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Project Summary

Dispersion in Complex Terrain: A Report of a Workshop Held at Keystone, Colorado, May 17-20, 1983

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Since 1979, the American Meteorological Society has collaborated with the Environmental Protection Agency through a cooperative agreement to improve the scientific basis of air quality modeling. Under this continuing agreement, the American Meteorological Society conducted a workshop on dispersion in complex terrain held in Keystone, CO, during May 17-20, 1983. The purpose of the workshop was to encourage atmospheric scientists working in the area of complex terrain dispersion modeling to exchange recently acquired information on atmospheric processes in mountainous terrain and to make recommendations regarding the present application of air quality models to complex terrain settings and the research necessary to meet future needs.

The workshop report contains the thoughts and judgments of 32 atmospheric scientists who gathered to exchange technical information and research results on atmospheric processes in complex terrain and to comment on matters relating to adjustments in current air quality modeling practices.

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 presence of mountainous terrain introduces significant complexities in the atmospheric transport and diffusion processes affecting ambient air quality concentrations in a given area. Terrain acts to distort otherwise organized flow patterns, resulting in the creation of regions of converging and diverging flows, enhanced shear effects, and turbulent eddies. These alterations affect, to a large degree, flow trajectories and ambient turbulence levels. Terrain also determines the development of local circulations in mountain-valley settings. The net effect on air pollution concentrations depends critically on the specific geometric and topographic relationships and on the characteristics of the flow fields. For similar source sizes and release heights, emissions from an air pollution source located in complex terrain may result in concentrations on nearby high terrain several times larger than the maximum ground-level concentration expected in the absence of the high terrain.

Similarly, stagnation effects in confined valleys can result in the buildup of concentrations much higher than those which would be observed under similar large-scale meteorological conditions over flat terrain. For these reasons, the prediction of air quality concentrations in regions of complex terrain has remained a key area of concern regulatory agencies, and methods for quantifying atmospheric dispersion processes have received considerable attention over the past several years.

A workshop on dispersion in complex terrain was convened by the American Meteorological Society under a cooperative agreement with te U.S. Environmental Protection Agency. Its purpose was to encourage atmospheric scientists working in this area to exchange recently acquired information on atmospheric processes in complex terrain and to make recommendations regarding the present application of air quality models to complex terrain settings and the research necessary to meet future needs.

Conclusions

This section summarizes the major conclusions of the workshop participants concerning the present state-of-understanding of dispersion in complex terrain.

A. *Interaction of Elevated Plume with Windward-Facing Terrain Features*

The largest ground-level concentrations associated with elevated release near terrain rising above plume height are often associated with stable atmospheric conditions. The dynamics of the air flow depend on the Froude number of the upstream flow based on hill height. A related parameter, the dividing or critical streamline height, appears to separate vertically a flow regime that can transport a plume up and over a terrain object from a flow regime that constrains plumes to stagnate or to pass around the sides of a terrain feature. Verification of these above concepts has emerged from physical modeling efforts for a variety of terrain shapes and from field measurement results. Mathematical models are presently being refined to accommodate these situations. Further verification is needed, however, for various scales of terrain geometries.

B. *Turbulent Dispersion Rates in Regions of Complex Terrain*

Atmospheric turbulent dispersion rates in complex terrain can often be expected to exceed those over flat terrain with otherwise similar conditions. This is especially true under stably stratified conditions, resulting from presence of gravity-driven drainage flows, gravity waves, production of shear from flow deformation, and creation of eddies from upwind terrain features. The effect on ground-level concentrations depends on the specific source-receptor geometry.

C. *Lee Side Effects*

The flow on the lee side of terrain features can, under certain conditions, also cause high ground-level concentrations. During neutral conditions, flow "separation" can occur on leeward slopes, causing poor ventilation of emissions from lee side sources within the wake cavity region. Under stably stratified conditions, streamlines passing over the crest may pass closest to the surface on the leeward side. This could give rise to highest ground-level concentrations on the lee side from plumes originating upwind of a terrain feature. No widely accepted models exist for these situations.

