AERMOD

LATEST FEATURES AND EVALUATION RESULTS

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AERMOD: Latest Features and Evaluation Results

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ABSTRACT

AERMOD is an advanced plume model that incorporates updated treatments of the boundary layer theory, understanding of turbulence and dispersion, and includes handling of terrain interactions. The model was formally proposed by EPA in April 2000 as a replacement for the

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ISCST3 model. Several model enhancements were made as a result of public comment, including the installation of the PRIME downwash algorithm. The latest version of the model, version 02222, has been placed on EPA's web site for beta test purposes. This paper reviews the latest features and updated evaluation results for AERMOD version 02222.

INTRODUCTION

In 1991, the **A**merican **M**eteorological **S**ociety (AMS) and the United States **E**nvironmental **P**rotection **A**gency (EPA) initiated a formal collaboration with the designated goal of introducing recent advances in boundary layer meteorology into regulatory dispersion models. A working group (**A**MS/**E**PA **R**egulatory **M**odel **I**mprovement **C**ommittee, AERMIC) of three AMS and five EPA scientists was formed for this collaborative effort. AERMIC members and participants in model code development and testing are listed as the authors of this paper.

For many years now, we have known that an update to EPA's basic regulatory models is needed (e.g., see Weil[1]). Responding to this need, AERMIC was formed in 1991 to update EPA models with current state-of-the-art Planetary Boundary Layer (PBL) parameterizations. The early efforts of AERMIC are described by Weil[2]. As we went through the design process and considered the nature of present regulatory models, AERMIC's goal became more comprehensive. In addition to improving how regulatory models characterize the PBL, we decided that other areas such as terrain interactions and surface releases needed attention. This broadened scope resulted in the development of a complete replacement for EPA's Industrial Source Complex Short-Term model version 3 (ISCST3)[3] by: 1) adopting ISCST3's input/output computer architecture; 2) updating, where practical, antiquated ISCST3 model algorithms with newly developed or current state-of-the-art modeling techniques; and 3) insuring that all processes presently modeled by ISCST3 will continue to be handled by the **AER**MIC **Mod**el (AERMOD).

In developing AERMOD, we have strived to follow certain design criteria to yield a model with desirable regulatory attributes. We felt that the model should: 1) be robust in estimating regulatory design concentrations (i.e., provide reasonable estimates under a wide variety of conditions with minimal discontinuities); 2) be easily implemented (user friendly, reasonable input requirements and computer resources), as is the current ISCST3 model; 3) be based on state-of-the-art science that captures the essential physical processes while remaining fundamentally simple; and, 4) accommodate modifications with ease as the science evolves.

We chose a phased approach in developing AERMOD. An initial version of the model subjected to a "developmental" model evaluation with five databases was released to the public prior to the Sixth EPA Modeling Conference in August 1995. After this release and receipt of public comments, AERMIC conducted additional (independent) evaluations and made some further improvements in response to public comments. A formal peer review[4] of AERMOD was conducted in 1998, and an independent model evaluation[5,6] consisting of five additional databases was completed in 1998.

The complete AERMOD modeling system consists of two pre-processors and the dispersion model itself. The **AER**MOD **met**eorological preprocessor (AERMET) is a stand-alone program

which provides AERMOD with the information it needs to characterize the state of the surface and mixed layer, and the vertical structure of the PBL. The **AER**MOD **map**ping program (AERMAP) is a stand-alone terrain pre-processor, which is used to both characterize terrain and generate receptor grids for AERMOD.

PROPOSED RULEMAKING

On April 21, 2000, the EPA proposed[7] to replace ISCST3 with AERMOD version 99351. EPA described this new model as an advanced dispersion technique that incorporates state-of-the-art boundary layer parameterization techniques, convective dispersion, plume rise formulations, and complex terrain/plume interactions. Relative to ISCST3, AERMOD as proposed contained new or improved algorithms for: 1) dispersion in both the convective and stable boundary layers; 2) plume rise and buoyancy; 3) plume penetration into elevated inversions; 4) treatment of elevated, near-surface, and surface level sources; 5) computation of vertical profiles of wind, turbulence, and temperature; and 6) the treatment of receptors on all types of terrain (from the surface up to and above the plume height). Table 1 provides a more extensive list of the comparison features between AERMOD and ISCST3.

AERMOD as proposed did not incorporate newly developed building downwash algorithms that were developed independently and concurrently for the PRIME model (as installed in ISC-PRIME[8]), sponsored by EPRI. At the 7th USEPA Modeling Conference held in June 2000 and in the written comments provided afterward, many public comments focused upon the need to enhance AERMOD with the advancements in building downwash treatments that PRIME offers.

IMPLEMENTATION OF PRIME IN AERMOD

There were several issues involved with implementing[9] the PRIME downwash algorithms into the AERMOD model. The PRIME algorithm as implemented in ISC-PRIME was designed to use vertical profiles of wind and temperature that are consistent with the ISCST3 profiles, whereas AERMOD generates vertical profiles of wind and temperature based on similarity scaling and can also incorporate a full profile of measurements. PRIME was implemented in AERMOD to use the AERMOD meteorological profiles.

The ISC-PRIME model uses ambient turbulence intensities based on PG stability class to determine the distance at which the wake turbulence intensity has decayed to ambient levels, and also uses Pasquill-Gifford (PG)-based dispersion beyond the wake. The PRIME algorithm was implemented in AERMOD to use ambient turbulence intensities based on the AERMOD profiles.

The more significant issues were related to the use of a non-Gaussian probability distribution function (PDF) for the vertical dispersion in the convective boundary layer (CBL) in AERMOD, and AERMOD's treatment of the direct, indirect and penetrated plumes in the CBL. The ISC-PRIME model uses a Gaussian vertical distribution for both convective and stable conditions, consistent with the ISCST3 model.

Table 1. Comparison of dispersion model features: AERMOD vs. ISCST3.

Feature	ISCST3	AERMOD (version 02222)	Comments
Types of sources modeled	Point, area, and volume sources	Same as ISCST3	Models are comparable
Plume Rise	Uses Briggs equations with stack-top wind speed and vertical temperature gradient	In stable conditions, uses Briggs equations with winds and temperature gradient at stack top and half-way to final plume rise; in convective conditions, plume rise is superposed on the displacements by random convective velocities	AERMOD is better because in stable conditions it factors in wind and temperature changes above stack top, and in unstable conditions it accounts for convective updrafts and downdrafts
Meteorological Data Input	One level of data accepted	An arbitrarily large number of data levels can be accommodated	AERMOD can adapt multiple levels of data to various stack and plume heights
Profiling Meteorological Data	Only wind speed is profiled	AERMOD creates profiles of wind, temperature, and turbulence, using all available measurement levels	AERMOD is much improved over ISCST3 in this area
Use of Meteorological Data in Plume Dispersion	Stack-top variables for all downwind distances	Variables measured throughout the plume depth (averaged from plume centerline to 2.15 sigma-z below centerline; changes with downwind distance)	AERMOD treatment is far more advanced than that of ISCST3; accounts for meteorological data throughout the plume depth
Plume Dispersion: General Treatment	Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions	AERMOD's unstable treatment of vertical dispersion is a more accurate portrayal of actual conditions
Urban Treatment	Urban option either on or off; no other specification available; all sources must be modeled either rural or urban	Population is specified, so treatment can consider a variety of urban conditions; sources can individually be modeled rural or urban	AERMOD provides variable urban treatment as a function of city population, and can selectively model sources as rural or urban
Characterization of Modeling Domain Surface Characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen ratio, providing user flexibility to vary surface characteristics	AERMOD provides the user with considerably more options in the selection of the surface characteristics
Boundary Layer Parameters	Wind speed, mixing height, and stability class	Friction velocity, Monin-Obukhov length, convective velocity scale, mechanical and convective mixing height, sensible heat flux	AERMOD provides parameters required for use with up-to-date planetary boundary layer (PBL) parameterizations; ISCST3 does not
Mixed Layer Height	Holzworth scheme; uses interpolation based upon maximum afternoon mixing height	Has convective and mechanical mixed layer height; convective height based upon hourly accumulation of sensible heat flux	AERMOD's formulation is significantly more advanced than that of ISCST3, includes a mechanical component, and in using hourly input data, provides a more realistic sequence of the diurnal mixing height changes

Feature	ISCST3	AERMOD (version 02222)	Comments
Terrain Depiction	Elevation at each receptor point	Controlling hill elevation and point elevation at each receptor, obtained from special terrain pre-processor (AERMAP) that uses digital elevation model (DEM) data	AERMOD's terrain pre-processor provides information for advanced critical dividing streamline height algorithms and uses digital data to obtain receptor elevations
Plume Dispersion: Plume Growth Rates	Based upon 6 discrete stability classes only; dispersion curves (Pasquill-Gifford) are based upon surface release experiments (e.g., Prairie Grass)	Uses profiles of vertical and horizontal turbulence (from measurements and/or PBL theory); variable with height; uses continuous growth functions rather than a discrete (stability-based) formulation	Use of turbulence-based plume growth with height dependence rather than that based upon stability class provides AERMOD with a substantial advancement over the ISCST3 treatment
Plume Interaction with Mixing Lid: convective conditions	If plume centerline is above lid, a zero ground-level concentration is assumed	Three plume components are considered: a "direct" plume that is advected to the ground in a downdraft, an "indirect" plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixed layer and disperse to the ground)	The AERMOD treatment avoids potential underpredictions suffered by ISCST3 due to its "all or nothing" treatment of the plume; AERMOD's use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3
Plume Interaction with Mixing Lid: stable conditions	The mixing lid is ignored (assumed to be infinitely high)	A mechanically mixed layer near the ground is considered. Plume reflection from an elevated lid is considered.	AERMOD's use of a mechanically mixed layer is an advancement over the very simplistic ISCST3 approach
Building Downwash	Combination of Huber-Snyder and Scire-Schulman algorithms; many discontinuities	New PRIME downwash algorithm installed	AERMOD benefits from the technological advances offered by the PRIME model

To address these issues, the AERMIC committee adopted an approach that defines two plume "states", one corresponding to a plume that is influenced by building downwash, and the other corresponding to a plume that is not influenced by building downwash. AERMOD models the "wake state" plume using the PRIME algorithms with the adaptations described above, and models the "non-wake state" plume using the regular AERMOD algorithms for a source without building downwash. The contributions from the two plume states are combined using a weighting factor that is a function of the receptor location relative to the building wake.

For a receptor located within the wake region, the AERMOD model uses the concentration calculated by the PRIME algorithm, and the model transitions to the AERMOD estimate (without downwash) beyond the wake region. The lateral and vertical extents of the wake region are defined internally by the PRIME algorithm. For purposes of transitioning to the AERMOD estimate, the longitudinal extent of the wake region is defined as the maximum of 15R and the distance where wake turbulence intensity decays to the ambient level, where R is the wake length scale and is a function of the building dimensions. Beyond the wake region, the total concentration is calculated as follows:

$$\chi_{TOTAL} = \gamma \chi_{PRIME} + (1-\gamma)\ \chi_{AERMOD} \tag{1}$$

The weighting function, γ, is equal to 1.0 within the wake region, and beyond the wake region is calculated as follows:

$$\gamma = \exp\left(\frac{-(x-\sigma_{xg})^2}{2\sigma_{xg}^2}\right)\exp\left(\frac{-(y-\sigma_{yg})^2}{2\sigma_{yg}^2}\right)\exp\left(\frac{-(z-\sigma_{zg})^2}{2\sigma_{zg}^2}\right) \tag{2}$$

where:

x = downwind distance of receptor from upwind edge of the building;

y = lateral distance of receptor from building centerline;

z = receptor height above stack base, including terrain and flagpole;

σ_{xg} = maximum of 15R and the distance to transition from wake to ambient turbulence;

σ_{yg} = lateral distance from building centerline to lateral edge of the wake at receptor location; and

σ_{zg} = height of the wake at the receptor location.

