6.18 MODELLING THE AIR POLLUTION TRANSPORT FROM THE SÃO PAULO METROPOLIS TO NEAR AND MIDDLE DISTANCE PLACES.

Kerr A A F S[1], Biemann N[1], Anfossi D[2], Trini Castelli S[2], Carvalho J[3]
[1]Instituto de Física, Universidade de São Paulo, São Paulo, SP, Brazil, CEP 05315/970; CP.66.318, akerr@if.usp.br; nauber@if.usp.br
[2]Istituto di Scienze dell'Atmosfera e del Clima - Sezione di Torino, CNR, Corso Fiume 4, 10133 Torino, Italy, anfossi@to.infn.it, trini@to.infn.it
[3]Universidade Luterana do Brasil, Faculdade de Engenharia Ambiental, Canoas, RS, Brazil, jonas@ulbra.tche.br

INTRODUCTION

São Paulo metropolis is classified among the mega-cities with the most intense air pollution problem in the world (Mage et al., 1996). CETESB (2003), the environmental control agency of São Paulo State, estimates that the local atmosphere receives an annual load of 2.6 Mt of typical urban air pollutants, 96% of this being generated by vehicles, specially by cars for personal use (52%). The days with inadequate air quality levels are in general related to O_3, CO and PM10. Seventeen million local inhabitants are mainly affected.

This work is part of a larger project developed by several research groups, since 1998, studying in depth the local meteorology and its association with air pollution problems in the metropolitan area. The aim of our specific research was to evaluate the transport of pollutants from São Paulo to near and middle distance areas. In the metropolis neighbourhoods, there are other populous cities, besides crops and biological reserves that could receive significant loads of air pollution. The days 11, 12 and 13 of August 2000, selected to be analysed, correspond to a period of intense measurement campaign for meteorological parameters and for several air pollutants in the main project. In this work only CO was evaluated.

THE COUPLED MODEL SYSTEM SPRAY/RAMS/MIRS

The Regional Atmospheric Modelling System (**RAMS**, version 3b) is a well known prognostic model designed to simulate a large range of atmospheric flows in a large spectrum of scales (Pielke et al., 1992). The model contains many options for the description of physical processes in the atmosphere. RAMS allows nesting from large-scale area to smaller scale because it is based on the 2-way grid interactive procedures. **MIRS** (Model for Interfacing RAMS and SPRAY) reads the meteorological fields produced by RAMS and prepares an input file to SPRAY. Topography, wind speed and potential temperature are the minimum information requested, then turbulent kinetic energy, diffusion coefficients and surface fluxes are treated when available. MIRS calculates the surface layer parameters (friction velocity u_*, temperature scale θ_* and Monin-Obukhov length L), on the basis of the similarity theory, by the surface fluxes or, when these last are not available, by the Louis (1979) parameterisation. Several methods are available for determining the PBL height z_i (see Trini Castelli, 2000), and from the u_*, L e z_i values, the convective velocity scale w_* can be calculated. Then it computes the variances of the wind velocity fluctuations and the Lagrangian time scales. If needed, the third moment of the vertical velocity component is assigned following Chiba (1978) and the fourth moment is calculated from the method suggested by Ferrero and Anfossi (1998). **SPRAY** is a Lagrangian stochastic one-particle model designed to study the dispersion of passive pollutants in complex terrain (Tinarelli et al. 1994 and 2000, Ferrero and Anfossi, 1998), where the inhomogeneity of the variables that determine the dispersion process play an important role. It is based on a 3D form of the Langevin equation for the random velocity (Thomson, 1987). The model makes use of the

Gaussian PDF in the horizontal directions, while in the vertical direction the PDF is assumed to be non-Gaussian (two different approaches can be chosen: a bi-Gaussian one, truncated to the third order, and a Gram-Charlier one, truncated to the third or to the fourth order. Both fixed and variable time step can be adopted. Plume rise, if any, is accounted for (Anfossi, 1985; Anfossi et al., 1993).