D. *Valley Situations*

A number of air pollutions phenomena are associated with the constraints on ventilation that valleys impose or with the gravity-driven local flows created by valley side walls. The most severe effects are the occurrence of multi-day air pollution episodes within deep valleys during periods in which high pressure systems stagnate over a region. Mathematical models for air pollution applications in deep valleys are in the developmental stage at the present time.

E. *Physical Modeling Capabilities*

The use of physical modeling principles with wind tunnels and towing tanks has increased markedly over the past several years. These techniques allow systematic investigations of flow situations under controlled conditions not practically achievable with field studies. Properly interpreted, the results of these tests add substantially to the understanding of phenomena. Limitations remain for the study of two-dimensional terrain feaures under stable conditions and in the spectral range of turbulence, which can be simulated.

F. *Mathematical Modeling Capabilities*

As new information emerges from theoretical efforts, physical modeling, and field experiments, better and more refined mathematical models are being developed that simulate many of the phenomena, although no model as yet can simulate all of the phenomena for a given setting. The verification of models is difficult due to the general lack of extensive data bases. The trend of lower computer costs will encourage the development of more advanced models capable of using more extensive input data.

Recommendations

The following section summarizes the major recommendations of the workshop participants regarding use of the science and needs for further research and development.

A. The workshop participants supported the approach by current major research efforts in gathering field and laboratory experimental data for ultimate use in developing better mathematical models.

B. A need to quantify uncertainty in model predictions was identified, with the recognition that more information about flow conditions is needed to estimate mean values from deterministic models.

C. Participants believed that the dispersion of pollutants in complex topography involves interactions of air flows and terrain structure leading to certain natural fluid dynamic time and space scales that are not necessarily as important in simpler (e.g., flat) terrain problems. If such time scales are larger than the averaging time of application interest, estimates of concentrations by deterministic models would contain larger uncertainties. Thus, it was suggested that the stochastic nature of the phenomena be recognized and accepted by those developing or applying models for these circumstances.

D. The meteorological input data needs for complex terrain models are greater than those required for level terrain models. Specific requirements for vertical profiles of temperature and velocity emerge from the need to estimate Froude numbers and dividing streamline height. On-site turbulence measures were also identified as being especially appropriate for complex terrain modeling efforts.

E. The workshop participants identified a number of specific technical areas needing further research to advance our ability to predict ground-level concentrations of pollutants in complex topography. Table 1 lists the topics in summary fashion and identifies the status of available observational data, physical conceptualizations, and modeling efforts. The order of topics in this list does not signify the order of the priorities.

Table 1. Recommended Future Research Topics

Topic	*Hypotheses or Subcomponents to be Tested*	*Data Gathering Status/Needs*	*Physical Model Status/Needs*	*Mathematical Modeling*
Stable Plume Impaction	Dividing Streamline Height; Scales of Applicability	Data Available or Scheduled to Be Gathered	Partially Accomplished	Some Accomplished
Effects on Lee Side Sources	*Downwash; Dividing Streamline Height*	*Field Data Needed*	*Some Accomplished*	*Development Needed*
Fumigation in Complex Terrain	*Boundary Layer Depth; Turbulence Characteristics*	*More Field Data Needed*	*Modeling Needed*	*Some Accomplished*
Stagnant Air Masses within Valleys	*Interaction of Boundary Layer with Free Atmosphere; Sloshing and Net Ventilation Rates*	*Field Data Not Yet Needed*	*More Modeling Needed*	*More Development Needed*
Convective Flows in Complex Terrain	*Interaction of Boundary Layer with Slopes*	*Field Data Not Yet Needed*	*Exploratory Modeling Needed*	*Some Accomplished*
Mesoscale Transport	*Flow Field Models; Boundary Layer Depths*	*More Data Needed*	*Not Applicable*	*Some Accomplished*
Coastal/Complex Terrain Interface	*Boundary Layer Depths; Data Representativeness*	*Field Data Not Yet Needed*	*Modeling Needed*	*Modeling Needed*

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The complete report, entitled "Dispersion in Complex Terrain: A Report of a Workshop Held at Keystone, Colorado, May 17-20, 1983," (Order No. PB 86-122 694/AS; Cost: $11.95, subject to change) will be available only from:

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