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TECHNICAL PAPER

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Sensitivity of Two Dispersion Models (AERMOD and ISCST3) to Input Parameters for a Rural Ground-Level Area Source

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ABSTRACT

As of December 2006, the American Meteorological Society/U.S. Environmental Protection Agency (EPA) Regulatory Model with Plume Rise Model Enhancements (AERMOD-PRIME; hereafter AERMOD) replaced the Industrial Source Complex Short Term Version 3 (ISCST3) as the EPA-preferred regulatory model. The change from ISCST3 to AERMOD will affect Prevention of Significant Deterioration (PSD) increment consumption as well as permit compliance in states where regulatory agencies limit property line concentrations using modeling analysis. Because of differences in model formulation and the treatment of terrain features, one cannot predict a priori whether ISCST3 or AERMOD will predict higher or lower pollutant concentrations downwind of a source. The objectives of this paper were to determine the sensitivity of AERMOD to various inputs and compare the highest downwind concentrations from a ground-level area source (GLAS) predicted by AERMOD to those predicted by ISCST3. Concentrations predicted using ISCST3 were sensitive to changes in wind speed, temperature, solar radiation (as it affects stability class), and mixing heights below 160 m. Surface roughness also affected downwind concentrations predicted by ISCST3. AERMOD was sensitive to changes in albedo, surface roughness, wind speed, temperature, and cloud cover. Bowen ratio did not affect the results from AERMOD. These results demonstrate AERMOD's sensitivity to small changes in wind speed and surface roughness. When AERMOD is used to determine property line concentrations, small changes in these variables may affect the distance within which concentration limits are exceeded by several hundred meters.

IMPLICATIONS

The results presented demonstrate the potentially severe effects that the change in the preferred regulatory model may have on the ability of emitting facilities to meet regulatory standards.

INTRODUCTION

As of December 2006, the American Meteorological Society (AMS)/U.S. Environmental Protection Agency (EPA) Regulatory Model with Plume Rise Model Enhancements (AERMOD-PRIME; hereafter AERMOD) developed by the AMS/EPA Regulatory Model Improvement Committee (AERMIC) replaced the Industrial Source Complex Short Term Version 3 (ISCST3) dispersion model as the EPA preferred regulatory model. AERMOD accounts for several planetary boundary layer (PBL) effects not accounted for by ISCST3. These include effects of vertical variations in the PBL, treatment of plume meander, and the use of divided streamlines to account for dispersion in complex terrain.[1] Furthermore, AERMOD's meteorological preprocessor (AERMET) also uses more detailed meteorological data such as friction velocity, Monin–Obukhov length, convective velocity scale, temperature scale, and surface heat flux than that used by ISCST3.[1]

Evaluating AERMOD's performance using 17 field study databases, Perry et al.[2] reported that AERMOD was most successful at predicting concentration distributions for tall-stack releases of buoyant pollutants into complex terrain but was less successful in predicting low pollutant concentrations, particularly in stable conditions. Perry et al.[2] analyzed only one database characterized by nonbuoyant emissions in flat terrain from a near-ground-level source (Prairie Grass database). Although they characterized AERMOD's performance using the Prairie Grass database as "good," the highest 1-hr concentrations predicted by AERMOD were substantially lower than those predicted by ISCST3. Evaluating the same Prairie Grass database, Irwin[3] concluded that downwind concentrations predicted by AERMOD matched observed downwind concentrations well, except in the most unstable atmospheric conditions in which modeled concentrations were lower than observed values.

The switch in approved regulatory models may be significant for several reasons. First, the change from ISCST3 to AERMOD will affect Prevention of Significant Deterioration (PSD) increment consumption. The Clean Air Act Amendments of 1977 contained a subpart for the "prevention of significant deterioration" of air quality by limiting the allowable increase in ambient concentrations of particulate matter less than or equal to 10 μm aerodynamic equivalent diameter (PM_{10}), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). PSD increment consumption is the "marginal degradation of ambient air quality beyond baseline values."[4] As an integral part of an overall air quality analysis, a PSD increment consumption analysis is unique because it may only be assessed by using air quality models to determine the impact a given source will have on a discrete receptor. Therefore, the transition from ISCST3 to AERMOD may have substantial impacts on PSD increment analysis. For a given source, if AERMOD predicts higher downwind concentrations than ISCST3, a facility may receive a more restrictive permit than formerly required, possibly resulting in lower production or requiring more expensive air pollution control devices.[4]

Second, many state air pollution regulatory agencies (SAPRAs) have begun to utilize a special use of the National Ambient Air Quality Standards (NAAQS) as property line concentrations not to be exceeded. Although this application of the NAAQS is outside the intended scope of the federal standards, many states have adopted such limits in an effort to protect public health and welfare. Because of the expense and labor requirements of on-site sampling campaigns to determine compliance with property line concentration limits, SAPRAs often use air pollutant dispersion models to predict property line concentrations on the basis of emissions estimates and local climate conditions. The transition from ISCST3 to AERMOD as the regulatory model of choice may affect a given source's ability to comply with property line concentration limits, including many existing permit limits, on the basis of modeling analyses.

