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MODELING AIR-QUALITY IN COMPLEX TERRAIN USING MESOSCALE AND DISPERSION MODELS - PART 1: EVALUATION OF A MESOSCALE MODEL

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ABSTRACT

Air-quality in a complex terrain (Colorado-River-Valley/Grand-Canyon Area, Southwest U.S.) is modeled using a higher-order closure mesoscale model and a higher-order closure dispersion model. Non-reactive tracers have been released in the Colorado-River valley, during winter and summer 1992, to study the dispersion of pollutants from a coal-fired power plant. The main objectives of the extensive field program MOHAVE ("Measurements Of Haze And Visibility Experiment") were to investigate and identify the possible short- and long-term impacts of atmospheric pollutants from major urban areas and industrial sources on the Grand Canyon and its vicinity. In part I, the mesoscale model (MIUU model) is described. The model results are compared with data from the meteorological network of surface and upper-air stations within MOHAVE. The model results are also compared with those from another mesoscale model (MM5). In part II, the dispersion model is described. It is an Eulerian diffusion model. The model simulations of air-quality in the MOHAVE complex terrain during the program are compared with the available data.

Keywords: Mesoscale modeling, Dispersion, Air-quality in complex terrain

INTRODUCTION

Dispersion models need realistic three-dimensional atmospheric fields as input for transport and dispersion studies of atmospheric pollutants. In this study, data from the extensive field program MOHAVE (Measurements Of Haze And Visibility Experiment) (e.g. Green, 1999; Pitchforc et al., 1999) have been used to evaluate the meteorological output of two atmospheric mesoscale models. The models are the Meteorological Institute of Uppsala University's model (MIUU model) and the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5).

Project MOHAVE was conducted in the southwestern United States (see Figure 1) and included meteorological, chemical and visibility measurements at several stations. Upper-air observations were

The MIUU model is a higher-order turbulence closure model of level 2.5 (according made at several sites using radiosondes, wind profilers and a radio acoustic sounding system (RASS). The main goal of project MOHAVE was to assess the effects of the Mohave Power Plant (MOPP), a large coal-fired power plant in Colorado River Valley in southern Nevada, circa 120 km to the south-southeast of Las Vegas, upon visibility in the southwestern United States, in particular at Grand Canyon national park (Green, 1999).

Model Description

The MIUU model is a higher-order turbulence closure model of level 2.5 (according to Mellor and Yamada, 1974). It applies a terrain-following coordinate system (Pielke, 1984), is hydrostatic and includes prognostic equations for the mean variables and turbulent kinetic energy (e.g., Enger et al., 1993). The turbulence closure scheme was corrected to include wall effects in the redistribution terms for the second-order moments (Andrén, 1990), in order to account for the influence of the underlying surface. Andrén (1990) pointed out, that this is of importance particularly for air pollution applications. Additionally, the model includes routines for clouds, radiation and soil surface temperature and humidity. The model output, i.e., the velocity, temperature and turbulent kinetic energy fields, is then used in the dispersion model (see Part II) together with the turbulent length scale, to compute all the second-order moments, that are required in the prognostic equations for the atmospheric pollutant or tracer concentrations (Andrén, 1990).

A new lateral boundary condition, based on a modified version of Davies (1976) flow relaxation scheme, is used in the model to introduce the large-scale synoptic fields from the NCEP/NCAR Reanalysis project (Kalnay et al., 1996). A terrain-following flow relaxation parameter is applied, in order to allow mesoscale phenomena in the planetary boundary layer to develop in the vicinity of the lateral boundaries. Therefore, the flow-relaxation parameter K (according to Davies, 1976) is chosen to be zero at the ground surface approaching its maximum

