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Project Summary

Rocky Mountain Acid Deposition Model Assessment: Acid Rain Mountain Mesoscale Model (ARM3)

Ralph E. Morris, Robert C. Kessler, Sharon G. Douglas, Kenneth R. Styles, and Gary E. Moore

The Acid Rain Mountain Mesoscale Model (ARM3) is a mesoscale acid deposition/air quality model that was developed for calculating incremental acid deposition (sulfur and nitrogen species) and pollutant concentration impacts in complex terrain. The development of the ARM3 was based on comments and recommendations from western regulatory agencies who required an acid deposition/air quality model to estimate long-term sulfur and nitrogen deposition and short-term PSD pollutant concentration impacts at mesoscale distances (5 to 200 km). The ARM3 is designed to simulate long-term acid deposition and pollutant concentrations for periods up to a year by stepping through the year at approximately hourly time steps. Although the model was designed primarily to simulate impacts in regions within the Rocky Mountains, it can be applied anywhere, provided the proper inputs are prepared. However, since the model uses pseudo first-order chemistry, it is not suitable for applications in regions dominated by nonlinear chemistry.

The ARM3 consists of six components: a terrain preprocessor, a land-use preprocessor, a precipitation preprocessor, a mesoscale meteorological model, a Lagrangian acid deposition/air quality model, and a postprocessor. The mesoscale meteorological model contains a new diagnostic wind model that accounts for the kinematic, deflection, and thermal effects that alter the flow fields due to complex terrain. The Lagrangian acid deposition/air quality model has the following attributes: two options for calculating plume height above ground; three options for determining dispersion rates, including one that accounts for terrain roughness; a dry deposition algorithm based on the resistance approach; a wet deposition algorithm based on the scavenging approach; and two options for calculating chemical transformation.

The primary objective in the development of the ARM3 was to construct an acid deposition/air quality model based on existing models for use by western regulatory agencies to calculate the incremental contribution of specific sources to acid deposition and pollutant concentrations in the complex terrain of the Rocky Mountains. The model was designed to be easy to use, cost-effective, useful in predicting both sulfur and nitrogen species deposition, and adequate to account for the major processes that lead to acid deposition and pollutant transport in complex terrain.

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

Although acid deposition may not be as acute in the western United States as it is in the eastern United States, its presence in the western United States has become an increasing concern to public and regulatory agencies. Their concern stems from the strong sensitivity exhibited by high western lakes to acid deposition and from the rapid industrial growth expected to occur in certain areas of the West. For example, several planned energy-related projects in the Overthrust Belt in southwestern Wyoming, including natural gas sweetening plants and coal-fired power plants, may considerably increase emissions of acid precursors in northeastern Utah and northwestern Colorado and significantly affect ecosystems in the sensitive Rocky Mountain areas.

Under the 1977 Clean Air Act, the U.S. Environmental Protection Agency (EPA), along with other federal and state agencies, is mandated to preserve and protect air quality throughout the country. As part of the Prevention of Significant Deterioration (PSD) permitting processes, federal and state agencies are required to evaluate potential impacts of new emission sources. In particular, Section 165 of the Clean Air Act stipulates that, accept in specially regulated instances, PSD increments shall not be exceeded and air-quality-related values (AQRVs) shall not be adversely affected. Air-quality-related concerns range from near-source plume blight to regional-scale acid deposition problems. By law, the Federal Land Manager of Class I areas has a responsibility to protect air-quality-related values within those areas. New source permits cannot be issued by the EPA or the states when the Federal Land Manager concludes that adverse impacts on air quality or air-quality-related values will occur. EPA Region VIII contains some 40 Class I areas in the West, including two Indian reservations. Similar designations are being considered for several of the remaining 26 Indian reservations in the region. State and federal agencies, industries, and environmental groups in the West need accurate data concerning western source-receptor relationships.

To address this problem, EPA Region VIII needs to designate an air quality model to estimate mesoscale pollutant transport and deposition over the complex terrain of the Rocky Mountain region for transport distances ranging from several kilometers to several hundred kilometers. The EPA recognizes the uncertainties and limitations of currently available air quality models and the need for continued research and development of air quality models applicable over regions of complex terrain.

The primary objective of the Rocky Mountain Acid Deposition Model Assessment Project is to assemble a mesoscale air quality model based primarily on models or model components currently available for use by federal and state agencies in the Rocky Mountain region. To develop criteria for model selection and evaluation, the EPA formed an atmospheric processes subgroup of the Western Atmospheric Deposition Task Force, referred to as WADTF/AP. This group comprises representatives from the National Park Service, U.S. Forest Service, EPA Region VIII, the National Oceanic and Atmospheric Administration, and other federal, state, and private organizations. The design of this new model was based on comments from the WADTF expressing a desire for a cost-effective Lagrangian model capable of calculating incremental, long-term acid deposition and short-term concentration impacts over mesoscale distances in complex terrain.