Several investigations have been conducted to determine the differences in predicted pollutant concentrations on the basis of AERMOD and ISCST3 model runs. Long et al.[5] compared modeled concentrations of pollutants from multiple source types in the San Francisco Bay area and found that, except for 1-hr concentrations, AERMOD predicted consistently lower pollutant concentrations than did ISCST3. Long[6] found that 3-hr concentrations predicted by ISCST3 were much higher than those predicted by AERMOD from an elevated point source in a river valley with rolling terrain, but AERMOD's 24-hr predicted concentrations were greater than or equal to those predicted by ISCST3. Furthermore, Long[6] reported that peak and second-highest values between models were not paired in space or time. Comparing the performance of ISCST3 and AERMOD in a complex terrain scenario and a flat terrain scenario with multiple point, area, and volume sources, Tarde and Westbrook[7] found that AERMOD predicted higher 24-hr concentrations of PM_{10} in flat areas but lower concentrations than ISCST3 in complex terrain. Morrison[8] found results opposite to those of Tarde and Westbrook,[7] with ISCST3 predicting higher 24-hr concentrations than AERMOD in flat terrain with abrupt land-use changes and AERMOD predicting higher 24-hr concentrations in intermediate complex terrain. Morrison[8] also reported that ISCST3 predicted much higher 1-hr concentrations than AERMOD in complex terrain, but the models predicted similar 1-hr concentrations in the flat terrain scenario. In general, AERMOD seems to perform better in complex terrain than does ISCST3.[9]

Comparing modeled pollutant concentrations predicted by AERMOD with observed concentrations, Schewe and Wagner[10] reported that 3- and 24-hr concentrations predicted by AERMOD were below observed levels from a refinery located in complex terrain in eastern Kentucky. However, annual concentrations predicted by AERMOD were higher than those observed. Kumar et al.[11] also observed that model prediction was below observed concentrations but became better as the length of the averaging period increased from observations made in an urban area of Lucas County, OH.

Because of differences in model formulation and the treatment of terrain features, one cannot predict a priori whether ISCST3 or AERMOD will predict higher or lower pollutant concentrations downwind of a source. Furthermore, although ISCST3 and AERMOD are both double Gaussian plume dispersion models, ISCST3 limits dispersion phenomena to one of six discrete stability classes, whereas AERMOD allows for more resolved plume dispersion characterization based on substantially more user inputs such as land use/land cover (LULC) and PBL characterization.

When using AERMOD, EPA suggests values of albedo, Bowen ratio, and surface roughness for eight different land-use categories as a function of season in the AERMET User's Guide.[12] Using design concentrations, Grosch[13] evaluated the sensitivity of AERMOD to LULC parameters, modeling point sources at four heights using three values of each of the LULC parameters above. Grosch[13] concluded that the effect of these parameters on design concentrations was sufficiently complex to preclude prediction of their effect on concentrations resulting from emissions from any given source. However, the author found that design concentrations were most significantly affected by variations in surface roughness.

Analyzing the sensitivity of AERMOD-modeled concentrations from several source classes, Long et al.[5] also found that concentrations from all sources were most sensitive to surface roughness. The authors found that, behind surface roughness, concentrations downwind of an elevated point source and a ground-level point source in the San Francisco Bay area were most sensitive to solar radiation whereas concentrations downwind of a volume source were most sensitive to cloud cover.

The objectives of this paper are to:

(1) Determine the sensitivity of AERMOD to LULC and meteorological inputs; and
(2) Compare highest downwind concentrations from a ground-level area source (GLAS) predicted by AERMOD to those predicted by ISCST3.

MODEL INPUTS

The LULC and meteorological inputs analyzed in this research are described below.

LULC Parameters

- Albedo is the fraction of incoming solar radiation reflected back into space excluding absorption. Albedo can range from 0.1-in.-thick deciduous forest to 0.9 above fresh snow.

Table 1. Base scenario user inputs.

Variable	AERMOD	ISCST3
Albedo	0.2	N/A
Bowen ratio	1.5	N/A
Surface roughness (m)	0.05	N/A
Barometric pressure (kPa)	101.3	N/A
Solar radiation (W/m^2)	See Table 3 (max = 1000 W/m^2)	See Table 3 (max = 1000 W/m^2)
Wind speed (m/sec)	3.7	3.7
Average wind direction (degrees)	180	180
Temperature (K)	See Table 3 (average = 294.5 K)	See Table 3 (average = 294.5 K)
Relative humidity (%)	0	N/A
Total sky cover (tenths)	0	N/A
Mixing height (m)	N/A	1000

Notes: N/A = not applicable.

- Bowen ratio is the ratio of sensible heat flux to latent heat flux, or the proportion of solar radiation used to evaporate moisture from the ground and from plant and leaf surfaces. The Bowen ratio varies diurnally but is usually relatively constant during the day. Bowen ratio can range from 0.1 over water to 10 over desert surfaces.
- Surface roughness is the height at which the mean horizontal wind speed is zero. Surface roughness is a function of the height of obstacles obstructing wind flow and can range from 1 mm over a calm water surface to 3.7 m in heavy residential areas. Values over 1.5 m are uncommon. In ISCST3, surface roughness can only be specified as "rural" or "urban," whereas values can be specified precisely in AERMOD. The urban setting in ISCST3 corresponds to a surface roughness of 1 m, whereas the exact value of surface roughness for rural is not specified.[14]

Meteorological Parameters

- Solar radiation is the radiant energy emitted by the sun that reaches the earth's surface.
- Wind speed is measured at 10 m elevation.
- Mixing height is the height above ground to which pollutants vertically disperse because of heating by the sun (convective mixing) or turbulence caused by wind shear (mechanical mixing). Convective mixing is a daytime phenomenon and usually dominates over mechanical mixing. Mixing height is calculated by AERMET but must be specified in ISCST3.
- Temperature is the ambient temperature measured at the elevation specified by the user in AERMET.
- Cloud cover is the fraction of the sky covered by clouds.