For applications involving terrain effects and building downwash, the AERMOD component is calculated with the standard terrain treatment, and the PRIME component is calculated with the minimum terrain weighting factor of 0.5, since the wake region is considered to be near neutral due to the building-enhanced turbulence. The use of the receptor height above stack base in the calculation of the vertical component of γ indicates that if the terrain is within the wake, then the

PRIME component should dominate. However, if the plume is rising above the wake and terrain extends above the wake, then the AERMOD component should become imprtant.

During the developmental evaluation of AERMOD with PRIME, preliminary results indicated a tendency for the model to overpredict during light wind convective conditions. The PRIME algorithm includes a test on the trajectory angle of the rising plume to determine if the plume will escape the effects of the building. If the trajectory of the plume falls below 45 degrees from horizontal before the plume rises above the top of the wake, then the plume is subjected to building downwash influences. The light wind convective conditions for the Bowline data were evaluated to determine a "best fit" for this critical trajectory angle based on the normalized mean square error, and a best fit was found for a critical angle of 20 degrees. Based on this result, PRIME was implemented in AERMOD using a critical angle of 20 degrees to determine if wake effects apply.

OTHER MODIFICATIONS TO AERMOD

Many commentors supported the implementation of AERMOD as an improved and advanced dispersion model. Some of the public comments (in addition to those advocating the installation of the PRIME advancements into AERMOD) led to additional improvements to AERMOD version 02222, released by EPA as a beta test version and described in an updated Model Formulation Document[10].

- An option to use representative measurements of delta-T and wind speed in lieu of cloud cover in AERMET for characterizing boundary layer parameters in stable conditions has been included. This option is new and has not been extensively tested by the user community.

- AERMAP was modified to remove its dependence upon the terrain domain for determining controlling hill heights for each receptor. This change involved the concept that a terrain feature has an influence zone on the surrounding area up to about 10 hill relief heights. For each receptor, terrain features more distant than 10 hill relief heights are not considered in AERMAP.

- AERMAP was modified to be able to convert receptor, source and elevation coordinates from North American Datum (NAD) of 1927 and other datums to NAD 1983 using the United States Geological Survey (USGS) sanctioned program, NADCON version 2.1.

- AERMET was modified to read Forecast Systems Laboratory (FSL) upper air and Hourly United States Weather Observations (HUSWO) surface meteorological data formats.

- A correction was made to AERMOD to avoid elevated concentrations for terrain below stack base from the virtual image source. This fix also addressed some of the public comments regarding anomalous AERMOD concentrations from a hypothetical stack located on the top of a hypothetical terrain feature.

- In AERMOD, the urban mode was modified to allow the user to input the urban roughness length as an optional parameter. The latest version of AERMOD also includes an adjustment

to the friction velocity and the Monin-Obukhov length for urban stable cases, by equating the "convective" sigma-w based on the urban "convective" velocity scale with the mechanical sigma-w based on the friction velocity evaluated at a height of 7 times the urban roughness length.

- The reference urban mixing height for a reference population of 2,000,000 was changed from 500 m to 400 m to better match literature references and observed data.

- The minimum layer near the ground for calculating effective parameters was changed from the lowest 2 m to 5 m to avoid problems for high roughness length applications.

- Enhancements were made to AERMOD based on the ISCST3 model version 00101. These included

  1) the use of globally allocatable arrays for data storage;

  2) expanded data structures to allow for output of concentration and deposition in a single model run (for use when deposition algorithms are added to AERMOD);

  3) EVENT (individual period) processing for short-term culpability analyses;

  4) post-1997 PM_{10} processing;

  5) TOXICS option enhancements such as optimizations for area sources, the Sampled Chronological input Model (SCIM) option, and Season and Hour-of-Day (SEASONHR) output file option;

  6) explicit treatment of multiple-year meteorological data files and ANNUAL averages;

  7) the SHRDOW and SHRDOW7 options for specifying emissions that vary by Season, HouR-of-Day, and Day-of-Week; and

  8) improved data structures for field length and filename lengths.

- Other minor corrections and/or adjustments were made to the AERMOD code due to public comments or user/beta-test comments. They are documented in the comments sections of the model source codes. Some of the more notable changes involve the following features:

  - The meander feature that has the most effect in very light winds is now applicable for both stable and unstable conditions, has been removed from the PRIME downwash component of the model, and combines "plume" and "pancake" components of concentrations rather than just blending the lateral dispersion term.

  - There is a modification to the potential temperature gradient profile for extrapolating above the highest measurement height for cases with observed temperature profiles.

- A modification was made to the upper limit on the integration for the critical dividing streamline height.

In addition to the full-scale version of AERMOD, an ad-hoc group within EPA and the states is working to develop a screening version of AERMOD, AERSCREEN. When completed, AERSCREEN will generate screening meteorological data appropriate for the site in question and execute the AERMOD model to provide a conservative estimate of concentration impacts.

Another ad-hoc group, largely from the state of West Virginia, is working on an objective method to use digitized land use data to develop input values to AERMET for roughness length, albedo, and Bowen Ratio. This technique, referred to as AERSurface, will help to improve the consistency of the formulation of this input to AERMET.

MODEL EVALUATION DESIGN

The model evaluation was designed to provide diagnostic as well as descriptive information about the model performance. The procedures used were designed to address the following questions:

- Does AERMOD provide good predictions for the "right" reasons (a model physics evaluation)?

- How well does AERMOD predict the peak ground-level concentrations that are used to assess compliance with air quality regulations (an operational performance evaluation)?

- Is AERMOD's performance significantly better than that of other applied models, such as ISCST3, HPDM (Hanna and Paine[11]), RTDM (Paine and Egan[12]), and CTDMPLUS[13,14]?

The ISCST3, RTDM, and CTDMPLUS models are currently approved by the EPA for general use in regulatory applications ("Appendix A" models). AERMOD is being proposed for use in place of these models, although CTDMPLUS would still be available for applications involving a well-defined hill or ridge. HPDM was developed by EPRI as a state-of-the-art model for use in simple terrain. Comparison of AERMOD performance to that of HPDM is useful as a benchmark. Other advanced models such as SCIPUFF[15] and ADMS[16] were considered when this model comparison effort was initiated. However, these models were not released to the public at that time and thus were not included.

The average model error (or "residual") examined over a broad range of input variables is used to evaluate the model physics. The residual is examined by plotting the ratio of the model prediction to observed values for data paired in time as a function of various model input variables (e.g., distance, wind speed, and mixing height). Residual plots can be examined for partial data sets such as for stable or unstable conditions. If a significant trend is observed in the predicted-to-observed ratio as a function of the abscissa variable, then the model physics associated with or responsible for this feature can be further examined.

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots (Chambers et al.[17]). Q-Q plots, are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations are then plotted by rank against the observed concentrations also sorted by rank. These concentration pairs are no longer paired in time or location. However, the plot is useful for answering the question, "Over a period of time and over a variety of locations, does the distribution of the model predictions match those of observations?" Scatterplots, which use data paired in time (and / or space), provide a more strict test, answering the question: "At a given time and place, does the magnitude of the model prediction match the observation?" It is the experience of model developers (e.g., Weil, et al.[18] and Liu and Moore[19]) that wind direction uncertainties can and do cause disappointing scatterplot results from what are otherwise well-performing dispersion models. Therefore, the Q-Q plot instead of the scatterplot is a more pragmatic procedure for demonstrating model performance of applied models. Venkatram[20] makes a cogent argument for the use of Q-Q plots for evaluating regulatory models.

In addition to the residual and Q-Q plots, the difference between AERMOD and ISCST3 was assessed with a robust test statistic (robust highest concentration, or RHC[21]) that represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the concentration distribution. With this procedure, the effect of extreme values on model comparison is reduced. The RHC statistic is reported for each of the 10 databases. The robust highest concentration is given by:

$$RHC = \chi\{n\} + \left(\overline{\chi} - \chi\{n\}\right) \ln\left(\frac{3n-1}{2}\right) \tag{3}$$

where n = Min (m_o, m), m_o is the number of values used to characterize the upper end of the concentration distribution, m is the number of values exceeding a specified threshold value, $\overline{\chi}$ is the average of the n - 1 largest values, and $\chi\{n\}$ is the nth largest value. In this evaluation, the value of m_o was taken to be 26 except for databases with a limited sample size (for which m_o was taken to be 11).

Highlights of the evaluation results for the proposed regulatory version of AERMOD were first presented by Paine, et al.[5.] As with Paine, et al., the evaluation results here include selected residual plots and Q-Q plots to address the model performance issues noted above. In the AERMOD evaluation, many of the statistical tests and comparisons with observations were applied to analyze the performance of the model and various model algorithms. The observed peak concentration for a given arc of samplers was compared to the predicted arc maximum. The comparisons included time and downwind-distance pairings to challenge the model components. Residual plots (predicted/observed, paired in time and downwind distance) of concentration estimates were used to judge whether AERMOD was performing correctly and was yielding better results (than existing models). Generally, residuals were plotted as a function of distance, although residuals versus other parameters, such as friction velocity, Monin-Obukhov length, and

mixing height, proved to be extremely valuable diagnostic tools. In addition, Q-Q plots were used to examine the ability of the model to reproduce the distribution of observed concentrations over a wide range of environmental conditions. Reproducing the measured distribution, particularly the high concentration end, is important in regulatory applications.

For the intensive tracer data sets (Prairie Grass, Kincaid SF_6, Indianapolis, and Tracy), concentration residuals of the form $<C_p/C_o>$ were plotted as a function of downwind distance (arc distance) for each of two stability regimes, convective and stable. Here, C_o is the maximum observed concentration and C_p the maximum predicted concentration on an arc at a given time. The brackets, $<C_p/C_o>$, indicate the mean of the ratio. These data were paired in time and downwind distance. For the tracer databases, observations and predictions corresponded to maximum concentrations on each arc of samplers, rather than at each individual sampler, to eliminate the effect of wind direction uncertainties on the evaluation results. The use of arc maxima was possible due to the dense coverage of samplers along each arc. For the other nondownwash data sets (Kincaid SO_2, Lovett, Baldwin, Clifty Creek, Martins Creek, and Westvaco), where the sampler array was not sufficiently dense to arrange the data in arcs, residual plots by distance were not meaningful. In contrast to the tracer studies (where a C_o, C_p pair are available for each arc-distance of each time period), the long-term databases have only a single C_o, C_p pair selected (for each time period) as the maximum observed and predicted concentrations, respectively in the entire receptor array.

For the tracer databases, results for 1-hour averages are reported (with the Prairie Grass 10-minute measurements used). For the long term SO_2 data sets, 3-hour, 24-hour, and annual results are reported. All of the observed concentrations for the long-term databases are subject to an additional uncertainty related to the estimate of background concentration that is subtracted from the monitored observations. In addition, it should be realized that SO_2 monitors typically have a detection limit on the order of 6 ppb (16 mg m^{-3}), and baseline (zero) drifts of up to 10 ppb (26 mg m^{-3}). Concentrations below the detection limit are typically set to half of the limit (8 mg m^{-3}), even though they may actually be zero. Baseline drift is generally ignored. Therefore, the uncertainties due to the combined errors in SO_2 measurements from the detection limit treatment, ignored baseline drifts, and background concentration estimates reflect on the reliability of the observed concentrations, particularly for annual averages. Peak short-term averages are not affected significantly because the uncertainty is typically a small percentage of the reported value.

