United States
Environmental Protection
Agency

Atmospheric Sciences
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S3-88/011 May 1988

EPA

Project Summary

Parametric Methodologies of Cloud Vertical Transport for Acid Deposition Models

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A CUmulus VENTing (CUVENT) cloud module has been developed that calculates the vertical flux of mass between the boundary layer and the cloud layer by an ensemble of nonprecipitating cumulus clouds. This model has been designed to be integrated into the Regional Acid Deposition Model (RADM) to establish the effect of cloud venting in that model. In the first phase of this project, using data obtained during the VENTEX field program, a parameterization scheme was developed for the cloud model so that it may be incorporated directly into the RADM. This parameterization scheme uses basic meteorological data to predict the convective cloud amount at cloud base and cloud distribution parameters. In the second phase, a number of improvements and changes were made to the CUVENT algorithm so that it may interface with the RADM by being integrated into the Regional Scavenging Module (RSM). The changes included the incorporation of sidewall detrainment and the development of limiting conditions for the existence of nonprecipitating cumulus clouds relative to certain seasons, of a realistic cloud liquid water profile, and of a simplified model to estimate cloud base cloud amount. In order to meet the requirements of the RSM, CUVENT provided information about a single cloud, the "processor cloud," that represented the ensemble of nonprecipitating cumulus clouds. In the final phase, a "table look-up" version of CUVENT was developed in order to significantly reduce the amount of the computer execution time. The new and improved version of CUVENT that was developed in the second phase was used to establish the tables of parameters needed for the processor cloud. The tables were developed for five characteristic atmospheres and ten cloud amounts.

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 primary purpose of this research project was to develop a cloud model (CUVENT) that calculated the vertical flux of mass out of the planetary boundary layer into the cloud layer due to an ensemble of nonprecipitating, subgrid scale, air mass convective clouds. CUVENT, by design, is a submodule to the Regional Acid Deposition Model (RADM), which is being developed by the National Center for Atmospheric Research/State University of New York, and will serve to establish the effects of cloud venting for the RADM.

Approach

CUVENT was established in three separate phases. These are summarized below:

a. Phase 1:

The first phase consisted of two major steps:

1. the selection and modification of a model to calculate the vertical transport of mass due to an ensemble of nonprecipitating, subgrid scale, air mass convective clouds; and
2. development of a closure procedure for that cloud model that is consistent with the RADM.

The cloud model that was selected for CUVENT determines acceptable cloud classes that are defined by entrainment rates which are functions of atmospheric state. This model assigns the entrainment rate to a particular cloud size, which is represented by cloud depth and by a fractional cloud amount. The greatest entrainment rate is assigned to those clouds having the least depth, and the smallest entrainment rate, to clouds having the greatest depth. The percent of area covered by each cloud class is also determined. Given these parameters and the primary forcing functions, heat and moisture convergence, the model computes the vertical flux of mass due to the ensemble of nonprecipitating cumulus clouds.

This model, called CUVENTI, was originally developed to be applied using observed data. Radiosonde data were used to define the moist static energy distribution, and satellite data were used to determine the cloud parameters. However, RADM operates in a predictive mode and is self-consistent. Incorporation of observed data will produce unacceptable errors. Since CUVENTI is to be integrated into the RADM, it also must be self-consistent in the sense that it can only use data provided to it by the RADM. Therefore, a procedure had to be developed to adapt the cloud model to the predictive mode; i.e., the closure procedure, RADM provides data through which the moist static energy distribution can be calculated. Therefore, the basic aspects of the closure procedure consisted of three major parts:

1. A test for moist convergence;
2. The estimation of the cloud base convective cloud amount;
3. The development of the convective cloud amount as a function of cloud classes.

The test to determine whether moist convection existed at a particular time consisted of two parts:

1. A test to determine whether the forcing function, the surface heat flux, was consistent with convection; and
2. A test to determine whether moisture conditions were consistent with moist convection.

A fundamental part of this test centered around the relative location of the entrainment zone and the lifting condensation (LCL) zone.

If the atmosphere supports moist convection based on tests discussed in the above paragraph, then the convective cloud amount was determined. A statistical model was developed which estimates the convective cloud amount at cloud base using basic meteorological parameters. The data that were used to develop the statistical model were obtained during the National Acid Precipitation Assessment Program (NAPAP) venting experiment (VENTEX) that took place near Lexington, Kentucky, in the summer of 1984. Surface, upper air, sodar, laser, and aircraft measurements were made to characterize the lower atmosphere during current cumulus convection and to characterize the cumulus clouds in terms of the cloud amount, the cloud depth, and the cloud width. The measurement program was a joint effort by Battelle Pacific Northwest Laboratories, Argonne National Laboratory, and the Research Triangle Institute.

The statistical model for the cloud amount consisted of terms that characterized the major forcing function for air mass convective clouds: the surface heat flux and the moisture parameters in the boundary layer. The major parameters were the dew-point depression at the surface and at the top of the boundary layer, the surface heat flux and the time rate of change of the surface heat flux, the height of the lifting condensation level, and the height of the top of the boundary layer. One hundred and five separate comparisons were used to construct the model; the resulting correlation for these comparisons was 0.81.