METHODS

Particulate matter (PM) emissions were modeled from a 1000- by 1000-m GLAS in flat terrain oriented such that the edges fall along cardinal direction lines. The area source was located at 35 ° N latitude and 101 ° W longitude at an elevation of 1100 m above sea level (near Amarillo, TX). A homogeneous emission rate of 10 μg/m^2/sec was used with an average wind direction from the south. A base scenario (Tables 1 and 2) was established such that only one variable of interest was altered in any given analysis. The base scenario reflects typical conditions on the Texas High Plains. Daily temperature and daytime solar radiation follow sine functions (Table 2).

For ISCST3, the Pasquill–Gifford stability class was determined based on the Solar Radiation δ-T (SRDT) method.[15] A negative vertical temperature gradient was assumed at night (when solar radiation $\leq$50 W/m^2). On the basis of this assumption, the results of this model analysis should not be applied under conditions where a temperature inversion is present.

Each of the aforementioned inputs was varied independently to determine the corresponding sensitivities of AERMOD and ISCST3. The range and resolution of model

Table 2. Temperature and solar radiation for base scenario.

Hour	Solar Radiation (W/m^2)	Temperature (K)
1	0	290
2	0	289
3	0	289
4	0	289
5	0	290
6	0	291
7	239	292
8	464	293
9	663	295
10	823	296
11	935	297
12	993	298
13	993	299
14	935	300
15	824	300
16	664	300
17	466	299
18	241	298
19	0	297
20	0	296
21	0	295
22	0	293
23	0	292
24	0	291

inputs analyzed are shown in Table 3. Caution must be exercised when analyzing the extreme values from LULC analyses because parameters are interrelated. As noted by Grosch,[13] "a surface roughness length of 0.0001 [m], found only over water, cannot be combined with a Bowen ratio of 10, which represents a very dry surface."

Upper air data for AERMOD were generated to match surface data. One upper air sounding was used at an elevation of 1000 m above ground level. Barometric pressure at 1000 m was determined to be 90.16 kPa on the basis of eq 1.

$$\ln(P) = -3.42\left[\ln\left(\frac{298}{298 - 0.01z}\right)\right] + 4.618 \qquad (1)$$

where P is the pressure (kPa), and z is the elevation (m).[16]

In all model runs, the temperature at 1000 m above ground was set to be 10 °C lower than at ground level on the basis of an adiabatic lapse rate of 1 °C per 100 m elevation change. Wind direction at 1000 m was assumed to be the same as at the surface station, but wind speed was adjusted according to eq 2 (adapted from Stull[17]).

$$\left(\frac{u_2}{u_1}\right) = \left(\frac{z_2}{z_1}\right)^{p} \qquad (2)$$

where z_1 and z_2 are the elevations at 1 and 2, u_1 and u_2 are the wind speeds at z_1 and z_2, and p is the exponent.

The value of p is a function of surface roughness and atmospheric stability. Values used in this analysis are shown in Table 4.[16]

BREEZE AERMOD version 6.1.24 was used in conjunction AERMET Pro version 6.1.2 (Trinity Consultants) for AERMOD analyses utilizing the FORTRAN executable file "AERMOD_EPA_07026." For each test, meteorological parameters were processed using AERMET, thus generating new AERMET profile and surface files for each test run. BREEZE ISC GIS Pro version 5.2.1 was used for ISCST3 analyses. A receptor grid was placed downwind of the source using 1- by 1-m gridded spacing and receptor heights of 2 m. Models were run for 24 hr, and the highest 1-, 3-, and 24-hr concentrations were recorded along with the distance from the northern edge of the source to the location where the highest concentrations were predicted. Regression analyses were conducted using the curve estimation regression function in SPSS (SPSS, Inc.).

Table 4. Exponents for eq 2.

Pasquill–Gifford Stability Class	Exponent (p) Surface Roughness < 0.7 m	Surface Roughness ≥ 0.7 m
A	0.07	0.15
B	0.07	0.15
C	0.10	0.20
D	0.15	0.25
E	0.35	0.30
F	0.35	0.30

Notes: Adapted from Cooper and Alley.[16]

RESULTS AND DISCUSSION

The base scenario resulted in maximum modeled 1-hr concentrations of 272.8 and 172 μg/m^3 for AERMOD and ISCST3, respectively. Maximum modeled 24-hr concentrations for AERMOD and ISCST3 were 203.7 and 135.7 μg/m^3, respectively. For all scenarios with both models, the 3-hr concentrations were usually within 2 μg/m^3 of 1-hr concentrations.

Albedo

The maximum 1- and 24-hr concentrations calculated by AERMOD with varying albedo values are shown in Figure 1. Maximum 1- and 3-hr concentrations were unaffected by variations in albedo, as would be expected given that these concentrations occur at night, when there is no incoming solar radiation and the atmosphere is most stable. The lowest maximum 24-hr concentration (0.6% below the base scenario) corresponded to an albedo value of 0.1, and the highest maximum 24-hr concentrations (25% higher than the base scenario) corresponded to an albedo value of 0.85. Concentrations increased linearly with albedo values between 0.1 and 0.6 ($p < 0.0005$; $R^2 = 0.994$). Concentrations also increased linearly for albedo values between 0.6 and 0.9 ($p = 0.001$; $R^2 = 0.896$), but

Table 3. Variable range and resolution for sensitivity analysis.