MODEL EVALUATION RESULTS FOR NON-DOWNWASH DATABASES

The combined developmental and independent performance evaluation[5,6] of AERMOD involved four short-term tracer studies and six conventional long-term SO_2 monitoring databases in a variety of settings. The purpose of the evaluation studies was to be sure that AERMOD had been tested in a variety of types of environments for which it will be used. Compared with many widely used applied models, AERMOD has been subjected to a large degree of testing with these evaluation databases.

The evaluation of AERMOD was accomplished in two phases. The first phase, the "developmental evaluation," was performed concurrently with the development of the model. As

each model feature was tested, a relevant portion of the developmental evaluation was repeated with five databases to identify any problems that might have been introduced with that feature. Because the model could have been inadvertently biased by particular characteristics of the developmental databases, a second phase, the "independent evaluation," was conducted using five additional data sets.

AERMOD is intended to handle a variety of pollutant source types, including surface and buoyant elevated sources, in a wide variety of settings such as rural and urban as well as flat and complex terrain. With this in mind, data were selected from five diverse field studies for the developmental evaluation. Due to space limitations, maps of the various sites are not provided in this report, but can be found on the Internet in Paine, et al.[5]. A brief description of these data sets is provided below.

Developmental Evaluation (No Downwash)

The Prairie Grass study (Barad[22]; Haugen[23]) used a near-surface, non-buoyant tracer release in a flat rural area in Nebraska. This study involved a tracer of SO_2 released at 0.46 m above the surface. Surface sampling arrays (arcs) were positioned from 50 m to 800 m downwind. Meteorological data included the 2-m level wind direction and speed, the root-mean-square wind direction fluctuation, and the temperature difference (ΔT) between 2 m and 16 m. Other surface parameters, including friction velocity, Monin-Obukhov length, and lateral plume spread were estimated. Wind, turbulence, and temperature were obtained from a multi-leveled instrumented 16-m meteorological tower. A total of 44 ten-minute sampling periods were used, including both convective and stable conditions.

The Kincaid SF_6 study (Liu and Moore[19]; Bowne et al.[24]) involved an elevated, highly-buoyant tracer release in a flat rural area of Illinois. Two intensive measurement periods each lasting six weeks were conducted during the spring and summer of 1980 and 1981. During these periods, approximately 200 monitors were placed on arcs ranging from about 500 m to 50 km downwind of the single 187-m stack and provided 1-hour averaged concentration samples for a total of 1,801 arc-hours. Meteorological data included wind speed, direction, and temperature from a tower instrumented at 2, 10, 50, and 100 m levels, and nearby National Weather Service (NWS) data. Estimates of lateral plume spread were obtained from the sampling arcs.

The Indianapolis study (Murray and Bowne[25]) consisted of an elevated, buoyant tracer (SF_6) released in a flat-terrain urban to suburban area from a single 84-m stack. Data are available for approximately a four- to five-week period with 177 monitors providing 1-hour averaged samples along arcs from 250 m to 12 km downwind for a total of 1,297 arc-hours. Meteorological data included wind speed and direction, sigma-theta on a 94-meter tower; and wind speed, ΔT (2m - 10m) and other supporting surface data at three other 10-m towers. Observed plume rise and estimates of plume sigma-y are also available from the database.

The Kincaid SO_2 study (Liu and Moore[19]; Bowne et al.[24]) was conducted at the same location as the Kincaid SF_6 study. It involved a buoyant, continuous release of SO_2 from a 187-m stack in rural flat terrain. The study included about six months of data between April 1980 and June 1981 (a total of 4,614 hours of samples). There were 30 SO_2 monitoring stations providing 1-hour

averaged samples from about 2 km to 20 km downwind of the stack. The meteorological data were the same as in the Kincaid tracer study.

The Lovett Power Plant study (Paumier et al.[26]) consisted of a buoyant, continuous release of SO_2 from a 145-m tall stack located in a complex terrain, rural area in New York State. The data spanned one year from December 1987 through December 1988. Data were collected from 12 monitoring sites (ten on elevated terrain and two near stack-base elevation) that were located about 2 to 3 km from the plant. The monitors provided hourly-averaged concentrations. The important terrain features rise approximately 250 m to 330 m above stack base at about 2 to 3 km downwind from the stack. Meteorological data include winds, turbulence, and ΔT from a tower instrumented at 10 m, 50 m, and 100 m. National Weather Service surface data were available from a station 45 km away.

Independent Evaluation (No Downwash)

The independent evaluation of AERMOD initially employed the first three databases described below. Results for two additional databases were added in response to peer review comments.

The Baldwin Power Plant (Hanna and Chang[27]) is located in a rural, flat terrain setting of southwestern Illinois and has three identical 184-m stacks aligned approximately north-south with a horizontal spacing of about 100 m. There were 10 SO_2 monitors that surrounded the facility, ranging in distance from two to ten km. On-site meteorological data was available during the study period of 1 April 1982 through 31 March 1983 and consisted of hourly-averaged wind speed, wind direction, and temperature measurements taken at 10 m and wind speed and wind direction at 100 m.

The Clifty Creek Power Plant is located in rural southern Indiana along the Ohio River with emissions from three 208-m stacks during this study. The area immediately north of the facility is characterized by cliffs rising about 115 m above the river and intersected by creek valleys. Six nearby SO_2 monitors (out to 16 km from the stacks) provided hourly averaged concentration data. Meteorological data from a nearby 60-m tower covered the two-year period from 1 January 1975 through 31 December 1976, although only the data from 1975 were used in this evaluation. This database was also used in a major EPA-funded evaluation of rural air quality dispersion models in the early 1980s[28].

The Martins Creek Steam Electric Station is located in a rural area along the Delaware River on the Pennsylvania/New Jersey border, approximately 30 km northeast of Allentown, PA and 95 km north of Philadelphia, PA. The area is characterized by complex terrain rising above the stacks. Sources included multiple tall stacks ranging from 122 to 183 m in height. The seven SO_2 monitors[29] were located on Scotts Mountain, which is about 2.5 - 8 km southeast of the Martins Creek facility. On-site meteorological data covered the period from 1 May 1992 through 19 May 1993. Hourly temperature, wind speed, wind direction, and sigma-theta (standard deviation of the horizontal wind direction) at 10 m were recorded from an instrumented tower located in a flat area approximately 2.5 km west of the plant. In addition, hourly multi-level wind measurements were taken by a sodar located approximately three km southwest of the Martins Creek station.

The Westvaco Corporation's pulp and paper mill in rural Luke, Maryland is located in a complex terrain setting in the Potomac River valley (Strimaitis et al.[30]). A single 183-m buoyant source was modeled for this evaluation. There were 11 SO_2 monitors surrounding the facility, with eight monitors well above stack top on the high terrain east and south of the mill at a distance of 800 - 1500 m. Hourly meteorological data (wind, temperature, and turbulence) were collected between December 1980 and November 1991 at three instrumented towers: the 100-m Beryl tower in the river valley about 400 m southwest of the facility; the 30-m Luke Hill tower on a ridge 900 meters north-northwest of the facility; and the 100-m Met tower located 900 m east-southeast of the facility on a ridge across the river.

The Tracy Power Plant (DiCristofaro et al.[31]) is located 27 km east of Reno, Nevada in the rural Truckee River valley completely surrounded by mountainous terrain. A field tracer study was conducted at the power plant in August 1984 with SF_6 being released with the moderately buoyant plume from a 91-m stack. A total of 128 hours of data were collected over 14 experimental periods. Stable atmospheric conditions were dominant for this study. On-site meteorological data (wind, temperature, and turbulence) for Tracy were collected from an instrumented 150-m tower located 1.2 km east of the power plant. The wind measurements from the tower were extended above 150 meters using a Doppler acoustic sounder and temperature measurements were extended with a tethersonde.

Evaluation Results

For completeness, EPA re-ran the evaluation of the 10 non-downwash databases. The earlier evaluation results indicated that AERMOD shows superior performance relative to ISCST3 over all of the databases tested. The newest evaluation results are very similar to the results reported by Pain et al.[5]. A summary of the robust highest concentration prediction results is provided in Table 2. More complete results[5,6] that include Q-Q plots and some residual plots for the previous evaluation are available and would show very little change for the updated evaluation.

Table 2. Summary of AERMOD evaluation results – nondownwash databases (previous results[5] in parentheses).

Database	Ratio of Modeled/Observed Robust Highest Concentrations*
Prairie Grass (SO_2) Flat, grassy field (Nebraska, USA)	AERMOD: 0.89 (0.87) (1-hr avg) ISCST3: 1.50 (1-hr avg)
Kincaid (SF_6) Flat, rural (Illinois, USA)	AERMOD: 0.77 (0.76) (1-hr avg) ISCST3: 0.68 (1-hr avg)
Kincaid: (SO_2) Flat, rural (Illinois, USA)	AERMOD: 0.98 (1.01) (3-hr avg) ISCST3: 0.56 (3-hr avg) AERMOD: 0.94 (0.97) (24-hr avg) ISCST3: 0.45 (24-hr avg) AERMOD: 0.30 (0.30) (annual peak) ISCST3: 0.14 (annual peak)

Database	Ratio of Modeled/Observed Robust Highest Concentrations*
Baldwin (SO_2): Flat, rural (Illinois, USA)	AERMOD: 1.24 (1.31) (3-hr avg) ISCST3: 1.43 (3-hr avg) AERMOD: 0.97 (1.02) (24-hr avg) ISCST3: 1.14 (24-hr avg) AERMOD: 0.97 (0.97) (annual peak) ISCST3: 0.63 (annual peak)
Indianapolis (SF_6) Flat, urban (Indiana, USA)	AERMOD: 1.11 (1.20) (1-hr avg) ISCST3: 1.30 (1-hr avg)
Clifty Creek (SO_2) Moderately hilly terrain, rural (Indiana, USA)	AERMOD: 1.05 (1.25) (3-hr avg) ISCST3: 0.98 (3-hr avg) AERMOD: 0.67 (0.72) (24-hr avg) ISCST3: 0.67 (24-hr avg) AERMOD: 0.54 (0.54) (annual peak) ISCST3: 0.31 (annual peak)
Tracy (SF_6): Hilly terrain, rural (Nevada, USA)	AERMOD: 1.04 (1.07) (1-hr avg) ISCST3: 2.81 (1-hr avg) CTDMPLUS: 0.77 (1-hr avg)
Martins Creek (SO_2): Hilly terrain, rural (Pennsylvania/New Jersey, USA)	AERMOD: 1.12 (1.06) (3-hr avg) CTDMPLUS: 4.80 (3-hr avg) ISCST3: 7.25 (3-hr avg) RTDM: 3.33 (3-hr avg) AERMOD: 1.78 (1.72) (24-hr avg) CTDMPLUS: 5.56 (24-hr avg) ISCST3: 8.88 (24-hr avg) RTDM: 3.56 (24-hr avg) AERMOD: 0.78 (0.74) (annual peak) CTDMPLUS: 2.19 (annual peak) ISCST3: 3.37 (annual peak) RTDM: 1.32 (annual peak)
Lovett (SO_2)	AERMOD: 1.03 (1.00) (3-hr avg) CTDMPLUS: 2.36 (3-hr avg) ISCST3: 8.20 (3-hr avg) AERMOD: 1.01 (1.00) (24-hr avg) CTDMPLUS: 2.02 (24-hr avg) ISCST3: 9.11 (24-hr avg) AERMOD: 0.85 (0.78) (annual peak) CTDMPLUS: 1.71 (annual peak) ISCST3: 7.49 (annual peak)

Database	Ratio of Modeled/Observed Robust Highest Concentrations*
Westvaco (SO_2): Hilly terrain, rural (Maryland/Virginia, USA)	AERMOD: 1.06 (1.08) (3-hr avg) CTDMPLUS: 2.14 (3-hr avg) ISCST3: 8.50 (3-hr avg, estimated*) AERMOD: 1.07 (1.14) (24-hr avg) CTDMPLUS: 1.54 (24-hr avg) AERMOD: 1.59 (1.64) (annual peak) CTDMPLUS: 0.93 (annual peak)

*Notes:

1. The Robust Highest Concentration (RHC) is a statistical estimator for the highest concentration. It is determined from a tail exponential fit to the high end of the frequency distribution of observed and predicted values. The number of points used for the fit is arbitrary, but usually ranges between 10 and 25.

