Transactions on Ecology and the Environment vol 3, © 1994 WIT Press, www.witpress.com, ISSN 1743-3541

Comparison of a diagnostic model and the MEMO prognostic model to calculate wind fields in Mexico City

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ABSTRACT

Wind field models may be classified into diagnostic or prognostic ones. The first type basically undertakes an interpolation on the basis of available observations, while the second type attempts a simulation of the atmospheric boundary layer dynamics by solving the appropriate atmospheric transport equations. In spite of their simplicity and computational effectiveness, diagnostic models may not be applicable for cases where only sparse observations are available.

In the present paper the prognostic mesoscale model MEMO and the diagnostic wind model CAPA are applied to the Valley of Mexico. Results of both models are compared to observations which were not used as input to CAPA. The comparison shows that in the urban area of Mexico City (where sufficient observational information is available) both models provide reasonable estimates for the wind velocity, the results of MEMO being closer to the observed values.

INTRODUCTION

Due to its particular characteristics, Mexico City represents a unique study case for air pollution research. Population growth is an important factor that contributes to the high levels of photochemical air pollution in Mexico City's urban area. Values of ozone up to 400 ppb and extremely high particle concentrations are a result of the elevated emission levels in the city, and its meteorological and topographical characteristics favour the ocurrance of smog episodes (Lacy [1]).

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In recent years, a considerable effort is being undertaken to abate air pollution in Mexico City. One aim is to develop tools capable of assisting policy makers to properly select among various options. Air pollution models are important in this context, as they allow to describe the mechanisms governing local wind flow and pollutant transport and transformation in the airshed of interest. Therefore, such models may be applied to assess the effectiveness of any control or program to the emissions situation and hence to improve the air pollution abatement strategies.

In this paper, the results of a simulation with the nonhydrostatic mesoscale model MEMO and those of the diagnostic model CAPA are compared to observations which were not used as input to CAPA. The comparison aims primarily at checking under which conditions the computationally very efficient wind field diagnosis may be useful for practical applications.

MEMO: A NONHYDROSTATIC MESOSCALE MODEL

MEMO is one of the core models of the EUMAC Zooming Model (Moussiopoulos [2]). The original version of MEMO was developed at the University of Karlsruhe. Further development is currently undertaken at both the Aristotle University Thessaloniki and the University of Karlsruhe. In the last years MEMO has been increasingly installed and utilized at several research institutions throughout Europe. Recently, the model was also installed at the National Autonomous University of Mexico (UNAM) in the frame of the project "Modelo prognóstico no-hidrostático para el valle de México".

The prognostic mesoscale model MEMO describes the dynamics of the atmospheric boundary layer for unsaturated air. The model solves the continuity equation, the momentum equations and several transport equations for scalars (including the thermal energy equation and, as options, transport equations for water vapor, the turbulent kinetic energy and non-reactive pollutant concentrations). Detailed descriptions of MEMO are given elsewhere (Moussiopoulos [2]; Moussiopoulos *et al* [3]).

CAPA: A DIAGNOSTIC MODEL

CAPA (Código de Aproximación de Parámetros Atmosféricos; Fuentes *et al* [4]) is a meteorological model adapted at the UNAM from the Diagnostic Wind Model, originally developed at CALTECH by Goodin *et al* (Goodin *et al* [5]; Douglas *et al* [6]). As the DWM, CAPA estimates the wind data in horizontal grid points at several user-specified levels by interpolation, making use of gridded topographic information and surface and upper-air wind data. Advantages of the model are its flexibility, that allows to weight the used data, to include the effect of physical barriers, and to minimize the divergence that is induced when calculating the vertical velocity component from the continuity equation. The difference between CAPA and the DWM consists basically in the estimation of vertical wind profiles at different points and the assignment of characterization factors to each meteorological station, to reduce negative effects associated with the the station's location and surroundings. Both changes have been included in CAPA in order to improve its performance in the Mexico City case. It should be noted that only limited meteorological information is currently available in the Valley of Mexico.

MEXICO CITY SITUATION AND MODELLING PARAMETERS

Mexico City is situated in a valley at an altitude of about 2200 m above sea level (ASL) and it is almost completely surrounded by mountains: Sierra de Guadalupe to the North, Sierra de Santa Catarina to the East and Sierra de las Cruces, Ajusco and Chichinautzin to the Southwest. The highest mountain peaks in the area are the volcanoes Popocatepetl and Ixtaccihuatl at the East, both exceeding 5000 m ASL.