THE PARAMETERIZATION OF THE SIMULATION

RAMS simulated the meteorological fields using two nested grids: Grid-1, covering an area of 450X450 km², with a resolution of 18 km and centre at 23.550S and 46.500W; Grid-2, covering an area of 184.5X184.5 km², with a resolution of 4.5 km and centre at 23.388S and 46.677W. The dispersion simulations used only the fine grid, nevertheless the coarse grid improves the quality of the general circulation information transmitted to the fine grid. The vertical grid had 30 steeps and was unique for all horizontal grids. The first vertical level had a depth of 100 m and the depth of the other levels increased progressively until a limit of 500 m. The meteorological information to initialise RAMS was available at the standard pressure levels, at 00, 06, 12 and 18 UTC, with a resolution of 2.5 degree in latitude and longitude (CPTEC – www.cptec.inpe.br). The input topography data was performed by the EROS data Center (from U.S. Geological Survey; resolution of 30”). The other parameterisations were kept constant or based on RAMS inner files.

Table 1. Symbols Meaning

RMSP	São Paulo Metropolitan Region
SP	São Paulo Metropolitan Region
JU	Jundiaí
CA	Campinas
AM	Americana
SO	Sorocaba
SJC	São José dos Campos
JA	Jacareí
BXS	Baixada Santista Metropolitan Region
ITU	Itu
S	São Roque
C	Cotia
E	Embu
R	Ribeirão Pires
M	Mogi das Cruzes
BP	Bragança Paulista
AT	Atibaia

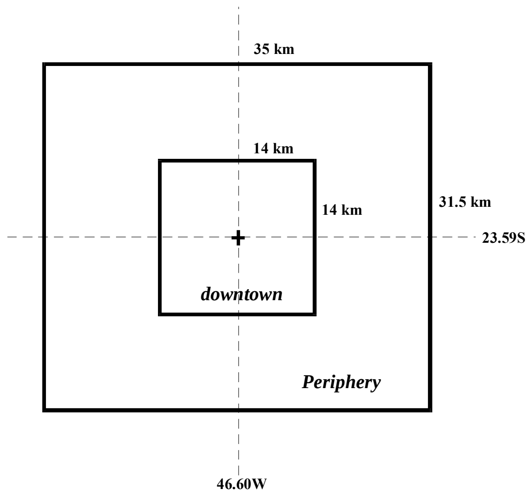

Figure 1. Structure of the CO source area over São Paulo.

The Mellor and Yamada (1982) level 2.5 turbulence closure was used in RAMS. From the RAMS tke (turbulent kinetics energy) gridded values, MIRS calculated the 3-D wind standard deviation field. From these values and the diffusion coefficients, the Lagrangian decorrelation time scales were computed. The Planetary Boundary Layer height was defined using the criterion of the critical value for the Richardson number. Finally, MIRS estimated the third moment of the vertical velocity fields using the relations developed by Chiba (1978).

The CO source for SPRAY was composed using the following:

1) The inventory made by Cetesb (2001), estimating that vehicles emits $1.62x10^6$ t/year at the RMSP, representing 98% of the total CO emission (Cetesb, 2001).
2) The rate between downtown emissions and the periphery was 3.6 (Freitas, 2003).
3) The CO area source may be represented by two superposed rectangles (Figure-1), as could be inferred from a satellite image given by Freitas, 2003.

Considering all that, we assumed only a continuous vehicular emission at a height of 0.45m, which gives an emission rate of $3.27x10^{12}$ mg/day at the downtown square and $1.17x10^{12}$ mg/day at the periphery rectangle.

RESULTS AND DISCUSSION

The direction of the wind fields generated by RAMS at ground level are coherent with the data reported in the downtown area of the RMSP and at Campinas (CA). The general circulation prevailed during the period of simulation. The most frequent direction in the RMSP area was SE, being 20% at 157.5 degree, 18% at 135 degree and 13% at S.