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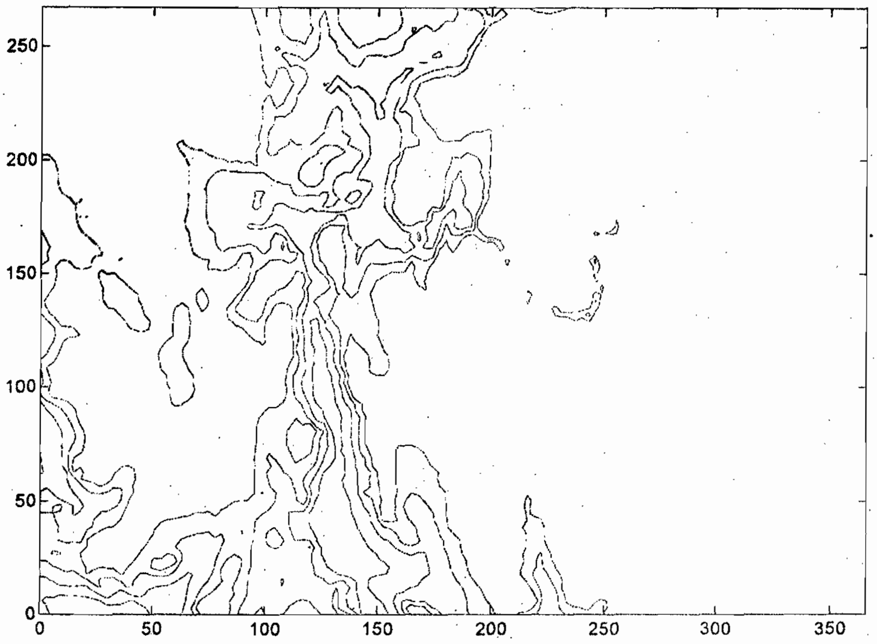

Figure 1. **Model domain as used for MIUU-model simulations. The total domain is used for the atmospheric model simulations, the inner square is used for the dispersion-model simulations. Stations where observations were made are shown. Circles indicate meteorological surface observations, triangles meteorological upper-air observations and squares tracer measurements. For details and coordinates see Pitchford et al. (1999).**

value of 0.0015 at 500 meters above ground level (AGL) for the horizontal wind components, and 4000 meters AGL for temperature and humidity. Between these heights and the model top, the parameter K is set to 0.0015. Between ground level and 500 meters AGL, or 4000 meters AGL, respectively, a linear interpolation is used for the parameter K. The functional F (according to Davies, 1976) was chosen to be zero everywhere, and no relaxation was applied for the vertical wind component. The pressure fields of the NCEP/NCAR Reanalysis project were interpolated to the model grid points to obtain the large-scale synoptic pressure gradient forces.

Since Reanalysis data were available only every six hours, the large-scale synoptic pressure, temperature, humidity, and velocity fields were interpolated linearly in between these times. The method allowed the run of the model for more than 9 days simulation, without experiencing any instabilities.

The MM5 mesoscale model is well-known and thoroughly described in Grell et al. (1995). A detailed description is omitted here for brevity reasons.

Model Simulation

The MIUU model was run from 5 Standard Mountain Time (SMT = UTC –7 hours) on August 5, 1992, to 5 SMT on August 14, 1992. NCEP/NCAR Reanalysis data have been used to prescribe the large-scale synoptic pressure-fields and to update the boundary values of the mesoscale model using the method described above. Surface elevation and land-use have been obtained from the International Geosphere-Biosphere Programme Data and Information System (Belward, 1996). Total cloudiness was set to 0.1 during the whole period and 5 K were added to the NCEP/NCAR Reanalysis temperatures, to get a better agreement with measurements. The model was run with 30 vertical levels, and without using any cloud routines.

MM5 model simulations for MOHAVE have been performed and described by Isakov (1998). A brief description of the simulations can be found in Koracin et al. (2000). MM5 was run from 17 SMT on August 5, 1992, to 16 SMT on August 14, 1992. MM5 preprocessing includes an advanced objective analysis of the synoptic data from the global network, providing detailed initial and boundary conditions for the simulations. A nonhydrostatic version with 35 vertical levels was used. To include more upper-air observations in the initialization process, an expanded grid of 60 km beyond the lateral boundaries of the model was used for the preprocessing.

In both models, a horizontal resolution of 3 km was used. The model domain covered the area between 34.5° and 37° North and 112° to 116° West (see Figure 1). For the MM5 runs, terrain was obtained from a 30" Defence Mapping