A mathematical modeling system for describing the various physical and chemical processes associated with acid deposition and air quality must consist of several modules describing processes such as wind transport, dispersion, plume rise, chemical transformation, and wet and dry deposition. Although the modeling system must be an integrated and internally consistent package, it can be conveniently divided into two distinct principal parts:

- Simulation of meteorological processes.
- Simulation of pollutant transport, dispersion, chemical transformation, and deposition.

Procedure

The ARM3 was assembled from existing operational mesoscale meteorological and acid deposition models. Four candidate mesoscale meteorological models were selected for possible use in constructing the ARM3: the California Institute of Technolog Wind Model (CIT/WINDMOD), the Pacifi Northwest Laboratory MELSAR ME model (PNL/MELSAR-MET), the Lo Alamos National Laboratory ATMOS model (LANL/ATMOS1), and th Systems Applications, Inc. Comple Terrain Wind Model (SAI/CTWM). Th candidate acid deposition models were the Environmental Research an Technology MESOPUFF-II model (ERT MESOPUFF-II), the Pacific Northwes Laboratory MELSAR-POLUT mode (PNL/MELSAR-POLUT), the System Applications, Inc., Regional Impact o Visibility and Deposition model (SA RIVAD), and the Systems Applicatior Inc., Comprehensive Chemistry and Ac Deposition Model (SAI/CCADM).

The candidate models were eva uated and the most appropriat components were implemented in th ARM3. Model components were selecte based on the rigor of their technic approach and consistency with th overall modeling approach. The modelin approach was based on the recom mendations of the western regulator agencies.

Results and Discussion

Overview of the Modeling System

The ARM3 consists of sever interrelated programs and input data file The ARM3 modeling package include input data to simulate any region with the master modeling domain, whic contains Colorado, Wyoming, and mo of Utah. To simulate other regions, th user must supply the input dat Accompanying the ARM3 programs a sufficient meteorological, terrain, ar land-use data to simulate an impa assessment for the calendar year 198 The ARM3 was designed to be a se contained modeling system for which t user defines only the mesosca modeling domain, the grid spacing, t meteorological update interval, and t sources and receptors of interest.

Model Structure and Program Interaction

The ARM3 modeling packa consists of six Fortran 77 programs a several related data files. The six Fortr programs that make up the ARM3 are follows:

PRELND, the land-use pr processor. This program uses data fr the Geographic Information Syster

(GIS) land cover data base, supplied for the entire United States, and creates gridded fields of surface roughness and fractional land cover for the user-selected mesoscale modeling domain.

PRETER, the terrain preprocessor. This program calculates the average terrain heights and terrain roughness values for the user-selected mesoscale modeling domain. Terrain data is supplied for the master modeling grid (Colorado, Wyoming, and most of Utah); other regions can be simulated if the user provides the 1-km terrain data.

PRECIP, the precipitation preprocessor. This program uses 24-hour and hourly precipitation measurements to create gridded fields of precipitation amounts on the user-selected mesoscale modeling domain at the user-selected meteorological update frequency.

METDWM, the mesoscale meteorological model. The meteorological model uses the data supplied by the preprocessors and surface and upper air meteorological observations to create several vertical levels of gridded wind fields and gridded fields of mixing heights, temperatures and dew points, temperature and dew point lapse rates, stability, and other meteorological variables.

CONDEP, the Lagrangian concentration and deposition simulation model. This program calculates hourly concentration and deposition amounts from user-specified sources at user-specified receptors. The CONDEP can be run for several different sources or source configurations using the same meteorological data from the preprocessors and meteorological model

PSTPRC, the postprocessor. This program creates tables of maximum concentrations at several averaging times and cumulative deposition amounts from the concentration and deposition data created by CONDEP.

METDWM, the Mesoscale Meteorological Model

The heart of the mesoscale meteorological model is a new diagnostic wind model (the DWM) that was constructed from the most advanced components of the four candidate meteorological models. The new DWM uses all existing wind observations while simulating the effects of complex terrain on wind flows in regions with sparse observational data. The generation of the wind field by the DWM is accomplished in two steps. Step 1 is largely based on the approach used in the SAI/CTWM but formulated in a terrain-following coordinate system. The domain-mean wind for the modeling region is adjusted for the kinematic effects of terrain, thermodynamically generated slope flows, and blocking effects. Step 1 produces a spatially varying gridded field of u and v wind components at several vertical levels.

Step 2 involves the incorporation of wind observations into the wind fields generated by Step 1. An objective analysis scheme is used to produce a new gridded wind field. The scheme is designed so that the observations are weighted heavily in subregions where they are deemed representative of the mesoscale air flow; in subregions where observations are deemed unrepresentative, the wind values produced by Step 1 are weighted heavily. Once the new gridded wind field is generated, the vertical velocity out of the top of the modeling domain can be minimized.

The procedures used to generate gridded fields of other meteorological data required by an acid deposition/air quality model (including boundary-layer heights, temperatures, relative humidities, stability, precipitation, and other micro-meteorological variables, such as friction velocity and Monin-Obukhov length) were based on the PNL/MELSAR-MET model. Gridded fields of nonwind meteorological data are interpolated to the mesoscale modeling domain using orographic adjustments based on an analysis of climatological data from the western Rocky Mountains.

