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Project Summary

EPA Complex Terrain Model Development: Fifth Milestone Report - 1985

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The Fifth Milestone Report documents work accomplished on the EPA Complex Terrain Model Development project from June 1984 through May 1985, and describes in detail the August 1984 Full Scale Plume Study (FSPS), including its setting, the experimental design, and the resulting data base. The FSPS produced a 128-hour data set of SF_6 and CF_3Br concentrations, ground-based and airborne lidar measurements, photographs, 8-mm movies, videotapes, and extensive meteorological data. The highest ten SF_6 and CF_3Br concentrations and a modeling analysis of 14 hours are discussed in the milestone report.

The milestone report presents a variety of modeling and analyses using the Cinder Cone Butte (CCB), Hogback Ridge (HBR), and FSPS data bases. For example, the HBR data have been used to show that the path of the oil-fog plume centerline was predicted well by assuming the layer of air below the dividing streamline was "dead" and by incorporating the effects of temperature stratification. Boundary layer similarity relationships were shown to simulate satisfactorily the winds and temperature measured at CCB and HBR up to an altitude of about 10L (ten times the Monin-Obukov length). The report also discusses the highest ground-level tracer concentrations measured at the CCB, HBR, and FSPS sites. The meteorological characteristics of the concentration events and the differences among the sites are discussed.

The further development of the Complex Terrain Dispersion Model (CTDM) is described, and mathematical descriptions of the modifications to the model are presented. The latest version of the model has been tested using a subset of impingement hours from the CCB, HBR, and FSPS data bases. The initial 14-hour FSPS data base was also used to test four existing complex terrain models—COMPLEX I and II, Valley, and RTDM.

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 Complex Terrain Model Development (CTMD) project is being sponsored by the U.S. Environmental Protection Agency (EPA) to develop, evaluate, and refine practical plume models for calculating ground-level air pollutant concentrations that would result from emission sources located in hilly or mountainous terrain. The primary objective of the project is to develop models to simulate 1-hour average concentrations during stable atmospheric conditions.

The CTMD project was begun in June 1980. Four major field experiments have been completed during the last five years to collect data for development and evaluation of various modeling approaches.

The first field experiment, Small Hill Impaction Study No. 1 (SHIS #1), was conducted during the fall of 1980 at Cinder Cone Butte (CCB), Idaho. CCB is a roughly axisymmetric, isolated 100-m tall hill located in the broad Snake River Basin near Boise, Idaho. SHIS #2 was performed during October 1982 at the Hogback Ridge (HBR) near Farmington, New Mexico. HBR is a long, 90-m tall ridge located on the Colorado Plateau near the western slopes of the San Juan Mountains. Both small hill studies consisted of flow visualization and tracer experiments conducted during stable flow conditions with supporting meteorological, lidar, and photographic measurements. At these sites the tracer gases were released from mobile cranes or a tower.

The third and fourth field experiments were conducted at the Tracy Power Plant (TPP) located next to the Truckee River east of Reno, Nevada. The third experiment, performed in November 1983, was undertaken as a feasibility and design study for the Full Scale Plume Study (FSPS). It was cosponsored by the Electric Power Research Institute (EPRI). The November experiment not only demonstrated the feasibility of conducting the FSPS at the TPP, but with the expanded scope made possible by EPRI's participation, it also produced a data base that is useful for modeling purposes. The FSPS was performed at Tracy in August 1984.

The data bases compiled from the CCB, HBR, and November Tracy experiments are available from the EPA Project Officer. The FSPS data base will be available in late 1985. The data bases compiled from each of the experiments include the following components:

- Source information: emission rates, locations, and heights of SF_6, CF_3Br, and oil-fog releases
- Meteorological data: measurements of the approach flow as well as information on flow and dispersion near the terrain
- Tracer gas concentrations: data from more than 50,000 individual samples collected during the experiments from as many as 100 sampler locations in each experiment
- Lidar data: sections across the plume characterizing the trajectory and growth of the plume upwind of, interacting with, and sometimes in, the lee of key terrain features
- Photographic data: still photographs taken from fixed locations, aerial photographs taken at CCB and Tracy from an aircraft flying overhead, and (occasional) 16-mm and 8-mm movies and videotapes

During the course of the CTMD project, four Milestone Reports (Lavery et al. 1982; Strimaitis et al. 1983; Lavery et al. 1983; and Strimaitis et al. 1984) have been published. These reports (EPA-600/3-82-036, EPA-600/3-83-015, EPA-600/3-83-101, and EPA-600/3-84-110), which are available from EPA, describe the progress in developing and evaluating complex terrain models using the CCB and HBR data bases. They also describe in detail the two small hill studies, the November Tracy study, and a series of towing tank and wind tunnel studies performed at the EPA Fluid Modeling Facility in support of the modeling.