As previously discussed, the cloud classes were defined by an entrainment rate, as well as the cloud depth. In order to establish the cloud amount for a given cloud class, it was necessary to assume that the cloud depths are continuous over the spectrum of cloud classes, that the cloud depth is a function of the cloud width for nonprecipitating convective clouds. Utilization of these assumptions permitted development of a mathematical expression that established the cloud amount as a function of the cloud depth. The system of equations that defined thermodynamics and dynamics of the cloud processes and defined the parameters necessary to solve the cloud model produced a self-consistent cloud flux model (CUVENT) which defined the vertical mass flux due to an ensemble of nonprecipitating air mass convective clouds. The establishment of CUVENT in this matter made it consistent with the predictive mode of the RADM.

b. Phase 2:

In the second phase of this research project, a number of improvements and changes were made to CUVENT. These included:

1. the incorporation of sidewall detrainment;
2. the development of a test which limits conditions for the existence of an ensemble of nonprecipitating air mass clouds to certain seasons;
3. the development of a more realistic cloud liquid water profile for CUVENT; and
4. the development of a simplified model to estimate cloud amount at cloud base.

In CUVENTI, the first generation version of CUVENT, detrainment took place at the cloud top only. Under these conditions, the maximum predicted vertical velocity in the cloud was found near cloud top and the vertical velocity went rapidly to zero at cloud top. Most observations of the vertical velocity distribution in cumulus clouds have indicated that the maximum vertical velocity is generally found midlevel in the cloud. Such vertical velocity distribution can be obtained by incorporating sidewall detrainment in the cloud model.

Cloud liquid water is needed in CUVENT in order to calculate the updraft moist static energy, and it is essential in the solution for each cloud class. In this model, the vertical distribution of cloud liquid water was provided as a data set that was derived from the literature.

The initial statistical model which was used to estimate the convective cloud amount at cloud base for CUVENTI used two terms which might have complicated the integration of CUVENT into the RADM. One of these terms was the time rate of change of surface heat flux. In order to calculate this term, it was required that the surface heat flux from the previous hour is saved in memory at each RADM grid point. Furthermore, the precision and accuracy needed for the term that involved the difference in height between the top of the entrainment zone and the bottom of the lifting condensation zone was questionable using RADM meteorological data. In order to remove the complication of requiring a memory array for the surface heat flux and in dealing with the questionable accuracy of the term involving the height difference, it was decided that both these terms should be removed from the model and a new model be developed whose terms are physically consistent with fair weather cumulus, but are more practical and have no need for storage capabilities. Such a model was developed and the terms in the model were the dewpoint depression at the top of the boundary layer, the surface heat flux, the height of the lifting condensation level, and the free convection scaling velocity. This model provided a correlation coefficient with observations of 0.79.

The air mass cumulus clouds which are accounted for by CUVENT have a definite warm season preference. This preference was used to limit utilization of CUVENT. In order to develop this warm season preference and to determine restriction limits, a frequency analysis was established which matched the existence of nonprecipitating cumulus clouds with the surface dry bulb temperature and the surface dewpoint temperature. Based on this analysis, it was decided to use the 80 percentile from the cumulative probability distribution to define the restriction limit for cumulus clouds. The 80 percentile value provided a surface temperature of 10 degrees and a surface dewpoint temperature of 0°C (i.e., the restriction limit states that there is an 80 percent probability that nonprecipitating cumulus clouds will exist if the surface temperature is greater than 10°C and the surface dew point is greater than 0°C).

CUVENTI was designed to estimate the vertical mass flux by nonprecipitating clouds. This configuration for CUVENTI was developed for its integration with the RADM. Subsequently, CUVENT was assigned to be a subroutine to the Regional Scavenging Model (RSM). In order to meet the requirements of the RSM, CUVENT had to provide information about a single cloud that could be used to represent the ensemble of subgrid scale nonprecipitating clouds. This single cloud was hereafter referred to as the "processor cloud." CUVENTI was modified to develop the information about the processor cloud that is required by the RSM. That information included the updraft vertical velocity distribution, the updraft temperature distribution, the updraft specific humidity distribution, the cloud amount distribution, the cloud liquid water distribution in the updraft, the cloud liquid water distribution in areas outside the updraft, and the precent area covered by updraft.

After all changes and improvements were made, the new version of the CUVENT algorithm was called CUVENTIA. CUVENTIA underwent various sensitivity analyses to examine the behavior of algorithm as the vertical distribution of temperature and dewpoint (moist static energy) change from one atmospheric state to another. Various temperature and dewpoint profiles were used and results were presented in terms of the vertical velocity distribution in the processor cloud.

c. Phase 3:

In the final phase of this research project, a "Table Look-Up" version of CUVENT, CUVENTIIA, was developed in order to reduce significantly the computer execution time of the algorithm. CUVENTIA was used to develop the tables of significant parameters for the processor cloud. The tables were developed for five characteristic atmospheric categories and ten cloud amounts. The distinction between atmospheric categories was based on the lapse rate and moisture in the cloud layer. Fifteen atmospheric states that were characterized by their temperature and dewpoint profiles were examined. The reduction from fifteen to five categories was based on the change in cloud parameters for the processor cloud across the range of atmospheric states defined by the categories. These within-category variations were small for the five chosen categories. However, compromises had to be made because there was a restriction on the acceptable storage requirement that CUVENT could demand from the RADM system. These two factors limited the number of atmospheric categories to five.

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The complete report, entitled "Parametric Methodologies of Cloud Vertical Transport for Acid Deposition Models," (Order No. PB 88-191 374/AS; Cost: $32.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650

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EPA/600/S3-88/011

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988—548-013/87