Variable	Minimum	Maximum	Resolution
Albedo	0.1	0.9	0.05
Bowen ratio	0.1	10	0.1
Surface roughness (m)[a]	0.001	3.7	0.01 for 0.001 < SR < 0.1 0.1 for 0.1 < SR < 3.7
Average solar radiation (W/m^2)	400	1200	50
Wind speed (m/sec)	1	30	1
Mixing height (m)[b]	20	2000	20 for 20 < z < 300 50 for 300 < z < 2000
Average temperature (K)	270	310	5
Cloud cover (tenths)[c]	0	10	1

Notes: [a]For ISCST3, the rural dispersion option was used for SR < 0.7 m, and the urban dispersion option was used for SR ≥ 0.7 m; [b]Varied in ISCST3 only, mixing heights are automatically calculated in AERMOD; and [c]Varied total sky cover alone (opaque sky cover = 0) and total sky cover with opaque sky cover. SR = surface roughness.

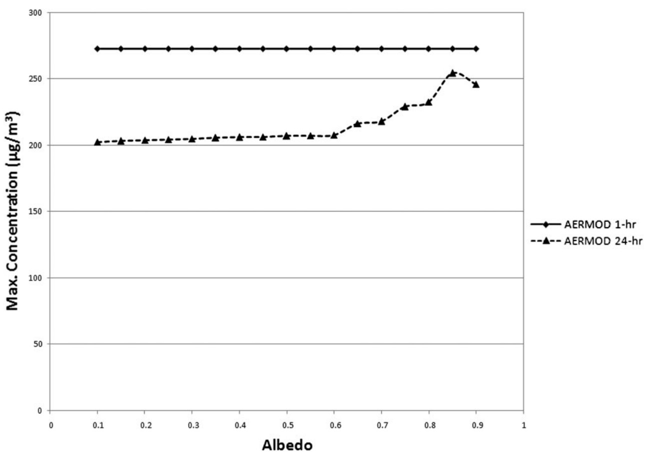

Figure 1. Maximum 1- and 24-hr AERMOD concentrations as a function of albedo.

the slope of the regression in the upper range of values was over 14 times the slope in the lower range of values.

Figure 2 shows 24-hr plume concentrations downwind of the source at 2-m elevation as predicted by AERMOD for albedo values of 0.1 and 0.85. The maximum distance downwind at which a concentration of 150 $\mu g/m^3$ (the 24-hr NAAQS for PM_{10}) is found is 117 and 252 m for albedo values of 0.10 and 0.85, respectively. The maximum distance downwind at which a concentration of 50 $\mu g/m^3$ is found is 1850 and 2682 m for albedo values of 0.10 and 0.85, respectively.

ISCST3 does not account for albedo in its dispersion modeling algorithms, thus ISCST3 concentrations were unaffected by changes in albedo. For all values of albedo, AERMOD predicted higher maximum downwind concentrations than ISCST3.

Bowen Ratio

Changes in the Bowen ratio had no effect on concentrations predicted by AERMOD. Sensible heat flux in the convective boundary layer (CBL), which affects convective mixing parameters, Monin–Obukhov length, and many other dispersion parameters, is a function of Bowen ratio.

$$H = \frac{0.9R_n}{(1 + 1/B_0)} \quad (3)$$

where H is the surface sensible heat flux (W/m^2), R_n is the net radiation (W/m^2), and B_o is the Bowen ratio.[1]

Bowen ratio likely did not affect predicted downwind concentrations in this study because mechanical mixing in the PBL outweighed effects of convective mixing. ISCST3 does not account for Bowen ratio in its dispersion model algorithms.

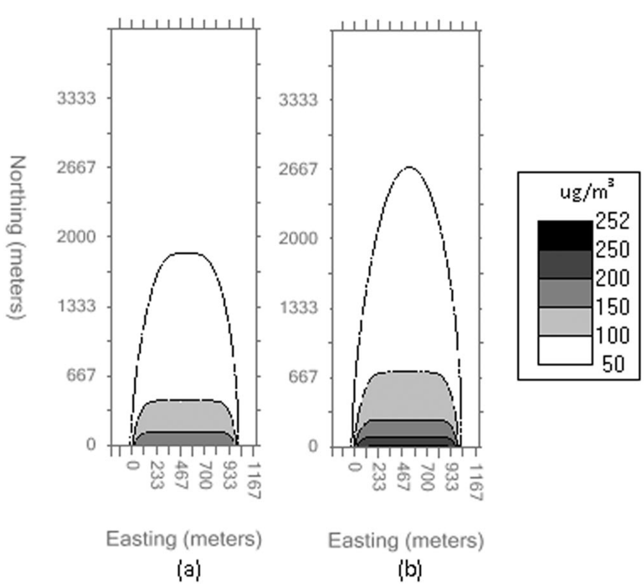

Figure 2. 24-hr AERMOD concentrations at 2-m elevation downwind of source for albedo values of (a) 0.10 and (b) 0.85.

Surface Roughness

The maximum 24-hr concentrations calculated by AERMOD and ISCST3 as surface roughness values varied are shown in Figure 3. The 1- and 3-hr concentrations were higher than 24-hr concentrations but followed similar trends.

Maximum concentrations calculated by AERMOD changed lognormally with surface roughness ($p < 0.0005$; $R^2 = 0.923$) whereas the step change in maximum concentrations calculated by ISCST3 was a function of choosing an urban versus rural dispersion option. The lowest maximum 24-hr concentration calculated by AERMOD (86% below the base scenario) corresponded to a surface roughness value of 3.7 m, and the highest maximum 24-hr concentration (192% higher than the base scenario) corresponded to a surface roughness value of 0.001 m. Within the typical range of surface roughness values used in modeling (0.001–1.5 m), a difference in concentrations of more than a factor of 10 was observed.

