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Implementation of the Multiscale Climate Chemistry Model (MCCM) for Central Mexico

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Abstract

A model capable of reproducing the pollution in Central Mexico is now being implemented. Among the advantages of this model is its capacity for high resolution (up to 250 m.) using two way or one way nesting. This fact allows for unprecedented detailed studies of the flow of pollution in the region. Principles of operation of MCCM, its capacity for automatically use satellite information to set up the boundary conditions and results form the detailed study of pollution in the region will be presented.

1 Introduction

An air quality model called Multiscale Climate Chemistry Model (MCCM) is being implemented for the central region of Mexico. It includes modules for meteorology, photolysis, biogenic emissions, radiation, and deposition among others. The meteorological module of MCCM is based on the fifth-generation Penn State/NCAR Mesoscale Model see [4]. MM5 is non hydrostatic with terrain following coordinates, has a multi-scale option, is capable of 4-dimensional data-assimilation, has an interface with actual weather forecast models (GCM and observations), contains explicit cloud schemes and multilevel soil/vegetation parameterization.

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An advantage of MCCM is that the meteorological model is directly coupled with a chemistry-transport-model and a photolysis module. The biogenic emissions module is coupled with radiation and RADM2 [1] or RACM [5] chemical mechanisms. Also, a deposition module is coupled with higher order closure turbulence parameterization, a WALCEK aqueous phase chemistry extension to RACM can be used, and a third-order Smolarkiewicz scheme is used for pollutant advection. The code is geared for massive-parallelization. For a detailed description of these see Grell [6].

The gas phase chemistry used in this study was RADM2 [1]. This mechanism considers for the inorganic part, 14 stable species, 4 reactive intermediaries and 3 abundant-stable species. The organic part considers 26 stable species and 16 peroxy radicals. The photo-chemistry is based on the aggregated molecular approach for reactivity [7]. The photolysis module uses a radiative transfer model. This module calculates photolysis frequencies for reaction gas phase chemistry that considers changes in the radiation with height and changes in air composition such as ozone, aerosols and water vapor. The biogenic module calculates organic emissions of isoprene, monoterpenes and other organic and inorganic compounds such as nitrogen soil emissions. This kind of emissions depends on temperature, radiation and type of vegetation. The dry deposition module calculates the elimination of trace compounds from the atmosphere depending on deposition velocity which is calculated using aerodynamic, sub-layer and surface resistance [8]

2 Emissions Inventory

The emissions inventory includes mobile, punctual and area sources. These data is obtained from emission inventories performed by the city government [3]. The compounds considered are nitrogen oxides (NO_x),sulfure dioxide (SO_2), carbon moxide (CO) and volatile organic compounds (VOC). The temporal resolution is 1 hr and the spatial resolution is 2 km. The domain includes an area of 32,400 km^2.

The emissions were divided in two classes depending on their source: antropogenic due to human activities and biogenic mainly due to forests. Although the first class represents the main contribution to emissions, the emissions from natural sources could represent, in some cases an important source of the emissions of VOC's [2][9].

3 Scenario calculations

The results with the IFU-model MCCM achieved so far - compared with operational monitoring data in 1996 - showed reasonable and realistic wind fields and mixing heights as well as realistic concentrations of ozone and other pollutants with high spatial resolution (down to 1 km x 1 km). In order to investigate the effect of changes in present data base of anthropogenic emissions, a set of scenarios were established on the simulated air

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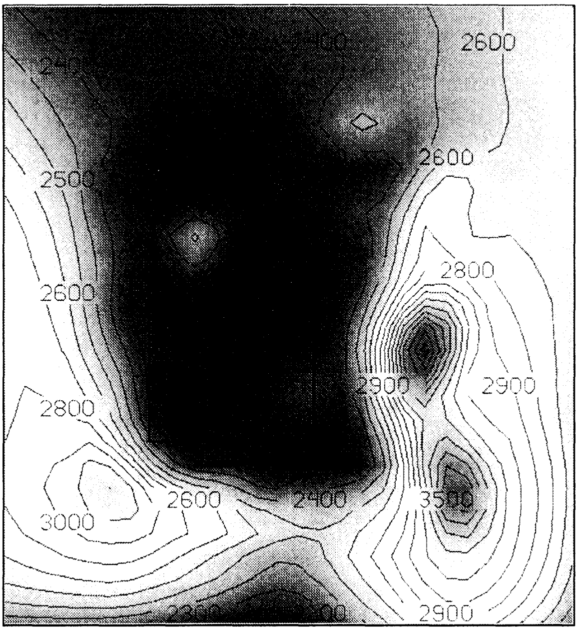

Figure 1: Model domain for the scenario calculations; model dimensions are 29 x 29 x 15, the horizontal resolution is 4 km. Second domain. The rectangular represent the area, where the number of exceedances were counted

quality. The results of such scenarios allowed rough estimations of the effect of mitigation strategies aimed to improve air quality in the Valley of Mexico Metropolitan Area. However, these results give only a hint for the potential of strategies under present atmospheric and economic conditions. For realistic considerations effects of changing climate and economical development have to be taken into account.

