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5B.1 AERMOD'S SIMPLIFIED ALGORITHM FOR DISPERSION IN COMPLEX TERRAIN

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1. INTRODUCTION

The AMS/EPA Regulatory Model Improvement Committee's dispersion model, AERMOD (Cimorelli et al., 1996), is designed to handle both flat and complex terrain within the same framework. The structure of AERMOD incorporates our knowledge of flow and dispersion in complex terrain. Under stable conditions, the flow and hence the plume, tends to remain horizontal when it encounters an obstacle. This tendency for the flow to remain horizontal gives rise to the concept of the dividing streamline height, denoted by H_c (Snyder et al., 1983). Below this height, the fluid does not have enough kinetic energy to surmount the top of the hill; a plume embedded in the flow below H_c either impacts on the hill or goes around it. On the other hand, the flow and hence the plume above H_c can climb over the hill.

Under unstable conditions, the plume is more likely to climb over the obstacle. However, the plume is depressed towards the surface of the obstacle as it goes over it. The implied compression of the streamlines is associated with speed-up of the flow and amplification of vertical turbulence. These and other effects are accounted for in models such as the Complex Terrain Dispersion Model, CTDMPLUS (Perry, 1992), that attempt to provide accurate concentration estimates for plumes dispersing in complex terrain. Models like CTDMPLUS become necessarily complicated if we want to incorporate complex terrain effects as realistically as possible.

The formulation of AERMOD attempts to capture the essential physics of dispersion in complex terrain in as simple a framework as possible.

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S. Perry is on assignment to the National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

2. TECHNICAL APPROACH

AERMOD assumes that the concentration at a receptor, located at a position (x,y,z), is a weighted combination of two concentration estimates: one assumes that the plume is horizontal, and the other assumes that the plume climbs over the hill. The concentrations associated with the horizontal plume dominate during stable conditions, while that caused by the terrain-following plume is more important during unstable conditions. These assumptions allow us to write the concentration, $C(x,y,z)$, as

$$C(x,y,z) = fC_f(x,y,z) + (1-f)C_f(x,y,z_e). \qquad (1)$$

The first term on the right-hand side of Equation (1) represents the contribution of the horizontal plume, while the second term is the contribution of the terrain-following plume. The weighting factor, f, is defined later. Note that, in the first term, $C_f(x,y,z)$ is evaluated at the receptor height, z, to simulate a horizontal plume. In the second term, the concentration is evaluated at an effective height, z_e, which will be discussed later.

The formulation of the weighting factor, f, uses the observation that the flow below the critical dividing streamline height, H_c, tends to remain horizontal as it goes around the terrain obstacle (Snyder et al., 1983). This suggests the following formulation for f:

$$f = f(\phi) , \qquad (2a)$$

where

$$\phi = \frac{\int_0^{H_c} C_f(x,y,z)\mathrm{d}z}{\int_0^{\infty} C_f(x,y,z)\mathrm{d}z} , \qquad (2b)$$

ϕ (x,y) represents the fraction of the plume mass (assuming that the plume is horizontal) below the critical dividing streamline height at the receptor location (x,y). This fraction goes to zero under unstable conditions because H_c is zero. The weight, f, can be defined in two ways:

OPTION I:

$$f = \phi , \qquad (3a)$$

$$z_e = 0.5\min(H_p, z_h) + (z - z_h) . \qquad (3b)$$

OPTION II:

$$f = \frac{1}{2}(1+\phi) , \qquad (4a)$$

$$z_e = (z - z_h) . \qquad (4b)$$

In Equations (3) and (4), z_h represents the height of the terrain at the receptor location (x, y) and H_p represents the plume height. Then, $(z - z_h)$ represents the height of the receptor above local terrain. Notice that each option for f is associated with a formulation for the effective height, z_e.

In Option I, the horizontal plume makes a contribution only under stable conditions; ϕ, and hence f, go to zero under unstable conditions.

The contribution made by the terrain-following plume is calculated at the receptor by assuming that the receptor is on a pole stuck into the plume at a specified distance above or below the plume centerline. When the plume height, H_p, is less than terrain height, z_h, we see that z_e works out to be

$$z_e = \frac{H_p}{2} + (z - z_h) . \qquad (5)$$

For a receptor on the hill surface, $z = z_h$, the use of z_e is equivalent to calculating a concentration on a pole at half the distance between the ground and the plume centerline.

When the plume height, H_p, is greater than the terrain height, z_h, at the receptor, the concentration at a receptor on the hill surface is equivalent to calculating the concentration on a pole that has a height of $z_h/2$.

The use of z_e in estimating the concentration on the hill surface ensures that the concentration is always greater than its value at ground-level in the absence of the hill. The "half-height" type of correction embodied in the formulation of z_e is borrowed from the Rough Terrain Dispersion Model (RTDM; Paine and Egan, 1987). However, unlike RTDM, the current formulation does not require adjustments related to unrealistic reflection at the hill surface.

