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Using Prognostic Model-Generated Meteorological Output in the AERMOD Dispersion Model: An Illustrative Application in Philadelphia, PA

Jawad S. Touma and Vlad Isakov
National Oceanic and Atmospheric Administration/Atmospheric Sciences Modeling Division (in partnership with U.S. Environmental Protection Agency), Research Triangle Park, NC

Alan J. Cimorelli
U.S. Environmental Protection Agency, Region 3, Philadelphia, PA

Roger W. Brode
U.S. Environmental Protection Agency, Research Triangle Park, NC

Bret Anderson
U.S. Environmental Protection Agency, Region 7, Kansas City, MO

ABSTRACT

In this study, we introduce the prospect of using prognostic model-generated meteorological output as input to steady-state dispersion models by identifying possible advantages and disadvantages and by presenting a comparative analysis. Because output from prognostic meteorological models is now routinely available and is used for Eulerian and Lagrangian air quality modeling applications, we explore the possibility of using such data in lieu of traditional National Weather Service (NWS) data for dispersion models. We apply these data in an urban application where comparisons can be made between the two meteorological input data types. Using the U.S. Environment Protection Agency's American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model (AERMOD) air quality dispersion model, hourly and annual average concentrations of benzene are estimated for the Philadelphia, PA, area using both hourly MM5 model-generated meteorological output and meteorological data taken from the NWS site at the Philadelphia International Airport. Our intent is to stimulate a discussion of the relevant issues and inspire future work that examines many of the questions raised in this paper.

IMPLICATIONS

Although this paper demonstrates that it is possible to use meteorology from prognostic models as input into the AERMOD dispersion model, there are many issues that need to be addressed before these data can be used on a routine basis, as a substitute for using representative NWS or on-site data. Specific suggestions for further study are provided.

INTRODUCTION

Meteorological data are key components of air quality dispersion models being used by U.S. Environmental Protection Agency (EPA) and other agencies to assess strategies to reduce the impacts of air pollution on human health and the environment. EPA has recently promulgated a new dispersion model to replace the Industrial Source Complex (ISC) model. This new model, the American Meteorological Society/U.S. EPA Regulatory Model (AERMOD),[1] uses more advanced representations of the planetary boundary layer (PBL). Through the use of similarity scaling theory and a unique approach that allows consideration of the vertical inhomogeneity of the PBL, AERMOD's minimum meteorological requirements remained similar to ISC's, that is, readily available National Weather Service (NWS) data. However, if available, AERMOD is capable of using additional data that will provide a more complete description of the PBL; for example, vertical profiles of wind, temperature, and turbulence.

With the advent of routinely available prognostic meteorological data, the prospect exists for using the additional data provided by such models in AERMOD. Furthermore, the practice of using NWS data presents a number of problems that may be ameliorated through the use of prognostic data. However, in order for this approach to become a reality, many issues related to scientific appropriateness, practical feasibility, and robustness of approach need to be addressed. A few examples of the issues are as follows: (1) which of the prognostic model's physics options should be chosen for local scale applications?; (2) on what scale and grid resolution should the prognostic model be run?; (3) what portion of the large amount of data produced by the prognostic models should be used for input into AERMOD?; and (4) should the prognostic data be input directly into AERMOD or pass through AERMOD's meteorological preprocessor AERMET?[2]

The purpose of this paper is to introduce the prospect of using prognostic meteorological data as input to steady-state dispersion models (specifically, AERMOD) by identifying possible advantages and disadvantages and by presenting a comparative analysis for one application (Philadelphia, PA). It is important to note that the approach used for this analysis, to create meteorological inputs for AERMOD from prognostic data, represents only one option out of a wide range of possibilities. It is the authors' hope that this paper will stimulate a discussion of the relevant issues and inspire future work that examines many of the questions that this paper raises.

CAPABILITIES AND LIMITATIONS OF THE TWO APPROACHES

Although it is clear that prognostic model-generated meteorological output may add capability that would not be possible with single station measurements, it is also clear that the use of prognostic data opens up a new set of both scientific and implementation issues. To rationally decide on both the appropriateness and feasibility of switching from NWS to prognostic model-generated meteorological data, we must first understand the potential capabilities and limitations of each approach.

Despite the longstanding history of using NWS meteorological observations as input for air quality dispersion models, there are issues inherent with the use of such data. Furthermore, with the introduction of AERMOD, several new issues have arisen. A few examples of such issues as they relate to AERMOD are as follows.

First, meteorological data used to drive air quality models are often based on surface observations collected some distance away (10–100 km) from the actual source of emissions, raising concerns regarding the representativeness of the meteorological data for a particular application. Because AERMOD constructs profiles of wind, temperature, and turbulence based on boundary layer scaling concepts, the issue of representativeness must also take into account variations in land use patterns between the meteorological measurement site and the source application site, because variations in surface characteristics (i.e., surface roughness, Bowen ratio, and albedo) associated with these land use patterns may significantly affect model results.

Second, for multisource applications that are spread over a large heterogeneous area (e.g., an urban area), it is often difficult to accept a single point measurement, whether from NWS or on-site data, as representative of the atmospheric flow and turbulence affecting the entire area.

Third, observations at NWS sites are taken at a single height that is generally ~10 m above ground level. The use of a single measurement height represents the extent of the data that can be used in earlier models, such as ISC. However, with the advent of AERMOD, vertical profiles of the important meteorological variables can be used, if available, to better characterize the PBL.

Fourth, NWS wind measurement instruments have relatively high starting thresholds of ~3 knots (~1.5 m/sec). As a result, NWS data can include a large number of hours with wind speeds below the starting threshold, which are classified as calms and assigned a value of zero. Existing dispersion models, including AERMOD, lack the capability of estimating plume transport and dispersion under calm conditions, which effectively eliminates these cases from the impact assessment.

Lastly, AERMOD can directly use atmospheric turbulence measurements as input, if available. Unfortunately, such data are not available from NWS stations.