Both models were applied to calculate the wind fields for February 22, 1991 on a 60x60 km^2 domain grid, which includes the biggest part of Mexico City's urban zone. The scale of the horizontal axes corresponds with UTM coordinates, the coordinates of the lower right corner being UTMx=448, UTMy=2119. The horizontal resolution is 1 km for all tests.

To reduce the effect of the lateral boundary conditions on the wind pattern close to the domain boundaries, MEMO allows nested grid simulations. For an adequate description of the mesoscale wind flow phenomena in the Valley of Mexico, therefore, in the present study nested grid simulations were performed. Specifically, in order to numerically provide boundary values at a higher spatial and temporal resolution, an one-way nesting tecnique was applied and thus 'coarse grid' simulations results of MEMO were taken to generate boundary conditions for the 'fine grid' simulations (Moussiopoulos *et al* [7]). The 'coarse grid' covered an area of 120x120 km^2 with a horizontal resolution of 3 km.

For MEMO-simulations, 35 non-equidistantly distributed layers were considered in the vertical direction, the minimum spacing above the metropolitan area of Mexico City being approximately 15 m. The model top was set at the height of 10 km. CAPA uses 6 non-equidistantly distributed vertical layers, although for computer requirement comparison, a run has been performed with the same number of vertical layers as MEMO.

Initial and boundary conditions for the MEMO-simulations were derived from available upper air soundings at the Mexico City International Airport and from surface measurements at Tulancingo de Bravo, Cuernavaca, Puebla, Toluca and

Pachuca. The location of these sites is indicated in Figure 1. The input to CAPA consisted of measured values of meteorological parameters at 10 surface stations from Mexico City's monitoring network.

Terrain data were obtained from the Mexican Instituto Nacional de Estadística, Geografia e Informática (INEGI) at 50 m horizontal intervals. From these data an average terrain height was computed for each 1 km square.

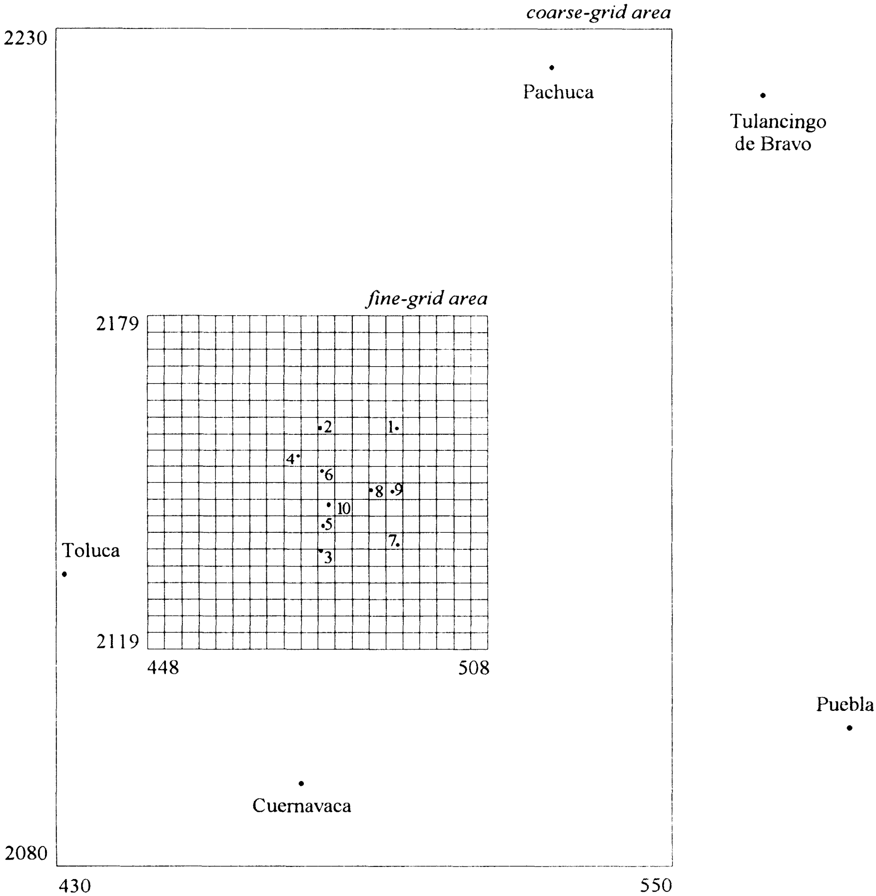

Figure 1 Location of modelling region and measuring stations. Mexico City meteorological stations are: *Xalostoc* (1), *Tlalnepantla* (2), *Pedregal* (3), *Acatlan* (4), *Plateros* (5), *Tacuba* (6), *Cerro de la Estrella* (7), *Merced* (8), *Hangares* (9) and *Tacubaya* (10).