Figure 4 shows plume concentrations downwind of the source at 2-m elevation as predicted by AERMOD for surface roughness values of 0.05 and 0.10 m. The minor alteration of surface roughness by 50 mm changes the maximum distance downwind at which a concentration of 150 $\mu g/m^3$ is found from 34 m (surface roughness = 0.10 m) to 120 m (surface roughness = 0.05 m). The

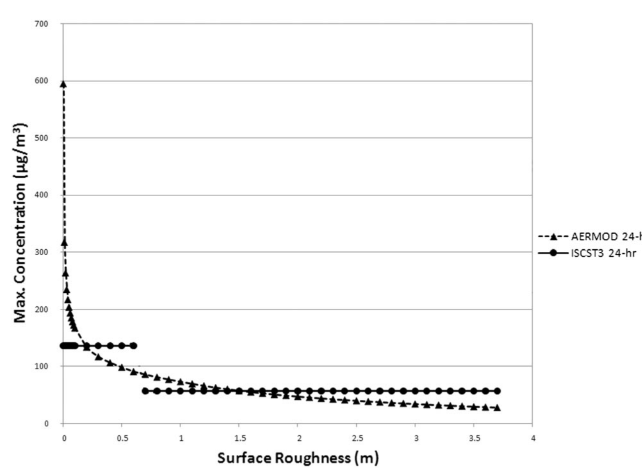

Figure 3. Maximum 24-hr AERMOD and ISCST3 concentrations as a function of surface roughness.

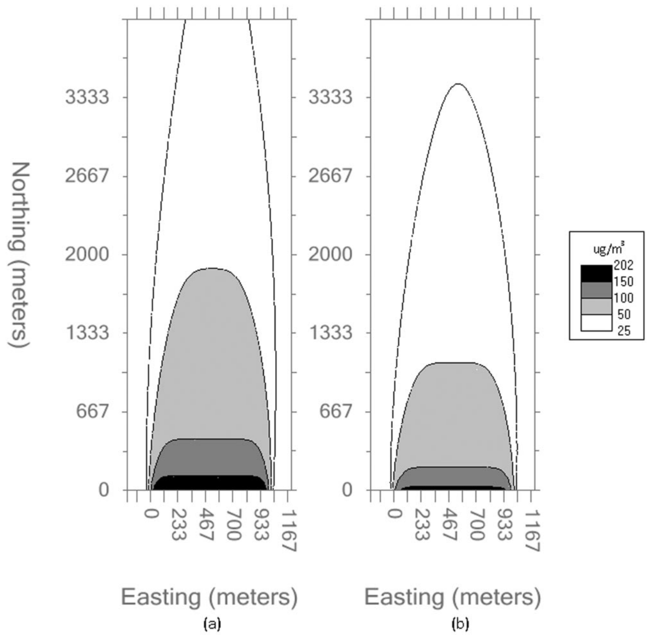

Figure 4. 24-hr AERMOD concentrations at 2-m elevation downwind of source for surface roughness values of (a) 0.05 (base scenario) and (b) 0.10 m.

maximum distance downwind at which a concentration of 50 μg/m^3 is found is 1086 and 1893 m for surface roughness values of 0.10 and 0.05 m, respectively.

Solar Radiation

The concentrations calculated by AERMOD as solar radiation values varied did not change. Again, this is likely due to the preeminence of mechanical mixing over convective mixing in the modeled domain. The maximum 1- and 24-hr concentrations calculated by ISCST3 as solar radiation values varied are shown in Figure 5. Maximum 1- and 3-hr concentrations were unaffected by variations in solar radiation, as would be expected given that these concentrations occur at night. The lowest maximum 24-hr concentration (1.9% below the base scenario) corresponded to the highest solar radiation scenario, and the highest maximum 24-hr concentrations (9.3% higher than the base scenario) corresponded to the lowest solar radiation scenario. As solar radiation increases, heating of the earth's surface increases, leading to less stable atmospheric conditions. Unstable conditions then lead to greater dispersion of airborne pollutants. Maximum concentrations varied as step functions as changes in solar radiation led to differences in Pasquill–Gifford stability classes. For all values of solar radiation, AERMOD predicted higher maximum downwind concentrations than ISCST3.

Wind Speed

Maximum 1-, 3-, and 24-hr concentrations decreased with increasing wind speed in both models. The highest 1-hr concentration predicted by AERMOD (2527 μg/m^3) occurred at a wind speed of 1 m/sec and was 4 times higher than the 1-hr concentration predicted by ISCST3 at the same wind speed. Similarly, the maximum 24-hr concentration predicted by AERMOD in a 1-m/sec wind (1937 μg/m^3) was 3.9 times higher than that predicted by ISCST3. As seen in Figure 6, the 24-hr concentrations predicted by AERMOD are higher than those predicted by ISCST3 for wind speeds below 6 m/sec, but marginally lower than those predicted by ISCST3 for higher wind speeds. Regression curves for the 1- and 24-hr concentrations predicted by AERMOD and ISCST3 are of the form

$$C = ax^{b} \tag{4}$$

where C is the maximum concentration (μg/m^3), x is the wind speed (m/sec), and a and b are curve fit coefficients. The values of a and b are shown in Table 5.

A Q-Q plot of 24-hr concentrations predicted by ISCST3 and AERMOD as wind speed varied above 3 m/sec (Figure 7) illustrates the higher sensitivity of AERMOD to wind speed under conditions of low wind velocity. Each point in Figure 7 represents the maximum 24-hr concentration determined for a given wind speed, with wind speed decreasing from left to right. AERMOD is increasingly sensitive relative to ISCST3 as wind speed decreases below 3 m/sec.

