECTOR   4   90  120
   SECTOR   5  120  150
   SECTOR   6  150  180
   SECTOR   7  180  210
   SECTOR   8  210  240
   SECTOR   9  240  270
   SECTOR  10  270  300
   SECTOR  11  300  330
   SECTOR  12  330  360
**           Season   Sect    Alb      Bo        Zo
   SITE_CHAR    1       1     0.19     0.44     0.023
   SITE_CHAR    1       2     0.19     0.44     0.015
   SITE_CHAR    1       3     0.19     0.44     0.024
   SITE_CHAR    1       4     0.19     0.44     0.026
   SITE_CHAR    1       5     0.19     0.44     0.023
   SITE_CHAR    1       6     0.19     0.44     0.019
   SITE_CHAR    1       7     0.19     0.44     0.016
   SITE_CHAR    1       8     0.19     0.44     0.034
   SITE_CHAR    1       9     0.19     0.44     0.026
   SITE_CHAR    1      10     0.19     0.44     0.019
   SITE_CHAR    1      11     0.19     0.44     0.017
   SITE_CHAR    1      12     0.19     0.44     0.031
   SITE_CHAR    2       1     0.15     0.26     0.031
   SITE_CHAR    2       2     0.15     0.26     0.023
   SITE_CHAR    2       3     0.15     0.26     0.035
   SITE_CHAR    2       4     0.15     0.26     0.039
   SITE_CHAR    2       5     0.15     0.26     0.034
   SITE_CHAR    2       6     0.15     0.26     0.028
   SITE_CHAR    2       7     0.15     0.26     0.024
   SITE_CHAR    2       8     0.15     0.26     0.040
   SITE_CHAR    2       9     0.15     0.26     0.032
   SITE_CHAR    2      10     0.15     0.26     0.025
```

SITE_CHAR	2	11	0.15	0.26	0.024
SITE_CHAR	2	12	0.15	0.26	0.042
SITE_CHAR	3	1	0.19	0.53	0.051
SITE_CHAR	3	2	0.19	0.53	0.049
SITE_CHAR	3	3	0.19	0.53	0.104
SITE_CHAR	3	4	0.19	0.53	0.133
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SITE_CHAR	3	8	0.19	0.53	0.049
SITE_CHAR	3	9	0.19	0.53	0.043
SITE_CHAR	3	10	0.19	0.53	0.033
SITE_CHAR	3	11	0.19	0.53	0.041
SITE_CHAR	3	12	0.19	0.53	0.077
SITE_CHAR	4	1	0.19	0.79	0.045
SITE_CHAR	4	2	0.19	0.79	0.042
SITE_CHAR	4	3	0.19	0.79	0.097
SITE_CHAR	4	4	0.19	0.79	0.127
SITE_CHAR	4	5	0.19	0.79	0.112
SITE_CHAR	4	6	0.19	0.79	0.071
SITE_CHAR	4	7	0.19	0.79	0.042
SITE_CHAR	4	8	0.19	0.79	0.044
SITE_CHAR	4	9	0.19	0.79	0.038
SITE_CHAR	4	10	0.19	0.79	0.028
SITE_CHAR	4	11	0.19	0.79	0.035
SITE_CHAR	4	12	0.19	0.79	0.070

Attachments:

pah2012.txt	3.6 KB
pah2011.txt	3.6 KB
pah2010.txt	3.6 KB
pah2009.txt	3.6 KB
pah2008.txt	3.6 KB
evv2012.txt	3.6 KB
evv2011.txt	3.6 KB
evv2010.txt	3.6 KB
evv2009.txt	3.6 KB
evv2008.txt	3.6 KB

AERMOD IMPLEMENTATION GUIDE

Last Revised: March 19, 2009

AERMOD Implementation Workgroup

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, North Carolina

PREFACE

This document provides information on the recommended use of AERMOD to address specific issues and concerns related to the implementation of AERMOD for regulatory applications. The following recommendations augment the use of experience and judgment in the proper application of dispersion models. Advanced coordination with reviewing authorities, including the development of modeling protocols, is recommended for regulatory applications of AERMOD.

ACKNOWLEDGMENTS

The AERMOD Implementation Guide has been developed through the collaborative efforts of EPA OAQPS, EPA Regional Office, State and local agency dispersion modelers, through the activities of the AERMOD Implementation Workgroup. The efforts of all contributors are gratefully acknowledged.

CONTENTS

1.0 WHAT'S NEW IN THIS DOCUMENT

Revisions dated March 19, 2009:

The following sections have been affected by this revision:

4.3 TERRAIN ELEVATION DATA SOURCES FOR AERMAP

This new section discusses sources of terrain elevation data for input to AERMAP to determine receptor elevations and hill height scales, including terrain data in the traditional U. S. Geological Survey (USGS) Digital Elevation Model (DEM) data format, and the newer National Elevation Dataset (NED) data in GeoTIFF format also supported by AERMAP, beginning with version 09040. The importance of documenting sources of terrain data in the modeling protocol is emphasized.

4.4 MANUALLY ENTERING TERRAIN ELEVATIONS IN AERMAP

This section, formerly numbered as Section 4.3, includes revisions to reflect the support for both DEM and NED elevation data in AERMAP, beginning with version 09040.

4.5 USE OF AERMAP TO DETERMINE SOURCE ELEVATIONS

This new section discusses the use of AERMAP to determine terrain elevations for sources, and encourages the use of source elevations based on plant surveys as a generally preferred option over the use of AERMAP.

2.0 DOCUMENT BACKGROUND AND PURPOSE

2.1 BACKGROUND (10/19/07)

In April 2005, the AERMOD Implementation Workgroup (AIWG) was formed in anticipation of AERMOD's promulgation as a replacement for the Industrial Source Complex (ISCST3) model. AERMOD fully replaced ISCST3 as the regulatory model on December 9, 2006 (EPA, 2005a), after a one-year grandfather period. The primary purpose for forming the AIWG was to develop a comprehensive approach for dealing with implementation issues for which guidance is needed. A result of this initial AIWG was the publication of the first version of the AERMOD Implementation Guide on September 27, 2005.

In 2007, a new AIWG was formed as a standing workgroup to provide support to EPA's Office of Air Quality Planning and Standards (OAQPS). This document represents the combined efforts of AIWG and OAQPS in relation to the implementation of the AERMOD regulatory model.

2.2 PURPOSE (10/19/07)

This document provides information on the recommended use of AERMOD to address a range of issues and types of applications. Topics are organized based on implementation issues, with additional information as appropriate on whether they impact the modules of the AERMOD modeling system (AERMOD, AERMET, and AERMAP) or related programs (AERSURFACE, AERSCREEN, and BPIPPRM). The document contains a section which highlights changes from the previous version. This is located in Section 1 of the document for use as a quick reference. Each section is also identified with the date (mm/dd/yy) that it was added or last updated. Only sections with substantive changes or new recommendations are identified with new revision dates. Revision dates are not updated for sections with only minor edits to clarify the wording or to correct typographical errors.

The recommendations contained within this document represent the current best use practices as determined by EPA, through the implementation of AIWG. The document is not intended as a replacement of, or even a supplement to the *Guideline on Air Quality Models* (EPA, 2005b). Rather, it is designed to provide consistent, technically sound recommendations to address specific issues and concerns relevant to the regulatory application of AERMOD. As always, advance coordination with the reviewing authorities on the application of AERMOD is advisable. Modeling protocols should be developed, and agreed upon by all parties, in advance of any modeling activity.