Although some of these issues can be alleviated by collecting on-site measurements, it is an expensive solution, and for many applications is not practical. However, by using outputs from prognostic meteorological models, such as MM5,[3] it may be possible to resolve many of these issues. Data from these models are becoming more readily available on a national scale, with the prospect in the near future of routinely available multiyear datasets.[4]

There are many possible advantages in using output from prognostic models such as MM5 as input to AERMOD, as described below.

First, these data have an extensive history of use in photochemical grid air quality models, such as the Community Mutli-Scale Air Quality model,[5] and their accuracy has improved over the past decade. Prognostic models are increasingly being used by the National Oceanic and Atmospheric Administration in routine air quality forecast modes, and data from new generation prognostic models are expected to be even better.

Second, prognostic models can provide complete grid-averaged PBL data for any region in the United States at 36- and 12-km grid scale resolutions.

Third, as the modeling community moves toward integrating dispersion models with photochemical grid models (a "one-atmosphere" modeling approach involving combined national-to-local-scale air quality assessments), the meteorological data input will become consistent.[6]

Fourth, prognostic model outputs for light wind conditions are not limited by instrument thresholds associated with NWS measurements. Because AERMOD has been specifically designed to accept wind speeds <1 m/sec (unlike earlier models, such as ISC), there is a potential for prognostic model data to improve the ability of the AERMOD model to estimate concentrations under such conditions.

Lastly, profiles of wind and temperature, which can be used by AERMOD, are available directly from these models. In the future, additional outputs from prognostic models, such as turbulent kinetic energy, may be used to construct turbulence profiles for use in AERMOD.

Several challenges, however, remain. For example, prognostic model outputs are provided at the grid cell level (typically 36 km but can be nested to a 12- and a 4-km grid resolution) and represent conditions over an entire grid-cell volume. Dispersion models, such as AERMOD, require data to accurately represent local meteorological conditions, such as wind speed and direction, and boundary layer turbulence, which influence transport and dispersion near emission sources. It is not clear at this time how well the spatially smoothed outputs from the prognostic models will represent transport and dispersion, especially if the important source-receptor distances are subgrid scale.

OVERVIEW OF THE AERMOD MODEL

In 1991, the American Meteorological Society and EPA initiated a formal collaboration to develop a state-of-the-science dispersion model that reflected advances in PBL meteorology and science. This joint effort resulted in the development of AERMOD, a steady-state plume dispersion model for air quality assessments of inert pollutants that are directly emitted from a variety of sources.[7–9] Based on an advanced characterization of the atmospheric boundary layer turbulence structure and scaling concepts, AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including point, area, or volume sources). The model uses hourly sequential preprocessed meteorological data to estimate concentrations at receptor locations for averaging times from 1 hr to multiple years. AERMOD incorporates both dry and wet particle and gaseous deposition, as well as source or plume depletion. Through final rulemaking (effective December 9, 2005), the agency established AERMOD as the preferred air dispersion model in its "Guideline on Air Quality Models" (http://www.epa.gov/ttn/scram).

Figure 1 shows the flow and processing of the complete AERMOD modeling system, which consists of the AERMOD dispersion model and two input data preprocessors: the AERMOD meteorological preprocessor (AERMET) and AERMOD mapping program (AERMAP). AERMET is a stand-alone program that uses meteorological information and surface characteristics to calculate the boundary layer parameters for use by AERMOD to construct similarity profiles. In addition, AERMET passes all of the meteorological observations, including any measured profiles of wind, temperature, and turbulence, to AERMOD. AERMAP[10] is a stand-alone terrain preprocessor that calculates terrain and critical hill height values for each receptor for input into AERMOD.

AERMOD is a steady-state plume dispersion model in that it assumes that concentrations at all distances during a modeled hour are governed by the set of hourly meteorology inputs,[7,8] which are held constant. Using available meteorological data and similarity theory scaling relationships, AERMOD constructs hourly gridded vertical profiles of required meteorological variables, including wind speed, wind direction, potential temperature, and vertical and horizontal turbulence, which are used by the model to calculate plume rise, as well as transport and dispersion of each plume. This more refined treatment of the vertical structure of the PBL in AERMOD represents one of the significant scientific improvements in the model relative to the simpler treatment in ISC, which assumed uniform vertical profiles for all of the meteorological variables except wind speed. The minimum meteorological data requirements for AERMOD are commensurate with requirements for the ISC model and can be met through routine NWS meteorological data. For applications of AERMOD involving on-site meteorological data, vertical profiles of wind speed, wind direction, turbulence, and temperature are calculated within AERMOD using all of the available meteorological observations, with interpolations and extrapolations of those measurements to complete the gridded vertical profiles based on similarity scaling.

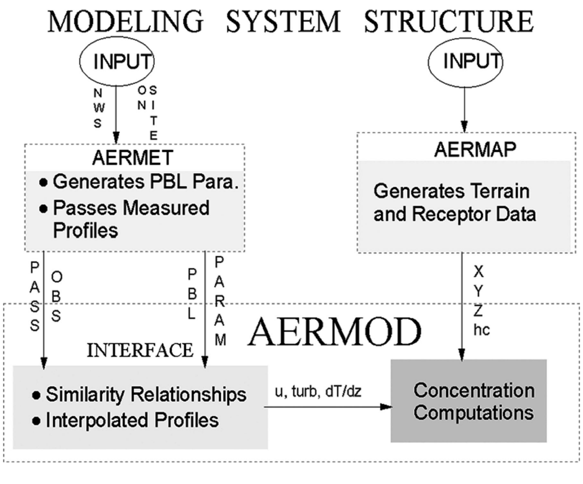

Figure 1. AERMOD modeling system structure.