2. The estimated 3-hour ISCST3 result for Westvaco is derived from the EPA Complex Terrain Model Development study (Strimaitis et al.[30]) in which several models, including CTDMPLUS and COMPLEX-I (now part of ISCST3), were evaluated.

The overall model evaluation results for AERMOD version 02222 with nondownwashing databases can be summarized as follows, taking one composite (geometric mean) ratio of predicted to observed RHC value for short-term averages at each site, and also taking the annual average ratio at sites with year-long databases:

- 1.03 is the overall predicted-to-observed ratio for short-term averages (with a range among sites from 0.76 to 1.35).

- 0.73 is the overall predicted-to-observed ratio for annual averages (with a range among sites from 0.30 to 1.64).

While the predicted-to-observed ratios did not vary substantially for AERMOD between simple and complex terrain sites, there was a large change in the average ratio for ISCST3 : 0.96 for simple terrain and 6.4 for complex terrain.

MODEL EVALUATION RESULTS FOR DOWNWASH DATABASES

A developmental evaluation of the AERMOD model with PRIME added was conducted on four developmental databases prior to its application to four independent databases. Paine[32] describes these databases and others that were originally considered for the EPRI PRIME evaluation study. The developmental databases (described below) included one half of the days selected at random from a full year of data for the Bowline power plant database located on the Hudson River near Haverstraw, New York, the Millstone power plant located on the Connecticut coast, the Duane Arnold Energy Center (DAEC) located in eastern Iowa, and the Alaska North Slope field study near Prudhoe Bay, Alaska. The Bowline Point database was used in both the developmental and evaluation evaluations because it was the only full year database, and more complete

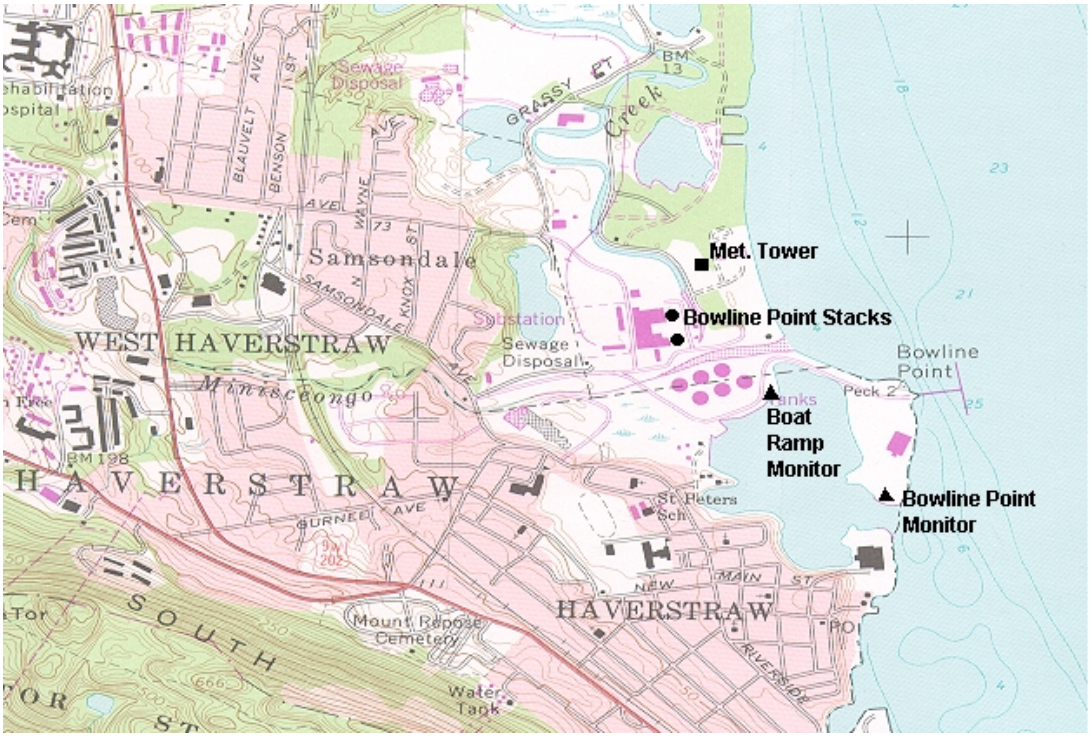
development testing of both ISC-PRIME and AERMOD version 02222 required the use of half of this database.

The main purpose of testing with the developmental databases was to assure that the AERMOD predictions were consistent with the ISC-PRIME predictions for stack-receptor combinations dominated by building downwash. However, as noted earlier, one correction was made to AERMOD to adjust the threshold trajectory angle of the rising plume that determines whether the plume will escape the effects of the building. As noted below, the evaluation results for the developmental databases included both underpredictions and overpredictions for both AERMOD and ISC-PRIME. However, no attempt was made in the developmental phase of testing to further adjust the downwash algorithm.

Developmental Evaluation (Downwash)

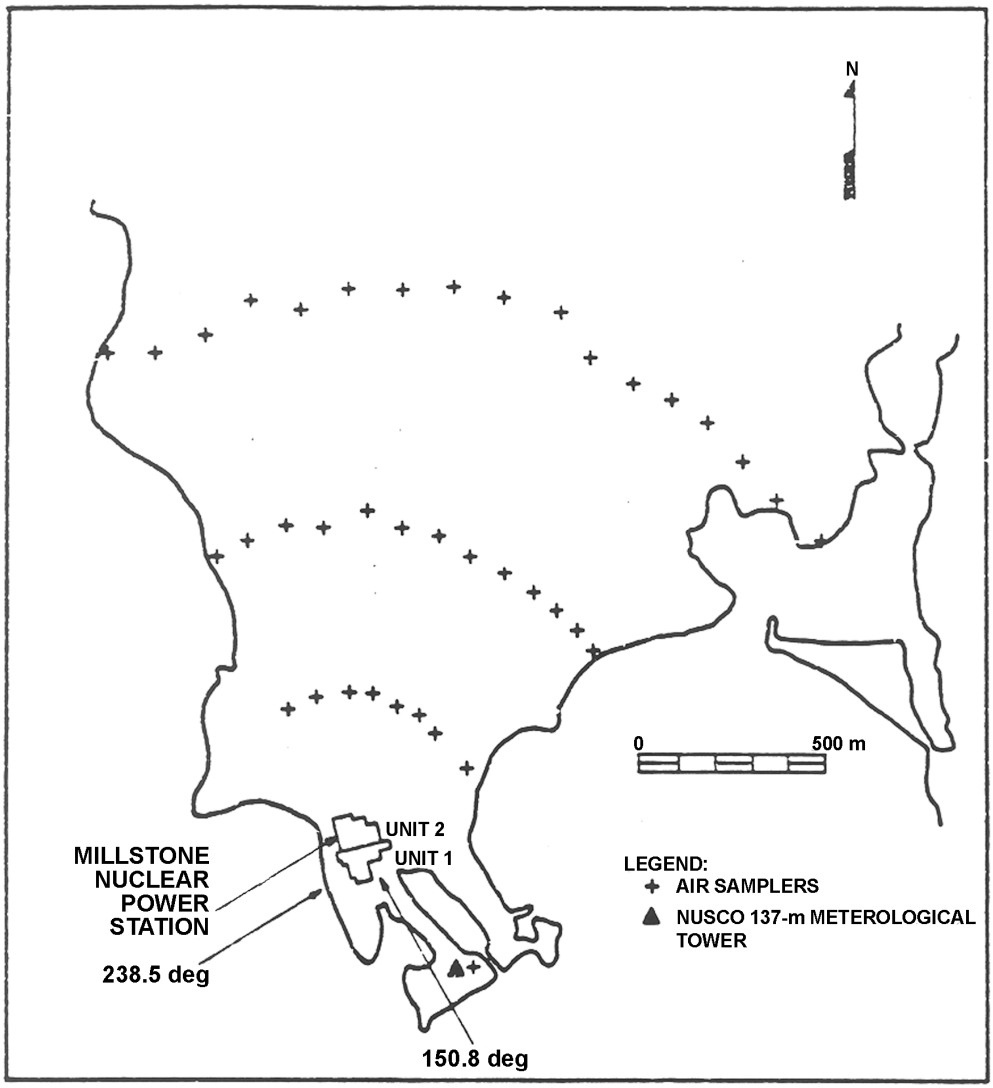
The Bowline Point site[33], located in the Hudson River valley in New York State, is shown in Figure 1 (topographic map). The electric utility site included two 600-MW units, each with an 86.9-m stack and a dominant roof tier with a height of 65.2 m high in a rural area. There were four monitoring sites as shown in Figure 1 that ranged from about 250 to 850 m from the stacks. Hourly emissions data was determined from load data, coal analyses, and site-specific relationships between loads and fuel consumption. Meteorological data was obtained from a 100-m tower at the site. This site was also used as an independent evaluation database with the entire year included.

Figure 1. Bowline Point Study Area (SO_2 Releases)



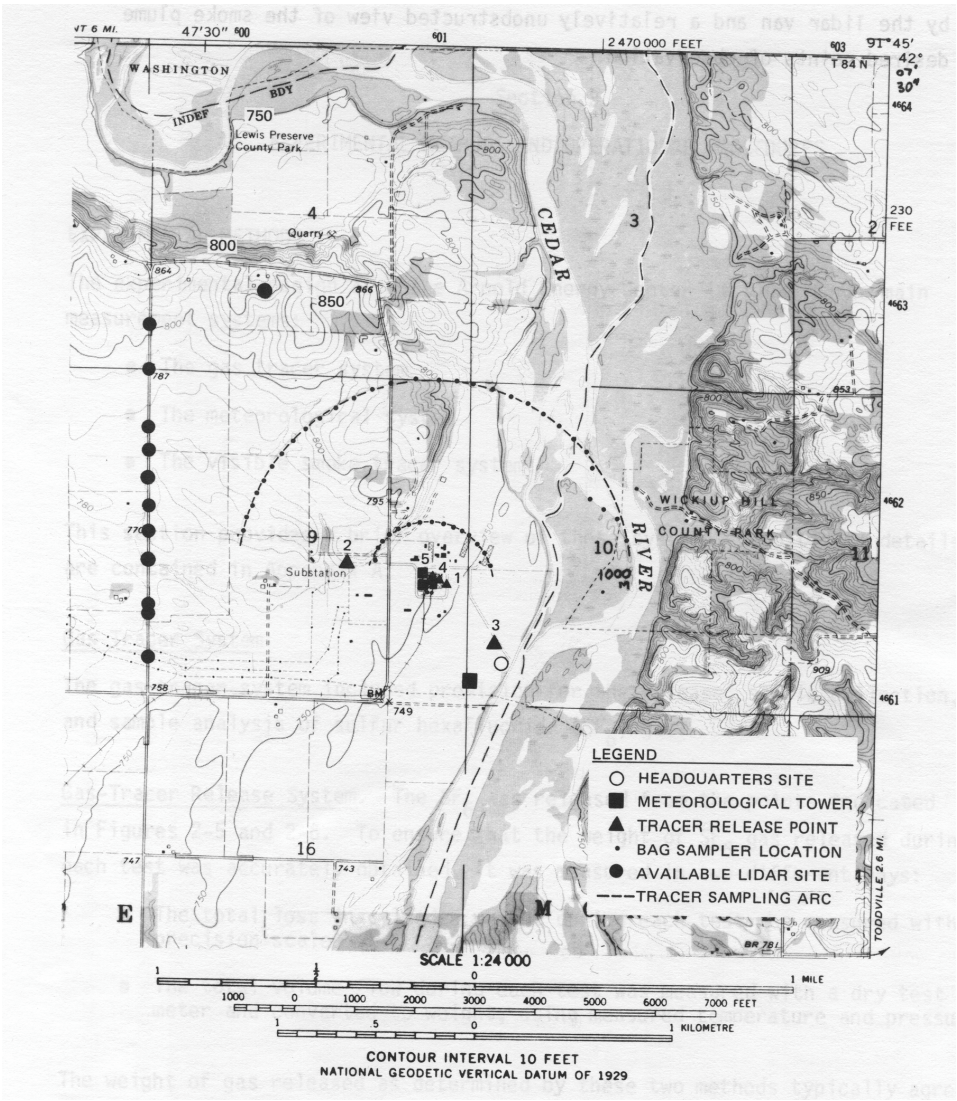
The Millstone nuclear power plant is located on the Connecticut coast, near Niantic. The model evaluation database[34] features 36 hours of SF_6 emissions from a 48-m reactor stack and 26 hours of Freon emissions from a 29-m turbine stack. Exit temperatures were close to ambient (about 295K) with exit velocities of about 10 m/s for both the reactor stack (48.3 m) and the three turbine stacks (29.1 m). These stacks were associated with 45-m and 28-m building tiers, respectively. The monitoring data consisted of three arcs at 350, 800 and 1,500 m. Meteorological data were available from an on-site tower at the 10-m and 43-m levels. There was about an even split between stable and unstable hours, with mostly on-shore winds and fairly high wind speeds. There were only 3 stable hours with wind speed less than 4 m/s, and the majority were above about 7 m/s and several above 10 m/s. Figure 2 shows the layout of the study area.

