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Project Summary

Analytical Solutions of a Gradient-Transfer Model for Plume Deposition and Sedimentation

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The air pollution literature was reviewed for methods to incorporate dry deposition in a Gaussian plume model. A gradient-transfer or K-theory model for the atmospheric transport and ground deposition of gaseous and particulate pollutants emitted from an elevated continuous point source is outlined. This analytical plume model treats gravitational settling and dry deposition in a physically realistic and more straightforward manner than other approaches. For practical application of the model, the eddy diffusivity coefficients in the analytical solutions are expressed in terms of the widely used Gaussian plume dispersion parameters.

This Project Summary was developed by EPA's Environmental 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

Pollutant gases and suspended particles released into the atmosphere are transported by the wind, diffused and diluted by turbulence, and removed by several natural processes. An important removal mechanism is dry deposition on the earth's surface by gravitational settling, eddy impaction, chemical absorption, and other processes. Dry deposition of airborne pollutants affects their concentrations and residence times. Moreover, dry deposition of acidic and toxic pollutants may adversely impact the local ecology, human health, organisms, structures, and ancient monuments. It is important therefore, to obtain reliable estimates of dry deposition and its effects.

In this study, the air pollution literature was reviewed for methods to incorporate dry deposition in a Gaussian plume model. A gradient-transfer or K-theory model for diffusion and dry deposition of gaseous and particulate pollutants from an elevated continuous point source was formulated. The model was applied to study two deposition case types. The ground-level concentrations predicted by the model were compared with corresponding results from a source depletion model. A field study to measure one or more of the model parameters was proposed.

Conclusions

An atmospheric transport and deposition model for gaseous or suspended particulate pollutants emitted from an elevated point source was formulated. This analytical model, based on gradient-transfer or K-theory, treats gravitational settling and dry deposition in a more physically realistic and straightforward manner than the usual tilted-plume source depletion approach. Essentially the method consists of solving the atmospheric advection-diffusion equation subject to a radiation boundary condition that equates the sum of the turbulent flux and the gravitational settling flux to the pollution deposition flux at the surface. Though several analytical solutions of this problem are available in the air pollution literature of the past two decades, the approach has not been widely used. This may be attributed to the complexity of the available solutions, and the usual difficulty in specifying the eddy diffusivity (K) coefficients under different atmospheric stability conditions. In the model developed in this study, the K coefficients in the analytical solutions are expressed in terms of the widely used Gaussian plume dispersion parameters, which are functions of downwind distance and stability class. This allows one to utilize the vast amount of empirical data on these parameters, for a variety of diffusion conditions, within the framework of the standard turbulence-typing schemes.

In order to facilitate comparison of results from different models, the new diffusion-deposition algorithms for stability and mixing conditions are presented as analytical extensions of the well-known Gaussian plume diffusion algorithms presently used in EPA models. In the limit when settling and deposition velocities are zero, the new algorithms reduce to the current Gaussian plume equations. Thus the atmospheric transport and deposition model outlined here retains the ease of application, and is subject to the basic assumptions and limitations, associated with Gaussian plume type models.

The parameterized deposition model was applied to study two important deposition cases: (1) pollutant particles having an appreciable settling velocity that is equal to the dry deposition velocity, and (2) gases or fine suspended particles that deposit on the ground without significant settling. The variations with downwind distance of ground-level concentrations, vertical concentration profiles, surface deposition fluxes, and net deposition and suspension ratios were obtained. Deposition velocity and atmospheric stability had significant effects on these results.

Four types of Gaussian diffusion-deposition models were briefly reviewed, and the ground-level concentrations predicted by the present analytical gradient-transfer model have been compared with corresponding results from the source depletion model. A systematic comparison of the performance of the various models has not been done and none of them has been satisfactorily tested against observations. General statements on the relative merits and deficiencies of these models are, at present, somewhat subjective, and largely rely on the key physical assumptions used in the model formulations and on the complexity of the methods.

A field study is proposed to measure one or more of the model parameters, and to obtain a good data set for model validation over a distance of at least 10 km from the source. The proposed study, based on a modified Bowen ratio-turbulent variance approach that avoids the difficulties associated with the well-known vertical gradient and eddy-correlation methods, will provide needed data on mean concentrations, ground deposition flux, and deposition velocity.

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The complete report, entitled "Analytical Solutions of a Gradient-Transfer Model for Plume Deposition and Sedimentation," (Order No. PB 82-215 153; Cost: $11.50, subject to change) will be available only from:
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