INVESTIGATION OF CO DISPERSION FROM SÃO PAULO METROPOLIS BY MEANS OF A MODELLING SYSTEM FOR COMPLEX TERRAIN

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INTRODUCTION

The São Paulo metropolis (RMSP) is located 700 to 1000 m above the sea level, 55 km from the Atlantic Ocean shoreline, after the steep slopes of the *Serra do Mar* (Sea Sierra). In a 100 km range around the metropolis there is also a part of the Mantiqueira sierra (900 - 2500 m high), other small mountain ranges, valleys and rivers plains. The land use is complex, with preserves of tropical forest, crops, many artificial lakes for urban water supply or hydroelectricity generation, three metropolitan areas (São Paulo - 8,051 km², Campinas - 3,673 km², Baixada Santista – 2,373 km²) and several urban centres. This work evaluates the transport of CO emitted at the RMSP on days 11, 12 and 13 of August 2000. They correspond to a period of intense measurement campaign for meteorological parameters and for several air pollutants in the main project we participated.

THE COUPLED MODEL SYSTEM SPRAY/RAMS/MIRS

The modelling system SPRAY/RAMS/MIRS was selected to perform simulations, because of its capability of dealing with the complexities of this region in preceding works. **RAMS** - The Regional Atmospheric Modelling System (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) has the objective of reading the RAMS outputs and preparing the SPRAY inputs (see Trini Castelli, 2000). In particular, it has the task of prescribing all the turbulence information not directly given by RAMS, such as the 2-D mixing height field, the 3-D wind standard deviation, Lagrangian decorrelation time scale and the third and fourth order moment of the vertical velocity fields. Thus, MIRS prepares a single file, with the temporal sequences of interest, containing all the above-mentioned fields, having the appropriate format for SPRAY. **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

Meteorological fields

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 coarse grid improves the quality of the general circulation information transmitted to the fine grid used in the dispersion simulations. The unique vertical grid had 30 steeps, being he first with 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, resolution of 2.5 degree (CPTEC – www.cptec.inpe.br). The input topography data was from U.S. Geological Survey (resolution of 30"). The land use classification (original resolution of 500m) was obtained from satellite information, classified by Freitas (2003). The other parameterisations were kept constant or based on RAMS inner files.

CO dispersion fields

CO, O_3, and PM10 are all related with inadequate air quality levels in the RMSP. Nevertheless, CO is more interesting when looking at the air pollution transport from the metropolis. It could be considered chemically stable during simulations, focusing the problems strictly on the pollutant transport. Else, 98% of the total CO emission in the RMSP is associated to vehicles (Cetesb, 2001, 2005). That enables a fair definition of the source, obtained as follow (Landmann, 2004):

1. The density and velocity of vehicles in the streets was evaluated with EMME/2, a software used by the sector of traffic control in the RMSP;
2. An average emission factor (g/km) for CO was used, based in the average composition of the fleet (models, fuel, age);
3. Then the CO emission (kg/h) was evaluated for the meshes of 5x5 km² in a grid over the RMSP (Figure-1.a). The annual emission estimated by this method, 1.69×10^6 t/year, is very close to the 1.62×10^6 t/year estimated by Cetesb (2001).

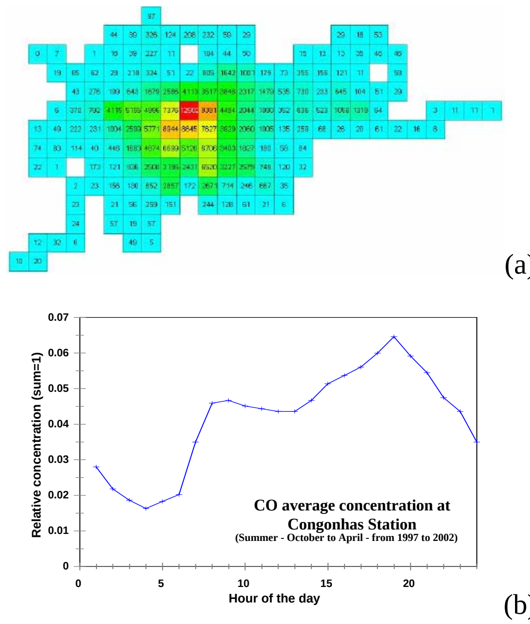

Figure-1.(a) Structure of the CO-area source over the RMSP. (b) Daily cicle of the CO average concentration at Congonhas Station

The CO area-source was also time modulated based in the normalised CO concentration measured in the Cetesb station at Congonhas (Figure-1.b). Settled just in the side of an avenue with intense traffic, the concentration daily profile of that station is very close to the local crude vehicular emissions. An enhanced representation of the CO emissions itself, was obtained using only the averaged daily profile for typical summer periods (from 1997 to 2002), when the background concentrations are low. Emission height was settled at 0.45m.

