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Numerical modeling of atmospheric dispersion during the MOHAVE field study

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ABSTRACT

The design of daily meteorological and dispersion simulations for the MOHAVE project is presented. These simulations are being performed at CSU for a year long study using the CSU Regional Atmospheric Modeling System (RAMS) coupled with a Lagrangian particle dispersion model.

INTRODUCTION

The Measurement Of Haze And Visual Effect (MOHAVE) program is a year long field study being conducted in the desert southwest United States to assess the impact of the Mohave Power Project (MPP) and other potential sources of air pollution to specific Class I areas located in the region. The measurement phase of this study was conducted between September 1, 1991 and August 31, 1992. The intensive periods of the study (one during winter and one during summer) included the release of a perfluorocarbon (PFT) tracer from MPP.

The Colorado State University team is participating in the modeling component of the project using a non-hydrostatic mesoscale meteorological model (RAMS) coupled with a Lagrangian particle dispersion (LPD) model. The modeling domain covers the southwestern United States with its extremely complex terrain. Daily meteorological simulations are being performed with the RAMS on two nested grids. Source- and receptor-oriented approaches are being used as complementary tools for dispersion modeling.

The goal of this paper is to present our design of the daily meteorological and dispersion simulations which are currently being performed at CSU for a year long study. All computations are being performed on two IBM RISC-6000 workstations dedicated to the project.

METEOROLOGICAL SIMULATIONS

The meteorological model being used in this study was initially a combination of two different models. The first, originally developed by Pielke [4] and im-

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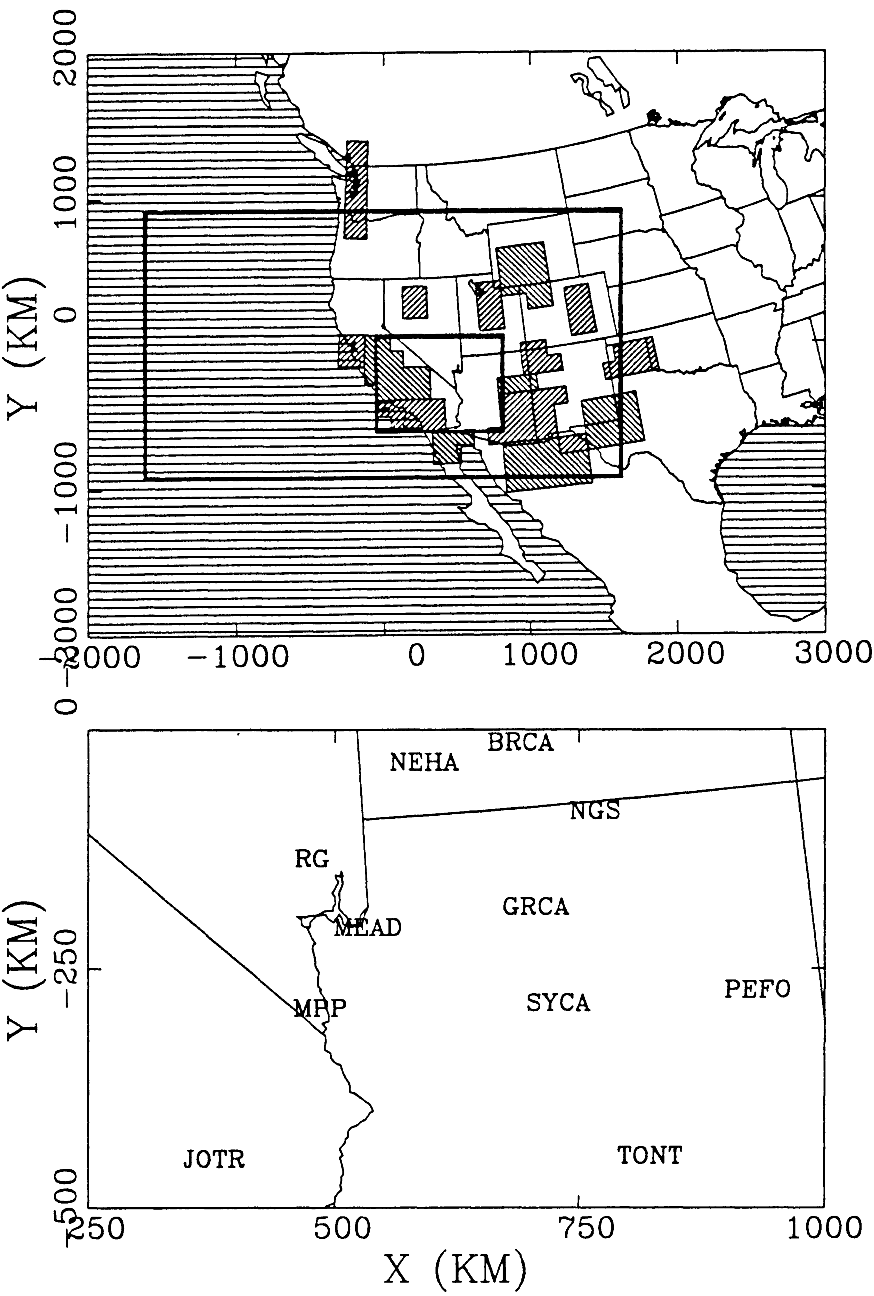