3.0 METEOROLOGICAL DATA AND PROCESSING

3.1 DETERMINING SURFACE CHARACTERISTICS (01/09/08)

When applying the AERMET meteorological processor (EPA, 2004a) to prepare the meteorological data for the AERMOD model (EPA, 2004b), the user must determine appropriate values for three surface characteristics: surface roughness length {z_o}, albedo {r}, and Bowen ratio {B_o}. The surface roughness length is related to the height of obstacles to the wind flow and is, in principle, the height at which the mean horizontal wind speed is zero based on a logarithmic profile. The surface roughness length influences the surface shear stress and is an important factor in determining the magnitude of mechanical turbulence and the stability of the boundary layer. The albedo is the fraction of total incident solar radiation reflected by the surface back to space without absorption. The daytime Bowen ratio, an indicator of surface moisture, is the ratio of sensible heat flux to latent heat flux and is used for determining planetary boundary layer parameters for convective conditions driven by the surface sensible heat flux. This section provides recommendations regarding several issues associated with determining appropriate surface characteristics for AERMOD modeling applications.

3.1.1 Meteorological data representativeness considerations (01/09/08)

When using National Weather Service (NWS) data for AERMOD, data representativeness can be thought of in terms of constructing realistic planetary boundary layer (PBL) similarity profiles and adequately characterizing the dispersive capacity of the atmosphere. As such, the determination of representativeness should include a comparison of the surface characteristics (i.e., z_o, B_o and r) between the NWS measurement site and the source location, coupled with a determination of the importance of those differences relative to predicted concentrations. Site-specific meteorological data are assumed by definition to be representative of the application site; however, the determination of representativeness of site-specific data for AERMOD applications should also include an assessment of surface characteristics of the measurement and source locations and cannot be based solely on proximity. The recommendations presented in this section for determining surface characteristics for AERMET apply to both site-specific and non-site-specific (e.g. NWS) meteorological data.

The degree to which predicted pollutant concentrations are influenced by surface parameter differences between the application site and the meteorological measurement site depends on the nature of the application (i.e., release height, plume buoyancy, terrain influences, downwash considerations, design metric, etc.). For example, a difference in z_o for one application may translate into an unacceptable difference in the design concentration, while for another application the same difference in z_o may lead to an insignificant difference in design concentration. If the reviewing agency is uncertain as to the representativeness of a meteorological measurement site, a site-specific sensitivity analysis may be needed in order to quantify, in terms of expected changes in the design concentration, the significance of the differences in each of the surface characteristics.

If the proposed meteorological measurement site's surface characteristics are determined to NOT be representative of the application site, it may be possible that another nearby meteorological measurement site may be representative of both meteorological parameters and surface characteristics. Failing that, it is likely that site-specific meteorological data will be required.

3.1.2 Methods for determining surface characteristics (01/09/08)

Several sources of data may be utilized in determining appropriate surface characteristics for use in processing meteorological data for AERMOD. This may include printed topographic and land use, land cover (LULC) maps available from the U. S. Geological Survey (USGS), aerial photos from web-based services, site visits and/or site photographs, and digitized databases of land use and land cover data available from USGS. A sound understanding of the important physical processes represented in the AERMOD model algorithms and the sensitivity of those algorithms to surface characteristics is needed in order to properly interpret the available data and make an appropriate determination. The temporal representativeness of the source(s) of land cover data used relative to the meteorological data period to be processed should be considered as part of this assessment.

The availability of high resolution digitized land cover databases provides an opportunity to apply systematic procedures to determine surface characteristics based on an objective analysis of the gridded land cover data across a domain. A proper analysis of such data must take into consideration the relationship between surface characteristics and the meteorological measurements on which the surface characteristics will be applied. While the following discussion offers specific recommendations regarding the methods for determining surface characteristics from digitized land cover data, the general principles on which these recommendations are based are also applicable to determining surface characteristics from other sources of non-digitized land use and land cover data.

Based on model formulations and model sensitivities, the relationship between the surface roughness upwind of the measurement site and the measured wind speeds is generally the most important consideration. The effective surface roughness length should be based on an upwind distance that captures the net influence of surface roughness elements on the measured wind speeds needed to properly characterize the magnitude of mechanical turbulence in the approach flow. A number of studies have examined the response of the atmosphere to abrupt changes in the surface roughness, and provide some insight into the relationship between measured winds and surface roughness [e.g., Blom and Warenta (1969), Businger (1986), Högström and Högström (1978), Horst and Weil (1994), Irwin (1978), Rao, et al. (1974), and Taylor (1969)]. Such changes in surface roughness result in the development of an internal boundary layer (IBL) which grows with distance downwind of the roughness change, and defines the layer influenced by the transition in surface roughness. The size and structure of the IBL is very complex, even for idealized cases of uniform roughness upwind and downwind of the transition. The IBL is also affected by the magnitude and direction of the roughness change and the stability of the upstream flow. The IBL generally grows more slowly for stable conditions than for neutral or unstable approach flow, and will also tend to grow more slowly for rough-to-smooth transitions than for smooth-to-rough transitions. The relationship between surface roughness and measured wind speeds is even more complex in real world applications given the typically patchy nature of the heterogeneity of surface roughness elements.

The recommended upwind distance for surface roughness should take into account the fact that surface roughness effects in AERMOD are more important for stable atmospheric conditions than for neutral/unstable conditions, and that meteorological monitoring sites are typically characterized by open (low roughness) exposures in order to accommodate recommended siting criteria (EPA, 2000). For typical measurement programs, including NWS stations, the reference wind measurements will be taken for an anemometer height of approximately 10 meters above ground. An upwind distance based on the recommended siting criterion of at least 10 times the height of nearby obstacles (EPA, 2000), which would correspond to a distance of about 100m for typical obstacles such as trees and 2-3 story buildings, is considered inadequate for this purpose. However, the previous recommendation to use an upwind distance of 3 kilometers for surface roughness is considered too large because the boundary layer up to typical measurement heights of 10m will generally respond to changes in roughness length over much shorter distances. Including land cover information across an upwind distance that is too large could misrepresent the amount of mechanical turbulence present in the approach flow and bias model results, especially for low-level releases.

The recommended upwind distance for processing land cover data to determine the effective surface roughness for input to AERMET is 1 kilometer relative to the meteorological tower location. This recommended distance is considered a reasonable balance of the complex factors cited in the discussion above. If land cover varies significantly by direction, then surface roughness should be determined based on sector. However, the width of the sectors should be no smaller than a 30-degree arc. Further information on the definition of sectors for surface roughness is provided in the AERMET user's guide (EPA, 2004a). Exceptions to the recommended default distance of 1 kilometer for surface roughness may be considered on a case-by-case basis for applications involving site-specific wind speed measurements taken at heights well above 10m, in situations with significant discontinuities in land cover just beyond the recommended 1 kilometer upwind distance, or for sites with significant terrain discontinuities (e.g., the top of a mesa or a narrow, steep valley). Another factor that may need to be considered in some cases for determining an effective surface roughness length is the potential contribution of nearby terrain or other significant surface expression, not reflected in the land cover data, to the generation of mechanical turbulence. Use of a non-default distance for surface roughness estimation, or modification of surface roughness estimates to account for terrain/surface-expression effects, should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the modeling analysis.

The dependence of meteorological measurements and plume dispersion on Bowen ratio and albedo is very different than the dependence on surface roughness. Effective values for Bowen ratio and albedo are used to estimate the strength of convective turbulence during unstable conditions by determining how much of the incoming radiation is converted to sensible heat flux. These estimates of convective turbulence are not linked as directly with tower measurements as the linkage between the measured wind speed and the estimation of mechanical turbulence intensities driven by surface roughness elements. While local surface characteristics immediately upwind of the measurement site are very important for surface roughness, effective values of Bowen ratio and albedo determined over a larger domain are more appropriate.

