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A NEW PUFF ALGORITHM FOR NON-STATIONARY DISPERSION IN COMPLEX TERRAIN

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1. INTRODUCTION

Puff models have been used, especially recently, to attempt to more correctly represent the plume when the emission rate, the meteorology, or the complexities of the terrain show definite non-homogeneous and non-stationary characteristics which do not allow the use of steady state formulas (like the Gaussian plume equation) for the numerical representation of plume dispersion phenomena.

However, breaking up a plume into a series of independent elements presents some numerical and physical problems. In the discussion below, a new approach is proposed for solving such problems. This approach constitutes the body of a new puff computer code (AVPPM/2A) for plume representation.

This new algorithm has been developed to better treat non-stationary dispersion in complex terrain, one of the major problems in air quality modeling, especially in the Western United States. Today, both advanced three-dimensional meteorological models, and accurate instrumentation for wind and vertical turbulence measurements (e.g., Doppler Acoustic Sounder), provide, in fact, some detailed meteorological information that was previously unavailable and which air quality modeling techniques should now put to better use.

2. THE AEROVIRONMENT PUFF PLUME MODEL

Recent improvements of the puff model have taken into account wind shear effect, dynamic plume rise (Sheih, 1978), and the determination of the correct time increment for puff advection and diffusion (Ludwig et al., 1977). This latter problem (puff resolution), together with 1) the determination of the dynamic growing law of the puff σ's, and 2) the treatment of calm conditions, are the main topics of this new proposed puff algorithm.

2.1 The Determination of Δt

In the basic puff method each time interval Δt is characterized by the two following main substeps: 1) generation of a new puff at each source exit, and 2) advection and diffusion of all puffs in the domain. It has been shown (Ludwig et al., 1977) that a string of puffs is a good approximation of a Gaussian plume if 1) the puffs σ's are the same as used for the plume, and 2) the separation between two consecutive puffs is less than their streamwise σ. Unfortunately, this second condition can require, for receptors near the source, a computationally prohibitive Δt of a few seconds for a correct dispersion simulation.

The AVPPM method (Zannetti, 1980) provides a reasonable solution to the above problem. The interval Δt is chosen sufficiently large (e.g., 5 to 10 minutes) so that large computational problems are avoided. However, if required by a receptor's position for the area affected by plume dispersion, the mass of each puff is redistributed by a splitting technique. This artificial generation of puffs is shown in Figure 1 where the puff in A, which contains all the mass of the plume along the segment AB, has actually affected the entire quadrilateral ABB'A' during the interval Δt, $t + \Delta t$. The contribution at a receptor sufficiently distant (#2) is zero, but an accurate computation at the receptor #1 requires splitting the mass in A into a sufficient number of puffs inside the quadrilateral to meet the basic condition of puffs separation distance.

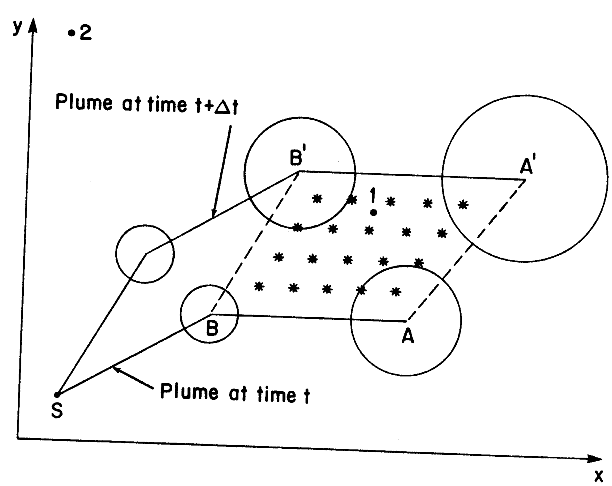

Figure 1. Schematic diagram showing how the mass of a puff can be split inside a quadrilateral (ABB'A') when a receptor position (#1) requires an accurate computation. Each asterisk represents the center of a split puff.

This method does not create serious computer storage and CPU time-consumption problems, since accurate splitting is computed only when required by a few receptor positions.

2.2 Puff Diffusion by σ Increase

At each time step, σ values of each puff increase according to $\sigma(t+\Delta t) = \sigma(t) + [\partial\sigma/\partial d]\Delta d$, where Δd is the downwind distance travelled during $[\Delta t, t+\Delta t]$. Then, unless we assume a very simple linear dependence between σ and the downwind distance, the value of $\partial\sigma/\partial d$ is a function of the total downwind distance d of the puff from the source. But, in non-stationary conditions such as those shown in Figure 2 where the turbulence increases at $t_0 + 3\Delta t$, the actual downwind distance d is not appropriate and must be substituted by the virtual distance d_v (Ludwig et al., 1977) with respect to the virtual source S'.

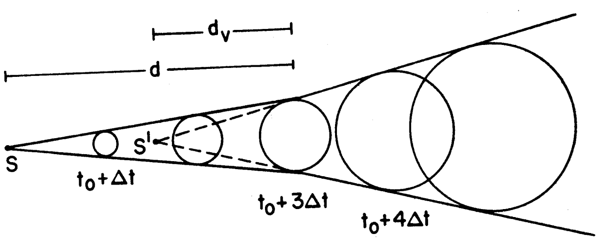

Figure 2. Time evolution of a single puff with a non-stationary change in turbulence at $t_0 + 3\Delta t$. The distances d and d_v refer to the puff at time $t_0 + 3\Delta t$.

This virtual distance is the downwind distance that the same puff, to have the same σ's, would have had to travel from the source if the turbulence state had always been the most recent one during the puff's entire life.

2.3 Calm Conditions

If we assume, for example, that the common power law $\sigma = ad^b$ holds for transport conditions ($u \geq u_{min}$), while the law $\sigma = a'(t - t_0)^{b'}$ holds for calm conditions ($u \leq u_{min}$), then, for $u = u_{min}$, we have $a' = au^b_{min}$ and $b' = b$.

The AVPPM model uses the above semi-empirical method for determining a' and b' to increase the puff σ's in calm conditions ($u < u_{min}$) as a function of the age $t - t_0$ of the puffs. The value u_{min} must be inferred from experimental data (an initial guess can be 1 m/s).

Considerations similar to those of Figure 2 show that, in calm conditions, the actual age of the puffs is not appropriate for the σ computation, and that virtual ages must be used at each change of turbulence state.

3. CONCLUSIONS

This AVPPM puff algorithm has been codified into a computer package. The current version (AVPPM/2A) requires a suitable three-dimensional meteorological input for the computation of the concentration at the receptors. Various options in the code allow different computational modes. In particular, since the code has been developed for both flat and complex terrain applications, the elevation above the ground of the center of each puff is forced, from one time step to the next, to remain within a pre-fixed range to better take into account terrain irregularities. Another characteristic feature is the computation of two vertical σ's, above and below the center of each puff, to better take into account turbulence vertical stratification.

Experimental data are expected to validate this approach, especially the algorithm which allows the treatment of calm conditions. Data are also expected to suggest puff concentration distributions different from the Gaussian one and easily incorporable into the method.

4. ACKNOWLEDGEMENTS

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