COMPARISON OF AERMOD PREDICTIONS BASED ON NWS VERSUS MM5

Case Study Description and Methodology

This comparison of AERMOD predictions uses information developed as part of a much larger Philadelphia Air Toxics Project effort between EPA Region 3 and the City of Philadelphia. The modeling domain used in this comparison is an area of ~40 km by 40 km that includes several thousand sources emitting benzene mostly at ground level, such as roadways. Hourly and annual average concentrations were calculated for ~1400 receptors at census tracts in Philadelphia and surrounding counties. Benzene was chosen for these comparisons because it has a low reactivity and is, thus, appropriate for use in AERMOD. Terrain in the modeling domain was assumed flat for the purposes of this comparison.

In this study, we applied AERMOD using two types of meteorological inputs: derived from NWS observations and extracted from MM5 simulations. In the first case, we used hourly observations from the Philadelphia International Airport and upper air soundings from Sterling, VA (Dulles International Airport), for 2001. In the second case, we used output from an existing national scale annual MM5 simulation for 2001 for the 12-km by 12-km grid cell encompassing the Philadelphia airport.

The MM5 is a limited-area, nonhydrostatic, terrain-following modeling system that solves for the full set of physical and thermodynamic equations, which govern atmospheric motions.[3] A complete description of the configuration and evaluation of the 2001 meteorological modeling is contained in McNally[11]; however, some of the key configuration settings are as follows: model version, 3.6.3; grid resolution, 12-km grid, nested within a larger 36-km grid; vertical layers, 34 with a surface layer of ~38 m; Kain-Fritsch 2 cumulus parameterization; Pleim-Chang PBL scheme; Reisner 2 explicit moisture scheme; rapid radiative transfer model (RRTM) long-wave radiation scheme; Pleim-Xiu land surface model; and four-dimensional data assimilation analysis nudging. The synoptic-scale data used for this initialization are obtained from conventional NWS rawinsondes, NWS surface observations, and the National Center for Atmospheric Research Eta archives. This is a well-accepted configuration

Table 1. Meteorological variables (surface file).

AERMOD Inputs	Comments
Year	
Month	
Day	
Julian Day	
Hour	
Sensible heat flux (W m^{-2})	Not used by AERMOD^{a}–provided for reference purposes only (QA and interpretation)
Surface friction velocity, u* (m sec^{-1})	Used to generate profiles of wind and mechanical turbulence; also related to mechanical mixing height
Convective velocity scale, w* (m sec^{-1})	Used to generate profiles of convective turbulence; also related to convective mixing height
Lapse rate 500 m above PBL height	Used to calculate fraction of plume penetrating through mixing height and height of penetrated plume
Convective mixing height, Zic (m)	Used in scaling of convective turbulence with height^{b}
Mechanical mixing height, Zim (m)	Used in scaling of mechanical turbulence with height^{b}
Monin-Obukhov length, L (m)	Used in scaling of wind speed and temperature with height; sign of L is used to determine whether stable or convective algorithms are used
Surface roughness length, z_o (m)	Used by AERMOD to construct theoretical vertical wind speed profile; used in the adjustment of u* to reflect urban effects (minor influence); used to set the deposition reference height and in calculating atmospheric resistance term for deposition calculations
Daytime Bowen ratio	Not used by AERMOD^{a}–provided for reference purposes only (QA and interpretation)
Noon time albedo	Not used by AERMOD^{a}–provided for reference purposes only (QA and interpretation)
Reference wind speed (m sec^{-1})	Used to construct wind speed profile
Reference wind direction	Used to construct wind direction profile
Height of reference wind (m) (anemometer height)	Used to construct wind speed profile; normally lowest valid measurement height above $7*z_o$
Reference ambient temperature (K)	Used to construct vertical profiles of temperature and potential temperature
Height of reference temperature (m)	Nominally 2 m for airports
Precipitation code	Used by AERMOD for deposition applications only
Precipitation amount (mm/hr)	Used by AERMOD for deposition applications only
Relative humidity (%)	Used by AERMOD for deposition applications only
Surface pressure (mb)	Used by AERMOD for deposition applications only
Cloud cover (tenths)	Used by AERMOD for deposition applications only

Notes: [a] Sensible heat flux, Bowen ratio, and albedo have a very limited influence for gas deposition applications through the calculation of the solar irradiance; [b] Larger of convective and mechanical mixing heights is used to define the height of the ″reflecting surface″ during convective hours.

of MM5 setup. No analysis was done to modify these selections to see how they might impact the AERMOD comparisons.

There are several ways to provide meteorological input data to AERMOD. Our objective for this paper was to illustrate the possibility of using meteorological modeled data as direct input to AERMOD. Therefore, we used hourly meteorological data and parameters from MM5, with appropriate adjustments and intermediate processing, in the form of surface and profile files formatted for input directly to the AERMOD model (i.e., bypassing AERMET). Other options are available and are discussed later (see Discussion section). As shown in Table 1, the surface input file for AERMOD contains basic meteorological variables representative of the surface layer, including wind speed, wind direction, and temperature. Several boundary layer scaling parameters are also included. Precipitation amount and type, relative humidity, surface pressure, and cloud cover are used in dry and wet deposition applications. Normally, AERMOD uses wind speeds and directions from a reference height of ~10 m, but MM5 uses a different vertical coordinate system, and winds at 10-m height are not typically available. MM5 output can include 10-m winds, when run with a better vertical resolution, or if certain boundary layer schemes are used. In this study, the reference winds extracted from the MM5 data were from the first model layer, 38 m, and were assigned a height of 19 m.

Similarly, Table 2 lists the variables needed for AERMOD's profile file with the corresponding MM5-derived input. The standard deviation of the horizontal wind direction and vertical wind speed fluctuations are optional. If available, they can be used to directly estimate the lateral

Table 2. Meteorological variables (upper air file).