Figure 1. Meteorological modeling domain (grids #1 1 and #2) and emission source areas identified for the receptor-oriented study (top) and selected receptors and local power plants used in forward in time particle simulations (bottom)

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proved and generalized over subsequent years as reported in [3, 2], and elsewhere was a hydrostatic, terrain-following horizontally homogeneous model. The second model was a non-hydrostatic cloud model which explicitly resolved cloud microphysical processes [6]. These two models were combined into one modeling system called RAMS, [5], which is capable of running with a number of different frameworks and numerical schemes to allow the user to build a model which is most useful for a particular research topic. Some of the more important features of this modeling system are a two-way interactive grid nesting scheme based on [1] which allow one to adequately resolve the large scale synoptic flow while telescoping down to finer resolutions around a particular area of concern. The model also allows for varying degrees of complexity in such things as microphysics and vegetation.

The daily simulations carried out for the MOHAVE study use two interactive grids with the first grid having horizontal grid increments of 50 km and the second 12.5 km. Figure 1 shows a horizontal view of the two grids with grid one having 66 by 38 horizontal grid points and grid two having 74 by 54 grid points. The timestep for grid one is 90s and for grid two, 45s. The grid one domain is centered at 38N and 120W. There are 33 vertical levels extending from the surface to 17km. The minimum vertical grid step is 150 m next to the surface. This is stretched by a ratio of 1.1 to a maximum of 2000 m.

Each of the modeled days during the year are being initialized with the National Meteorological Center (NMC) initialization data obtained at the National Center for Atmospheric Research (NCAR). This data is supplemented by standard National Weather Service data also obtained at NCAR. The NMC initialization data is obtained for NCAR at a frequency of one observation every 12 hours. Therefore, the RAMS initial conditions for any given day are updated at this frequency. These RAMS simulations do not use 4DDA but update the model fields through the lateral boundaries with the initial conditions being linearly interpolated between the 12 hour observation times.

DISPERSION SIMULATIONS

Dispersion model

A Lagrangian particle dispersion (LPD) model [7, 8] is applied in this project. The simplest fully random walk version (LPD1c) of this model with horizontal turbulent diffusion of particles neglected was selected for daily simulation. A discussion of the model versions including a computer time comparison is presented in a companion paper. The computer efficiency of the LPD1c model allows us to design a variety of dispersion simulations using daily output from the RAMS.. The dispersion model is run in two modes:

- a traditional source-oriented mode to calculate concentration fields forward in time for given emission sources;
- a receptor-oriented mode to calculate influence functions backward in time for a given receptor [9, 8].

The influence function depends on meteorology, deposition, and transformations of pollutants in the atmosphere, but is independent of emission sources. The averaged concentration at the receptor can be expressed with the aid of the influence function as a sum of contributions from 1) local sources within the modeling domain, 2) distant sources outside the modeling domain in terms of pol-

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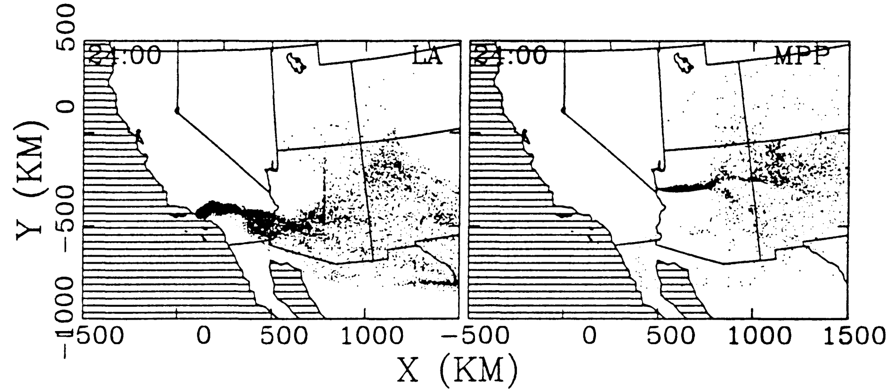

Figure 2. Example of particle distributions released from Los Angeles and MPP (2400 LST, February 11, 1992)