Figure 2. Millstone Study Area (SF_6 and Freon Releases)



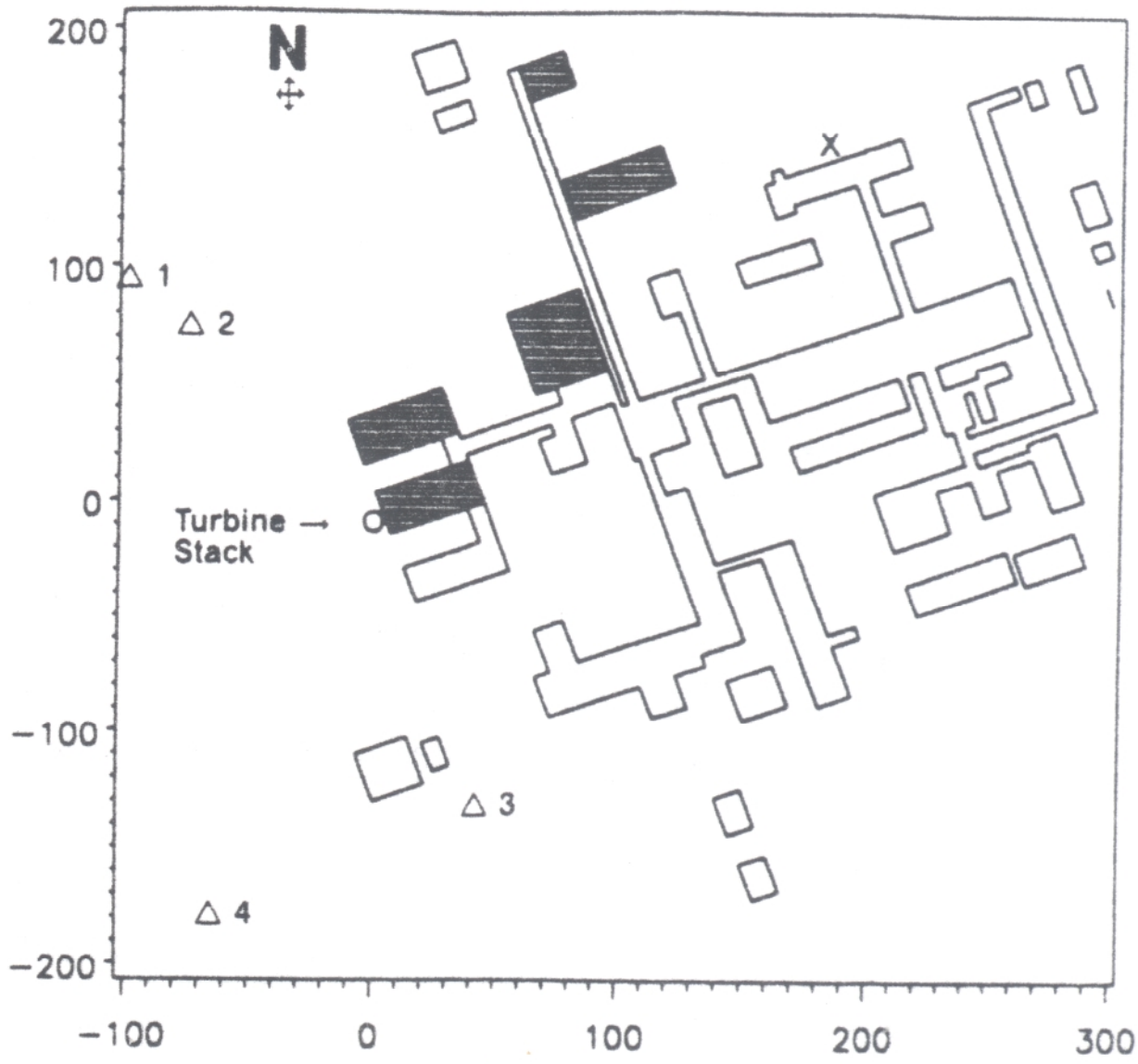
The Duane Arnold Energy Center (DAEC) is located in rural Iowa, located about 16 km northwest of Cedar Rapids. It is located in a river valley with some bluffs on the east side. Terrain varies by about 30 m across the receptor network with the eastern half of the semicircular receptor arcs being flat and the western half elevated. The tracer study[35] involved SF_6 releases from two rooftops (46-m and 24-m levels) and the ground (1-m level). Building tiers for the rooftop releases were 43 and 24 m high, respectively. The 1-m and 24-m releases were non-buoyant, non-momentum, while the 46-m release was close to ambient, but had about a 10 m/s exit velocity. The number of tracer release hours was 12, 16 and 11 from the release heights of 46 m, 24 m, and 1 m, respectively. There were two arcs of monitors at downwind distances of 300 and 1000 m (see Figure 3). Meteorological data consisted of winds at 10, 24, and 50 m. The meteorological conditions were mostly convective (30 out of 39 hours), with fairly light wind speeds. Only one hour had a wind speed above 4 m/s (4.6) , and almost half of the hours were less than 2 m/s.

Figure 3. DAEC Study Area (SF_6 Releases)



The Alaska North Slope tracer study[36,37] (see Figure 4) involved 44 hours of buoyant SF_6 releases from a 39-m high turbine stack. Tracer sampler coverage ranged over seven arcs from 50 to 3,000 m downwind. Meteorological data, including wind speed, wind direction, temperature, sigma-theta, and sigma-w, were available from an on-site tower at the 33-m level. Atmospheric stability and wind speed profiles were influenced by the smooth snow-covered tundra surface with negligible levels of solar radiation in the autumn months. All experiments (44 usable hours) were conducted during the abbreviated day light hours (0900 – 1600). Wind speeds taken at the 33-m level during the tests were less than 6 m/s during one and part of another test, between 6 and 15 m/s during four tests, and in excess of 15 m/s during three tests. Stability conditions were generally neutral or slightly stable.

Figure 4. Depiction of Alaska North Slope Oil Gathering Center Turbine Stack, Meteorological Tower (X), and Camera Locations Used to Visualize Plume Rise[43]

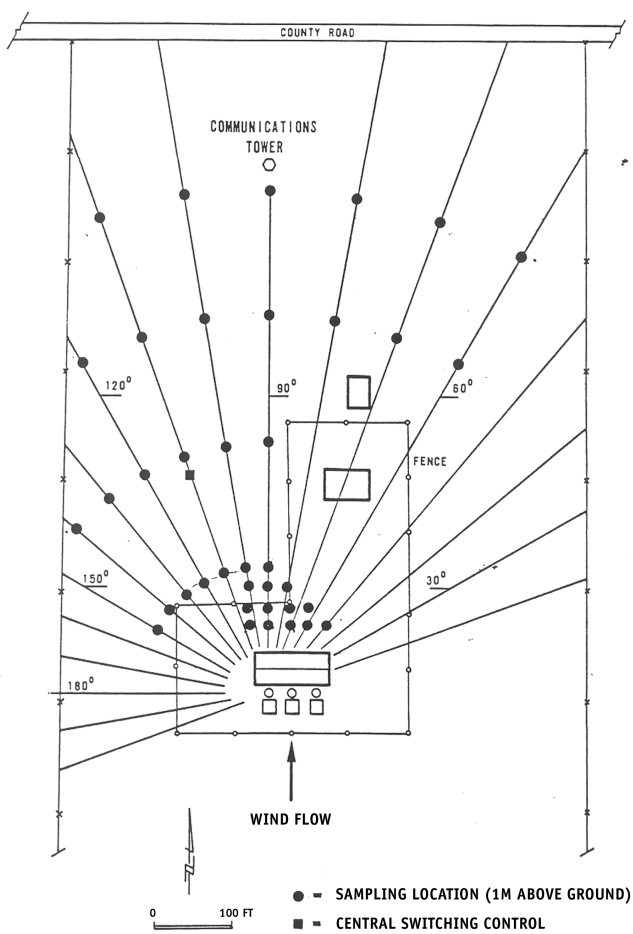


Independent Evaluation (Downwash)

Besides the full year of Bowline Point data (described above), the independent building downwash evaluation databases consist of the American Gas Association (AGA) tracer experiments, the Experimental Organic Cooled Reactor (EOCR) study, and the Lee Power Plant wind tunnel study. Previous model evaluation results for these databases have been reported by Paine and Lew[38].

The AGA experiments[39] occurred during spring and summer 1980 at gas compressor stations in Texas and Kansas. At each test facility, one of the gas compressor stacks was retrofitted to accommodate SF_6 tracer gas emissions. In addition, stack height extensions were provided for some of the experiments (with the normal stack height close to 10 m). The stack height to building height ratios for the tests ranged from 0.95 to 2.52. There were a total of 63 tracer releases over the course of the tests, and the tracer samplers were located between 50 and 200 m away from the release point (see Figure 5). An instrumented 10-m tower was operated at both experimental sites. The tracer releases were generally restricted to daytime hours. Stability classes range from neutral to extremely unstable, except for three hours that were slightly stable. Wind speeds range from 2 to 11 m/s over the 63 hours.