The recommended approach for processing digitized land cover data to determine the effective Bowen ratio and albedo for input to AERMET is to average the surface characteristics across a representative domain without any direction or distance dependency. The recommended default domain is a 10km by 10km region centered on the measurement site. Use of the measurement location to define the domain is likely to be adequate for most applications. However, a domain representative of the application site may be more appropriate for some applications, particularly if the majority of sources are elevated releases. The use of an alternative domain for Bowen ratio and albedo should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the modeling analysis.

Beyond defining the appropriate domains to use for processing digitized land cover data, additional considerations are needed regarding the computational methods for processing of the data. Due to the fact that the width of a sector increases with distance from the measurement site, the land cover further from the site would receive a higher effective weight than land cover closest to the site if a direct area-weighted averaging approach were used to calculate an effective surface roughness. An inverse-distance weighting is recommended for determining surface roughness from digitized land cover data in order to adjust for this factor, since the length of an arc (across a sector) is proportional to the distance from the center. In addition, a geometric mean is recommended for calculating the effective surface roughness due to the fact that the AERMOD formulations are dependent on the $ln(z_o)$. Note that the arithmetic average of the $ln(z_o)$ is mathematically equivalent to the geometric mean of z_o. Since the Bowen ratio represents the ratio between sensible heat flux and latent heat flux, the use of a geometric mean is also recommended for calculating effective values of Bowen ratio. Geometric means are more appropriate for calculating "average" values of ratios; for example, the "average" for Bowen ratios of 0.5 and 2.0 should be 1.0, which is accomplished with the use of a geometric mean. A simple arithmetic average is recommended for calculating effective values of albedo.

These recommendations for determining surface characteristics supersede previous recommendations and should be followed unless case-by-case justification can be provided for an alternative method. The recommendations described above are briefly summarized below:

1. The determination of the **surface roughness length** should be based on an inverse-distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.
2. The determination of the **Bowen ratio** should be based on a simple unweighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10km by 10km region centered on the measurement site.
3. The determination of the **albedo** should be based on a simple unweighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as

defined for Bowen ratio, with a default domain defined by a 10km by 10km region centered on the measurement site.

An important aspect of determining surface characteristics from digitized land cover data is the assignment of surface characteristic values for each of the parameters (surface roughness, Bowen ratio and albedo) to the land cover categories contained in the dataset. Several references are available to guide those assignments, including Sections 4.7.7 and 5.4 of the AERMET user's guide (EPA, 2004a), Garrett (1992), Gifford (1968), Oke (1978), Randerson (1984), and Stull (1988). Due to the somewhat subjective nature of this process, and the fact that specific land cover categories may include a wide range of values for some surface characteristics, the methods and assumptions used to assign surface characteristics based on land cover categories should be thoroughly documented and justified.

3.1.3 Use of AERSURFACE for determining surface characteristics (01/09/08)

EPA has developed a tool called AERSURFACE (EPA, 2008) that can be used as an aid in determining realistic and reproducible surface characteristic values, including albedo, Bowen ratio, and surface roughness length, for input to AERMET, the meteorological processor for AERMOD. The current version of AERSURFACE supports the use of land cover data from the USGS National Land Cover Data 1992 archives (NLCD92). The NLCD92 archive provides land cover data at a spatial resolution of 30 meters based on a 21-category classification scheme applied consistently over the continental U.S. AERSURFACE incorporates look-up tables of representative surface characteristic values by land cover category and seasonal category. Further details regarding application of the AERSURFACE tool are provided in the AERSURFACE User's Guide (EPA, 2008).

The AERSURFACE tool incorporates the recommended methods for determining surface characteristics from digitized land cover data described in Section 3.1.2. While the AERSURFACE tool is <u>not</u> currently considered to be part of the AERMOD regulatory modeling system, i.e. the use of AERSURFACE is not required for regulatory applications of AERMOD, the recommended methodology described in Section 3.1.2 should be followed unless case-by-case justification can be provided for an alternative method.

3.2 SELECTING UPPER AIR SOUNDING LEVELS (10/19/07)

The AERMET meteorological processor requires full upper air soundings (radiosonde data) representing the vertical potential temperature profile near sunrise in order to calculate convective mixing heights. For AERMOD applications within the U.S., the early morning sounding, nominally collected at 12Z (or UTC/GMT), is typically used for this purpose. Upper air soundings can be obtained from the Radiosonde Data of North America CDs for the period 1946 through 1997, which are available for purchase from the National Climatic Data Center (NCDC). Upper air soundings for the period 1994 to the present are also available for free download from the Radiosonde Database Access website (http://raob.fsl.noaa.gov/).

Both of these sources of upper air data offer the following three options for specifying which levels of upper air data to extract:

1) all levels,
2) mandatory and significant levels, or
3) mandatory levels only.

Options 1 and 2 are both acceptable and should provide equivalent results when processed through AERMET. The use of mandatory levels only, Option 3, will not provide an adequate characterization of the potential temperature profile, and is not acceptable for AERMOD modeling applications.

3.3 PROCESSING SITE-SPECIFIC METEOROLOGICAL DATA FOR URBAN APPLICATIONS (01/09/08)

The use of site-specific meteorological data obtained from an urban setting may require some special processing if the measurement site is located within the influence of the urban heat island and site-specific turbulence measurements are available (e.g., σ_θ and/or σ_w). As discussed in Section 5.4, the urban algorithms in AERMOD are designed to enhance the turbulence levels relative to the nearby rural setting during nighttime stable conditions to account for the urban heat island effect. Since the site-specific turbulence measurements will reflect the enhanced turbulence associated with the heat island, site-specific turbulence measurements should not be used when applying AERMOD's urban option, in order to avoid double counting the effects of enhanced turbulence due to the urban heat island.

As also discussed in Section 5.4, the AERMOD urban option (URBANOPT) should be selected for urban applications, regardless of whether the meteorological measurement site is located in an urban setting. This is due to the fact that the limited surface meteorological measurements available from the meteorological measurement program (even with measured turbulence) will not adequately account for the meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms.

4.0 TERRAIN DATA AND PROCESSING

4.1 MODELING SOURCES WITH TERRAIN-FOLLOWING PLUMES IN SLOPING TERRAIN (01/09/08)

Under the regulatory default mode (DFAULT option on the MODELOPT keyword), for all situations in which there is a difference in elevation between the source and receptor, AERMOD simulates the total concentration as the weighted sum of 2 plume states (Cimorelli, *et al.*, 2004): 1) a horizontal plume state (where the plume's elevation is assumed to be determined by release height and plume rise effects only, and thereby allowing for impingement if terrain rises to the elevation of the plume); and, 2) a terrain-responding plume state (where the plume is assumed to be entirely terrain following).

For cases in which receptor elevations are lower than the base elevation of the source (i.e., receptors that are down-slope of the source), AERMOD will predict concentrations that are less than what would be estimated from an otherwise identical flat terrain situation. While this is appropriate and realistic in most cases, for cases of down-sloping terrain where expert judgment suggests that the plume is terrain-following (e.g., down-slope gravity/drainage flow), AERMOD will tend to underestimate concentrations when terrain effects are taken into account. AERMOD may also tend to underestimate concentrations relative to flat terrain results for cases involving low-level, non-buoyant sources with up-sloping terrain since the horizontal plume component will pass below the receptor elevation. Sears (2003) has examined these situations for low-level area sources, and has shown that as terrain slope increases the ratio of estimated concentrations from AERMOD to ISC (which assumes flat terrain for area sources) decreases substantially.