Figures 2a and 2b represents the most frequent horizontal and a vertical slice of the simulated wind field. Figure-3a shows the correspondent CO horizontal concentration field simulated by SPRAY. The urban centres are delineated in the figure and the symbol associated to each one is given in Table-1. Atlantic Ocean is in correspondence of the SE corner. In that case the air flow passing by the RMSP follows the direction of the road that make its connection to populous cities in the inner part of the state, as Jundiaí, Campinas and Americana. Table-2 shows the CO concentration estimated for those cities. Others urban centres are far from the dispersion line.

Table 2. Estimated Concentrations for CO

Date (UTC)	Time (UTC)	Time (Local)	Estimated Concentration (mg/m³)			
			RMSP (SP-Maximum)	Jundiaí (JU)	Campinas (CA)	Americana (AM)
11/08/2000	15	12	6.36	0.04	0.04	0.014
	18	15	6.42	0.067	0.005	0.051
	21	18	7.71	0.04	0.06	0.060
	24	21	6.71	0.16	0.04	0.030
12/08/2000	03	00	6.61	0.12	0.058	0.080
	06	03	7.47	0.05	0.047	0.150
	09	06	6.41	0.34	0.12	0.280
	12	09	6.10	0.23	0.07	0.140
	15	12	6.24	0.039	0.0017	0.008

The maximum concentration estimated in the RMSP are comparable with the highest values measured by Cetesb (2001) in the same period, which are between 1 and 5.5 mg/m³ (average of 2.82 mg/m³ at Congonhas, the station with the highest CO loads). The CO concentrations measured at Campinas station were between 0.25 and 2.7 mg/m³ with an average of 0.96 mg/m³. The transported CO concentrations estimated for Campinas are relatively low (Table 2), although they could be 10 to 20% of the measured values for some periods.

The urban centre receiving the highest CO loads from the RMSP was Jundiaí, which is close to São Paulo. Nevertheless, the CO concentrations evaluated for Americana (AM) are often higher than at Campinas, although it is 30 km downstream during SE wind. This fact could be explained because, in the SE line, São Paulo is settled in a valley (Figure 3b) and the airflow must climb an elevation before reaching Campinas. Figure 2b shows an upward air flow, induced by the elevation after São Paulo, that injects material into high levels of the boundary layer, surpasses Campinas and reaches lowers levels before arriving to Americana. For the S wind, less frequent and registered after 15 UTC on 12 August, the CO plume centre line takes a terrain canalisation between Jundiaí and Atibaia generating only very low CO levels in the inner urban centres. The tropical rain forest preserve covers mainly the areas near the Atlantic coast (SE corner on Figure 3a). Therefore they are often upstream of São Paulo emissions. The inner part of São Paulo State, elsewhere, consists of fields of vegetables, fruits and other kind of crops around al the urban centres. They receive the loads of CO and other pollutants transported from the RMSP.

It is remarkable that in the simulations performed, both, the measured an estimated concentrations of CO did not exceed the daily air quality standard (10 mg/m³ per 8 h once a time in the year) and the air quality remained classified as good (less than 5 mg/m³ per 8 h) or acceptable (between 5 to 10 mg/m³ per 8 h) in the specific case of São Paulo.

CONCLUSIONS

The simulations performed in this work evaluated the dispersion of the nearly 4.44×10^{12} mg/day of CO emitted by the 6.5 million vehicles fleet in the RMSP on 11, 12 and 13 august 2000. It was studied an area of 184.5X184.5 km² around this mega-city. The SE wind over São Paulo was the most frequent direction in the period of simulation. Under this condition Jundiaí, Campinas and Americana remained along the central axis of dispersion receiving significant CO loads. The simulated concentrations due transport were higher at Jundiaí, followed by Americana, although this city is 30 km downstream from Campinas, along the SE line. Such occurrence was explained by a topographic injection of airflow over Campinas that subsequently slow down before arriving to Americana. The space between cities is plain of every type of crop. Those crops placed downstream the RMSP in the S and SE line are more intensely affected by the mega-city emissions. The comparison between simulated CO concentrations and measurements available at São Paulo and Campaigns showed that our results are reliable. Nevertheless our plan is to improve those simulations using a better land-use definition, increasing the spatial resolution of the CO source and, also, the time dependence of the source emissions.