This current phase of the CTMD project will end in December 1986. An initial, partially validated model, will be delivered to the Project Officer by October 1, 1985. A workshop will be held in early 1986 to present results from the field experiments, model development activities, and related work conducted both within and outside the CTMD project to the scientific community. The final stable plume impingement model(s) will be delivered in late 1986. A project report will be published in December 1986.

Principal Accomplishments

Refinement of the HBR Meteorological Data Base

The refinement of the meteorological data collected during SHIS #2, which involved the filtering and flagging of the raw 1-s counts data to reduce the effects of noise on the calculated measurements, is now complete. Corrections were also made on the basis of the audit results and the cosine response characteristics of the fixed propeller anemometers. Five-minute and one-hour averaged values of meteorological measures were calculated from the corrected and flagged 1-s data. The success of the refinement efforts is demonstrated by the improvement in consistency between collocated measurements.

HBR Streamline Analysis

Lidar data collected at HBR have been used to compare streamline heights upwind and over the crest of HBR to calculations from potential flow theory and from a linearized perturbation analysis. The comparisons suggest that for releases above the dividing streamline height (H_c) at HBR a substantial portion of the streamline deflection near the crest can be explained by potential flow of the air above H_c over a cylinder. This approach assumes the terrain is "cut-off" below H_c. The perturbation analysis shows some improvement in the simulation of the streamline height when stratification is included in the calculations.

Representativeness of Stable Boundary Layer Similarity Theory

Modeling the dispersion of an elevated plume requires meteorological data representative of plume height. Since this information is not always available, it is useful to consider if near-surface measurements can be used to infer information at plume elevations. This issue was addressed by using stable boundary layer similarity relationships to predict wind and temperature data at 40 m and 150 m from data obtained to 10 m and 2 m. The predictions were compared to measurements taken at CCB and HBR. The results indicate that the similarity relationships reproduce the observations fairly well to elevations less than about 10 L. Above 10L the predictions have little reliability. Since L is typically a few meters during stable conditions, near-surface measurements will not be useful for estimating meteorological conditions above about 50 m. Most major sources generate plumes the equilibrium heights of which are well above 50 m. Therefore, proper modeling of these sources will require meteorological data collected on tall towers or via acoustic sodar.

Investigations of Vertical Plume Growth

CTDM uses the expression

$$\sigma_z = \frac{\sigma_w t}{\left(1 + \frac{t}{2T_L}\right)^{0.5}}$$

to simulate the vertical diffusion of an elevated plume, where σ_w is the standard deviation of vertical velocity fluctuations, t is the travel time, and T_L is the Lagrangian time scale. Hourly-average lidar data from 14 FSPS impingement hours were used to perform an initial evaluation of the expression for σ_z. In particular, the evolution of σ_z after plume rise was investigated.

The initial growth (σ_{zb}) of the plume due to entrainment associated with its buoyant rise was estimated from the hourly-averaged lidar scan made in the vicinity of the stack, once the plume had leveled. Typically, σ_{zb} was measured at a distance of 700 m from the stack. The lidar scans taken downwind of this distance were then used to evaluate the subsequent growth of σ_z.

The observed values of σ_z beyond σ_{zb} suggest that the model for T_L and σ_z overestimates the lidar measurements of vertical plume growth. This tendency of the observed plume growth to be overestimated could be the result of modeling T_L incorrectly, not screening out the wave contribution to σ_w, or not accounting for a collapse of the plume in the vertical after plume rise. None of these possibilities has been investigated in detail.

An Analysis of the Highest Ground-Level Concentrations Observed at CCB, HBR, and the FSPS

The ten highest SF_6 and CF_3Br concentrations observed at CCB, HBR, and Tracy were presented to illustrate the associated meteorological conditions. The distributions of the tracer concentrations and the lidar and photographic data support the concept of a critical dividing streamline that separates stable air flow into two layers. At CCB the highest concentrations were observed most often when the tracer gas was emitted at an elevation near the calculated dividing streamline height. At the HBR, the highest concentrations were observed when the tracer gas was released below H_c. Evidently, at a long ridge setting like HBR, the flow below H_c is impeded by the ridge, thereby giving the tracer gas an opportunity to impinge on its windward side. At both sites, tracers released above H_c tended to flow over the terrain, and the higher concentrations were produced near the top or on the lee side.

Initial analysis of the Tracy data base suggests the full-scale site exhibits dispersion characteristics similar to both small scale sites. For the hours with the ten highest SF_6 concentrations, five have estimates of the plume height. All five plume heights (or effective release heights) are near the calculated height of the dividing streamline.

The Complex Terrain Dispersion Model

Over the last year, the major revisions to CTDM included the following:

- a generalization of the treatment of terrain so that now hills are simulated by ellipses in horizontal cross sections;
- a reformulation of WRAP (the component of CTDM that simulates horizontal flows below H_c) to simulate the effects of travel time on vertical plume growth; and
- changes to LIFT (the model component that simulates transport up and over the terrain) to simplify the treatment of the horizontal deflection of the plume, to include an estimate of how the turbulence changes over the hill, and to accommodate hills with horizontal cross sections that are elliptical in shape.

