United States
Environmental Protection
Agency

Atmospheric Sciences Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S3-85/056 Dec. 1985

EPA

Project Summary

Atmospheric Diffusion Modeling Based on Boundary Layer Parameterization

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The conclusions of a work group are presented in this project summary, outlining methods for processing meteorological data for use in air quality diffusion modeling. To incorporate the proper scaling parameters, the discussion is structured in accordance with the current concepts for the idealized states of the planetary boundary layer. A number of diffusion models are recommended, the choice of which depends on the actual idealized state of the atmosphere. Several of the models characterize directly the crosswind integrated concentration at the surface, thus avoiding, whenever justified, the assumption of a Gaussian distribution of material in the vertical. The goal of this study was to characterize the meteorological conditions affecting the diffusion for transport distances of 10 km or less. Procedures are suggested for estimating the fundamental scaling parameters. For obtaining the meteorological data needed for these estimations, a minimum measurement program to be carried out at a mast is recommended. If only synoptic data are available, methods are presented for the determination of the scaling parameters. Also, methods are suggested for estimating the vertical profiles of wind velocity, temperature, and the variances of the vertical and lateral wind velocity fluctuations.

This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The purpose of this discussion is to outline a set of methods for processing meteorological data for use in diffusion modeling. The emphasis is on those methods considered both physically realistic and numerically efficient.

Most of the early attempts to estimate the diffusion of air pollutants were based on the Gaussian-plume model. These models gave simple rules for obtaining the lateral spread based on wind-direction trace data and suggested that the effects of thermal stratification in the lower atmosphere be represented in broad categories of stability, defined in terms of meteorological data routinely available in surface weather observations.

By the early 1970s, air quality simulation models were viewed as a means of estimating the relative magnitudes of concentration distributions from various sources and thereby providing a rational basis for strategies leading to air quality improvement or maintenance. (Most of the air quality simulation models developed in response to these modeling requirements were based on the general Gaussian-plume model.) Invariably the models were constructed assuming that the dispersive characteristics of the atmosphere were vertically and horizontally homogeneous.

Current concepts regarding the structure of an idealized boundary layer are briefly reviewed, and the basic meteorological variables of interest to diffusion modeling are identified. Methods are proposed for specifying each of these basic variables. The goal is to characterize the meteorological conditions affecting the diffusion for transport distances on the order of 10 km or less over reasonably flat and homogeneous terrain. In this description of turbulence, the effects of clouds and fog are only considered in regard to radiation and surface energy balance. The relationship and importance of the variables to diffusion processes are reviewed.

Results and Discussion

Atmospheric diffusion is controlled by the turbulence in the air. The parameters describing the scales of turbulence are therefore of fundamental importance in a description of atmospheric diffusion. Most air pollution sources emit into the boundary layer, which can be defined as the lower layer of the atmosphere, where the influence of the surface is present due to friction. The character and turbulent state of the boundary layer is strongly affected by the diurnal heating and cooling cycle.

The unstable boundary layer is directly affected by solar heating of the ground. This layer has a very pronounced diurnal variation and typically reaches a height of 1-2 km over land in the summer. For the characterization of turbulence within this layer, three length scales are important: (1) the mixing height, z_i; (2) the height above the ground, z; and (3) the Monin-Obukhov stability length, L. The mixing height, z_i, defines the height above the surface in which pollutants are mixed by presence of turbulence. From these three parameters, two independent dimensionless parameters can be formed. The unstable boundary layer can be divided into several layers defined in terms of these parameters:

- surface layer ($z_o \ll z < \text{Min}(0.1 z_i; -L)$);
- free convection layer ($-L < z < 0.1 z_i$);
- mixed layer ($0.1 z_i < z < 0.8 z_i$ and $z/-L > 1$);
- entrainment layer ($0.8 z_i < z < 1.2 z_i$);
- near neutral upper layer ($0.1 z_i < z < 0.8 z_i$ and $z/|L| < 1$).