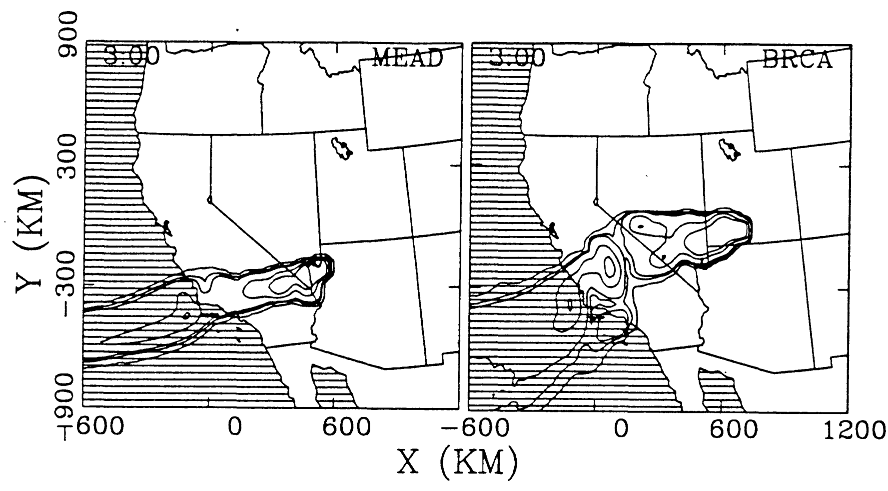

Figure 3. Time integrated influence function fields for Meadview and Bryce Canyon receptors (sampling period 7am-7pm MST, February 11, 1992; contours: $0.1, 0.5, 1., 5., 10., 50., 100., 200., ... \times 10^{-6}\ m^{-3}$)

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lution flux across the model boundaries, and 3) initial pollution in the modeling domain. For a sufficiently long period of simulation, the contribution from the initial concentration is negligible and the time-integrated influence function may be used to characterize the dispersion condition in the atmosphere for a given receptor. The influence function is calculated from backward in time trajectories of particles in the LPD model, where particles are released from the receptor during the assumed sampling time.

Figure 1 shows the receptors and emission sources considered in the study. All daily dispersion simulations are limited to the dispersion of a passive (conservative) tracer.

Source-oriented simulations

Three types of forward in time particle simulations are being performed.

Local emission sources. These simulations include three powerplants: Mohave Power Project (MPP), Navajo Generating Station (NGS) and Reid Gardner (RG) powerplant. Particles are released continuously from effective stack heights calculated for each power plant. Particles are traced for two days, and then the simulation is restarted from past particles positions and the model run is continued using the next two days of RAMS output. This approach is continued for every day of the year. The particles older than 3 days are erased. Surface concentration fields are calculated as well as time series of concentration at selected receptors.

Distant emission sources. These simulations are performed for the purpose of visualization of long range transport rather than to calculate actual concentration fields. Particles are released continuously from $20\times20\times0.2$ km volumes located at Los Angeles, San Francisco, Phoenix and Salt Lake City. Additionally, Las Vegas is included as the closest urban area to the region of interest. A fictitious source is added in a coastal area near the border of California and Oregon in order to study the possible effect of the location of new emission sources in a so-called clean air corridor extending northwest from the Grand Canyon area. Selected particle animations from these simulations and simulations of local emission sources will be recorded on video tape. Figure 2 shows examples of particle plumes released from the MPP and from the Los Angeles area.

Tracer releases. These additional particle simulations are planned to reproduce tracer releases from the MPP and Dangling Rope during the winter intensive period and from the MPP, Tehachapi Pass, and the Imperial Valley during the summer intensive period.

Receptor-oriented simulations

The backward in time particle simulations are performed for nine selected receptors: Meadview, Hopi Point, Joshua Tree, New Harmony, Sycamore Canyon, Bryce Canyon, Tonto, Petrified Forest, and Spirit Mountain. Particles are traced backward from receptors up to six days until only a small fraction of released particles remains within the modeling domain. Influence functions are computed for 12 hour sampling periods, 7am-7pm and 7pm-7am MST. Figure 3 demonstrates examples of time integrated influence functions averaged within the layer up to 500 m. The time series of influence functions is calculated for 1) three local power plants (MPP, NGS, and RG) treated as point emission sources with variable heights due to plume rise, and 2) 16 distant source areas (Figure 1) treated as large volume sources. The calculations for the source areas located