AERMOD Inputs	Comments
Year	Extracted year from date variable
Month	Extracted year from date variable
Day	Extracted year from date variable
Hour	Extracted year from date variable
Height (m)	Measurement height
Height flag	Flag = 1 for top measurement level
Wind direction	Used by AERMOD in constructing vertical profile^{a}
Wind speed (m sec^{-1})	Used by AERMOD in constructing vertical profile^{a}
Ambient temperature (C)	Used by AERMOD in constructing vertical profile^{a}
σ_θ (deg)	Used by AERMOD in constructing vertical profile^{a}
σ_w (m sec^{-1})	Used by AERMOD in constructing vertical profile^{a}

Notes: [a] The vertical profiles of wind, temperature and turbulence generated by AERMOD are forced to pass through any measurements input to AERMOD through the profile file. For a multilevel profile file, the measurements (or MM5-derived values) will, therefore, override the theoretical profiles based on similarity theory.

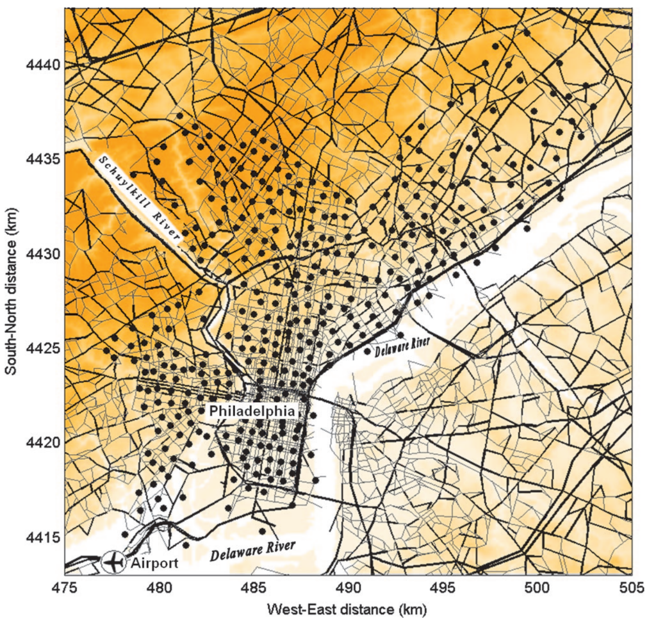

Figure 2. Modeling domain and locations of census tract centroids in Philadelphia County. Colors indicate elevations ranging from 0 to 150 m in the northwest domain.

and vertical turbulence intensities, respectively, and to determine the amount of plume spread. However, if turbulence measurements are not available, AERMOD estimates turbulence intensities from similarity relationships.

Analysis of Meteorology

This section provides a brief analysis of the meteorology for the area to provide some background for the comparisons presented in the next section. Philadelphia is located at the confluence of the Delaware and Schuylkill rivers on the eastern border of Pennsylvania. The Schuylkill River then runs into the Delaware River in South Philadelphia near the Philadelphia International Airport (Figure 2). The climate of the Philadelphia area is moderated somewhat by the Appalachian Mountains to the west and the Atlantic Ocean to the east, eliminating extended periods of extreme hot or cold weather. Precipitation is evenly distributed throughout the year with maximum amounts during the late summer months. Prevailing wind direction is from the southwest in the summer and northwesterly in the winter. Terrain is relatively flat in the central and southern parts of the city but with slightly higher elevation in the northern sections.

A comparison of wind roses between the NWS and MM5 for Philadelphia for 2001 is shown in Figure 3. The NWS measurements are collected at the airport, whereas the MM5 data are for the grid cell that encompasses the airport. Also, the NWS data correspond with the 10-m height, whereas the MM5 data are extracted from the lowest grid layer and are assigned to the midpoint of the grid (~19 m in our case). To investigate whether the selected period of 2001 is similar to the long-term patterns, we compared with the wind rose for a 10-yr period from 1981 to 1990. The NWS data for 2001 are typical of the long-term pattern and