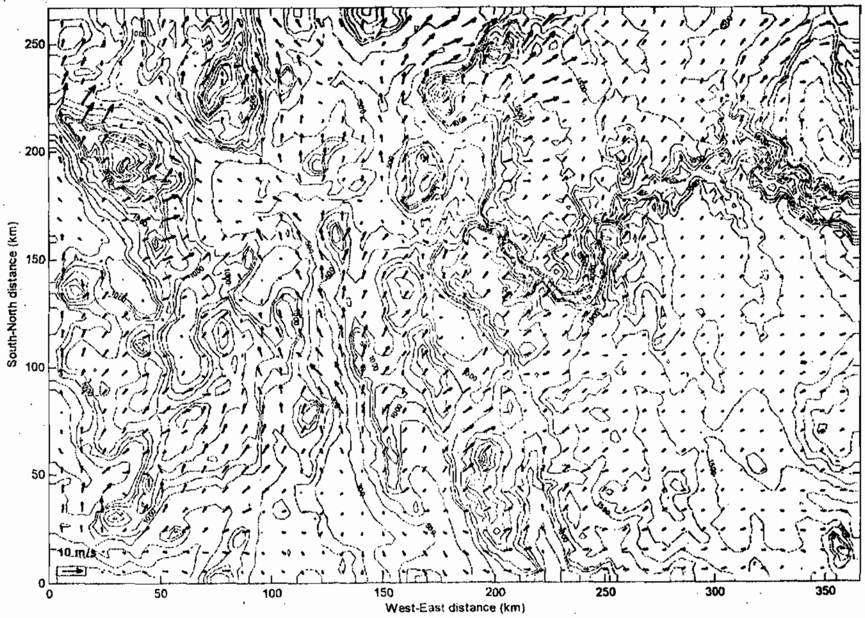

Figure 2. Horizontal wind vectors at 140 m AGL as simulated by the MIUU model at 12 SMT on August 5, 1992. A scaling arrow of 10 m/s is drawn in the lower left corner.

Agency Database, and then considerably smoothed. Thus, the terrain used in the MM5 simulations does not exactly correspond to Figure 1.

Model Results

Results from both models show that the strong channeling, exerted on the flow by the Colorado River valley, with heights of about 200 – 300 m ASL at the bottom of the valley and ridges of up to 1800 m ASL on both sides of the valley, is dominating most of the time. Since the valley axis is roughly south to north, the flow in the valley is usually to the South in winter and to the North in summer (e.g., Green, 1999). Figure 2 shows an example of the flow pattern at 140 m ASL obtained with the MIUU model.

Enger et al. (1993) found, when studying the flow regime of this part of the Colorado River valley, that the wind veering simulated over the range of topographic elevations is often larger than 100 degrees, in some cases as large as 180 degrees. This was also seen in the results of both models and in the measurements.

COMPARISON AND STATISTICAL EVALUATION AGAINST SURFACE AND UPPER AIR MEASUREMENTS

Figure 3 shows a comparison of MIUU and MM5 model results against surface measurements at Mohave Power Plant (MOPP). In both models, the agreement between measured and modeled wind speed is quite poor. Both measured and simulated wind directions clearly show the channeling effect of the Colorado River valley. However, also wind direction corresponds quite poorly to the measurements during larger

Table 1: Root mean square differences of MM5 and MIUU model simulations compared to upper-air observations at stations MOPP, COCE, DOS1, MEAD, OVER and TRUX. Stations are indicated by triangles in *Figure 1*. Number of profiles is indicated as $N_{Profiles}$. W indicates comparison to wind-profiler data, RS comparison to radio soundings. All differences are calculated as the mean for the entire height interval of the profiles, mostly from ground surface up to 5000 m AGL.

		Root Mean Square Differences: MM5					Root Mean Square Differences: MIUU				
	$N_{Profiles}$	Vector (m/s)	U (m/s)	V (m/s)	T (K)	Q (g/kg)	Vector (m/s)	U (m/s)	V (m/s)	T (K)	Q (g/kg)
MOPP	205 W	3.3	3.6	4.2	8.8*	-	3.1	3.5	4.5	10.8*	-
COCE	25 RS	3.3	2.7	3.4	2.3	3.0	3.2	2.5	4.0	2.0	3.1
DOS1	17 RS	2.7	2.8	3.1	2.3	1.6	2.4	2.5	2.9	3.7	2.0
MEAD	205 W	3.2	3.2	4.4	-	-	3.1	3.0	3.8	-	-
OVER	177 W	3.4	2.5	4.6	-	-	3.6	2.1	5.1	-	-
TRUX	205 W	3.2	3.3	4.7	-	-	2.8	3.5	3.7	-	-