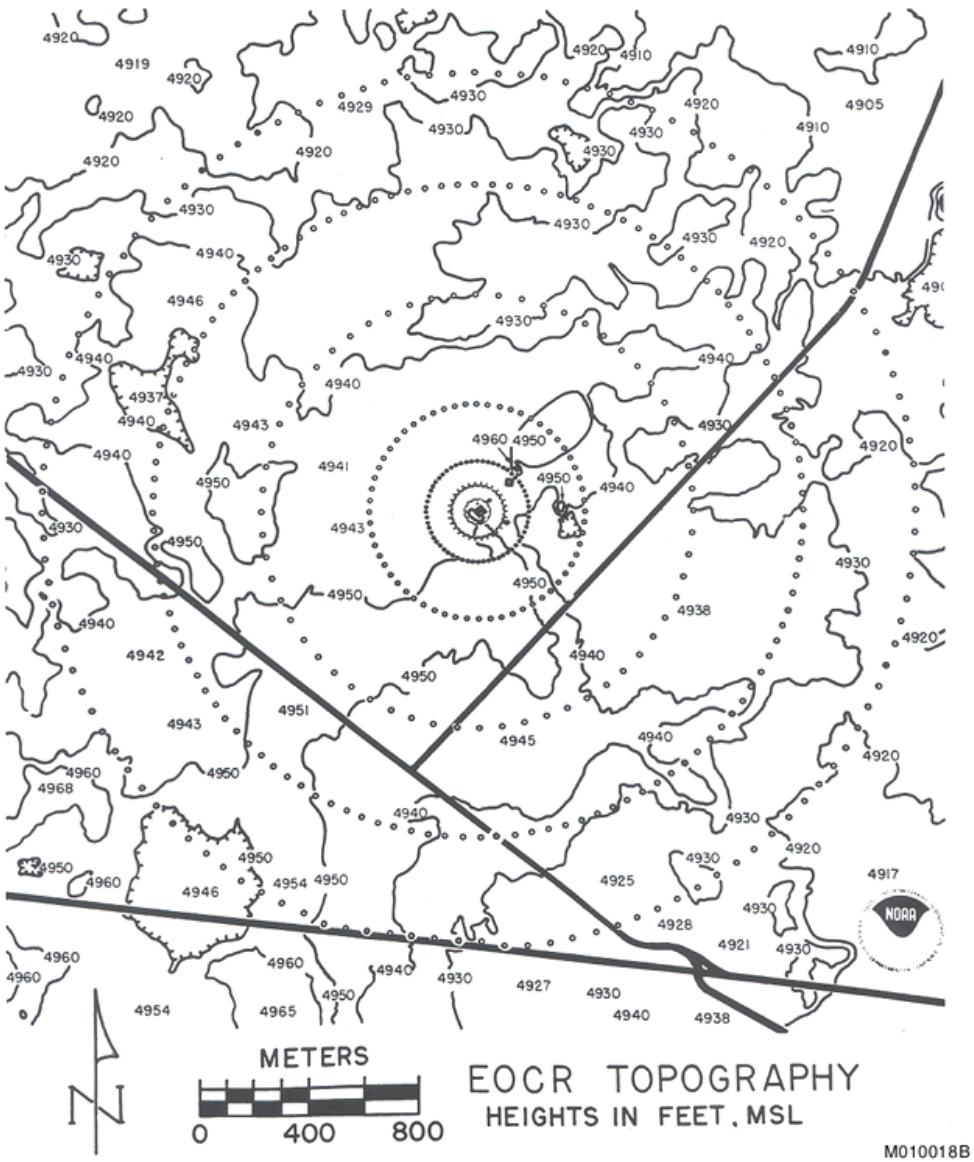
Figure 5. Plan View of the Locations of Tracer Samplers at Site 1, AGA Field Study (SF_6 Releases)



The EOCR study[40] involved the simultaneous release of three tracer gases (SF_6, F_{12}, and Freon-$12B_2$) at three levels around the Experimental Organically Cooled Reactor (EOCR) test reactor building at the Idaho National Engineering Laboratory in Southeast Idaho. The terrain was flat with low-lying shrubs. The main building was 25 m high with an effective width of 25 m. The tracer releases typically occurred simultaneously, and were conducted during 22 separate time periods. Tracer sampler coverage was provided at eight concentric rings at distances of about 50, 100, 200, 400, 800, 1200, and 1600 m from the release points (see Figure 6). The stability classes ranged from stable to unstable. The 10-m wind speeds for the cases selected ranged from 3 to 8 m/s.

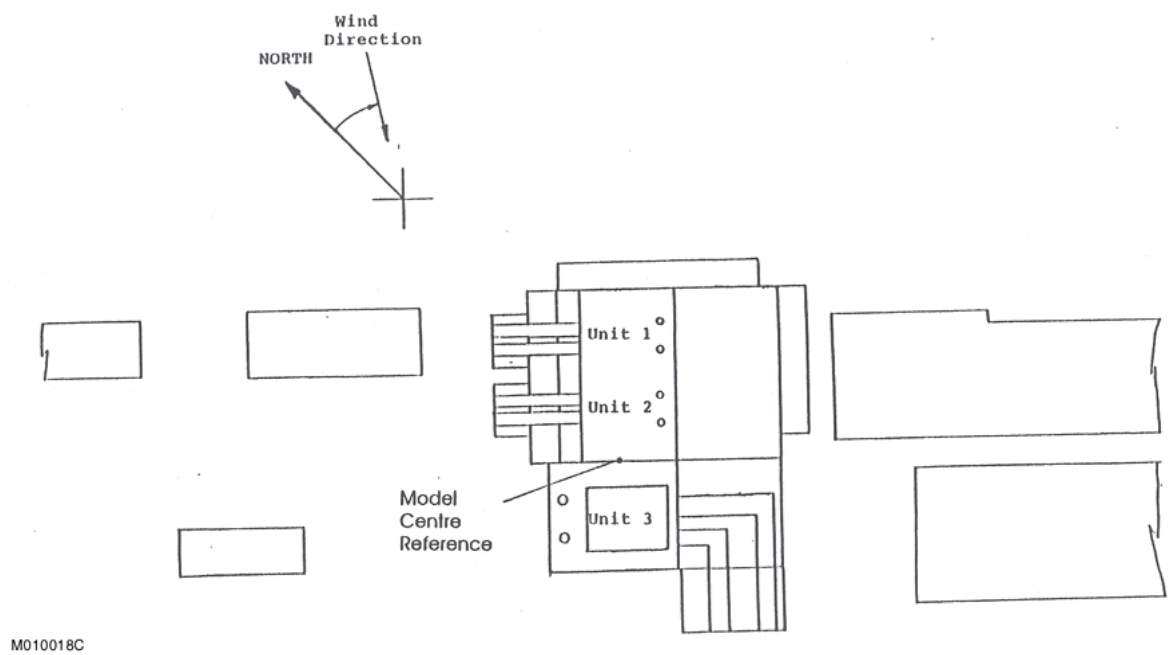
Figure 6. Terrain Map Featuring the Entire EOCR Grid with the Source at the Grid Center (SF_6 Releases).

Arcs are at distances of about 40, 80, 200, 400, 800, 1200, and 1600 m.



The Lee Power Plant wind tunnel study[41] featured releases from steam boiler stacks with a common height of 64.8 m, affected by a building tier with a height of 42.6 m. The world's largest fluid modeling study chamber at Monash University in Australia was used for these experiments (see plan view in Figure 7). Stable conditions were simulated by using an inverted model of the facility that was suspended from the ceiling of the tunnel. A stably stratified layer was developed along the tunnel by heating the inflowing air, and a buoyant plume was simulated by using a negatively buoyant gas mixture. A stable potential temperature lapse rate of 0.035 deK/m was modeled with a stack-top real-world equivalent wind speed of 7 m/s with several wind directions being tested. In neutral conditions, stack-top speeds (at the 64.8-m level) ranged in real-world equivalents from 5 to 40 m/s. There were 78 combinations of wind direction, wind speed, and plume buoyancy tested for the neutral cases, and 14 combinations for the stable cases. The tracer sampler coverage included ground-level concentrations at six distances ranging from the cavity zone to beyond the wake (150-900 m). Since the actual Lee Power Plant area is rural, the models were run with a rural source characterization. The EPRI model evaluation[38] considered both urban and rural source representations because of the enhanced turbulence levels present in the wind tunnel. Consistent with the EPRI model evaluation, the wind tunnel observations were adjusted from an assumed 5-minute duration to a full hour using a time-dependent 1/5 power law[42].

Figure 7. Plan View of the Lee Power Plant Model and Nearby Buildings Showing the Power Station Units and the Zero Reference Position Used in the Monash Wind Tunnel Tests



Evaluation Results

A summary of the robust highest concentration prediction results for the downwash databases is given in Table 3. Summaries of the results for each downwash database are provided below.

Table 3. Summary of AERMOD evaluation Results – downwash databases.

Database	**Ratio of Modeled/Observed Robust Highest Concentrations***
Bowline Point (buoyant, SO_2) Hudson River Valley, New York	AERMOD: 1.14 (3-hr avg) ISC-PRIME: 1.23 (3-hr avg) AERMOD: 1.43 (24-hr avg) ISC-PRIME: 1.42 (24-hr avg) AERMOD: 1.50 (annual avg) ISC-PRIME: 1.35 (annual avg)
Alaska North Slope (buoyant, SF_6)	AERMOD: 1.06 (1-hr avg) ISC-PRIME: 1.49 (1-hr avg)
Duane Arnold Energy Center (nonbuoyant, SF_6) (Iowa)	AERMOD: 0.69 (1-hr avg; 46-m release) ISC-PRIME: 0.76 (1-hr avg; 46-m release) AERMOD: 0.25 (1-hr avg; 24-m release) ISC-PRIME: 0.29 (1-hr avg; 24-m release) AERMOD: 0.51 (1-hr avg; 1-m release) ISC-PRIME: 0.38 (1-hr avg; 1-m release)
Millstone Nuclear Power Plant (nonbuoyant, SF_6) (Connecticut)	AERMOD: 0.44 (1-hr avg; 46-m release) ISC-PRIME: 0.41 (1-hr avg; 46-m release) AERMOD: 1.32 (1-hr avg; 29-m release) ISC-PRIME: 1.42 (1-hr avg; 29-m release)
American Gas Association (buoyant, SF_6) Texas and Kansas)	AERMOD: 0.92 (1-hr avg) ISC-PRIME: 0.76 (1-hr avg)
Experimental Organic Cooling Reactor (nonbuoyant, SF_6) (Idaho)	AERMOD: 1.72 (1-hr avg) ISC-PRIME: 1.69 (1-hr avg)
Lee Power Plant (buoyant, wind tunnel)	AERMOD: 0.51 (1-hr avg; neutral cases; rural) ISC-PRIME: 0.49 (1-hr avg; neutral cases; rural) AERMOD: 2.50 (1-hr avg; stable cases; rural) ISC-PRIME: 2.11 (1-hr avg; stable cases; rural)

AERMOD and ISC-PRIME had a similar evaluation outcome for the full-year Bowline Point database, featuring buoyant steam electric plant releases, with no significant differences in model performance. The 3-hour Q-Q plot is shown in Figure 8, and the 24-hour Q-Q plot is shown in Figure 9. For each averaging time, both models exhibit a modest overprediction tendency.