To avoid underestimating concentrations in such situations, it may be reasonable in cases of terrain-following plumes in sloping terrain to apply the non-DFAULT option to assume flat, level terrain. This determination should be made on a case-by-case basis, relying on the modeler's experience and knowledge of the surrounding terrain and other factors that affect the air flow in the study area, characteristics of the plume (release height and buoyancy), and other factors that may contribute to a terrain-following plume, especially under worst-case meteorological conditions associated with the source. The decision to use the non-DFAULT option for flat terrain, and details regarding how it will be applied within the overall modeling analysis, should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the analysis.

4.2 AERMAP DEM ARRAY AND DOMAIN BOUNDARY (09/27/05)

Section 2.1.2 of the AERMAP User's Guide (EPA, 2004c) states that the DEM array and domain boundary must include all terrain features that exceed a 10% elevation slope from any given receptor. The 10% slope rule may lead to excessively large domains in areas with considerable terrain features (e.g., fjords, successive mountain ranges, etc). In these situations, the reviewing authority may make a case-by-case determination regarding the domain size needed for AERMAP to determine the critical dividing streamline height for each receptor.

4.3 TERRAIN ELEVATION DATA SOURCES FOR AERMAP (03/19/09)

AERMAP has been revised (beginning with version 09040) to support processing of terrain elevations from the National Elevation Dataset (NED) developed by the U.S. Geological Survey (USGS, 2002). The revised AERMAP program supports the use of NED data in the GeoTIFF format. AERMAP still supports terrain elevations in the DEM format, and has also been enhanced to process DEM files of mixed format (e.g., 7.5-minute and 1-degree DEM files) in the same run. AERMAP currently does not support processing of elevation data in both the DEM format and the GeoTIFF format for NED data in the same run.

The USGS DEM archives are now static and will not be updated in the future, while the NED data are being actively supported and checked for quality. Therefore, NED represents a more up-to-date and improved resource for terrain elevations for use with AERMAP. Due to a number of problems that have been encountered with DEM data, AERMOD users are encouraged to transition to the use of NED data as soon as practicable. Problems encountered with DEM data include incorrect geo-referencing information for entire DEM files and elevations that reflect the tops of buildings and trees in some cases. The use of NED data should avoid these issues, and provides additional advantages over the use of DEM data, including the ability to download a single NED file to cover the entire modeling domain of interest, with a consistent horizontal resolution and reference datum (generally NAD83). Some applications of AERMAP using DEM data may involve inconsistent reference datums for adjacent DEM files, which can result in receptors being located within gaps between files due to the datum shift. Gaps may also occur within DEM files generated by various software tools to convert from one format to another when a NAD conversion is involved, e.g., converting1-degree DEM data to the 7.5-minute DEM format to fill areas not covered by available 7.5-minute data. The AERMAP User's Guide Addendum (EPA, 2009) provides a more detailed discussion of issues associated with gaps between DEM files or within DEM files, and describes how these cases are handled by AERMAP.

While NED is considered an improvement in the quality and consistency of elevation data for use with AERMAP, there are some issues associated with the GeoTIFF format supported by AERMAP that users should be aware of. The main issue of importance to AERMAP users is that the NED GeoTIFF files currently available from the USGS Seamless Data Server do not include the GeoKey specifying the units for the elevation data. The USGS documentation for NED data (USGS, 2002) indicates that elevations are in units of meters and are provided in floating point format. AERMAP will therefore assume units of meters if the elevation units GeoKey is absent. However, non-standard (i.e., non-USGS) NED data in GeoTIFF format may not be in units of meters. AERMAP provides an option for users to specify elevation units in these cases. However, users must exercise caution in using such data unless the correct units can be confirmed. The AERMAP User's Guide Addendum (EPA, 2009) provides a more detailed discussion of these and other potential issues associated with the GeoTIFF format supported for NED data.

The NED elevation data are currently available for the conterminous United States, Hawaii, Puerto Rico, and the Virgin Islands at a horizontal resolution of 1 arc-second (approximately 30 meters), and at a resolution of 2 arc-seconds for Alaska. Higher resolution NED elevation data at 1/3rd arc-second (about 10 meters) are available for most areas outside of Alaska, and even 1/9th arc-second data (about 3 meters) are available for some areas. These higher resolution data may become more widely available in the future. The appropriate horizontal resolution for the input terrain data and receptor network should be determined in consultation with the reviewing authority based on the specific needs of the project. Higher resolutions for both the terrain data and receptor network may be necessary in areas with significant terrain relief than for areas with relatively flat terrain. While acceptable, using the highest resolution elevation data available for determining receptor elevations and hill height scales may not always be justified. Since spatial coverage of terrain data for some resolutions may not be complete, it is also worth noting that use of a single resolution across the domain has advantages, and AERMAP places some restrictions on the order of DEM or NED file inputs when mixed resolution data are used.

Regardless of the receptor and terrain data resolutions used in AERMAP, it is advisable to check the accuracy of receptor elevations and hill height scales being input to AERMOD for significant terrain features that are likely to be associated with peak concentrations based on proximity and elevation in relation to the sources. Elevations for fenceline or other nearby receptors located within areas that have been altered due to facility construction may require special consideration since these changes in local topography may not be reflected in the USGS terrain files. Use of receptor elevations derived from plant survey data may be an acceptable alternative in these cases. The option available in AERMAP for the user to provide elevations may be utilized to determine hill height scales for these special cases, rather than the default option of determining elevations and hill height scales based on the input terrain data. However, care should be exercised to ensure that the hill height scales determined by AERMAP are also representative of the modified topography. If alternative data sources and/or methods are used to estimate receptor elevations, users must recognize that receptor elevations input to AERMOD should represent the best estimate of the actual terrain elevation at the receptor location. Use of a "conservative" estimate of the maximum elevation in the vicinity of the receptor location, such as the maximum within a "grid cell" centered on the receptor, is not appropriate for use in AERMOD based on the formulation of the terrain algorithms in the model, and may not result in a conservative estimate of concentrations.

Beginning with the version dated 09040, AERMAP can also process terrain elevations derived from the Shuttle Radar Topography Mission (SRTM) since they are available in the same GeoTIFF format as NED data from the USGS Seamless Data Server. SRTM elevation data is also available for most of the U. S. at 1 arc-second and 3 arc-second resolutions from various sources. However, SRTM elevations represent the height of the "reflective surface" for the radar signal, and therefore include the heights of obstacles such as buildings and trees (USGS, 2009). NED data represents the ground ("bare earth") elevation, which is a more appropriate input for determining receptor elevations and hill height scales for use in AERMOD. AERMOD users should therefore avoid the use of SRTM data to determine elevations for use in AERMOD. However, SRTM data are also available at 3 arc-second resolution for most of the globe, and may be the only practical alternative for applications beyond the U. S. While AERMAP can process both NED and SRTM data in GeoTIFF format in the same run, the only situation that might warrant such an approach would be applications along a border that extends beyond the domain covered by the NED data. The SRTM elevation data are typically based on the WGS84 horizontal datum, rather than the NAD83 datum used for most NED data. While AERMAP treats the WGS84 and NAD83 datums as equivalent, AERMAP will issue a warning message for any terrain file input as NED data that is not in the NAD83 datum to flag the possibility that non-NED data (or non-standard NED data) are being used.

Given the number of options available for elevation data inputs to AERMAP, and the range of issues associated with elevation data, users are encouraged to clearly document the source of elevation data used for AERMOD applications in the modeling protocol, including the resolution and horizontal reference datum for the data and any pre-processing that might have been done, such as converting from one format to another. Since the NED data are being checked for quality and updated as needed, AERMAP users should also consider acquiring updated terrain files on a periodic basis before use in regulatory modeling applications. If the option to provide receptor elevations to AERMAP is utilized, rather than using the default option of determining elevations based on the input terrain data, the sources and methods used to determine the provided elevations should be clearly documented along with a justification for use of that option.