Upcoming revisions to the model are also discussed in the milestone report.

The current version of CTDM has been tested using a subset of "impingement" hours from the CCB and HBR data bases and 13 hours from an initial 14-hour data set from the FSPS. A comparison of the modeled concentrations with the values observed at CCB suggests a reduction in the tendency of the model to overestimate the observed concentrations. The model simulates the HBR concentrations reasonably well.

CTDM underestimates the concentrations measured during the FSPS although many (7 of 13) are within a factor of two. This tendency toward underprediction arises primarily from the size of the computed hourly values of σ_y and σ_z, and not from the impingement assumptions.

The Semi-empirical HBR Model

A simple plume model in which the horizontal distribution of tracer gas is determined by a probability distribution function (PDF) developed from wind direction observations, and in which wind speed is associated with wind direction as well, was applied to a subset of CF_3Br cases from HBR. This model simulated the observed concentrations reasonably well (i.e., $m_g \simeq 1.0$ and $s_g < 2.0$).

Comparative Model Evaluations Using the 14-Hour FSPS Data Base

Valley, COMPLEX I and II, and RTDM were run using the 14-hour FSPS data set. CTDM was run for 13 of these hours in which the primary plume impact is on "Beacon Hill." Valley and COMPLEX II substantially overestimate the observed SF_6 concentrations.

The average top-two COMPLEX I concentrations are in fair agreement with the average top-two observed concentrations paired hourly. The average top-two residuals indicate that COMPLEX I overpredicts for 11 of the case-hours. The ratio of the maximum observed to predicted concentrations indicate that 10 of the case-hours lie within a factor of two.

RTDM was first run with the hourly values of the vertical and horizontal components of the turbulence intensity estimated at plume height to calculate σ_y and σ_z. The average top-two concentrations underpredict the observations for all case-hours. The ratio of the maximum observed to predicted concentrations indicate that none of the case-hours lie within a factor of two.

RTDM was then tested with its default Briggs rural (ASME, 1979) dispersion coefficients. The top-two average predicted concentrations are now much larger than those predicted from RTDM's algorithm that uses the measured turbulence data. The ratios of the maximum observed to predicted concentrations indicate that six of the case-hours now lie within a factor of two.

Again, CTDM was run using 13 hours of the initial FSPS data base. The averages of the highest two modeled concentrations for each hour underestimated the observations. Seven of the modeled concentrations were within a factor of two of the observations.

Recommendations for Further Study

Data Analysis and Model Formulation

High priority will be given to expanding the analysis of the vertical growth of the Tracy plume because it is apparent that a proper specification of σ_z (and σ_y) is critical to modeling concentrations at Tracy. More hours, including a wider range of meteorological conditions, will be included. It is particularly important to provide as complete a description of the effects of waves, as possible.

Other topics to be investigated include the following:

- the effects of averaging time and time-of-travel on ground-level concentrations,
- the algorithm for calculating the terrain effects factors in CTDM,
- the algorithm that simulates the region around and the variability of H_c, and
- the formulation of a PDF version of CTDM.

Once the modifications to the model are complete, CTDM will undergo a systematic series of sensitivity studies. These will help identify the conditions in which the terrain effects contained in CTDM have the greatest and least impact on the magnitude of the ground-level concentrations. The effects of uncertainties of the model input data on concentrations will also be analyzed. These will include direct input (wind speed, etc.), the various terrain parameters, and the location of the meteorological tower.

An analysis of the FSPS data will be undertaken to provide a description of the observed flow throughout the experiment area. The behavior of the visible plume from the Tracy stack and the corresponding tracer-gas concentrations measured at the ground will be characterized as a function of area-wide meteorological measurements. This analysis will serve to identify the roles of the upper-level flow and the local drainage flow in determining the character of the flow and turbulence in the valley.

Development of FSPS Meteorological Data Base

Because the height of the SF_6/oil-fog plume at Tracy was often greater than 150 m, and because the flow in the Truckee Valley was sheared at these elevations in very stable conditions, meteorological data relevant to the plume will have to be derived for many periods from measurements made by tethersonde, Doppler sodar, and rabals. The different characteristics of the measurement systems and the representativeness of the data imply that the development of a Modeler's Data Archive for FSPS will be somewhat more complex than those for CCB and HBR.

The audit of the meteorological tower systems indicated that the quality of data from these instruments is excellent and no major noise problems have been discovered. The principal effort in the refinement of these data will be the correction of the averaged speeds and directions from UVW propellers for non-cosine response.

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The complete report, entitled "EPA Complex Terrain Model Development: Fifth Milestone Report—1985," (Order No. PB 86-167 350/AS; Cost: $28.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
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