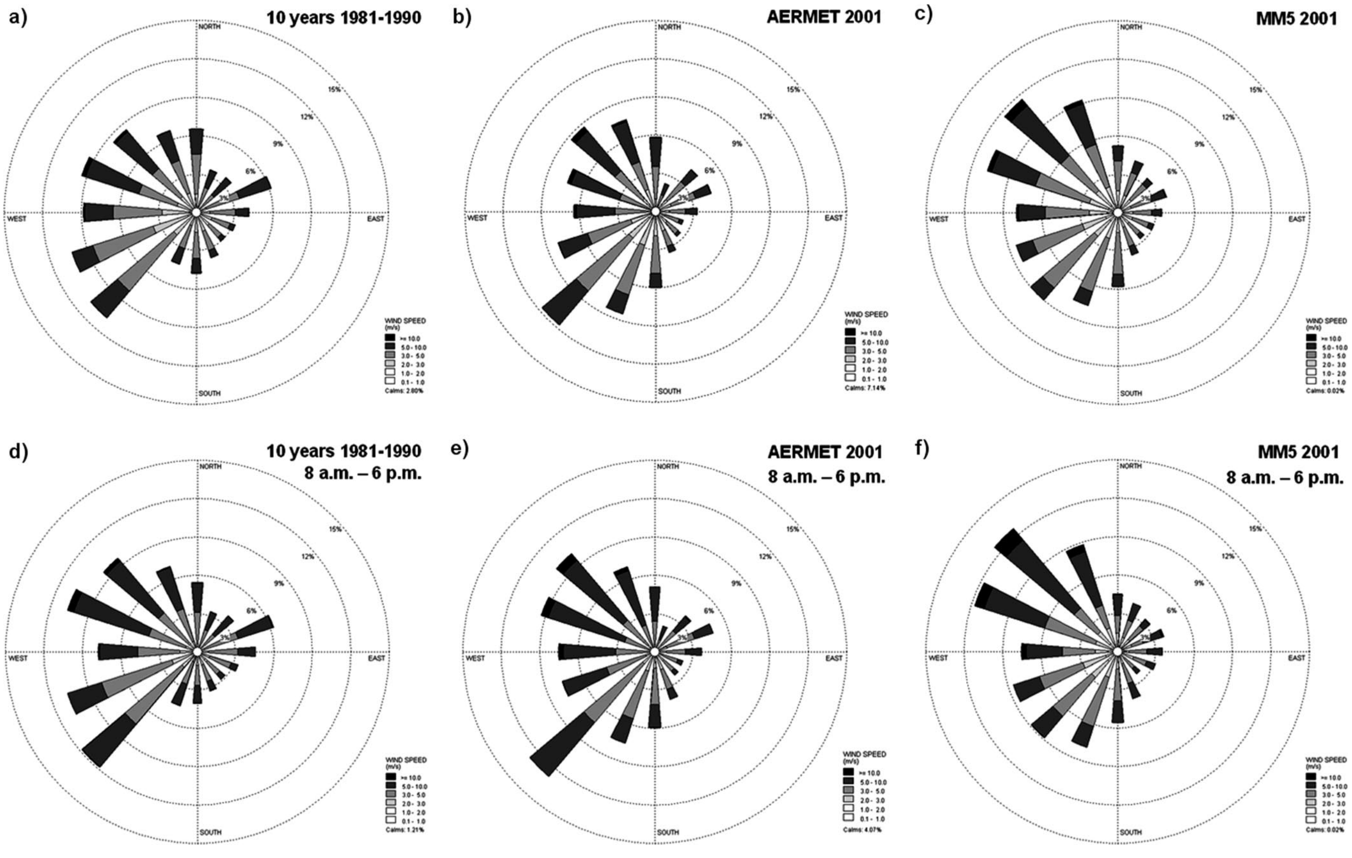

Figure 3. Wind roses in Philadelphia: using (a) NWS 10-yr period, (b) NWS data processed by AERMET for 2001, and (c) simulated by MM5 for 2001. Similar comparisons are provided for daytime hours only: (d) 10-yr period, (e) NWS data processed by AERMET, and (f) data from MM5.

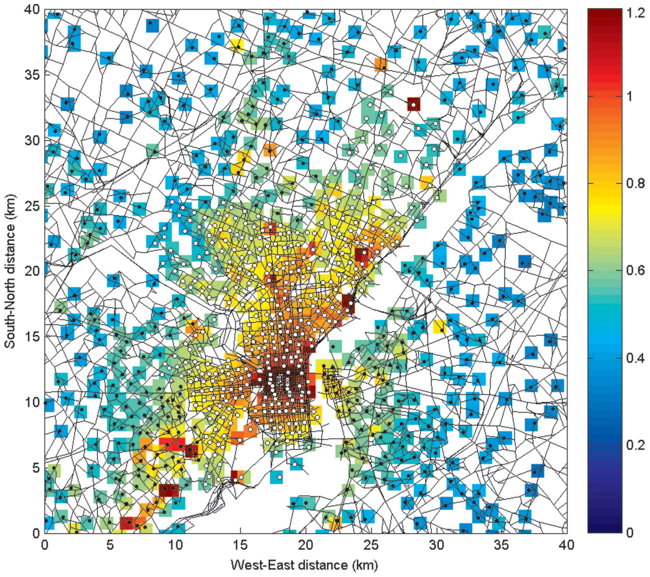

Figure 4. Modeling domain showing annual average benzene concentrations (μg/m^3) from AERMOD-NWS. Light dots are census tract centroids in Philadelphia County; dark dots = census tracts in other counties.

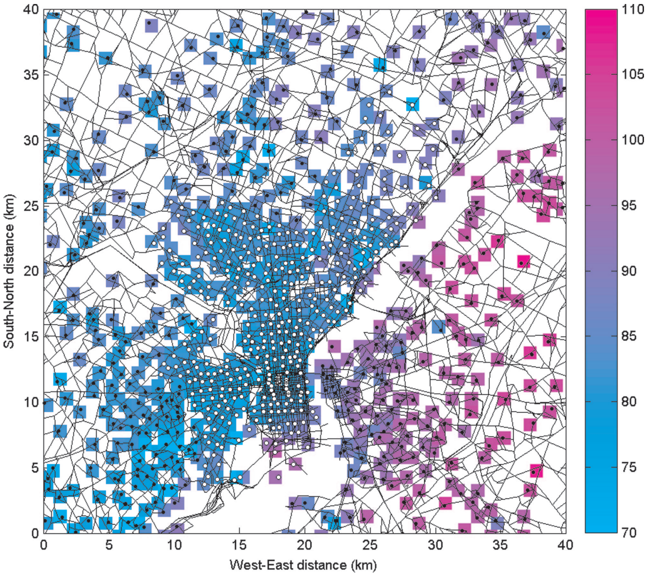

Figure 5. Normalized mean bias (%) of annual average benzene concentrations for AERMOD-MM5 and AERMOD-NWS.

both show a predominance of winds from the southwest through northwest sectors. By comparison, the MM5 output shows a more prominent northwesterly wind direction. This difference is somewhat more pronounced for daytime hours (Figure 3, d–f).

One possible explanation for some of the differences shown is that the 12-km MM5 grid is too coarse to discern topographic and other features of the local area that can influence wind flow.

Model Results

Figure 4 shows the predicted spatial distribution of the annual average concentrations (μg/m^3) of benzene in the Philadelphia metropolitan area using AERMOD-NWS for 2001. Annual averages are selected, because this is an appropriate averaging time for such urbanwide simulations that are typically performed for determining population exposure and risk. Concentrations are calculated at 1400 receptors located at the centroids of population census tracts. Census tracts are land areas defined by the U.S. Bureau of the Census that typically contain ~4000 residents each but vary in size depending on the population density, from <0.5 km^2 in high-population areas, such as cities, to ≥ 10 km^2 in rural areas. Census tract centroids are often used for this type of application, because they can be related to population exposure and also because portions of the emissions inventory are spatially allocated based on census tracts. White dots represent census tracts in Philadelphia County.