4.4 MANUALLY ENTERING TERRAIN ELEVATIONS IN AERMAP (03/19/09)

AERMAP currently does not have the capability of accepting hand-entered terrain data in an "xyz" format. AERMAP only accepts terrain data from digitized elevation files in the DEM or NED/GeoTIFF formats. Therefore, if no DEM or NED/GeoTIFF data are available for a particular application, terrain elevations may need to be determined through other means. One option may be to manually enter gridded terrain elevations in a form that mimics the DEM data format. Instructions for how to accomplish this can be found on the SCRAM web site http://www.epa.gov/scram001/ in a document titled "On inputting XYZ data into AERMAP." As noted in Section 4.3, if alternative sources and/or methods are used to estimate receptor elevations, users must recognize that receptor elevations input to AERMOD should represent the best estimate of the actual terrain elevation at the receptor location, and these alternative sources and methods should be documented in the modeling protocol. As also noted in Section 4.3, SRTM elevation data in GeoTIFF format is available for most of the globe, which may provide another alternative source of elevation data for use in AERMAP. However, SRTM data represents the heights of obstacles, such as buildings and trees, rather than ground elevations, and should be used with caution and only as a last resort.

4.5 USE OF AERMAP TO DETERMINE SOURCE ELEVATIONS (03/19/09)

AERMAP includes the capability of estimating terrain elevations for sources based on the same data and procedures used to estimate receptor elevations. However, the requirements for determining source elevations are somewhat different than the requirements for determining receptor elevations since a greater emphasis is placed on the accuracy of elevations at specific locations in the case of sources. While the accuracy of specific receptor elevations is also important, the main focus for receptors should be on how well the terrain features are defined by the receptor network as a whole, which is based on both the accuracy of the terrain data and the horizontal resolution of the receptor network. As noted in Section 4.3, it is advisable to check the accuracy of receptor elevations and hill height scales for significant terrain features that are likely to be associated with peak concentrations. These accuracy checks should also account for the relative elevation differences between the source and receptor since that will determine the elevation of the plume in relation to the terrain.

Given the issues and uncertainties associated with estimating the elevation at a specific location, and the potential sensitivity of AERMOD model results to differences in the relative elevations of sources and nearby receptors, users are discouraged from relying solely on AERMAP-derived source elevations in regulatory applications of AERMOD, especially for emission sources within the facility being permitted. These concerns are particularly important with newer facilities since regrading associated with construction of the facility may not be reflected in the digitized terrain data. Source elevations based on a reliable plant survey are generally considered to be the preferred option. If AERMAP-derived source elevations are used for the permitted facility, then some effort should be made to verify the accuracy of the elevations based on other reliable information, such as up-to-date topographic maps, taking into account adjustments for the horizontal datum if necessary. Use of AERMAP-derived elevations for other background sources included in the modeled inventory is generally of less concern than their use for the permitted facility, depending on the complexity of the terrain and the distances between sources within the modeled inventory. To facilitate proper review, the modeling protocol should clearly document the data and method(s) used to determine source elevations for input to AERMOD.

5.0 URBAN APPLICATIONS

5.1 URBAN/RURAL DETERMINATION (10/19/07)

The URBANOPT keyword on the CO pathway in AERMOD, coupled with the URBANSRC keyword on the SO pathway, should be used to identify sources to be modeled using the urban algorithms in AERMOD (EPA, 2004b). To account for the dispersive nature of the "convective-like" boundary layer that forms during nighttime conditions due to the urban heat island effect, AERMOD enhances the turbulence for urban nighttime conditions over that which is expected in the adjacent rural, stable boundary layer, and also defines an urban boundary layer height to account for limited mixing that may occur under these conditions. The magnitude of the urban heat island effect is driven by the urban-rural temperature difference that develops at night. AERMOD currently uses the population input on the URBANOPT keyword as a surrogate to define the magnitude of this differential heating effect. Details regarding the adjustments in AERMOD for the urban boundary layer are provided in Section 5. 8 of the AERMOD model formulation document (Cimorelli, *et al.*, 2004).

Section 7.2.3 of the *Guideline on Air Quality Models* (EPA, 2005b) provides the basis for determining the urban/rural status of a source. For most applications the Land Use Procedure described in Section 7.2.3(c) is sufficient for determining the urban/rural status. However, there may be sources located within an urban area, but located close enough to a body of water or to other non-urban land use categories to result in a predominately rural land use classification within 3 kilometers of the source following that procedure. Users are therefore cautioned against applying the Land Use Procedure on a source-by-source basis, but should also consider the potential for urban heat island influences across the full modeling domain. Furthermore, Section 7.2.3(f) of Appendix W recommends modeling all sources within an ***urban complex*** using the urban option even if some sources may be defined as rural based on the procedures outlined in Section 7.2.3. Such an approach is consistent with the fact that the urban heat island is not a localized effect, but is more regional in character.

Another aspect of the urban/rural determination that may require special consideration on a case-by-case basis relates to tall stacks located within or adjacent to small to moderate size urban areas. In such cases, the stack height, or effective plume height for very buoyant plumes, may extend above the urban boundary layer height. Application of the urban option in AERMOD for these types of sources may artificially limit the plume height. Therefore, use of the urban option may not be appropriate for these sources, since the actual plume is likely to be transported over the urban boundary layer. A proper determination of whether these sources should be modeled separately without the urban option will depend on a comparison of the stack height or effective plume height with the urban boundary layer height. The urban boundary layer height, z_{iuc}, can be calculated from the population input on the URBANOPT keyword, P, based on Equation 104 of the AERMOD formulation document (Cimorelli, *et al.*, 2004):

$$z_{iuc} = z_{iuo}\left(P/P_0\right)^{1/4} \qquad (1)$$

where z_{iu0} is the reference height of 400 meters corresponding to the reference population, P_0, of 2,000,000. Exclusion of these elevated sources from application of the urban option must be justified on a case-by-case basis in consultation with the appropriate reviewing authority.

5.2 SELECTING POPULATION DATA FOR AERMOD'S URBAN MODE (10/19/07)

For relatively isolated urban areas, the user may use published census data corresponding to the Metropolitan Statistical Area (MSA) for that location. For urban areas adjacent to or near other urban areas, or part of urban corridors, the user should attempt to identify that part of the urban area that will contribute to the urban heat island plume affecting the source(s). If this approach results in the identification of clearly defined MSAs, then census data may be used as above to determine the appropriate population for input to AERMOD. Use of population based on the Consolidated MSA (CMSA) for applications within urban corridors is not recommended, since this may tend to overstate the urban heat island effect.

For situations where MSAs cannot be clearly identified, the user may determine the extent of the area, including the source(s) of interest, where the population density exceeds 750 people per square kilometer. The combined population within this identified area may then be used for input to the AERMOD model. Users should avoid using a very fine spatial resolution of population density for this purpose as this could result in significant gaps within the urban area due to parks and other unpopulated areas, making it more difficult to define the extent of the urban area. Population densities by census tract should provide adequate resolution in most cases, and may still be finer resolution than desired in some cases. Since census tracts vary in size and shape, another acceptable approach would be to develop gridded estimates of population data based on census block or block group data. In such cases, a grid resolution on the order of 6 kilometers is suggested. Plotting population density with multiple "contour" levels, such as 0-500, 500-750, 750-1000, 1000-1500, etc., may also be beneficial in identifying which areas near the edge of the urban complex to include even though the population density may fall below the 750 threshold. The user should also bear in mind that the urban algorithms in AERMOD are dependent on population to the one-fourth power, and are therefore not highly sensitive to variations in population. Population estimates to two significant figures should be sufficiently accurate for application of AERMOD.