3.1 Methodology

A base case simulations with the model MCCM and present emission database for the valley of Mexico Fig. 1 has been carried out for a month with high pollution (December 1995). After that, simulations for the same period assuming different scenarios have been carried out. As a result, tables with number of threshold exceedances for O_3, CO, NO_X and PM2.5 were calculated for different scenarios, see Table 1. Model domain dimensions are 40 x 35 x 15 with a horizontal grid size resolution is 16 km. Results from this domain are the basis for a second domain (initial and boundary conditions) with 29 x 29 x 15, and a horizontal resolution is 4 km. The simulation time for one month is about 28 hours. The analysis of simulation results has been done in following way: for each simulation run (base

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case or scenario), the number of exceedances of threshold values have been counted for whole month in the second domain. Since one run contains hourly output for every grid point in the valley of Mexico, the maximum number of exceedances is 720 hours (corresponding to 30 days). The number of exceedances were counted only for the urban areas in the valley of Mexico, shown in the rectangle in Fig. 1).

Table 1: Explanation of fictice scenarios.

Case	**Explanation**
Base case	Present emissions
Scenario 0	Anthropogenic emission are set to zero
Scenario 1	Applying best achievable techniques
Scenario 2	Reduction of NOX and VOC by 50%
Scenario 3	Reduction of traffic emissions by 50%
Scenario 4	Reduction of emissions from solvent usage by 50%
Scenario 5	Area emissions are set to zero
Scenario 6	Point sources are set to zero
Scenario 7	Reduction of industrial emissions by 50%
Scenario 8	Reduction of NOx by 50%
Scenario 9	Reduction of VOC by 50%
Scenario 10	Traffic in Mexico City set to zero
Scenario 11	Improved emission factors for biogenic emissions
Scenario 12	Increase in temperature of 3 K

Base case stands for the present available emission data. In scenario 0 it is assumed, that anthropogenic emissions are set to zero in the model domain. By means of this scenario, the effect of long range transport to the local air quality can be assessed or in other words, the importance of the boundary conditions of chemical species can be determined. It shows the maximum improvement that can be achieved in the valley of Mexico for primary pollutants. Scenario 1 is a estimation for the case of implementing the best achievable techniques immediately. This leads to a strong reduction in anthropogenic emissions by about 60 to 80%. For scenario 2 a reduction of NO_X and VOC by 50% is assumed, for scenario 3 a reduction of traffic by 50%. Scenario 4 is selected in order to investigate the impact of lower emissions from solvent usage. Scenario 5 and 6 are dedicated to investigate the effect of area sources respective point sources. Scenario 7 was introduced to investigate the impact of industrial emissions. Here the emissions only from this source group were reduced by 50%. Scenario 8 and 9 are useful for theoretical considerations on the efficiency of measures in general (NOX or VOC). In scenario 10 traffic emissions in Mexico City in Fig. 1), are set to zero. Scenario 11 assumes improved emission factors for biogenic emissions. Purpose of scenario 12 is to investigate the effect of increased air temperature on photooxidants and biogenic emissions.

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4 Results

Ozone and photochemical oxidants are the main pollutants in the Mexico City area. In December 1995 the number of threshold exceedances amounted to about 270 hours (>0.12 ppm) and still 17 hours exceeding 0.18 ppm for the base case. From Fig. 2 it can be concluded, that any of the scenarios lead to a decrease of ozone. Especially scenario 1 with strongest reduction in VOC and NOX causes a strong decrease in number of exceedances. Other scenarios are much less effective. It should be emphasized, that due to the long lifetime of ozone of several days and the fixed boundary of ozone concentrations in the second domain, the solution inside of the domain is highly dependent on the boundary values. Therefore, scenario 0 without anthropogenic emissions shows almost no effect to the ozone concentration. A reduction of industrial emissions by 50% (scenario 7) leads to decrease of exceedances (0.12 ppm) by 30%. Scenario 8 leads to a decrease of exceedances (0.12 ppm) by almost 40%. Less effective in reducing ozone is reduction of VOC-emissions (Scenario 9), this gives 13% less exceedances (0.12 ppm). Results of scenario 10 indicate the dominant source in Mexico-City. Assuming no traffic emissions, the number of exceedances (0.12 ppm) decrease by 70%. Also plants are dominant VOC-emitters in the Valley of Mexico City. By including improved emission factors (scenario 11), the number of exceedances (0.12 ppm) increase by about 30%. Changes in temperature can lead to major changes in photooxidant concentration. An increase of 3 ^{o}K in the boundary layer (scenario 12) leads to an increase of exceedances (0.12 ppm) by 10%. This underlines the necessity, to consider climate change in future scenarios. This is very important, because from figure 3 it can be seen, that especially the number of exceedances for 0.18 ppm increase dramatically under scenario 11 and 12.