Figure 8. Q-Q Plot for Bowline Point 3-Hour Averages (SO_2)

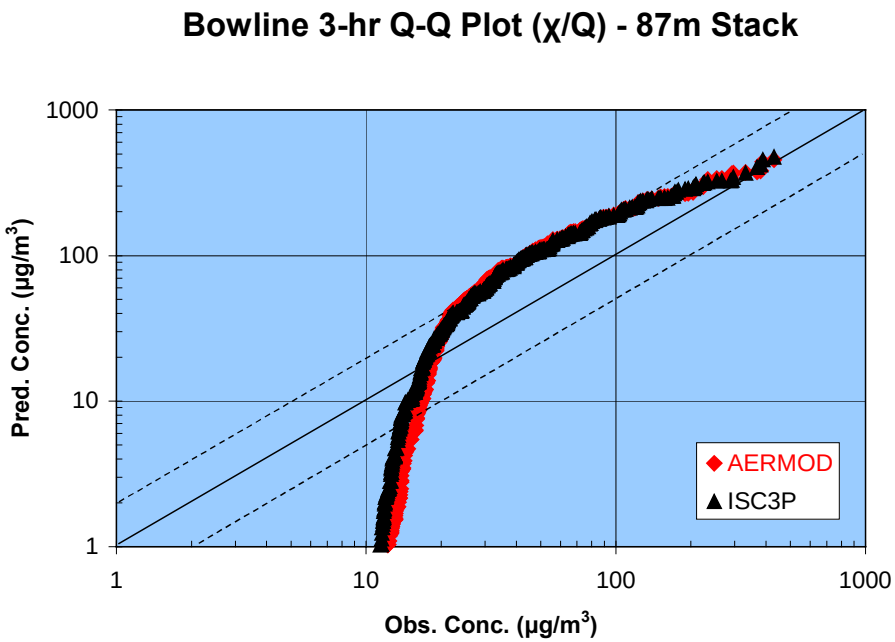
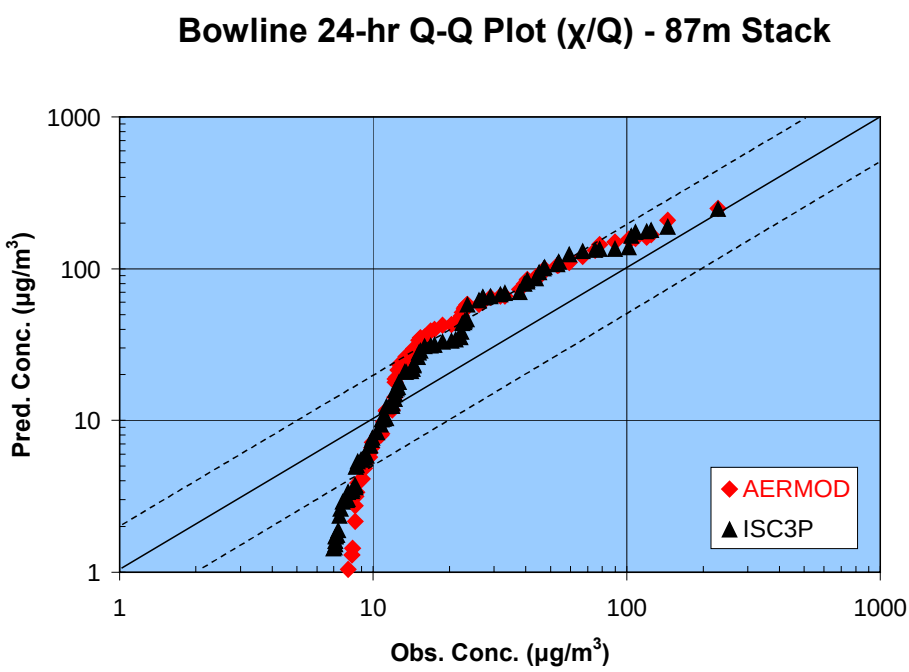


Figure 9. Q-Q Plot for Bowline Point 24-Hour Averages (SO_2)



Both models also had a similar evaluation outcome for two non-buoyant release heights (with two different tracer gases) at the Millstone Nuclear Power Plant. Figure 10 shows that both models overpredict by close to a factor of 2 for the 29-m Freon releases, but underpredict by about a factor of 2 for the 46-m SF_6 releases (see Figure 11).

Figure 10. Q-Q Plot for Millstone 1-Hour Averages for 29-m Releases (Freon)

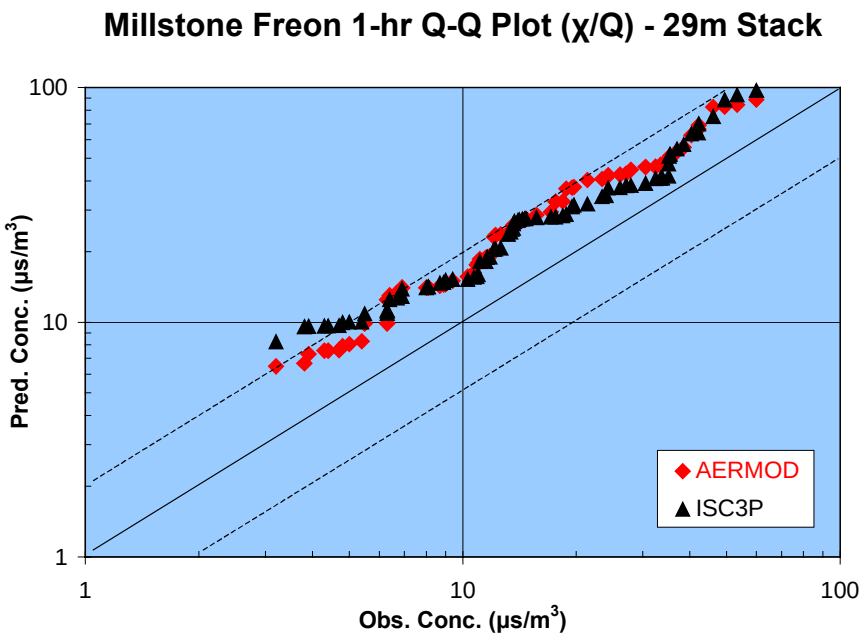
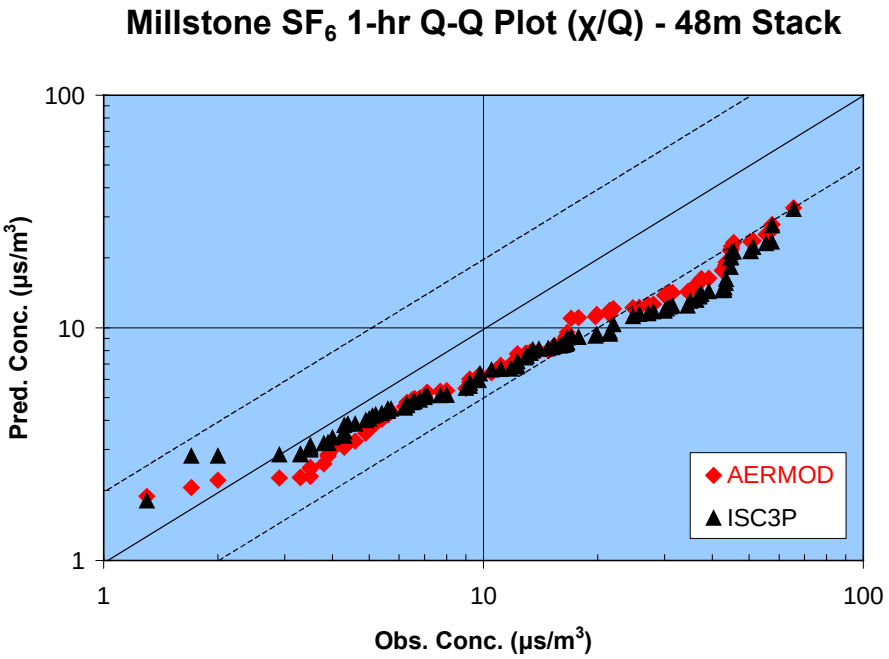


Figure 11. Q-Q Plot for Millstone 1-Hour Averages for 46-m Releases (SF_6)



The Duane Arnold Energy Center also featured similar evaluation outcomes for AERMOD and ISC-PRIME for the non-buoyant releases. Figure 12 shows a 1-m release Q-Q plot, in which both models generally underpredict, but AERMOD has less of an underprediction tendency. Both models underpredict for the 24-m releases (see Q-Q plot in Figure 13), with AERMOD showing a larger underprediction tendency except for the highest concentrations. The Q-Q plot in Figure 14 shows both models with peak concentrations that are nearly unbiased for the 46-m releases.

Figure 12. Q-Qt for DAEC 1-Hour Averages for 1-m Releases (SF_6)

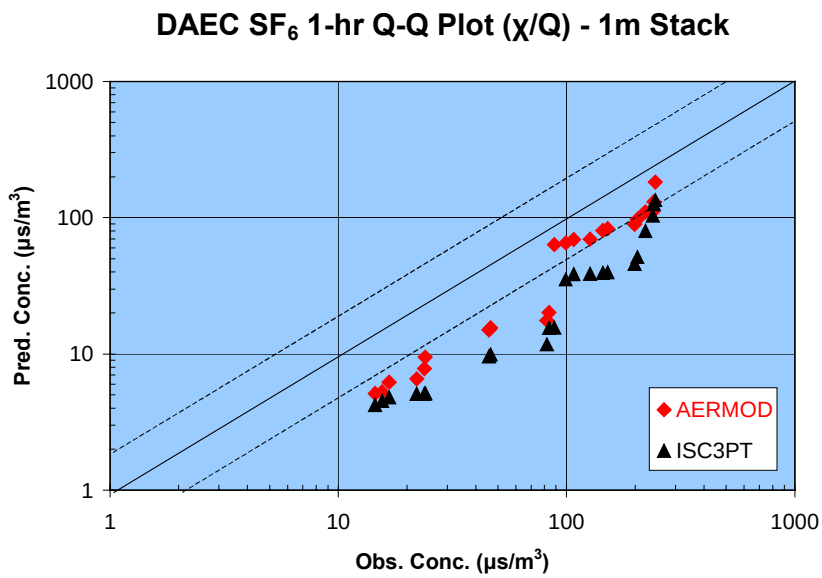


Figure 13. Q-Q Plot for DAEC 1-Hour Averages for 24-m Releases (SF_6)