5.3 OPTIONAL URBAN ROUGHNESS LENGTH – URBANOPT KEYWORD (10/19/07)

The URBANOPT keyword on the CO pathway in AERMOD (EPA, 2004b) includes an optional parameter to specify the urban surface roughness length. The urban surface roughness parameter is used to define a reference height for purposes of adjusting dispersion for surface and low-level releases to account for the enhanced turbulence associated with the nighttime urban heat island. This optional urban roughness length is <u>not</u> used to adjust for differences in roughness length between the meteorological measurement site, used in processing the meteorological data, and the urban application site. Details regarding the adjustments in AERMOD for the urban boundary layer, including the use of the urban roughness length parameter, are provided in Section 5. 8 of the AERMOD model formulation document (Cimorelli, *et al.*, 2004).

The default value of 1 meter for urban surface roughness length, assumed if the parameter is omitted, is considered appropriate for most applications. Any application of AERMOD that utilizes a value other than 1 meter for the urban roughness length should be considered as a non-regulatory application, and would require appropriate documentation and justification as an alternative model, subject to Section 3.2 of the *Guideline on Air Quality Models* (EPA, 2005b). The use of a value other than 1 meter for the urban surface roughness length will be explicitly treated as a non-DFAULT option in the next update to the AERMOD model.

5.4 METEOROLOGICAL DATA SELECTIONS FOR URBAN APPLICATIONS (01/09/08)

5.4.1 Urban applications using NWS meteorological data (01/09/08)

When modeling urban sources, the urban algorithms in AERMOD are designed to enhance the turbulence levels relative to the nearby rural setting during nighttime stable conditions to account for the urban heat island effect (Cimorelli, *et al.*, 2004). For urban applications using representative NWS meteorological data the AERMOD urban option (URBANOPT) should be selected (EPA, 2004b), regardless of whether the NWS site is located in a nearby rural or an urban setting. This is due to the fact that the limited surface meteorological measurements available from NWS stations will not account for the enhanced turbulence or other meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms. The determination of surface characteristics for processing NWS meteorological data for urban applications should conform to the recommendations presented in Section 3.1.

5.4.2 Urban applications using site-specific meteorological data (01/09/08)

In most cases, site-specific meteorological data used for urban applications should be treated in a manner similar to NWS data described in Section 5.4.1, regardless of whether the measurement site is located in a nearby rural or an urban setting. That is, the AERMOD urban option should be selected and the surface characteristics should be determined based on the recommendations in Section 3.1. This is due to the fact that the limited surface meteorological measurements available from the meteorological measurement program will not adequately account for the meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms. However, if the measurement site is located in an urban setting and site-specific turbulence measurements are available (e.g., σ_θ or σ_w), some adjustments to the meteorological data input to AERMOD may be necessary, as discussed in Section 3.3.

6.0 SOURCE CHARACTERIZATION

6.1 CAPPED AND HORIZONTAL STACKS (09/27/05)

For capped and horizontal stacks that are NOT subject to building downwash influences a simple screening approach (Model Clearinghouse procedure for ISC) can be applied. This approach uses an effective stack diameter to maintain the flow rate, and hence the buoyancy, of the plume, while suppressing plume momentum by setting the exit velocity to 0.001 m/s. To appropriately account for stack-tip downwash, the user should first apply the non-default option of no stack-tip downwash (i.e., NOSTD keyword). Then, for capped stacks, the stack release height should be reduced by three actual stack diameters to account for the maximum stack-tip downwash adjustment while no adjustment to release height should be made for horizontal releases.

Capped and horizontal stacks that are subject to building downwash should not be modeled using an effective stack diameter to simulate the restriction to vertical flow since the PRIME algorithms use the stack diameter to define the initial plume radius which, in turn, is used to solve conservation laws. The user should input the actual stack diameter and exit temperature but set the exit velocity to a nominally low value, such as 0.001 m/s. This approach will have the desired effect of restricting the vertical flow while avoiding the mass conservation problem inherent with effective diameter approach. The approach suggested here is expected to provide a conservative estimate of impacts. Also, since PRIME does not explicitly consider stack-tip downwash, no adjustments to stack height should be made.

6.2 USE OF AREA SOURCE ALGORITHM IN AERMOD (09/27/05)

Because of issues related to excessive run times and technical issues with model formulation, the approach that AERMOD uses to address plume meander has not been implemented for area sources. As a result, concentration predictions for area sources may be overestimated under very light wind conditions (i.e., $u << 1.0$ m/s). In general, this is not expected to be a problem for meteorological data collected using standard wind instruments since instrument thresholds are generally too high. However, the problem could arise with meteorological data derived from very low threshold instruments, such as sonic anemometers. While not currently accepted for regulatory applications of AERMOD, this problem has also arisen when data from a gridded meteorological model was used to drive AERMOD. Meteorological grid models can at times produce extremely light winds. During such conditions time-averaged plumes tend to spread primarily as a result of low frequency eddy translation rather than eddy diffusion. AERMOD treats this meander effect by estimating the concentration from two limiting states: 1) a coherent plume state that considers lateral diffusive turbulence only (the mean wind direction is well defined) and 2) a random plume state (mean wind direction is poorly defined) that allows the plume to spread uniformly, about the source, in the x-y plane. The final concentration predicted by AERMOD is a weighted sum of these two bounding concentrations. Interpolation between the coherent and random plume concentrations is accomplished by assuming that the total horizontal “energy” is distributed between the wind’s mean and turbulent components.

In order to avoid overestimates for area sources during light wind conditions, it is recommended that, where possible, a volume source approximation be used to model area sources. This approach can be applied with confidence for situations in which the receptors are displaced from the source. However, for applications where receptors are located either directly adjacent to, or inside the area source, AERMOD's area source algorithm will need to be used. For these circumstances, caution should be exercised if excessive concentrations are predicted during extremely light wind conditions. On a case-by-case basis, the reviewing authority should decide whether such predictions are unrealistic. One possible remedy would be to treat such hourly predictions as missing data.

It is EPA's intention to correct this problem. A version of AERMOD that includes meander for area sources will be developed as soon as practicable.

7.0 REFERENCES

Blom, J. and L. Wartena, 1969. The Influence of Changes in Surface Roughness on the Development of the Turbulent Boundary Layer in the Lower Layers of the Atmosphere. *J. Atmos. Sci.*, **26**, 255-265.

Businger, J.A., 1986. Evaluation of the Accuracy with Which Dry Deposition Can Be Measured with Current Micrometeorological Techniques. *J. Climate Appl. Meteor*., **25**, 1100-1124.

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine, R. B. Wilson, R. F. Lee, W. D. Peters, R. W. Brode, and J. O. Paumier, 2004. AERMOD: Description of Model Formulation, EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC.[1]

EPA, 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications. Publication No. EPA-454/R-99-005. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (PB 2001-103606)[1]

EPA, 2004a: User's Guide for the AERMOD Meteorological Preprocessor (AERMET). EPA-454/B-03-002. U.S. Environmental Protection Agency, Research Triangle Park, NC. [1]

EPA, 2004b: User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC. [1]

EPA, 2004c: User's Guide for the AERMOD Terrain Preprocessor (AERMAP). EPA-454/B-03-003. U.S. Environmental Protection Agency, Research Triangle Park, NC. [1]

EPA, 2009: Addendum - User's Guide for the AERMOD Terrain Preprocessor (AERMAP). EPA-454/B-03-003. U.S. Environmental Protection Agency, Research Triangle Park, NC. [1]

EPA, 2005a. Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. 40 Federal Register, Volume 70, Page 68218

EPA, 2005b. *Guideline on Air Quality Models*. 40 CFR Part 51 Appendix W. [1]

EPA, 2008. AERSURFACE User's Guide. EPA-454/B-08-001. U.S. Environmental Protection Agency, Research Triangle Park, NC. [1]

Garratt, J. R., 1992: *The Atmospheric Boundary Layer.* Cambridge University Press, New York, New York, 334pp.