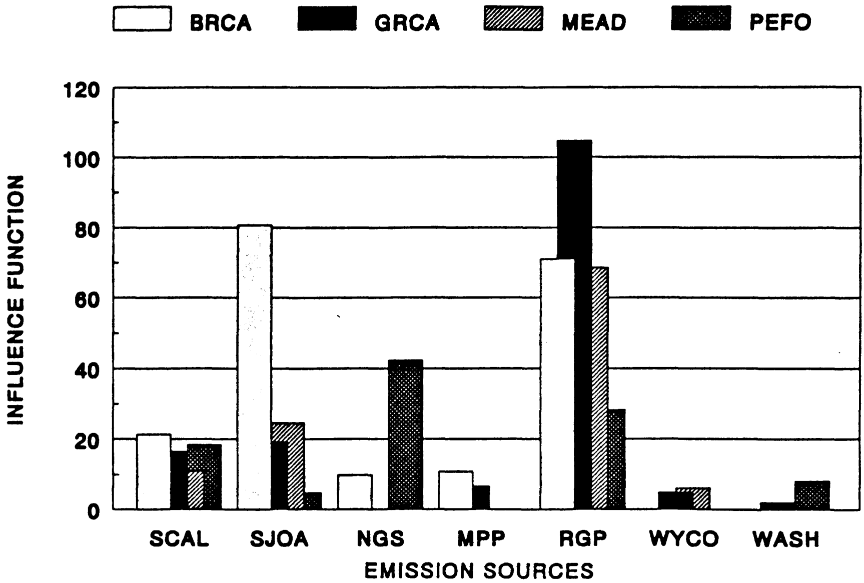

Figure 4. Potential impact of NGS, MPP and RG power plants and the South California, San Joaquin, Wyoming/Colorado and Washington source areas on the Bryce Canyon, Hopi Point (Grand Canyon), Meadview and Petrified Forest receptors expressed by influence functions ($\times 10^{-6}\ m^{-3}$) calculated for sampling period 7am-7pm MST, February 11, 1992

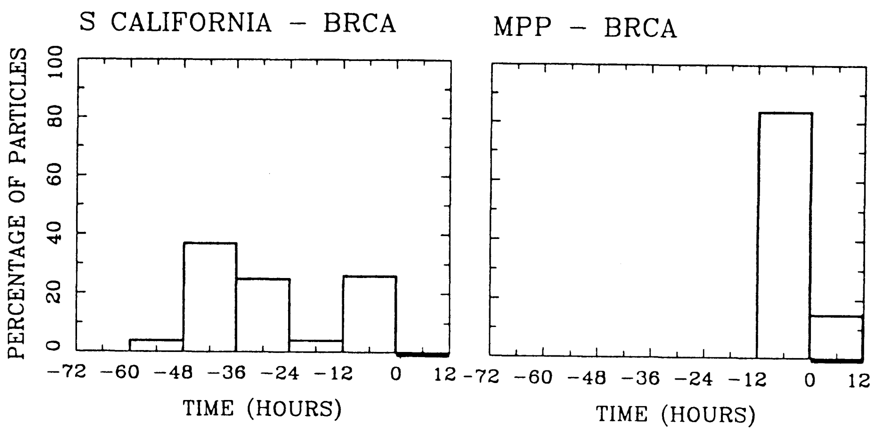

Figure 5. Release time history of particles for the MPP - Bryce Canyon and South California - Bryce Canyon source-receptor couplets (sampling period: 7am-7pm MST, February 11, 1992)

at the boundaries of the modeling domain are only approximate. Examples of the time integrated influence function calculated for different sources are shown in Figure 4 for four selected receptors. The presented values multiplied by the emission rate of a given source provide the contribution of this source to the concentration averaged at the receptor during the sampling period. Additionally, a distribution of particles affecting the receptor over the release time from the source is calculated for each source-receptor couplet (Figure 5) and stored in the data base. The 12 hour increment of time before the sampling period is used for this purpose. Figure 5 shows examples of particle time history for the MPP - Bryce Canyon and the South California - Bryce Canyon couplets.

FURTHER RESEARCH

This paper describes the basic program of daily meteorological and dispersion simulations performed within the Project MOHAVE. Additional activities are planned in a cooperation with other research teams which will be provided with meteorological output from the RAMS simulations. For the intensive periods of the field study the case studies will be performed using the RAMS with five nested grids and the Markov chain version of the LPD model. For selected cases, a sulfur chemistry mechanism and dry deposition will be implemented for dispersion simulations.

This project demonstrates the value of using state-of-the-art meteorological and dispersion models on high performance workstations in order to assess air pollution impacts over mesoscale and regional areas. Dispersion due to spatially and temporally differential mesoscale, regional and synoptic motions can be represented with this tool, as well as diffusion due to parameterized smaller scale motions. Existing regulatory models (e.g., see the list in [10]) are unable to represent these important atmospheric effects.

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