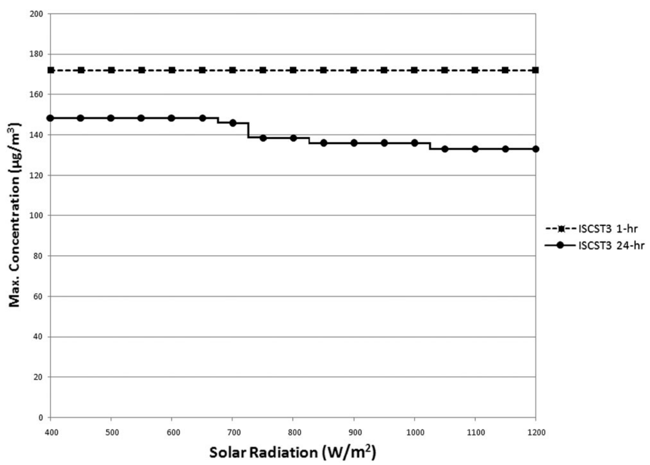

Figure 5. Maximum 1- and 24-hr ISCST3 concentrations as a function of solar radiation.

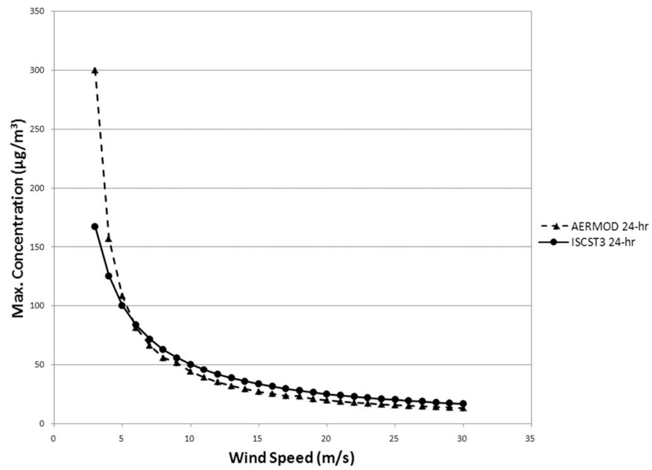

Figure 6. Maximum 24-hr AERMOD and ISCST3 concentrations as a function of wind speed (wind speed ≥ 3 m/sec).

Table 5. Curve fit coefficients for eq 4.

Model	Average Time (hr)	*a*	*b*	R^2	*p* Value
AERMOD	1	1786	−1.42	0.979	<0.0005
AERMOD	24	1335	−1.41	0.979	<0.0005
ISCST3	1	636	−1.00	1.000	<0.0005
ISCST3	24	502	−1.00	1.000	<0.0005

As seen in Figure 6, downwind concentrations modeled by AERMOD are much more sensitive to changes in wind speed in low-wind locations. The slope of the maximum 24-hr AERMOD concentration curve in Figure 6 changes from $-1882\ \mu g \cdot sec/m^4$ at a wind speed of 1 m/sec to $-0.5\ \mu g \cdot sec/m^4$ at a wind speed of 30 m/sec. This sensitivity points to the need for accurate wind speed data during relatively calm periods when using AERMOD to predict downwind concentrations of pollutants.

Temperature

The concentrations calculated by ISCST3 as average daily temperature values varied did not change. The maximum 1- and 24-hr concentrations calculated by AERMOD decreased linearly as temperature values increased (Figure 8). The lowest maximum 24-hr concentration calculated by AERMOD (8.5% below the base scenario) corresponded to an average temperature of 310 K, and the highest maximum 24-hr concentration (6.3% higher than the base scenario) corresponded to an average daily temperature of 270 K.

Increasing temperature leads to more negative values of the Monin–Obukhov length:

$$L = -\frac{\rho c_p T u_*^3}{kgH} \quad (5)$$

where L is the Monin–Obukhov length (m), ρ is the density of air (kg/m^3), c_p is the specific heat of air at constant pressure ($J/kg \cdot K$), T is the temperature of the surface layer (K), u_* is the friction velocity (m/sec), k is the von Karmen constant ($k = 0.4$), and g is the acceleration due to gravity ($g = 9.8\ m/sec^2$).[1]

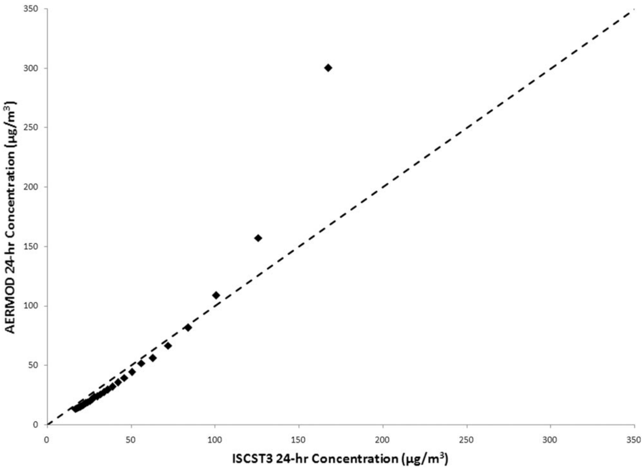

Figure 7. Q-Q plot of 24-hr concentrations predicted by ISCST3 and AERMOD as wind speed varies above 3 m/sec.