Option II ensures that the horizontal plume always makes a contribution to the concentration on the hill surface. When ϕ goes to zero under unstable conditions, f becomes $\frac{1}{2}$. This means, that under unstable conditions, the concentration at an elevated receptor is the average of the contributions from the horizontal plume and the terrain-following plume.

In Option II, the expression for z_e implies that no correction is made to the terrain-following plume to increase the concentration above the value occurring in the absence of the hill; the hill surface is ground-level as far as the plume is concerned.

At this stage, both options for f and z_e are incorporated into AERMOD and will be evaluated in the near future.

3. TERRAIN HEIGHT AND CRITICAL DIVIDING STREAMLINE HEIGHT

This section describes an objective method to estimate the terrain height, h_c, that is used to calculate the dividing streamline height, H_c. Consider a domain of interest, and a receptor at (x, y, z) for which we need an H_c to calculate the effect of terrain on dispersion. We assume that the effect of terrain on the flow at the receptor (x, y) decreases as the distance between the terrain feature and the receptor increases; in other words, a hill close to the receptor has more influence on dispersion than the same hill placed further away. AERMAP, the terrain preprocessor for AERMOD, is designed to evaluate an entire domain of gridded terrain heights and determine the influence of each grid height on each receptor location. For each receptor, this is accomplished by computing a distance-dependent effective height at each grid point, then selecting the actual terrain height associated with the largest effective height in the domain as that which is used to compute the dividing streamline height for that receptor.

Quantitatively, AERMAP does the following computations for each receptor to define a hill height, h_c, appropriate for H_c calculations:

$$\hat{h}(r) = hf(r/r_o), \qquad (6)$$

where $\hat{h}$ is the effective height of a hill whose real height is h, and r is the distance between the receptor (x,y) and the hill at $(\hat{x},\hat{y})$:

$$r = \left[(x-\hat{x})^2 + (y-\hat{y})^2\right]^{1/2}. \qquad (7)$$

The function $f(r/r_o)$ depends on r as well as a radius of influence, r_o, which, for the time being, is taken as:

$$r_o = \alpha h_{\max}; \alpha = 10, \qquad (8)$$

where $h_{\max}$ is the height of the highest terrain feature in the domain of interest. The function $f(r/r_o)$ is taken as

$$f(r/r_o) = \exp(-r/r_o). \qquad (9)$$

h(r) is computed for each grid point in the domain. $h_{max}(r)$ is the largest *h(r)* value in the domain. h_c is then taken as the actual terrain height at the location associated with $h_{max}(r)$. That is,

$$h_c = h_{max}(r) / f(r/r_o).$$

3. RESULTS

AERMOD was evaluated with data from the Lovett Power Plant Study (Paumier et al., 1992), which consists of SO_2 concentrations associated with a buoyant continuous release from a 145-m stack. This is the same data base used by Paumier, et al. (1992) to evaluate the CTDMPLUS. The site is complex terrain in a rural area. The data span one year from December 1987 to December 1988, and were collected at 12 monitoring sites (10 on terrain, and 2 on flat terrain) located within 3 km from the site. The important terrain features rise approximately 250 m to 330 m above stack base.

Figure 1, which plots the ranked observations against model predictions, compares the model performance of AERMOD with those of three other models. We see that AERMOD performs at least as well as the other models.

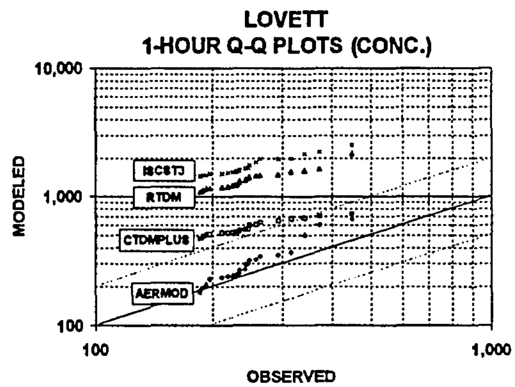

Figure 1. A comparison of the performance of AERMOD with other models. The data were collected from the Lovett Power Plant Study.

4. REFERENCES

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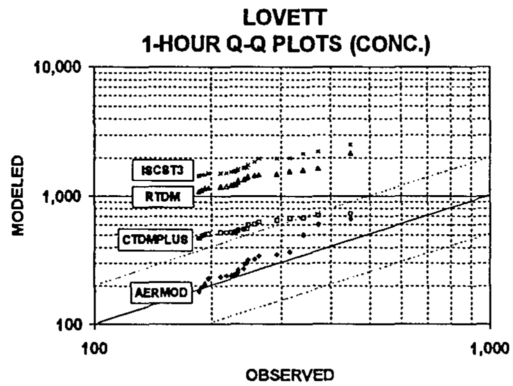

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16. ABSTRACT

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