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The wind fields were calculated with both models for a 24 hour period. For pre-conditioning purposes, in the case of MEMO the simulation started at 6 p.m. of the previous day. In the case of CAPA, where measured data are being used as input, several runs were performed, in each of which the measurements at one of the stations were omitted.

Both models were applied on a Sunsparc1 workstation with 64 Mbytes of RAM. To compare CPU-time, MEMO has also been run on an IBM Risk 6000 Workstation with 64 Mbytes of RAM.

RESULTS OF THE TWO MODELS

In Figure 2 the results of MEMO and CAPA are compared with available observations at three stations in the Mexico City urban area. In each case the CAPA results originate from a run where the measurements at the individual station were not taken into account. The locations of the three sites (Tlalnepantla, Plateros and Merced) are indicated in Figure 1.

Apparently, the wind direction predicted with MEMO is in good agreement with the observed values. In spite of stronger deviations from the observations compared to MEMO, CAPA also provides a good estimate for the actual wind direction. For both models, the calculated wind speed agrees fairly well with the measurements in the morning, but is rather low in the afternoon, the underestimation being more severe for CAPA than for MEMO. Moreover, it should be stressed that, although CAPA seems to lead to acceptable results in the region where data are available, its results at remote areas, where no observations are available, deviate strongly from corresponding results of MEMO. Most probably, results of CAPA in such areas will be less accurate than those in the urban area.

It should be also noted that in the case of CAPA the increase of the vertical layer number from 6 to 35 does not affect the results for the wind velocity.

As far as computational efficiency is concerned, CAPA is clearly superior: For a 30 hour simulation of the wind field on a 60x60x35 domain (i.e., a full day and a 6 hour pre-conditioning period), MEMO needs approximately 48 hours of computing time on the IBM workstation (ratio CPU/realtime approximately 0.6). On the Sunsparc1 workstation, about 120 hours of CPU-time are needed in the case of no optimization of the Fortran code. At present, different optimization levels are being used to compile the code, which are expected to make the simulations up to eight times faster. For the same time period and an equal number of grid points, CAPA needs only 7 hours of CPU-time. A CAPA-run with 6 vertical layers instead of 35 consumes about 45 minutes of CPU-time.