The range of variability in annual average concentrations across the domain is ~1 order of magnitude. As expected, concentrations are highest in areas of high traffic, such as downtown. Benzene emissions are distributed among mobile sources, industrial sources, and area sources, such as service stations and storage tanks. Mobile sources and area source emissions have a nonbuoyant, near ground level release height, and maximum concentrations are usually within a short distance away from the source. The figure also shows high concentrations south of downtown in the vicinity of the Philadelphia airport where there also are ground level emissions associated with airport activity.

The spatial distribution of differences in the annual average concentrations between AERMOD-NWS and AERMOD-MM5, expressed in terms of the normalized mean bias, is shown in Figure 5. The normalized mean bias is defined as $100^* [(C_{MM5} - C_{AERMET})/(C_{MM5} + C_{AERMET})/2]$; a value of 67 corresponds with a factor of 2 difference. In general, AERMOD-MM5 concentrations are higher by about a factor of 2–3, with the largest relative differences in the southeast part of the domain, possibly because of the predominant northwesterly flow in the MM5 winds seen in Figure 3.

To examine the model results in more detail, comparisons were also made of hourly average concentrations between AERMOD-NWS and AERMOD-MM5. Figure 6 presents a plot of ranked hourly average concentrations (unpaired in time and space) from AERMOD using the two meteorological datasets. The ranked AERMOD-MM5 hourly concentrations are about a factor of 2–3 higher overall than the ranked AERMOD-NWS concentrations, consistent with the comparison of annual average concentrations. Figure 7 presents a frequency distribution of all of the hourly average concentrations, including each hour and receptor, in the form of a histogram. Figure 7 shows a much higher frequency of hourly concentrations >50 μg/m^3 for AERMOD-MM5 than for AERMOD-NWS. This difference near the high end of the concentration distribution is because of the inclusion of additional light wind cases provided by MM5 that were not included in the NWS data, because they were below instrument threshold (i.e., calm winds) and other contributing factors, such as difference in wind patterns or difference in atmospheric stability.

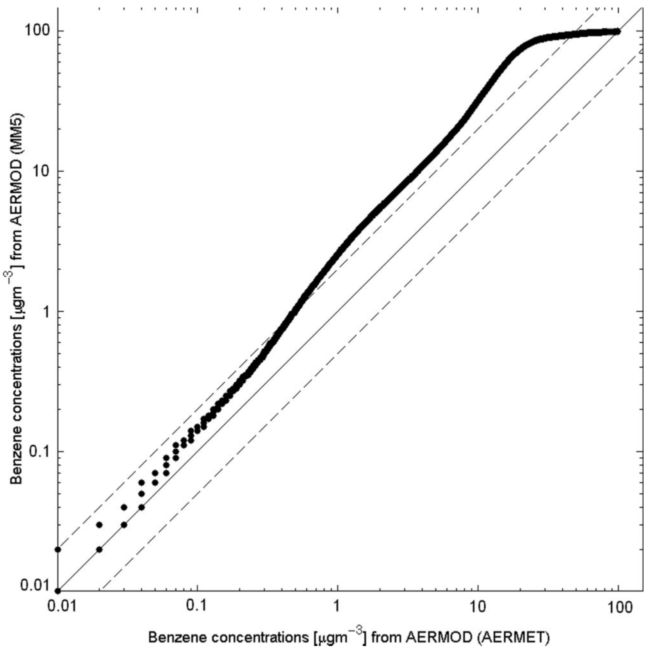

Figure 6. Comparison of ranked hourly concentrations from AERMOD-NWS and AERMOD-MM5.

To further analyze the differences in predicted concentrations, we compared key meteorological parameters estimated by AERMET based on NWS data with parameters derived from MM5 data. We focused this comparison on the dilution velocity, a measure of the dilution capacity of the boundary layer.[12] The dilution velocity, U_{dil}, is defined as a product of fluctuations of horizontal (σ_v) and vertical (σ_w) components of wind divided by wind speed: $\sigma_v\sigma_w/U$. It determines the rate at which the concentration from ground-level sources falls off with distance. An overprediction of the dilution velocity will lead to an underprediction of concentrations, whereas an underestimation of dilution velocity leads to overestimation of ground-level concentrations. We compared dilution velocities estimated from hourly meteorological variables from AERMET and MM5. To derive surface micrometeorological variables needed to estimate velocity fluctuations, we assumed that the surface layer was neutral, so that fluctuations of horizontal and vertical components of wind are related to friction velocity[13]:

$$\begin{aligned}\sigma_w &= 1.3u_* \\ \sigma_v &= 1.9u_* \qquad (1)\end{aligned}$$

Figure 8 compares dilution velocities constructed from the NWS data (AERMET) with the corresponding values estimated by MM5, paired in time. U_{dil} estimated by AERMET varies from ~0.1 to ~0.6 m sec^{-1}, with a median value of ~0.2 m sec^{-1}. The MM5-derived dilution velocities are generally lower than the NWS values, with a median value of ~0.1 m sec^{-1} or approximately a factor of 2 lower than for the NWS data. It should be noted that dilution velocities are not included for hours when the NWS data reported a calm wind, because the NWS dilution velocity is not defined for such cases. The generally lower dilution velocities for the MM5-derived data are