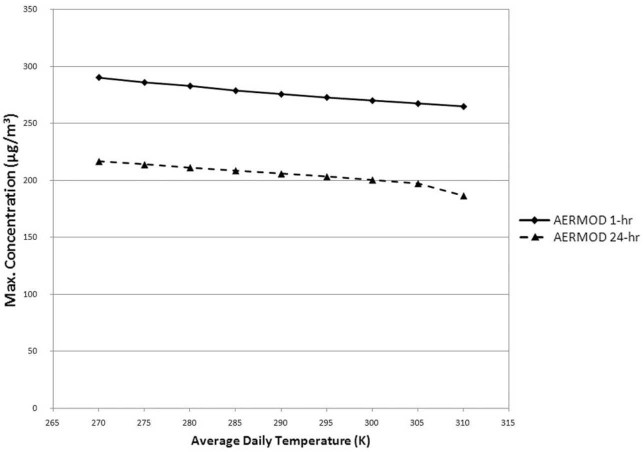

Figure 8. Maximum 1- and 24-hr AERMOD concentrations as a function of average daily temperature.

Greater magnitudes of the Monin–Obukhov length are indicative of great convective instability, which leads to greater pollutant dissipation and therefore lower concentrations. For all values of average temperature, AERMOD predicted higher maximum downwind concentrations than ISCST3.

Figure 9 shows 24-hr plume concentrations downwind of the source at 2-m elevation as predicted by AERMOD for average temperature values of 270 and 310 K. The maximum distance downwind at which a concentration of 150 $\mu g/m^3$ is found is 160 and 81 m for average temperatures of 270 and 310 K, respectively. The maximum distance downwind at which a concentration of 50 $\mu g/m^3$ is found is 2181 and 1583 m for average temperatures of 270 and 310 K, respectively.

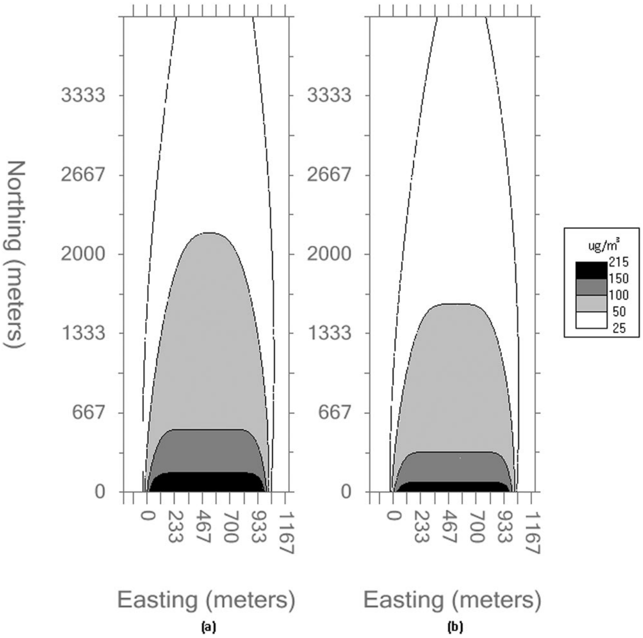

Figure 9. 24-hr AERMOD concentrations at 2-m elevation downwind of source for average temperatures of (a) 270 and (b) 310 K.

Cloud Cover

The concentrations calculated by ISCST3 as cloud cover values varied did not change. The concentrations calculated by AERMOD were unaffected by total sky cover if opaque sky cover remained negligible. However, the fraction of opaque sky cover did affect concentrations predicted by AERMOD (Figure 10). The maximum 1- and 24-hr concentrations predicted by AERMOD decreased with increasing cloud cover following a second-order polynomial trend ($p < 0.0005$, $R^2 = 0.999$ for 1 hr; $p < 0.0005$, $R^2 = 0.977$ for 24 hr). The lowest maximum 24-hr concentration calculated by AERMOD (24.4% below the base scenario) corresponded to a completely opaque sky cover, and the highest maximum 24-hr concentration corresponded to no cloud cover, as in the base scenario. For all values of cloud cover, AERMOD predicted higher maximum downwind concentrations than ISCST3.

Because maximum concentrations occur during stable conditions, the effect of cloud cover on predicted pollutant concentration is most pronounced in the stable boundary layer (SBL). The surface heat flux in the SBL is calculated in AERMOD as

$$H = -\rho c_p u_* \theta_* \quad (6)$$

where θ_* is the temperature scale (K; adapted from Cimorelli et al.[1]).

The temperature scale, θ_*, decreases with increasing cloud cover:

$$\theta_* = 0.09(1 - 0.5n^2) \quad (7)$$

where n is the fractional cloud cover. Therefore, as cloud cover increases, heat flux in the SBL becomes more negative, and dispersion increases.

Figure 11 shows 24-hr plume concentrations downwind of the source at 2-m elevation as predicted by AERMOD for no opaque cloud cover (base scenario) and full opaque cloud cover (opaque cloud cover = 10/10). The maximum distance downwind at which a concentration of 150 $\mu g/m^3$ is found is 120 m under clear skies and 31 m with complete cloud cover. The maximum distance downwind at which a concentration of 50 $\mu g/m^3$ is found is 1893 m under clear skies and 850 m with complete cloud cover.