Traditionally, the boundaries between the individual layers have not been expressed in the same set of dimensionless parameters. Here, some of the detailed structure that arises from the traditional way of describing the boundaries has been sacrificed. The proposed simplified version in some cases slightly deviates from the viewpoints traditionally held of the boundaries.

The stable boundary layer is created by cooling of the air adjacent to the ground. The depth of the inversion layer, h, is often taken as the height at which the (negative) heat flux has fallen to a certain (low) proportion of its surface value. The study of the stable boundary layer is much less advanced than its unstable counterpart. As buoyancy forces suppress the turbulence under stable conditions, the magnitude of fluctuations generally is very low and consequently difficult to measure. Also the structure of the turbulence is masked by other physical processes, such as gravity waves, drainage and slope flows, intermittent turbulence, and radiation divergence, that are supported in a stable atmosphere. The coexistence of these processes and turbulence complicate the interpretation of the data. No simple relation exists between the depth of the surface inversion, h, and the mixing height, z_i, through which the turbulence exchange processes take place. The depth, z_i, of the turbulent stable boundary layer can become progressively smaller at the same time as the depth of the surface based inversion h grows. The stable boundary layer can be divided into two layers:

surface layer ($z_o \ll z$, $\text{Min}(0.1 z_i; L)$); and

local and z-less scaling region ($\text{Min}(0.1 z_i; L) < z < z_i$ and $z/L < 10$).

Methods are discussed for specifying the surface roughness length, the surface fluxes of sensible heat and momentum, the Monin-Obukhov length, the mixing height, and the inversion height. Following the discussion on the basic state parameters of the atmospheric boundary layer, methods are discussed for estimating the profile of horizontal wind, the profile of temperature, and the profiles of horizontal and vertical standard deviations of the wind speed fluctuations. For each of the seven regimes identified for the unstable and stable boundary layer, methods are presented for estimating the surface concentrations from nonbuoyant releases of nondepositing material.

Conclusions and Recommendations

An outline of methods for processing meteorological data for use in diffusion modeling is presented. To incorporate the proper scaling parameters, the discussion was structured in accordance with current concepts for the idealized states (regimes) of the planetary boundary layer. The goal was to characterize the meteorological conditions affecting the diffusion for transport distances of 10 km or less. The distance to the maximum ground-level concentration is often within this range.

The diffusion is routinely found to be other than Gaussian in the vertical. Therefore, whenever justified, the recommended techniques characterize directly the crosswind integrated concentrations at the surface. For elevated releases within the near neutral upper layer or in the stable local scaling region, use of the Gaussian-plume model is recommended, where the dispersion parameters are estimated using statistical methods. Little is known regarding diffusion within the entrainment layer.

A special complication in the use of the suggested methods arises when the proper state of the diffusion process is at the border line between two regimes, in which, there is a jump in estimated concentration dependent on which regime is chosen. No procedures have been devised to avoid these jumps in calculated concentration.

For obtaining the meteorological data needed for estimating the fundamental meteorological scaling parameters, a measurement program is presented. The measurements should be carried out at a mast. The upper measurement level should be at a height $100 z_o$, but not less than 10 m. The lower measuring level should be at $20 z_o$, but not less than 1 m. Here, z_o is the *effective* surface roughness length. Also discussed in this report are methods for determining the fundamental scaling parameters if ony synoptic meteorological data are available.

It is anticipated that the suggested characterizations of the diurnal variation of the wind speed and direction profiles are too simplistic and will need further development. Furthermore, the turbulence profiles are highly idealized as the assumption is made that above the mixed layer, the turbulence is negligible. To complete the development of a meteorological processor, the methods outlined should be tested using available data. With the test results, future research can focus on those estimation methods requiring the greatest improvement and on developing methods to characterize the spatial variations in the meteorological variables.

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The complete report, entitled "Atmospheric Diffusion Modeling Based on Boundary Layer Parameterization," (Order No. PB 86-103 660/AS; Cost: $11.95, subject to change) will be available only from:

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EPA/600/S3-85/056