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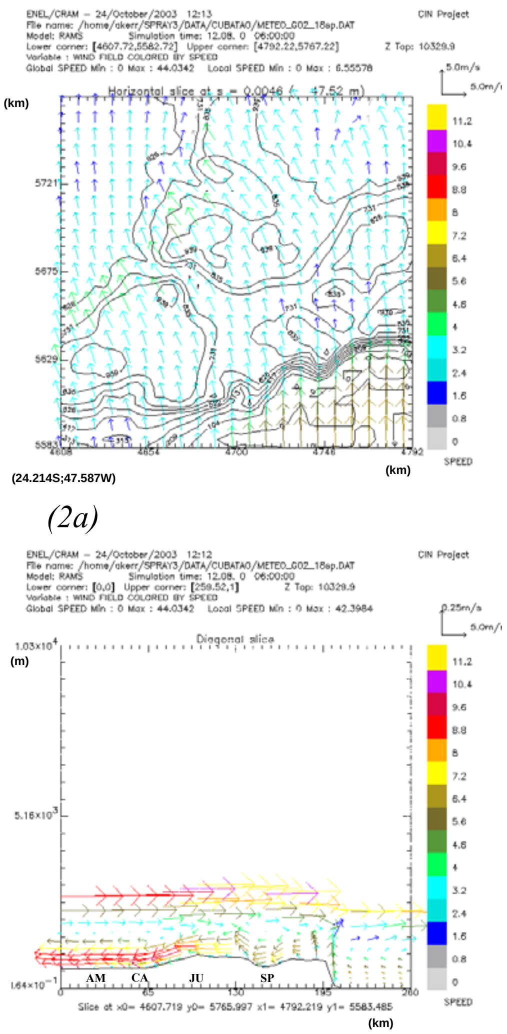
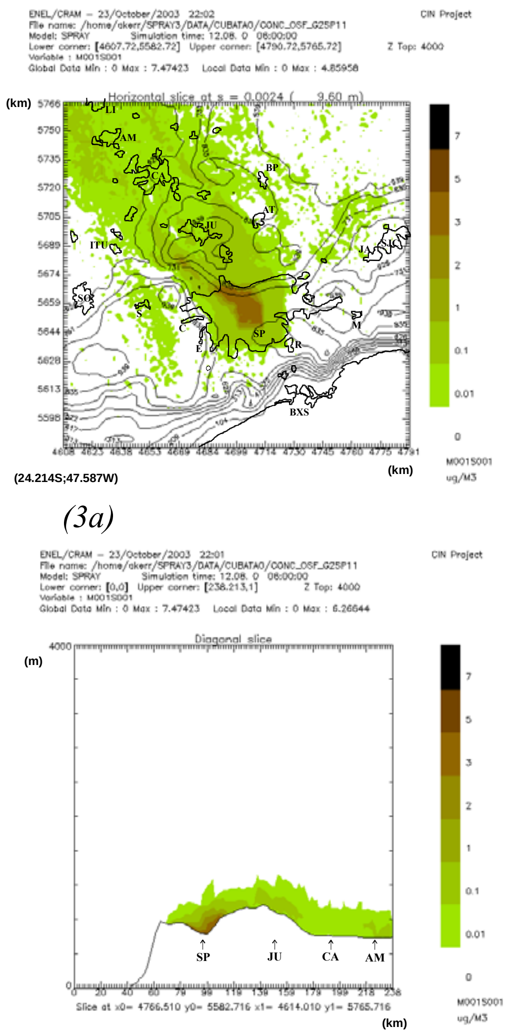


(2a)

(2b)

Figure 2. Simulations at 12 August 2000, 06 UTC. (a) Wind field at 47 m; (b) vertical slice at the signed points d



(3a)

(3b)

Figure 3. Simulations at 12 August 2000, 06 UTC. (a) Concentration field in the first 10 m; (b) vertical slice at the signed point