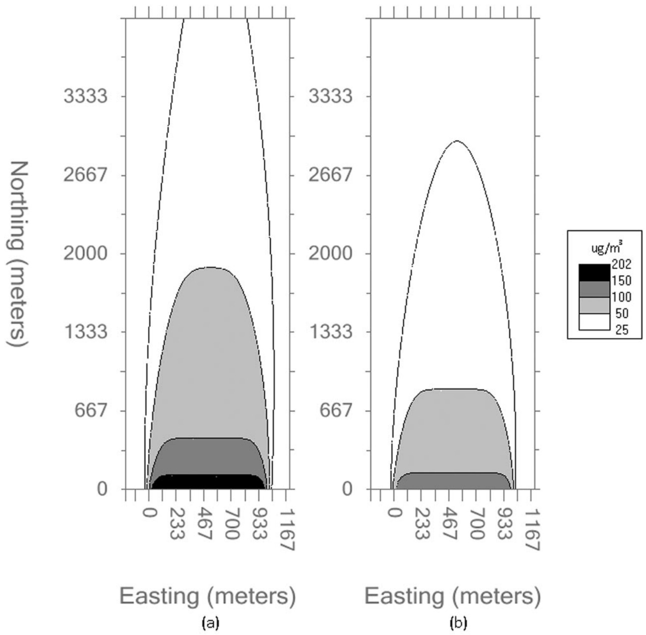

Figure 11. 24-hr AERMOD concentrations at 2-m elevation downwind of source for (a) no cloud cover (base scenario) and (b) full opaque cloud cover.

Mixing Height

Unlike ISCST3, AERMOD calculates mixing height on the basis of other meteorological parameters such as cloud cover, temperature, and solar incidence angle, therefore mixing height in AERMOD was not artificially varied for this analysis. The effects of mixing height on 1- and 24-hr concentrations predicted by ISCST3 are shown in Figure 12. Maximum 1-hr concentrations decreased as mixing height increased to 60 m, above which 1-hr concentrations were unaffected by mixing height. Maximum 24-hr concentrations decreased until mixing height reached

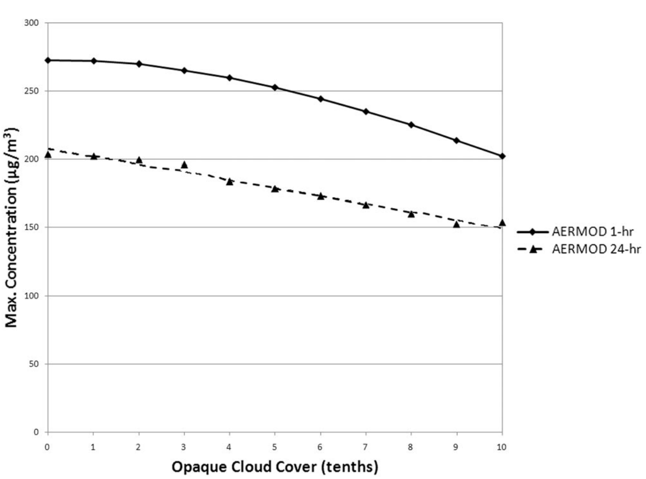

Figure 10. Maximum 1- and 24-hr AERMOD concentrations as a function of opaque sky cover.

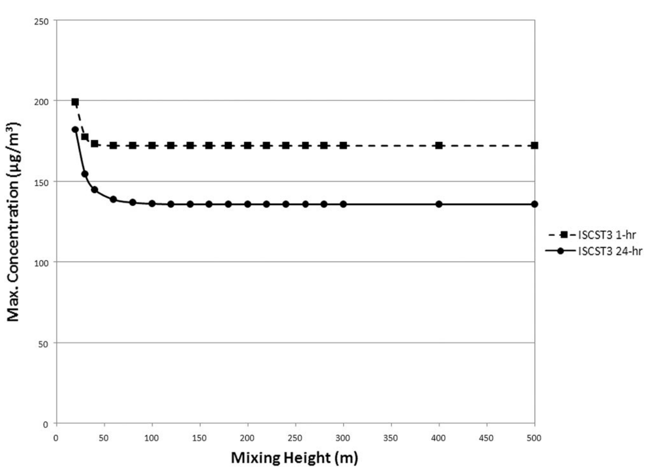

Figure 12. Maximum 1- and 24-hr ISCST3 concentrations as a function of mixing height.

160 m. At a mixing height of 20 m, the maximum 24-hr concentration predicted by ISCST3 was 34% higher than the base scenario maximum 24-hr concentration.

CONCLUSIONS

PM concentrations downwind of a GLAS are affected by many meteorological and geographical factors. When using dispersion models to predict downwind concentrations, it is important that the sensitivity of the model to any given input is understood. Concentrations predicted using ISCST3 are sensitive to changes in wind speed, temperature, solar radiation (as it affects stability class), and mixing heights below 160 m. Surface roughness also affects downwind concentrations predicted by ISCST3, but only two categories of surface roughness are considered in ISCST3. AERMOD is sensitive to changes in albedo, surface roughness, wind speed, temperature, and cloud cover. Bowen ratio did not affect the results from AERMOD, likely as a result of the greater mechanical mixing in the modeled domain.

It is troublesome that solar radiation levels do not impact concentrations predicted by AERMOD because it is well known that solar radiation impacts atmospheric stability and therefore pollutant dispersion. AERMOD proved particularly sensitive to changes in surface roughness when values were below 0.5 m and to wind speed when values were below 10 m/sec. Maximum concentrations predicted by AERMOD and ISCST3 correlated well when wind speeds exceeded 5 m/sec but diverged rapidly as wind speed decreased, with AERMOD predicting much higher maximum concentrations than ISCST3 in low-wind conditions.

The results of this paper point to the sensitivity of AERMOD to small changes in wind speed and surface roughness when predicting downwind pollutant concentrations. In situations in which AERMOD is used to determine whether PM concentrations exceed NAAQS at the property line of a facility, small changes in these variables may affect the distance within which NAAQS concentrations are exceeded by several hundred meters.

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