*** Comparison with RASS measurements of doubtful quality. Height interval: 100 – 1300 m AGL.**

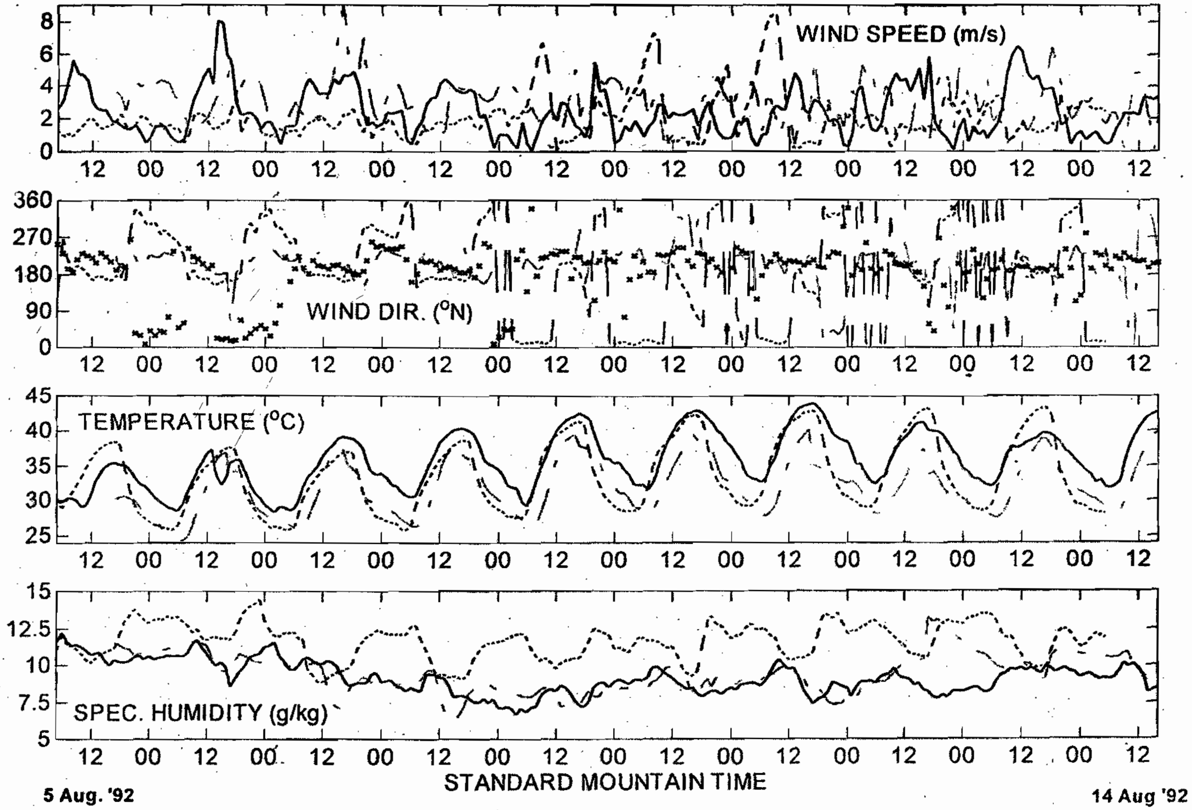

Figure 3. Comparison of model results with surface measurements at MOPP. Full lines/crosses indicate measurements, dashed lines MIUU model results and dash-dotted lines MM5 model results. The grid-point closest to MOPP is used for the model comparison.

time periods. For temperature, the MIUU model seems to perform slightly better, whereas for humidity, MM5 gives slightly better results.

Table 1, finally, shows a comparison of the modeled data with upper-air measurements. Only the time period, where results from both models were available, was chosen for the comparison. Root mean square (RMS) differences (e.g., Pielke, 1984) were calculated using all available upper-air data. RMS differences were calculated as the mean over the entire height interval of the respective profile at each station. Finally, the mean of the RMS differences of all available profiles at one station was calculated and included in Table 1. The number of profiles used is given as $N_{Profiles}$ in the table. As can be seen from the table, both models perform comparatively equally, giving a RMS difference of slightly over 3 m/s for the vector, around 3 m/s for the u-wind and around 4 m/s for the v-wind RMS differences. The comparison with RASS measurements (indicated by asterisks in the table), however, should not be taken seriously, since the quality of these measurements seems to be rather poor.

CONCLUSIONS

Two mesoscale models, the MIUU model and the MM5 model, have been compared to surface and upper-air observations. Statistical methods give only an insufficient answer to the question, which model actually is performing better. Thus, as Koracin et al. (2000) suggested, tracer measurements should be used to evaluate wind fields from different models. Future studies, using both MIUU and MM5 model results as input to a higher-order closure dispersion model, will hopefully give an answer to this question.

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