Gifford, F.A., 1968: "An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere," in *Meteorology and Atomic Energy*, ed., D.H. Slade. Division of Technical

[1] (Available @ www.epa.gov/scram001/)

Information, U.S. Atomic Energy Commission, Springfield, VA, 445pp.

Högström, A., and U. Högström, 1978. A Practical Method for Determining Wind Frequency Distributions for the Lowest 200 m from Routine Data. *J. Appl. Meteor.*, **17**, 942-954.
Horst, T.W., and J.C. Weil, 1994. How Far is Far Enough?: The Fetch Requirements for Micrometeorological Measurement of Surface Fluxes. *J. Atmos. and Oceanic Tech.*, **11**, 1018-1025.

Irwin, J.S., 1978. Proposed Criteria for Selection of Urban Versus Rural Dispersion Coefficients. (Draft Staff Report), Meteorology and Assessment Division, U.S. Environmental Protection Agency, Research Triangle Park, NC. (Docket No. A-80-46, II-B-8).

Oke, T. R., 1978: *Boundary Layer Climates.* John Wiley and Sons, New York, New York, 372pp.

Randerson, D., 1984, "Atmospheric Boundary Layer," in *Atmospheric Science and Power Production*, ed., D. Randerson. Technical Information Center, Office of Science and Technical Information, U.S. Department of Energy, Springfield, VA, 850pp.

Rao, K.S., J.C. Wyngaard, and O.R. Cote, 1974. The Structure of the Two-Dimensional Internal Boundary Layer over a Sudden Change in Surface Roughness. *J. Atmos. Sci.*, **31**, 738-746.

Sears, C., 2003. Letter to Docket No. A-99-05 Availability of Additional Documents Relevant to Anticipated Revisions to Guideline on Air Quality Models Addressing a Preferred General Purpose (flat and complex terrain) Dispersion Model and Other Revisions (Federal Register / Vol. 68, No. 173 / Monday, September 8, 2003).

Stull, R. B., 1988: *An Introduction to Boundary Layer Meteorology.* Kluwer Academic Publishers, The Netherlands, 666pp.

Taylor, P.A., 1969. The Planetary Boundary Layer above a Change in Surface Roughness. *J. Atmos. Sci.*, **26**, 432-440.

U.S. Geological Survey, 2002: The National Map – Elevation, Fact Sheet 106-02 (November 2002). http://egsc.usgs.gov/isb/pubs/factsheets/fs10602.html, U.S. Department of the Interior, Reston, Virginia 20192.

U.S. Geological Survey, 2009: Shuttle Radar Topography Mission DTED, http://edc.usgs.gov/products/elevation/srtmdted.html, U.S. Department of the Interior, Reston, Virginia 20192.

RESUME OF STEVEN KLAFKA, P.E., BCEE

Experience With Current Firm

President/Environmental Engineering Consultant
Wingra Engineering, S.C., Madison, Wisconsin (1991 to Present)

· Conducts environmental engineering projects related to air pollution control, hazardous waste management, compliance with regulations, and environmental impact studies. Formed Wingra Engineering in 1991.

· Provides environmental and regulatory consulting services for a diverse range of clients including manufacturing plants, electrical utilities, environmental advocacy groups, law firms and individuals.

· Worked for a wide range of industrial operations including foundries, glass manufacture, painting, coating, mineral quarries, lime manufacturing, coal handling, chemical manufacture, and electrical utilities.

· Completed projects in numerous states including Wisconsin, Minnesota, Iowa, Illinois, Ohio, Virginia, North Carolina, Tennessee, Oklahoma, Colorado, California, Oregon, and Washington.

· Services provided to clients include preparation of permit applications; dispersion modeling; risk assessment; environmental impact analysis; regulatory training; expert witness services; compliance inspections and audits; reporting and recordkeeping development; testing programs; and air pollution control system design and selection.

· Significant projects include approval of permit applications for major air pollution sources located near Class I national parks and wilderness areas; evaluation of cumulative air toxic risk of iron foundry operations; development of a pollution prevention program at a glass coating facility; and, expert witness for litigation regarding air pollution control, dispersion modeling and emission control methods.

Past Experience

Associate/Senior Environmental Engineer
Dames & Moore Consultants, Madison, Wisconsin (1988-1991)

· Conducted environmental audits and analyses to verify compliance with local air pollution control regulations at manufacturing facilities throughout the U.S., as well as Canada, India, Singapore and Taiwan.

· Managed and developed multi-disciplinary environmental impact studies for a wide variety of projects including utility turbine generating stations, a biomedical waste disposal facility, and a flat glass manufacturing facility.

Environmental Engineer, Wisconsin Department of Natural Resources
Bureau of Air Management, Madison, Wisconsin (1981-1988)

· Evaluated air pollution control permit applications for diverse range of air pollution sources. Evaluations included estimating air pollution emissions, verifying compliance with applicable regulations and policies, and using computer dispersion models to predict air quality impacts and determine health risks.

· Developed the air pollution control permit application forms used by the agency.

· Assisted in the development of the Wisconsin state policy for the control of hazardous air pollutant emissions.

Academic Background	B.S., Mechanical Engineering, University of Wisconsin, Madison, Wisconsin (1980). M.S., Civil & Environmental Engineering, University of Wisconsin (1994).
Professional Affiliations	Air and Waste Management Association, Past Chair for Wisconsin Chapter American Academy of Environmental Engineers

RESUME OF STEVEN KLAFKA, P.E., BCEE

Registration Registered Professional Engineer
Wisconsin (#E-24305), Illinois (#062-045104) and North Carolina (PE #023787)

Professional Honors Certified by the American Academy of Environmental Engineers
Designated Board Certified Environmental Engineer (BCEE) in 2002.

Publications

"Recent Air Pollution Control and Permit Experience in the Lime Industry", Annual Meeting of the Air & Waste Management Association, Pittsburgh, Pennsylvania, 2007.

"Evaluation of Cumulative Risk from an Iron Foundry", Annual Meeting of the Air & Waste Management Association, New Orleans, Louisiana, 2006.

"The Challenge of Air Quality Permit Approval for a Glass Plant near Mount Rainier and Olympic National Parks", Annual Meeting of the Air & Waste Management Association, New Orleans, Louisiana, 2006.

"New Source MACT and Residual Risk at an Iron Foundry", Presented at the Annual Meeting of the Air & Waste Management Association, San Diego, California, 2003.

"Influence of Emission Estimates on a BACT Determination for Iron Foundry Core Making Operations", Annual Meeting of the Air & Waste Management Association, Baltimore, Maryland, 2002.

"Challenging a Title V Operation Permit with the Part 70(8) Petition Process: An Aluminum Foundry Case Study", Annual Meeting of the Air & Waste Management Association, Baltimore, Maryland, 2002.

"Evaluating Local Impacts of a Utility SCR Retrofit Project", Annual Meeting of the Air & Waste Management Association, Baltimore, Maryland, 2002.

