United States
Environmental Protection
Agency

Atmospheric Sciences
Research Laboratory
Research Triangle Park, NC 27711

Research and Development

EPA/600/S8-88/004 Mar.1988

EPA

Project Summary

User's Guide to the CTDM Meteorological Preprocessor (METPRO) Program

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The Complex Terrain Dispersion Model (CTDM) is a refined air quality model for use in stable and neutral conditions in complex terrain applications. Its use of meteorological input data and terrain information is different than current EPA models; considerable detail for both types of input data are required and are supplied by preprocessors specifically designed for CTDM. This User's Guide presents a review of the structure of the atmospheric boundary layer and its implications for the design of CTDM and its meteorological preprocessor (METPRO). The CTDM meteorological preprocessor calculates required meteorological variables that are derived from conventionally available data. These required variables include the Monin-Obukhov length, the surface friction velocity, the surface roughness length, and the mixed layer height. The CTDM input data files contain these values as delivered by the meteorological preprocessor.

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 requirement for use of meteorological information in CTDM is based upon the current understanding of the Atmospheric Boundary Layer. A discussion of the design of the meteorological preprocessor,METPRO, and its linkage with CTDM is accompanied here by a summary of the features of the boundary layer and how they relate to plume dispersion calculations.

The Atmospheric Boundary Layer lies between the earth's surface and the geostrophic free atmosphere, in which surface effects upon the flow are negligible. The boundary layer can be considered to contain two distinct layers: the surface layer near the ground, capped by a mixed layer.

The nocturnal "mixed" layer features low turbulence levels and, often, laminar flow, so the term "mixed" is misleading. It is used here to mean the layer above the surface layer, a usage consistent with the daytime case. The surface layer is dominated by the frictional force and horizontal shear stress near the ground. The horizontal stress is caused by the drag of friction-retarded air molecules on faster-moving air molecules at higher levels. The depth of the surface layer, h, is defined to be the height above the ground through which the magnitude of the shear stress is approximately constant (varies by no more than about 10%). Other properties of the surface layer that are useful for modeling purposes are:

- vertical fluxes of heat and momentum that are nearly constant with height, and
- steady-state and horizontally homogeneous temperature and velocity fields.

These assumptions allow the vertical structure of the surface layer to be parameterized by similarity theory, developed for this purpose by Monin and Obukhov.

Similarity theory assumes that the vertical fluxes of heat, momentum and moisture are approximately constant throughout the surface layer. The resulting turbulence of the flow within the surface layer is solely determined by the mean temperature, T, the friction velocity, u^* (derived from the vertical momentum flux), and the sensible heat flux, H. These parameters are combined into a length scale referred to as Monin-Obukhov length, L. This length scale is composed of quantities that are approximately constant throughout the surface layer, and is an important length scale governing diffusion and profiles of wind, temperature, and turbulence in the surface layer. As such, it is a useful substitute for the discrete stability class value used by air quality models developed in the past.

During unstable conditions, the height of the mixed layer, drive by convection, can be defined as the layer through which the potential temperature is less than that of the heated layer at the surface, from which convective "thermals" or updrafts originate. The updrafts lose their buoyancy when their potential temperature becomes colder than that of the surrounding air of the top of the mixed layer (z_i). The daytime mixed layer can grow rapidly in response to a steadily increasing surface heat flux. During the afternoon, z_i reaches a maximum and remains relatively constant as the surface heat flux attains its peak value.

Near sunset, an abrupt transformation of the Atmospheric Boundary Layer occurs as the heat flux throughout the entire layer turns negative rapidly. The surface layer becomes stably stratified while the mixed layer above remains relatively unstable, at least initially. In some models of the boundary layer, the nocturnal case features a "mixed" layer above the surface layer with supergeostrophic wind speeds – the well-known low-level nocturnal jet phenomenon. This jet develops when the mixed layer becomes decoupled from the surface layer near sunset and surface friction is then not effective up to as great a height as during the daytime. The balance of forces on the stable mixed layer is then disturbed, and the wind can accelerate because the pressure force now has a component in the direction of the wind (which was directed toward lower pressure because of the friction force during the daytime). As a result, supergeostrophic wind speeds can occur above the nocturnal surface layer in the low-turbulence, laminar flow of the mixed layer. Of course, large-scale mechanisms such as the influence of low pressure areas and warm or cold fronts can dominate and prevent the low-level jet from appearing. In general, it is difficult to predict with certainty the onset and strength of the nocturnal jet.