Next we give the other parameterisation for the dispersion modelling. From the RAMS tke (turbulent kinetics energy- following Mellor Yamada, 1982, level 2.5 turbulence closure) 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.

RESULTS AND DISCUSSION

The quality of wind, temperature and humidity values simulated by Rams for August 11, 12 and 13 were evaluated by comparison with the available data for six ground meteorological stations. The measures used to compare are RMSE (root-mean-square error), RMSVE (root-mean-square vector error), FB (relative mean bias) and MD (mean difference). Tables 1 and 2 show that the agreement between simulated and measured data are similar or better than those obtained in other experiments (Pielke and Pearce, 1994; Cox et al. 1998; Freitas, 2003). Discrepancies are greater than the average only for temperature, although we also expected better results for humidity. We think that the problems with the simulation of these parameters, among others, are particularly associated to land use definition. Freitas (2003) reports expressive divergences between his classification and that performed by IGPB (International Geosphere Biosphere Programme). In addition, the seasonality of crops over large areas (like the sugar cane used in the alcohol fuel production) could introduce a significative uncertainty in the setting of land use. Else, the big urban centres, inputs like energy and humidity, must be better described.

Table-1 Comparison between the predicted and simulated surface wind

Station	Local	(lat,lon)	RMSVE (U and V)	MD speed	MD direction	FB speed	FB direction
sibi	RMSP	(-23.591;-46.629)	1.68	-0.57	-2.3	-0.33	-0.01
spii	RMSP	(-23.544;-46.660)	1.75	-0.05	-19.1	-0.03	-0.12
sscs	RMSP	(-23.617;-46.556)	1.85	-0.23	-4.8	-0.13	0.08
siag	RMSP	(-23.649;-46.625)	2.62	-0.88	-39.4	-0.47	-0.26
ssor	Sorocaba	(-23.502;-47.479)	1.48	-0.49	2.3	-0.21	0.01
spau	Paulinia	(-22.772;-47.154)	2.25	-0.07	17.1	0.18	0.11

Table-2 Comparison between the predicted and simulated temperature and humidity

Station	Local	(lat,lon)	Temperature (C)			Relative Humidity (%)	
			RMSE	MD	FB	RMSE	FB
sibi	RMSP	(-23.591;-46.629)	3.7	-1.9	-0.22	29	-0.32
spii	RMSP	(-23.544;-46.660)	3.5	-1.4	-0.17	11	-0.02
sscs	RMSP	(-23.617;-46.556)	3.5	-1.4	-0.17	11	-0.02
siag	RMSP	(-23.649;-46.625)	3.3	-1.0	-0.12	12	-0.08
ssor	Sorocaba	(-23.502;-47.479)	4.4	-1.9	-0.21	16	-0.18
spau	Paulinia	(-22.772;-47.154					

CO concentrations evaluated by SP points at the RMSP. A good agreeme in Figure 3). SPRAY results were ne SPRAY evaluated concentrations we poor agreement could be because o stations, contrasting with a heterogen on points with less intense CO concentration field simulated by SPR of the SE corner. In that case the air road that make its connection to popu the RMSP received the highest CO evaluated for Americana are often h downstream during SE wind. This fa high levels of the boundary layer, in t after São Paulo (Figure 4b), surpasse

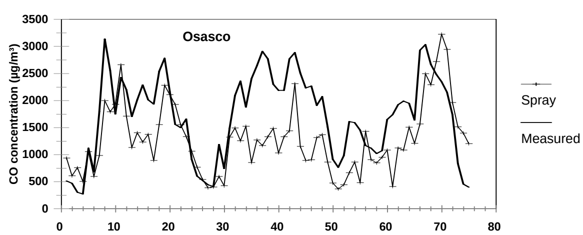

Figure 3 – CO concentrations at Osasco - RMSP.