"Using a Flexible Compliance Strategy to Issue a Title V Operation Permit", Annual Meeting of the Air & Waste Management Association, Baltimore, Maryland, 2002.

"Evaluation of Gas Turbine Air Quality Impacts from a Community Perspective", Electric Utilities Environmental Conference, Tucson, Arizona, January 2002.

"Recent New Source MACT Determinations and Air Quality Compliance Experience in the Iron Foundry Industry", Annual Meeting of the Air & Waste Management Association, Orlando, Florida, 2001.

"Complexities of Air Quality Permit Issuance for an Iron Foundry near Great Smoky Mountains National Park", Annual Meeting of the Air & Waste Management Association, Orlando, Florida, 2001.

"Air Quality Permit Issuance and Varying Interpretations of BACT in the Flat Glass Industry", Annual Meeting of the Air & Waste Management Association, Orlando, Florida, 2001.

"Evaluation of Gas Turbine Air Quality Impacts from a Community Perspective", Annual Meeting of the Air & Waste Management Association, Orlando, Florida, 2001.

"Benzene Emissions and Exposure - Targeting Sources for the Greatest Benefit", Annual Meeting of the Air & Waste Management Association, Orlando, Florida, 2001.

"Measurement of Organic Air Toxics at Iron Foundries", Annual Meeting of the Air & Waste Management Association, San Antonio, Texas, 1995.

"Air Toxics Emission from Two Wood and RDF-Fired Fluidized Bed Combustors", Annual Meeting of the Air & Waste Management Association, Cincinnati, Ohio, 1994.

"Recent Air Quality Compliance Experience at Wisconsin Gray and Ductile Iron Foundries", Annual Meeting of the Air & Waste Management Association, Cincinnati, Ohio, 1994.

"Composition of VOC Emissions from the Sycamore Landfill", Annual Meeting of the Air & Waste Management Association, Cincinnati, Ohio, 1994.

"Sulfur Dioxide Control in a Rotary Lime Kiln", Annual Meeting of the Air & Waste Management Association, Denver, Colorado, 1993.

"Air Toxics Control Alternatives for Iron Foundry Pouring, Cooling and Shakeout Operations", Annual Meeting of the Air & Waste Management Association, Kansas City, Missouri, 1992.

Steven Klafka, P.E., BCEE
Dispersion Modeling & Testimony Experience
As of September 13, 2013

Dispersion Modeling Analyses for SO2 NAAQS

Mayo Electric Generating Station
Roxboro, North Carolina
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
December 5, 2012

Cayuga Operating Company
Lansing, New York
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
April 3, 2013

Chalk Point Generating Station
Aquasco, Maryland
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
April 5, 2013

Allen Steam Station
Belmont, North Carolina
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
November 27, 2012

H. Wilson Sundt Generating Station
Tucson, Arizona
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
September 27, 2012

J.E. Corette Steam Electric Station
Billings, Montana
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
September 24, 2012

PacifiCorp Energy Dave Johnston Plant
Converse County, Wyoming
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
September 12, 2012

Shawnee Fossil Plant
Paducah, Kentucky
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
September 12, 2012

North Valmy Generating Station
Valmy, Nevada
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
August 21, 2012

Branch Steam Electric Generating Plant
Milledgeville, Georgia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
August 21, 2012

Albright Power Station
Albright, West Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
September 19, 2011

Chesapeake Energy Center
Chesapeake, Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
August 26, 2011

Clinch River Plant
Carbo, Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
October 24, 2011

Elrama Power Plant
Elrama, Pennsylvania
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
October 25, 2011

Glen Lyn Plant
Glen Lyn, Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
October 21, 2011

Kanawha River Plant
Glasgow, West Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
October 25, 2011

New Castle Power Plant
West Pittsburg, Pennsylvania
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
October 21, 2011

Yorktown Power Station
Yorktown, Virginia
Sierra Club Evaluation of Compliance with 1-hour SO2 NAAQS
August 31, 2011

Dispersion Modeling Analysis Submitted for Air Quality Permit Applications

NR 406 Construction Permit Application
Sand Cooler and Line 6 Shakeout Project
Waupaca Foundry, Inc. Plant 1
Waupaca, Wisconsin
February 18, 2013

NR 405 Construction Permit Application
Line 7 Modification Project
Waupaca Foundry, Inc.
Waupaca, Wisconsin
August 21, 2012

PSD Permit Application
Line 4 Modification Project
Waupaca Foundry, Inc. Plant 6
Etowah, Tennessee
July 11, 2012

Construction Permit Application
Container Glass Plant
Bennu Glass LLC
Port of Kalama, Washington
December 2, 2010

Construction Permit Application
Low-Iron Glass Project
Cardinal FG Company
Durant, Oklahoma
November 5, 2010

Air Quality Construction Permit Application
ThyssenKrupp Waupaca Inc.
Plant 6 Desulfurization Project
Etowah, Tennessee
October 14, 2010

Construction Permit Application
Cupola Project
ThyssenKrupp Waupaca, Inc. Plant 5
Tell City, Indiana
July 22, 2010

Prevention of Significant Deterioration
Air Quality Construction Permit Application
ThyssenKrupp Waupaca, Inc.
Plant 6 Phase 2 Project
Etowah, Tennessee
February 22, 2007

NR 406 Construction Permit Application
Lime Kiln #5 Project
CLM Corporation
Superior, Wisconsin
December 28, 2005

NR 406 Construction Permit Application
Plant 1 MACT / Upgrade Project
ThyssenKrupp Waupaca, Inc.
Waupaca, Wisconsin
July 14, 2004

Air Quality Permit Application
Cardinal FG Company Glass Plant Project
Napavine, Lewis County, Washington
October 22, 2003

NR 406 Construction Permit Application
Plant 4 Foundry Efficiency Project
ThyssenKrupp Waupaca, Inc.
Marinette, Wisconsin
June 23, 2003

PSD Air Quality Permit Application
Cardinal FG Company Glass Plant Project
Durant, Oklahoma
November 6, 2002

Testimony on Air Pollution Control Projects

2013
In the Matter of El Paso Electric Company Application for Air Quality Permit Nos. 102294 and PSD-TX-1290, Before the Texas State Office of Administrative Hearings, SOAH Docket No. 582-13-1520. Compliance with air quality modeling requirements for permit issuance.

2012
Alaska Community Action on Toxics, et al. v. Aurora Energy Services, LLC, et al., Control of Fugitive Dust from a Coal Terminal in Seward, Alaska.

2010
AGC Flat Glass North America versus Pilkington PLC, BACT for Control of NOx Emissions from Glass Furnaces, Richmond, Kentucky.

2009
Wieland v. Anderson and Tessier, No. 08-CV-495, State of Wisconsin, Circuit Court, Pierce County. Air Quality Impacts of Outdoor Wood Fired Boilers.

2006
Charles McEvoy v. IEI Barge Services, Inc., United States District Court for the Northern District of Illinois, Western Division, (Environmental) Civil Action No. 06C50080, Air Quality Impacts of a Coal Terminal.

2005
In the Matter of an Air Pollution Control Construction Permit Issued to Madison-Kipp Corporation, State of Wisconsin, Division of Hearings and Appeals, Case No. IH-04-12. Compliance with air pollution control permit issuance requirements.

2004
In the Matter of an Air Pollution Control Construction Permit Issued to Midwest Energy Resources Company, State of Wisconsin, Division of Hearings and Appeals, Madison, Wisconsin, Case No. IH-02-04. Compliance with air pollution permit issuance requirements.