The predictability of the structure of the low-turbulence nocturnal mixed layer is further complicated by the occurrence of momentum burst phenomena during conditions that favor the onset of the nocturnal jet. A useful parameter for determining the likelihood of the breakdown of the laminar flow of the nocturnal mixed layer is the Richardson number, Ri. Large values of Ri (>1) are associated with stable conditions, while low values (<0.15) are present when mechanical turbulence due to wind shear overcomes the resistance to turbulence motion presented by a thermally-stable atmosphere. A review of investigations into the critical value of Ri for the breakdown of laminar flow into turbulent motion yields a value of 0.25. Observations in wind tunnels and the atmosphere show that the critical value varies, with turbulence being certain if Ri < 0.15 and absent for Ri > 0.5.

During low-level jet periods, the laminar flow in the stable mixed layer can break down if the speed shear between the turbulent surface layer and laminar mixed layer aloft results in a Richardson number favoring the breakdown. The momentum in the mixed layer is then transported to the surface in a "burst," resulting in a temporary absence of the low-level jet. The Richardson number then can become large again, perhaps allowing the laminar flow in the mixed layer to become re-established. The low-level jet disappears in the morning when convective mixing transports momentum away from the jet and smooths out the vertical momentum distribution.

It is evident from the summary presented above that while the nocturnal surface layer, like the daytime surface layer, is reasonably well-behaved, the nocturnal mixed layer is highly unpredictable, even in flat terrain. Therefore, CTDM relies heavily upon direct measurements of wind, temperature, and turbulence in the nocturnal mixed layer. The role of the meteorological preprocessor, METPRO, is two-fold:

- deliver to CTDM observed and predicted values of the nocturn surface layer length, h, and th daytime mixed layer height, z_i;
- compute values of u^*, L, and th surface roughness length, z_0, so th CTDM can supplement dire measurements in the surface lay with computed profiles of win temperature, and turbulence.

Summary of METPRO Operation

METPRO can accept inpu meteorological data from several source (rawinsondes, National Weather Servic data, on-site measurements) ar produce an output file which contai hourly values of mixed layer heigh friction velocity, Monin-Obukhov lengt and surface roughness length. Dire observations of the mixed layer heig are used when available. Otherwis upper air data are used in the mixe layer height calculation after initi processing. METPRO uses si characteristics (surface moisture [Bow ratio], albedo, and surface roughness) conjunction with the input meteorologic data to determine a best estimate f mixed layer height as well as the fricti velocity and the Monin-Obukhov lengt

A variety of theoretical and empiric techniques are used to determine t boundary layer variables calculated METPRO. During daytime hours, energy balance method (among late ground, and air heating) is used determine the surface heat flux, which then used in conjunction with wind a temperature profile data to estimate z_i, and u^*. At night, the downward heat fl into the ground is a function of t surface wind speed and cloud cov Estimates of u^* and L in stable conditic are then used to calculate the height the stable surface layer.

The site characteristics which a used in the calculation of heat flux, L a u^* vary as a function of season a direction. These variations are account for in METPRO with the allowance of to eight different direction sect (angular widths are variable, but m sum to 360°) and monthly changes in t Bowen ratio, albedo, and surfa roughness.

Organization of the Manual

In the manual, the theory behind METPRO program is discuss separately from the operatio instructions for running the progra Section 2, which contains a discussio the technical basis for METPRO, need not be consulted by users who merely wish to run the program. Section 4 contains user instructions for METPRO. If mode 3 of METPRO is to be used (requiring computation of mixing heights), then Section 3, which describes the program (READ62) that decodes the NCDC's upper air data in TD6201 format, must be referenced.

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The complete report, entitled "User's Guide to the CTDM Meteorological Preprocessor (METPRO) Program," (Order No. PB 88-162 102/AS; Cost: $19.95) will be available only from:
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Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S8-88/004

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988—548-013/870