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Project Summary

ROADWAY—A Numerical Model for Predicting Air Pollutants Near Highways: User's Guide

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ROADWAY is a finite-difference model which solves a conservation of species equation to predict pollutant concentrations within two hundred meters of a highway. It uses surface layer similarity theory to predict wind and eddy diffusion profiles from temperature at two heights and wind velocity upwind of the highway. A unique feature of the model is its use of vehicle wake theory. It is assumed that vehicle wakes affect the wind and turbulence fields in a linear manner with wake intensity a function of vehicle speed, downwind distance, and distance from the wake center. The user has the option of considering NO, NO_2, and O_3 chemical reactions near the road. Output from the model consists of x-z fields of wind components, eddy diffusion coefficients; and concentration of pollutant.

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

ROADWAY is a numerical model for predicting air pollution levels near highways. It solves a conservation of species equation via finite-difference approximations. Temperature at two heights and wind velocity upwind of the highway are required. With these inputs, surface layer similarity theory is used to produce wind and turbulence profiles. A unique aspect of ROADWAY is its treatment of vehicle wakes which are superimposed linearly on the wind and turbulence fields. The vehicle wake intensity is a function of vehicle speed, downwind distance, and distance from the wake center. Additionally, the user has the option of considering NO, NO_2, and O_3 chemistry; reactions of these pollutants are calculated by a two-step mechanism applicable to the very near field. Output from the model consists of fields in the x-z plane for wind components, eddy diffusion coefficients, and concentrations of four pollutant species.

To estimate concentrations for any simulated hour, information on meteorology, highway configuration, and emissions are required. The meteorological information needed for the computation includes representative roughness length, temperature at two heights upwind of the highway, and hourly average wind speed and direction at the level of the upper temperature sensor. If the chemistry option is exercised, two photochemical reaction rate constants, background for each species, and conversion factors (gm/sec to ppm) are also required.

Since ROADWAY is a numerical model, it has none of the limitations generally associated with Gaussian algorithms. That is,

- it is a multilayer model which considers vertical variation of both wind and diffusivity,
- it can treat calm or light wind conditions, and

- it can simulate chemical reactions of the emitted pollutant species.

Also, the model can include up to ten traffic lanes and has features to reduce execution costs (at the expense of accuracy) and to provide intermediate output. ROADWAY was developed independent of tracer data, and has been demonstrated to perform as well as other highway models currently available.

ROADWAY has several limitations. A major restriction of the model is the requirement that the vehicle speed be much greater than the wind speed. This requirement, however, should be met in most instances of significant pollutant impacts. More importantly, the model is valid for all vehicle speeds when wind speeds are light. Another limitation is that ROADWAY does not consider wind meander which becomes important when the mean wind is parallel to the highway. Also, because its use is restricted to the very near field (within 200 m of the roadway), other algorithms would be better suited for calculating impacts at longer distances. Finally, since ROADWAY algorithms are numerically solved, computer execution costs are greater than those of algorithms based on the Gaussian simplification.

Discussion

The diffusion equation derived from a statement of the conservation of mass or species, forms the basis for the ROADWAY computational system. This equation is one of three partial differential equations used to describe distributed parameter systems otherwise known as fields.

The conservation of species equation (i.e., a diffusion equation), is used to predict pollutant concentration fields near highways. The finite-difference method used in ROADWAY represents the time-space continuum by a set of discretely spaced points, the grid produced by these points is not evenly spaced upon the field in ROADWAY since higher resolution is needed near the road and lesser away from it. An algebraic equation approximating the partial differential equation is derived for each grid point. The solution is found by solving these equations for all points in the grid after applying boundary conditions and initial values to the field. Since ROADWAY is a numerical model, it has none of the limitations of Gaussian solutions to the diffusion equation. That is,

- ROADWAY is a multilayer model which considers vertical variation of both wind and diffusivity,
- it treats calm or light wind conditions, and
- optionally computes chemical reactions of source pollutant species.

As mentioned previously, ROADWAY requires a reduced meteorological input data set. Realistic wind and turbulence profiles can be calculated using surface layer similarity theory. The model was developed on theoretical grounds and using wind tunnel experiments and is independent of tracer studies. It, nevertheless, performs as well as the most accurate highway models today. Up to ten traffic lanes can be simulated. The model can provide intermediate output and, at the expense of accuracy, has features to reduce execution costs.

Since the algorithms of ROADWAY are solved by a computer, the calculations are subject to truncation and roundoff errors. In the context of numerical analysis, truncation errors occur in approximating infinite series by a finite number of terms. Roundoff errors, on the other hand, are machine-dependent and occur because computations are done on the precision of a computer which introduces errors by the dropping off of digits. Another source of error is that related to computational instability. In solving the conservation of species equation, both the time and space variables must be discretized by means of finite-difference expansions. A small error made at one time step of the calculation can result in a larger error at a later time resulting in unbounded error growth. A segment of the ROADWAY code tests conditions to ensure that calculations remain stable.

A model limitation is that the vehicle speed must be much greater than the ambient wind speed. Considering usual freeway speeds and meteorological scenarios where significant pollutant impacts would occur, this may not be a limitation. More importantly, the model is valid for all vehicle speeds when winds are light which is when Gaussian approaches breakdown. ROADWAY does not consider wind meander; this becomes important when the mean wind is nearly parallel to the highway. The use of ROADWAY is restricted to the very near field-within two hundred meters of the roadway, beyond two hundred meters meteorological processes that are not accounted for in the model become important.

Another limitation is costs related to computer execution. Being a numerical model, ROADWAY is relatively expensive to run when compared to Gaussian-based models. Execution time using the chemistry option is on the order of 10 CPU minutes on a DEC VAX-11/780. ROADWAY implementation on a personal computer is entirely possible and execution costs in this environment would be much less.

Due to its applicability in only the near field and because of execution expense, ROADWAY is recommended for use in conjunction with a Gaussian model such as HIWAY-2.

Data Requirements

To estimate concentrations for any simulated hour, data for program control, as well as information on meteorology, highway configuration, and emissions are required.

The user must indicate whether the following features are to be employed:

- chemistry option,
- antidiffusion calculation option, and
- intermediate print option.

The meteorological information needed for the computations are:

- roughness length (m),
- temperature at two heights upwind of the high (K), and
- hourly average wind speed (m/sec) and direction (degrees).

The following highway configuration data are required:

- number of traffic lanes,
- width of each lane (m),
- width of the traffic median (m),
- angle between highway and a line running north-south (degrees),
- traffic volume,
- average vehicle speed (km/hr), and
- average vehicle dimensions (m)

The user must supply the following ai quality and emission data for each hou of simulation:

- background pollutant concentration (ppm),
- vehicle emission rates (g/km.veh) and
- factor to convert grams per secon (gm/sec) to parts per million (ppm for the pollutant.

If the user exercises the chemistr option, then background concentrations vehicle emission rates, and conversio factors must be provided for nitroge oxide (NO), carbon monoxide (CO), an nitrogen dioxide (NO_2). Also, the back ground ozone (O_3) must be given.

No sampling grid or receptor informa tion is required since both are internal generated by the model. The concentra tion output is in the form of x-z fiel which define a plane perpendicular the highway.

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The complete report, entitled "ROADWAY—A Numerical Model for Predicting Air Pollutants Near Highways: User's Guide," (Order No. PB 87-171 906; Cost: $18.95, subject to change) will be available only from:
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