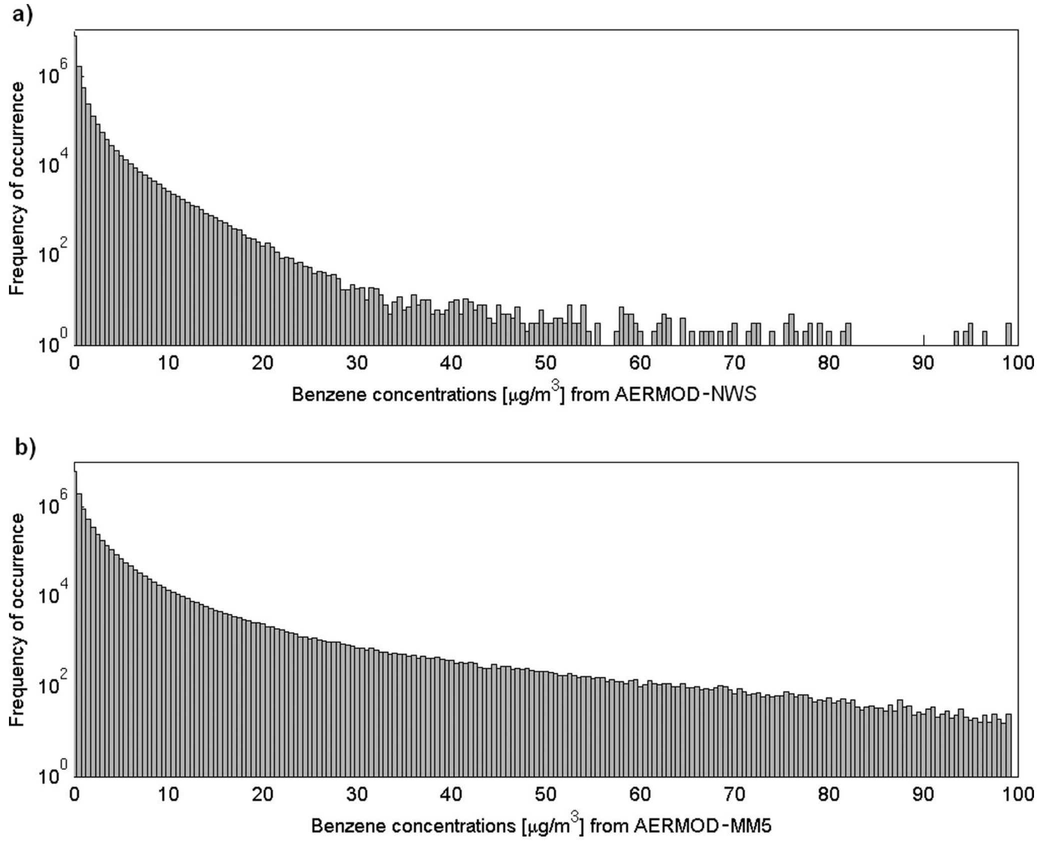

Figure 7. Histograms of modeled hourly benzene concentrations for all receptors from AERMOD using (a) AERMET and (b) MM5.

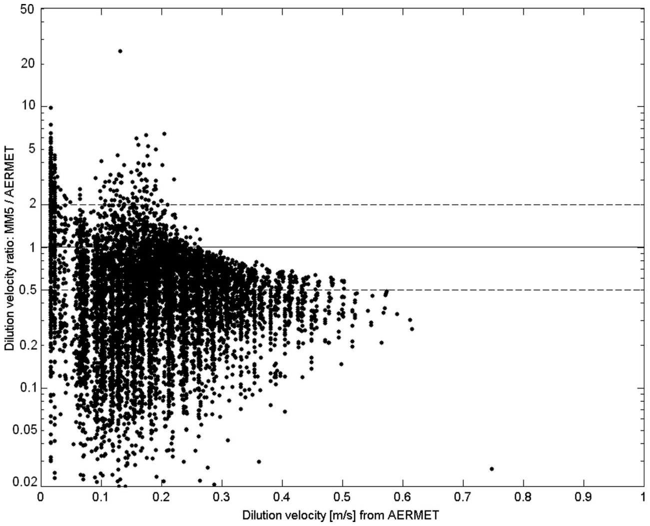

Figure 8. Comparisons of dilution velocity (m/sec) estimated from AERMET and MM5.

consistent with the higher predicted annual average concentrations described above, relative to the predictions based on NWS data.

DISCUSSION

There are multiple options for using prognostic model meteorology in dispersion modeling, depending on what variables are selected and how the data are incorporated within the AERMOD modeling system. We present two basic alternatives here to facilitate future testing and evaluation: direct input of MM5 data to AERMOD (the approach used in this paper) and input of MM5 data via the AERMET preprocessor. The first approach ensures that the data being provided to the AERMOD model are internally consistent, because they are all derived from the MM5 model. This approach was used in Wilmington, CA, to create meteorological inputs from MM5 and Eta models for AERMOD.[14] However, some parameters needed by AERMOD are not available in MM5 and were derived separately based on available data and AERMOD formulation (see Table 1).

The alternate approach of using AERMET to process the MM5 meteorological data provides a means of using the AERMET boundary layer algorithms to maintain consistency with the original AERMOD formulations. Passing MM5 data though AERMET also raises the option of using more site-specific surface characteristics than are represented by the MM5 gridded data, which could significantly influence the scaling parameters and mixing heights calculated by AERMET. This would, in turn, influence the turbulence profiles in AERMOD, unless a method is developed to pass MM5-derived turbulence values to AERMOD. These secondary influences from processing MM5 data through AERMET raises a concern that the basic energetics of the boundary layer may be altered in ways that are physically unrealistic or internally inconsistent.

To better understand the pros and cons of using local surface characteristics when processing MM5 data for AERMOD, it is important to understand how these surface characteristics are used within the AERMOD modeling system. Within AERMET, the surface characteristics are used to calculate the sensible heat flux and the similarity theory scaling parameters: Monin-Obukhov length (L), surface friction velocity (u*), and convective velocity scale (w*). Through the sensible heat flux, the surface characteristics also affect the convective mixing height calculation, and through u* they also affect the mechanical mixing height calculation.[7]

Within AERMOD itself, the influence of surface characteristics is more limited. As noted in Table 2, the hourly vertical profiles of wind, temperature, and turbulence generated within AERMOD are forced to match any measured (or MM5-derived) values input through the profile file. As a result, the effect of surface characteristics is likely to be negligible if hourly profiles of these variables are passed directly to AERMOD or through AERMET as pseudo-on-site data. The surface roughness will still influence the theoretical profile of wind speed, as determined by the reference wind speed and similarity scaling, and this theoretical profile is used in AERMOD for interpolating between measurements and extrapolating above or below the measurements. However, this influence will have a minimal effect on the final gridded vertical profile of wind speeds used by AERMOD when MM5-derived or on-site profiles are provided.