CONDEP, the Lagrangian Acid Deposition/Air Quality Model

The formulation of the Lagrangian acid deposition/air quality component of the ARM3 was based on the evaluation of the four candidate acid deposition/air quality models. As no one of these models is the best choice for calculating source-specific acid deposition impacts in the Rocky Mountain region, a new Lagrangian Gaussian puff model was designed, making use of the best components from the candidate models.

Transport within this new puff model is defined by the wind at the plume center, as determined by the DWM. The user has the option of calculating vertical transport of the Lagrangian puff using either empirical techniques or the vertical velocities generated by the DWM. Since there is considerable uncertainty in the vertical wind velocities generated by any wind model, the use of empirical adjustments is recommended for modifying the plume height above terrain due to complex terrain effects. The initial plume rise of the source emissions is calculated using formulas proposed by Briggs that have been adapted from the EPA-recommended CRSTER model.

Three options are available for defining dispersion in the ARM3: two from the MELSAR-POLUT model (with one accounting for the effects of terrain roughness on the dispersal of pollutants) and one from the dispersion algorithms of the MESOPUFF-II, which are a fit to Turner's dispersion curves. The square of total horizontal diffusion is defined as the sum of the squares of three components: (1) an initial diffusion resulting from nonatmospheric processes (e.g., buoyant plume rise), (2) diffusion resulting from atmospheric turbulence, and (3) diffusion resulting from horizontal wind shear. The square of the total vertical diffusion is the sum of the squares of two components: (1) an initial diffusion resulting from nonatmospheric processes, and (2) diffusion resulting from atmospheric turbulence.

Two different treatments of chemical transformation are available in the ARM3, based on the algorithms from the SAI/RIVAD and the ERT/MESOPUFF-II. The RIVAD and MESOPUFF-II chemical mechanisms are both called pseudo-first-order chemical mechanisms because any nonlinearities in the chemical transformation rates must be based on conditions that can be described within the Lagrangian puff (i.e., independent of background concentrations). The RIVAD mechanism is a highly condensed chemical mechanism that estimates the hydroxyl radical concentration (the primary gas-phase oxidizer of SO_2 and NO_2) based on the puff SO_2 and NO_2 concentrations and the ambient temperature and water vapor concentration. On the other hand, the MESOPUFF-II oxidation rates are based on an empirical fit to chemical box model simulations over a range of environmental conditions. Both pseudo-first-order mechanisms contain a surrogate heterogeneous (aqueous-phase) oxidation rate that is added to the homogeneous (gas-phase) to account for the aqueous-phase oxidation of SO_2 to sulfate. These chemical mechanisms are not appropriate for use in regions dominated by nonlinear chemistry.

The treatment of dry deposition in the ARM3 is based on the resistance approach, in which the deposition of pollutants to the ground is limited by a series of three resistances: (1) an aerodynamic resistance that depends on meteorological conditions and surface resistance, (2) a quasi-laminar layer resistance that depends on meteorological conditions, surface roughness, and species type, and (3) a surface resistance that is species- and surface-type-dependent. In addition, the deposition of particulate species contains a settling velocity that acts in parallel to the other resistances. The dry-deposition algorithms were adapted from the SAI/CCADM dry-deposition module, which in turn was based on dry deposition paramaterizations from three advanced Eulerian models: (1) the Acid Deposition and Oxidant Model (ADOM) developed by Environmental Research and Technology, (2) the Regional Acid Deposition Model (RADM) developed by the National Center for Atmospheric Research and the State University of New York at Albany, and (3) the Regional Transport Model Version III (RTM-III) developed by Systems Applications, Inc.

Wet deposition in the ARM3 is treated using the scavenging coefficient approach that was adapted from the MESOPUFF-II model. This algorithm contains provisions for both liquid and frozen precipitation scavenging.

Conclusions and Recommendations

A model for calculating incremental impacts of acid deposition and pollutant concentrations in the Rocky Mountains, the ARM3, has been developed using components from existing models that are scientifically sound and internally consistent with the overall modeling approach. Before each component was inserted into the modeling system, it was thoroughly evaluated to assure its scientific accuracy. The hybrid modeling system was designed in a highly modular fashion so that when new modules describing atmospheric processes become available they can be integrated easily into the modeling system. The ARM3 has not undergone any rigorous operational testing, sensitivity analysis, or validation. A limited model performance evaluation has been performed. However, further testing and evaluation of the ARM3 are needed in order to gain confidence in the model predictions. Model evaluation requires new research studies to collect field data on regional-scale meteorology and air chemistry of the Rocky Mountain region. The authors recognize the inherent uncertainties and limitations in all air quality simulation models.

Ralph E. Morris, Robert C. Kessler, Sharon G. Douglas, Kenneth R. Styles, and Gary E. Moore are with Systems Applications, Inc., San Rafael, CA 94903.
***Alan H. Huber** is the EPA Project Officer (see below).*
The complete report, entitled "Rocky Mountain Acid Deposition Model Assessment: Acid Rain Mountain Mesoscale Model (ARM3)," (Order No. PB 89-124 408/AS; Cost: $36.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Atmospheric Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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