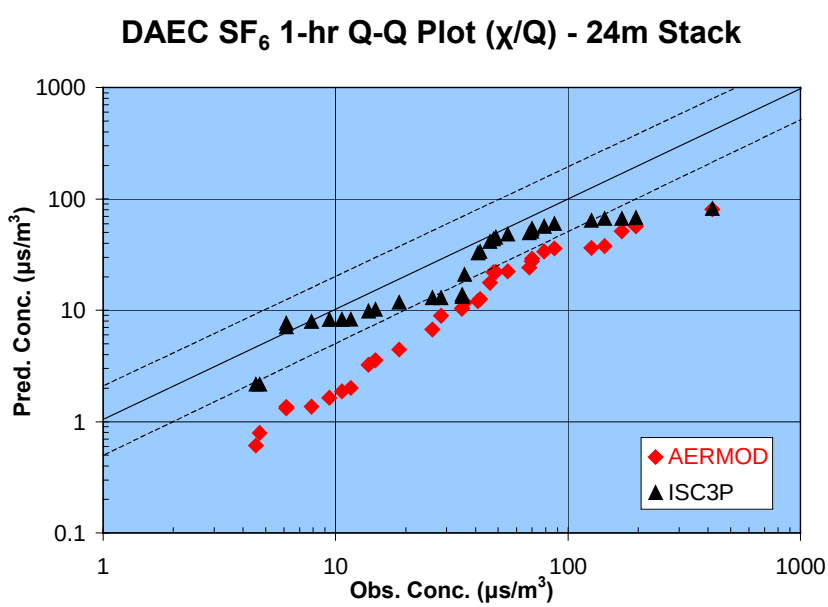
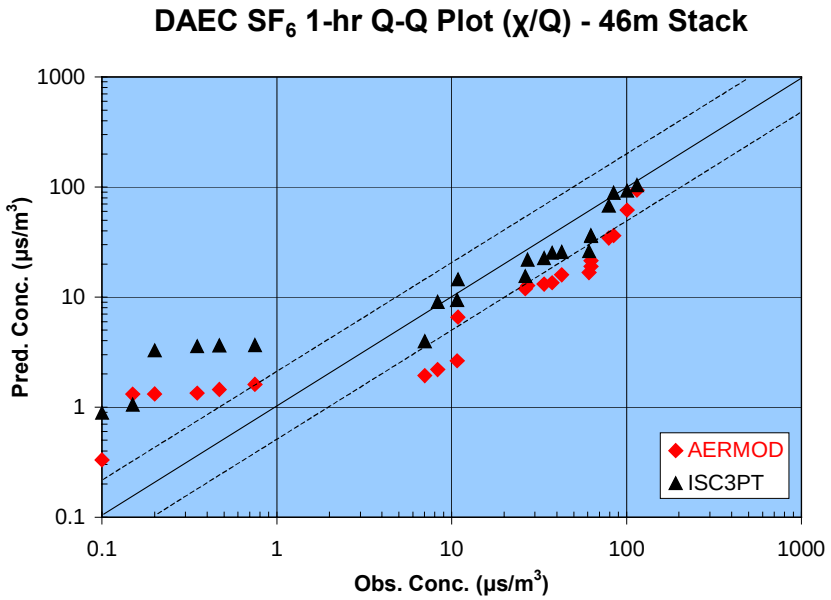
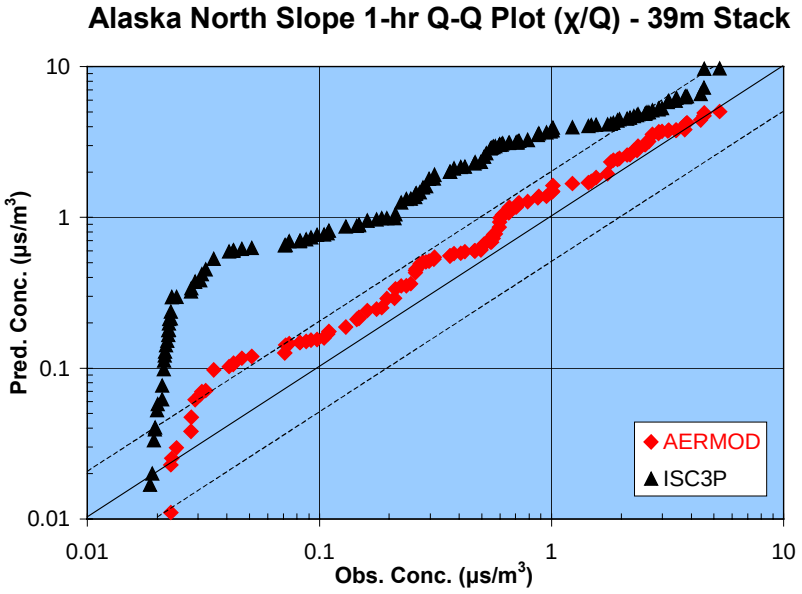


Figure 14. Q-Q Plot for DAEC 1-Hour Averages for 46-m Releases (SF_6)



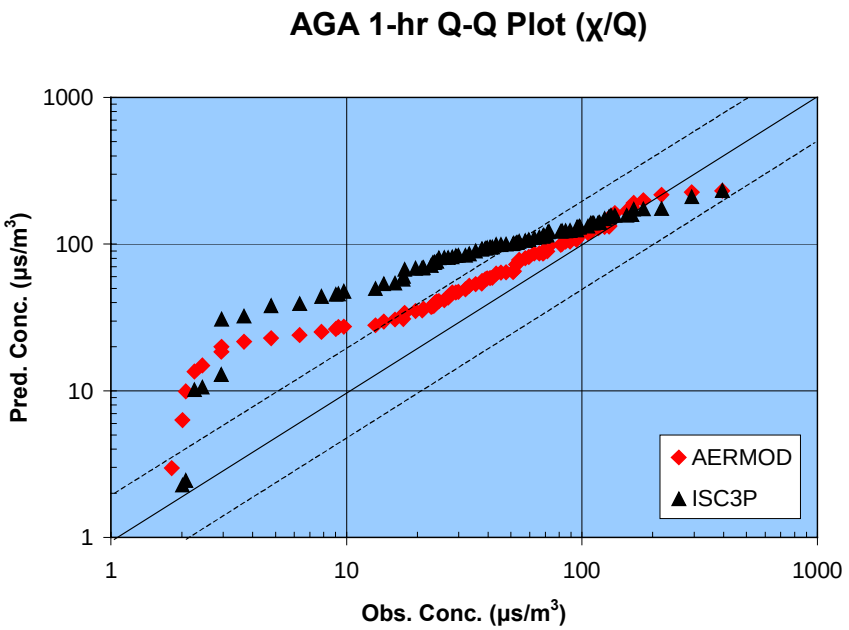
The modeling results for the buoyant releases at the Alaska North Slope experimental site are shown as a Q-Q plot in Figure 15. The AERMOD predictions are nearly unbiased (but slightly conservative), while the ISC-PRIME results are more than a factor of 2 high except for the highest predictions. This result shows some of the biggest performance differences between AERMOD and ISC-PRIME among all seven downwash evaluation databases.

Figure 15. Q-Q Plot for Alaska North Slope 1-Hour Averages for 39-m Releases (SF_6)



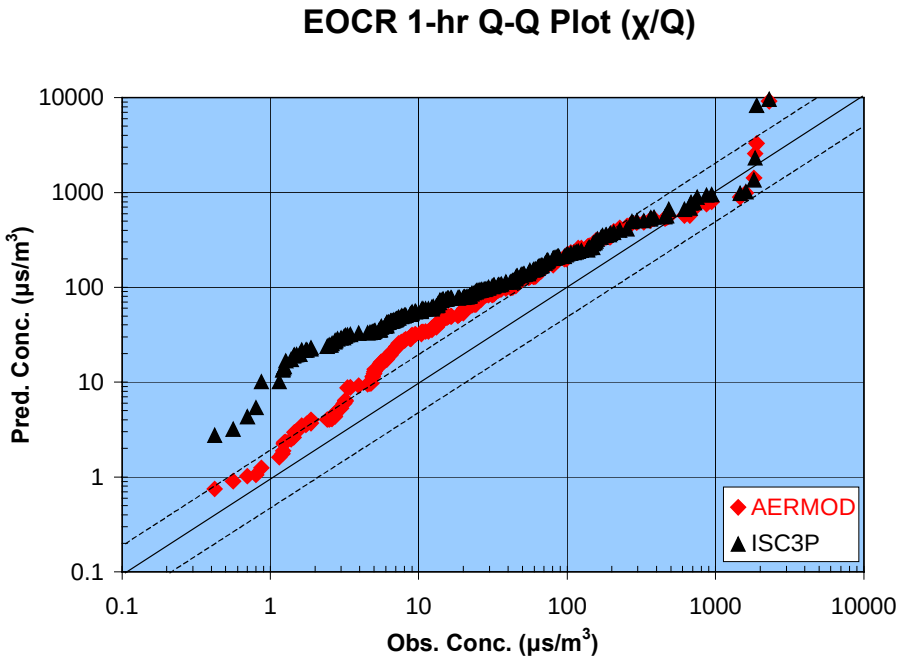
The Q-Q plot for the AGA experiments is shown in Figure 16. This plot shows that the AERMOD predictions parallel the 1:1 line over a larger concentration domain than the ISC-PRIME predictions. For subsets of the modeling cases, AERMOD shows a significant improvement especially for the cases involving stack-to-building height ratios greater than 1.25. Residual plots of prediction concentrations as a function of stability indicate consistently less biased AERMOD results over all stability types.

Figure 16. Q-Q Plot for AGA 1-Hour Averages (SF_6)



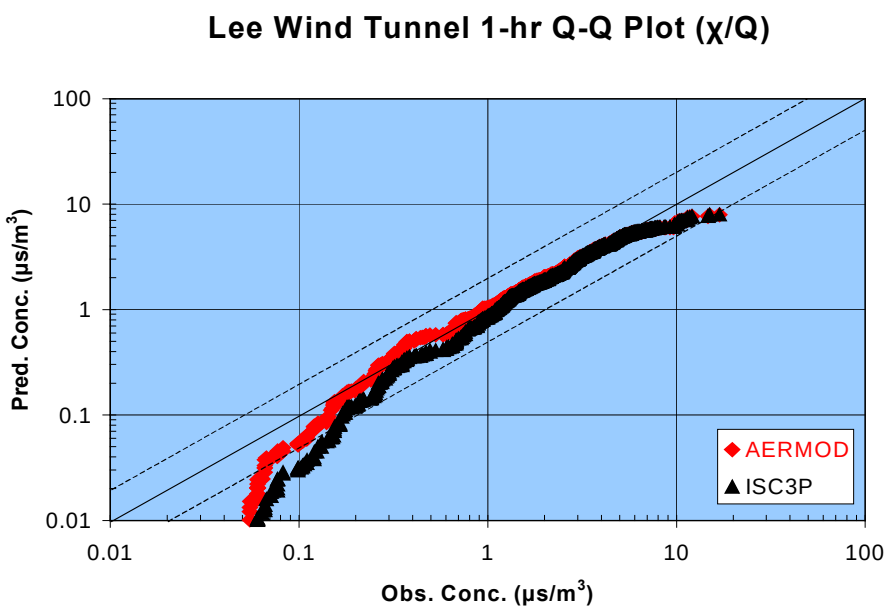
The Q-Q plot for the EOCR experiments is shown in Figure 17. Although the AERMOD predictions parallel the 1:1 line over a larger portion of the concentration domain, the two curves are nearly identical for the peak concentrations.

Figure 17. Q-Q Plot for EOCR 1-Hour Averages (SF_6)



The combined stable and neutral case Q-Q plot for the Lee power plant wind tunnel experiments is shown in Figure 18. This figure shows underpredictions for the peak concentrations, in contrast to the EPRI evaluation results[38] with urban source characterization.

Figure 18. Q-Q Plot for Lee Wind Tunnel Data



The overall model evaluation results for AERMOD version 02222 and ISC-PRIME with downwashing databases can be summarized as follows, taking one composite (geometric mean) ratio of predicted to observed RHC value for short-term averages at each site:

- 0.97 is the overall predicted-to-observed ratio for short-term averages using AERMOD.
- 0.94 is the overall predicted-to-observed ratio for short-term averages using ISC-PRIME.

CONCLUSIONS

Several enhancements to AERMOD have been made as a result of the public comments received by EPA after the Notice of Proposed Rulemaking was issued on April 21, 2000. The most notable change to AERMOD was the incorporation of the PRIME downwash algorithm. Other model changes address complex terrain implementation issues, urban dispersion issues, NADCON coordinate conversions, use of site-specific delta-T and wind speed data instead of cloud cover, issues regarding terrain below stack base, ISCST3 updates, and various other responses to beta test comments. The resulting beta test version is referred to as version 02222.

This AERMOD version has been re-run for the 10 non-downwash evaluation databases, with minor differences in the results from those previously reported. The overall short-term ratio of AERMOD version 02222 predicted/observed RHC concentrations is 1.03, averaged over the non-downwash databases, with improvements over the ISCST3 results, especially for complex terrain situations.

Seven downwash databases, divided into developmental and independent evaluation phases, were used for the AERMOD evaluation. Comparisons with ISC-PRIME performance indicate similar results for most databases, with occasional notable improvements, such as for the Alaska North Slope database. The overall short-term ratio of AERMOD version 02222 predicted/ observed RHC concentrations is 0.97 averaged over the downwash databases. These results were comparable in performance to those of ISC-PRIME, as expected.

DISCLAIMER

This paper has not yet been reviewed in accordance with the United States Environmental Protection Agency's peer review and administrative review policies for approval for presentation and publication. It does not necessarily reflect the views of the EPA. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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KEYWORDS

AERMOD

ISCST3

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Model Evaluation

PRIME

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