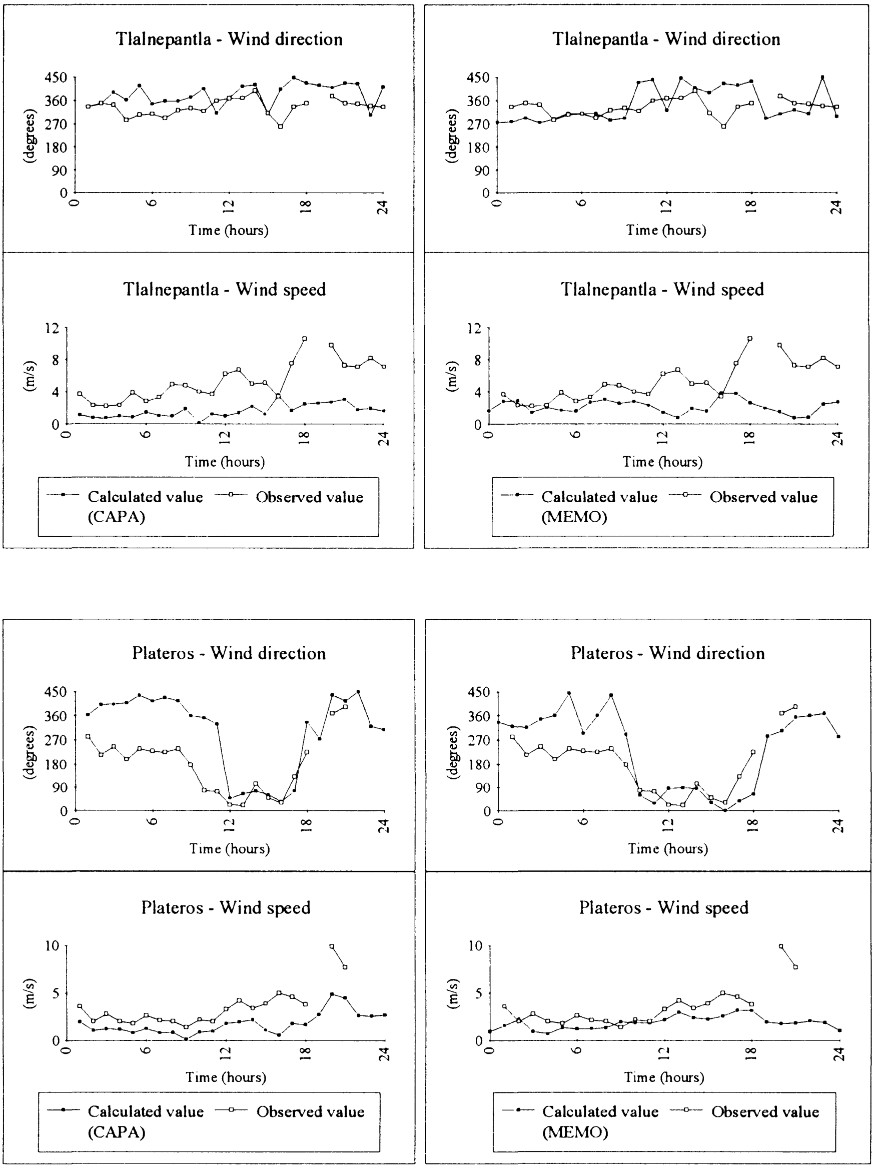

Figure 2 Diurnal variation of surface level wind speed and velocity at Tlalnepantla, Plateros and Merced (locations 2, 5 and 8 in Fig. 1): CAPA- and MEMO-predictions compared with observations.

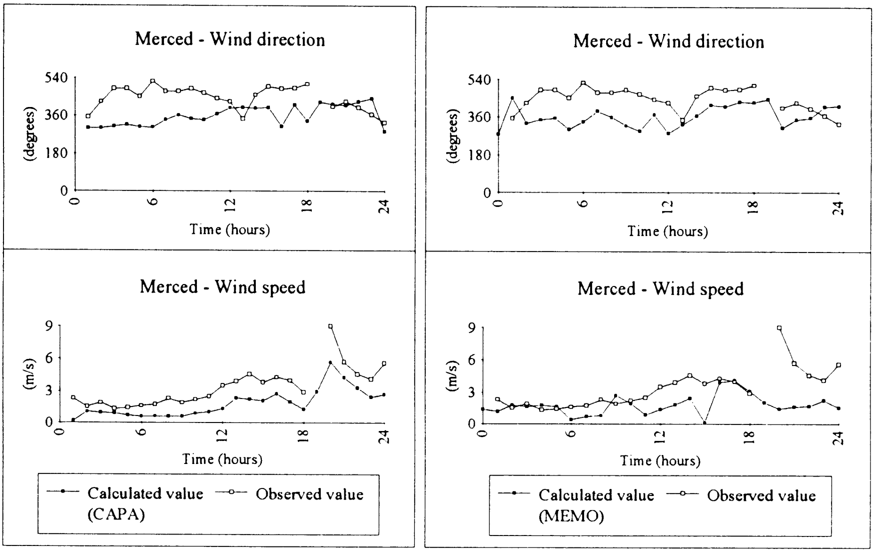

Figure 2 Diurnal variation of surface level wind speed and velocity at Tlalnepantla, Plateros and Merced (locations 2, 5 and 8 in Fig. 1): CAPA- and MEMO-predictions compared with observations, CONTINUED.

In summary, MEMO's computing time requirements are about one order of magnitude higher than those of CAPA. MEMO also needs a higher storage compared to CAPA, although the required 16 Mbytes should be available on any contemporary workstation.

CONCLUSIONS

The results presented indicate that the diagnostic wind model CAPA may prove very useful for quick estimates of the wind flow in the parts of the Valley of Mexico, where sufficient observational evidence is available.

The results of the nonhydrostatic mesoscale model MEMO are in better agreement with observations compared to those of CAPA. Hence, this prognostic model proves capable of reliably predicting the wind field in the Valley of Mexico, though at considerably higher computational expenses compared to a diagnostic model. Given that MEMO also provides the spatial and temporal variation of other meteorological variables, including temperature, humidity and turbulence quantities, this model represents a powerful tool for air quality investigations. Real time estimations, however, cannot be achieved with MEMO, unless high capacity computers are used.

ACKNOWLEDGEMENT

The authors like to thank DGAPA for supporting the project "*Modelo prognóstico no-hidrostático para el valle de México*".

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