The appropriateness of any specific approach for using prognostic model output in AERMOD may depend on the application. Different considerations may come into play for applications involving a few isolated sources with mostly localized, subgrid scale, impacts as opposed to applications involving many sources over a large domain. For example, sensitivity of the model to variations in surface roughness length is more pronounced for low-level releases, and passing MM5 data through AERMET with more localized surface characteristics may be appropriate. Alternatively, for urban scale applications, the effective smoothing of surface characteristics over the grid cell, as reflected in the MM5 data, may be more representative.

There are several additional issues related to using prognostic model output in AERMOD. One issue relevant to this comparison involves the use of the urban option within AERMOD. This option simulates the nighttime urban heat island effect by enhancing the turbulence levels and calculating an urban boundary layer height, which acts as a reflecting surface for elevated plumes. The AERMOD urban option only applies for stable hours, identified within the model based on the sign of L (positive for stable). If, as found for some periods in this study, MM5 sensible heat flux values remain positive through the nighttime hours (sign of L remains negative), then the urban option in AERMOD will not be invoked, and AERMOD will process those hours using the same convective algorithms used during the daytime. This raises several questions, including whether the MM5-estimated heat flux adequately accounts for the urban heat island effects and whether using the AERMOD convective algorithm at nighttime is an appropriate way to model the urban boundary layer. Another consideration for using MM5 with AERMOD is how well the vertical profiles of temperature generated by MM5 capture the nighttime stable lapse rate in the lowest 100–200 m, which is very important for stable plume rise calculations

SUMMARY

The objective of this paper was to introduce the prospect of using prognostic model-generated meteorological output as input to the AERMOD steady-state dispersion model. We are motivated by the belief that prognostic meteorological models can provide additional information about the PBL that could be used by AERMOD, beyond what is currently available from NWS data. To begin exploring this possibility, we compared AERMOD-predicted concentrations of benzene across a large urban area (Philadelphia) using MM5 model-generated meteorological data as direct input with results obtained using hourly meteorological observations from the Philadelphia International Airport NWS station, processed through AERMET.

Predicted concentrations from AERMOD-MM5 were generally higher than those from AERMOD-NWS by about a factor of 2–3. These differences can be attributed in part to higher dilution velocities for the AERMOD-NWS data and the large number of calm hours in the NWS data. However, given the wide range of possible approaches that could have been taken for using MM5 data in AERMOD, of which this paper presents one option, these comparative results should not be used to form any general conclusions.

What Needs to Be Done

Although this paper demonstrates that it is possible to use meteorology from prognostic models as input into the AERMOD dispersion model, there are many issues that need to be addressed before these data can be used on a routine basis. Our analysis indicates that more work needs to be done in the area of generating improved small/urban scale meteorological datasets, which we recognize is an important area. Specifically, there are several things to be done to fully explore the issues that have been raised in this paper. First, it will be necessary to analyze the sensitivity of the AERMOD model to the many options that are available for using output from prognostic models. Once these sensitivities are better understood, the next priority should be to evaluate the performance of AERMOD using such input against available field observations. In addition, a variety of specific issues must be resolved before AERMOD applications using meteorological output from prognostic models can be routinely accepted:

(1) Recognizing that prognostic model output represents a fundamentally different type of data (i.e., a grid volume average), than the point measurements collected at NWS stations or by on-site monitoring programs, we need to examine how best to use such data in air quality dispersion models that have been developed and evaluated using point measurements.

(2) Given the extensive amount of data available from prognostic models compared with the limited amount of data normally used in routine applications of a steady-state dispersion model, what portion of the MM5 data should be used to take full advantage of such data for dispersion modeling applications?

(3) It is important, in the context of dispersion modeling, to examine how well prognostic models represent the lower portions of the PBL (i.e., from the ground up to a few hundred meters) where emissions from most sources are released into the atmosphere, given that the scientific focus, and major current use, of prognostic meteorological data is to support synoptic and mesoscale forecasts.

(4) There are many possible outcomes from prognostic models depending on the options that a user selects. All of the experience to date has been in selecting those options that provide the best data for regional scale applications. If prognostic model output is to be used for local scale analyses in AERMOD, what user-specified options should be selected, and will they differ significantly from those selected for regional scale applications? One of the major considerations here may be the choice of grid resolution, both horizontal and vertical.

(5) For a typical dispersion modeling domain, there are multiple prognostic model grid cells to choose from. Therefore, before these data can be routinely used, guidance will be needed for selecting the grid cell for a particular application.

(6) For applications of AERMOD in urban areas, more study is needed to better understand and assess the effectiveness of the prognostic model to characterize the structure of the urban boundary layer because of heat island and roughness effects. Beyond this, the appropriateness of bypassing the urban option in AERMOD for nighttime hours with positive heat flux needs further investigation. Modifications to AERMOD may be needed to adequately address some of these issues.

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About the Authors

Jawad S. Touma and Vlad Isakov are with the National Oceanic and Atmospheric Administration/Atmospheric Sciences Modeling Division (in partnership with U.S. Environmental Protection Agency). Alan J. Cimorelli, Roger W. Brode, and Bret Anderson are with U.S. Environmental Protection Agency. Address correspondence to Jawad Touma, National Oceanic and Atmospheric Administration/Atmospheric Sciences Modeling Division (in partnership with U.S. Environmental Protection Agency), Research Triangle Park, NC 27711; phone: +1-919-541-5381; fax: +1-919-541-0044; e-mail: Touma.Joe@epa.gov.