In contrast to ozone, CO-concentrations in the valley of Mexico are clearly dominated by local emissions. Therefore, results from scenario 0 show no exceedances of any threshold. In the base case, every hour in the month, the concentration of 0.5 ppm is exceeded. Again scenario 1 is very effective in reducing CO-concentrations. Scenario 5 (without area emissions) also shows no exceedances. That means, that only area sources (mainly traffic) contribute to CO-concentrations. Therefore for scenario 10 (without traffic), the number of exceedances (except for 0.5 ppm) are zero. Effective measures in reducing CO-concentration are scenarios 8 and 9 leading to a decrease in exceedances of 2 ppm by 70%. The remaining scenarios do not have significant impact on CO-concentrations.

Similar to CO, the PM2,5 concentration of 0.5 ppm is exceeded every hour in the month in the base case. Since it is first of all a primary pollutant, it is locally emitted; therefore no exceedance occur in scenario 0. Scenario 1 is again most effective in reducing PM2,5-concentrations. In contrast to CO, point sources are main contributors to simulated PM2,5 concentrations. Scenario 6 without point sources shows no exceedances at

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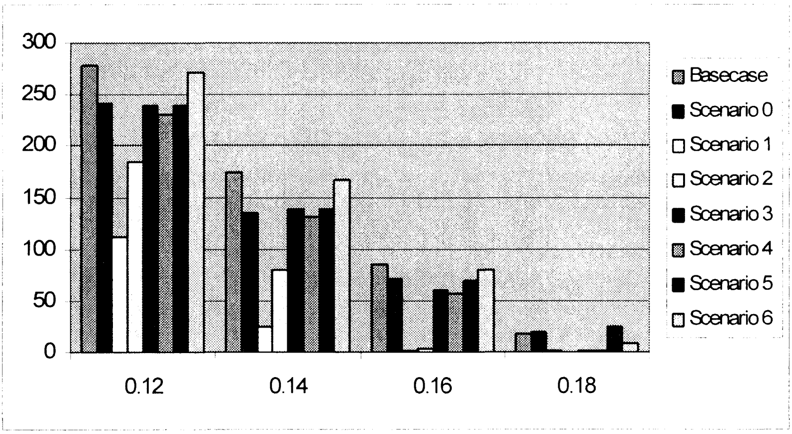

Figure 2: Number of threshold exceedances [hours] for ozone in the Valley of Mexico in December 1995 simulated by MCCM for base case and fictice scenarios 0 to 6; threshold values in ppm as average for Mexico-City.

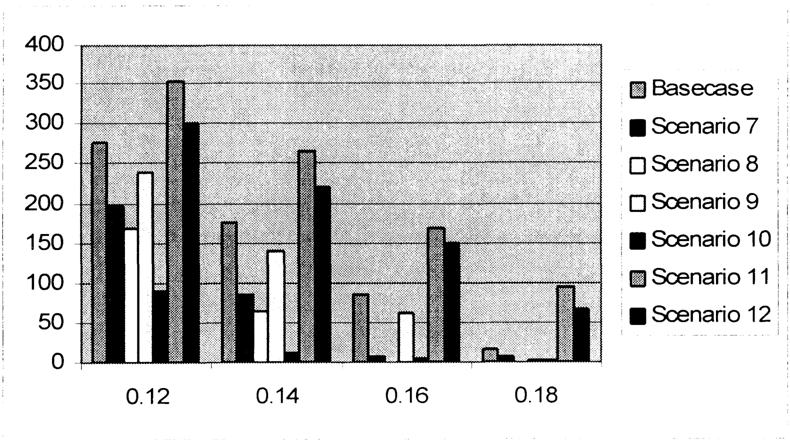

Figure 3: Number of threshold exceedances [hours] for ozone in the Valley of Mexico in December 1995 simulated by MCCM for base case and fictice scenarios 7 to 12; threshold values in ppm as average for Mexico-City.

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any hour in the month. Without traffic emissions (scenario 10) no more exceedances above 1 ppm are simulated. Scenarios 8 and 9 are effective measures especially to mitigate high exceedances of more than 2 ppm. Reduction of 70% in number of exceedances (2 ppm) have been calculated for both scenarios. The number of exceedances for NO_2 is also reduced for any scenario. Very effective is scenario 3, assuming a strong reduction of traffic.

Scenarios 7, 8, 9 and 10 are adequate strategies, to reduce exceedances effectively. However, it occurs the similar problem like in the case of ozone. Biogenic emissions as well as higher air temperature lead to a dramatic increase in peak values of NO_2. The number of exceedances are not higher than under base case conditions, but the changes in environmental conditions are strong enough, to compensate efforts in reducing anthropogenic emissions. Further scenarios are currently in study, these include the effect of coupling different scenarios together.

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