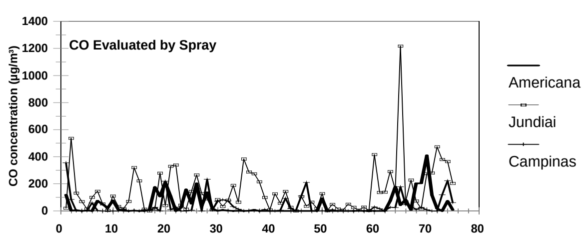

Figure 5 - Simulate CO concentrations

Americana. Only the urban centres located along SE line received significative CO loads, during the days of simulation. This wind direction was also prevailing in the RMSP during all the winter period (frequency of 38%). Notwithstanding that, the inner part of São Paulo State, elsewhere, consisting of fields of vegetables, fruits and other kind of crops around al the urban centres, also receiving the loads of CO and other pollutants transported from the RMSP. Nevertheless this particular period of simulation covered only days of relatively low concentrations levels, below of the daily air quality standard (10,000 μg/m³ per 8 h once a time in the year), for every point of the analysed area.

CONCLUSIONS

The wind field simulated by RAMS, and used in the dispersion modelling, showed a fair agreement with the available ground measurements. Humidity and specially the temperature simulation need some improvement. We think that care should be taken with land use dealing, due to the seasonality of large crop extension and to parameters like energy and humidity on the big urban centres. Comparisons between the CO concentrations simulated by SPRAY and the available measurements at the RMSP, showed an acceptable agreement. Besides the fair performance of the modelling system, we think that the good definition of the CO source also played an important role. Therefore, we consider reliable our simulations of the dispersion of the CO emitted by the 6.5 million vehicle fleet in the RMSP on 11, 12 and 13 august 2000. In the area studied (184.5X184.5 km² around this mega-city) the SE wind over São Paulo was the most frequent direction leaving the urban centres Jundiaí, Campinas and Americana in the central axis of dispersion. 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 could be explained by a topographic injection of airflow over Campinas that subsequently slow down before arriving to Americana. The space between cities is filled with every type of crops. Those crops placed downstream the RMSP in the S and SE line are more intensely affected by the mega-city emissions.

REFERENCES

Cetesb, 2001 and 2005: Relatório de qualidade do ar no Estado de São Paulo 2000 and 2004, Secretaria de Estado do Meio Ambiente, São Paulo, SP, BR (www.cetesb.sp.gov.br).

Cox, R.; Baure, B. L. Smith, T. (1998): A mesoscale model intercomparison, Bull. of the Am.. Meteorol. Soc., ***79****, 2, 265-283.*

Ferrero, E.; D.Anfossi (1998): "Sensitivity analysis of Lagrangian Stochastic models for CBL with different PDF's and turbulence parameterizations". Air Pollution Mod. and its Appl. XII, S.E. Gryning and N. Chaumerliac eds., Plenum Press, NY, 22, 673-680.

Freitas, Edmilson Dias de, 2003: Circulações Locais em São Paulo e sua Influência sobre a Dispersão de Poluentes, PhD at the IAG-USP, sup. by Dr. Pedro Leite da Silva Dias.

Landmann, Marcelo Camilli, 2004. Estimativa das emissões de poluentes dos automóveis na rmsp considerando as rotas de tráfego, at the Anppas Conference.

Mellor G.L and Yamada T., (1982): Development of a Turbulence Closure Model for Geophysical Fluid problems, Rev. Geopys. and Space Physics, ***20*** *, 851-875.*

Pielke,R. A.; Pearce, R. P.-editors (1994): Mesoscale modelling or the atmosphere Meteor. Monographs, American Meteorological Society **25***, 137-148.*

Pielke,R. A., W. R. Cotton, R. L. Walko, C. J. Tremback, M. E. Nicholls, M. D. Moran, D. A. Wesley, T. J. Lee and J. H. Copeland (1992): A comprehensive meteorological modelling system - RAMS. Meteor. Atmos. Phys. ***49****, 69-91.*

Tinarelli G., D. Anfossi, G. Brusasca, E. Ferrero, Giostra U., M.G. Morselli, Moussafir J. Tampieri F., Trombetti F. (1994): "Lagrangian Particle Simulation of Tracer

Dispersion in the Lee of a schematic Two-Dimensional Hill". Journal of Applied Meteorology, 33, 744-756.

Tinarelli G., D.Anfossi, M. Bider, E.Ferrero, S. Trini Castelli (2000): "A new high performance version of the Lagrangian particle dispersion model SPRAY, some case studies". Air Pollution Modelling and its Applications XIII, S.E. Gryning and E. Batchvarova eds., Kluwer Academic / Plenum Press, New York, 499-507.

Trini Castelli S., 2000: MIRS: A turbulence parameterisation model interfacing RAMS and SPRAY in a transport and diffusion modelling system. Rap. Int. ICGF/CNR No 412/2000.

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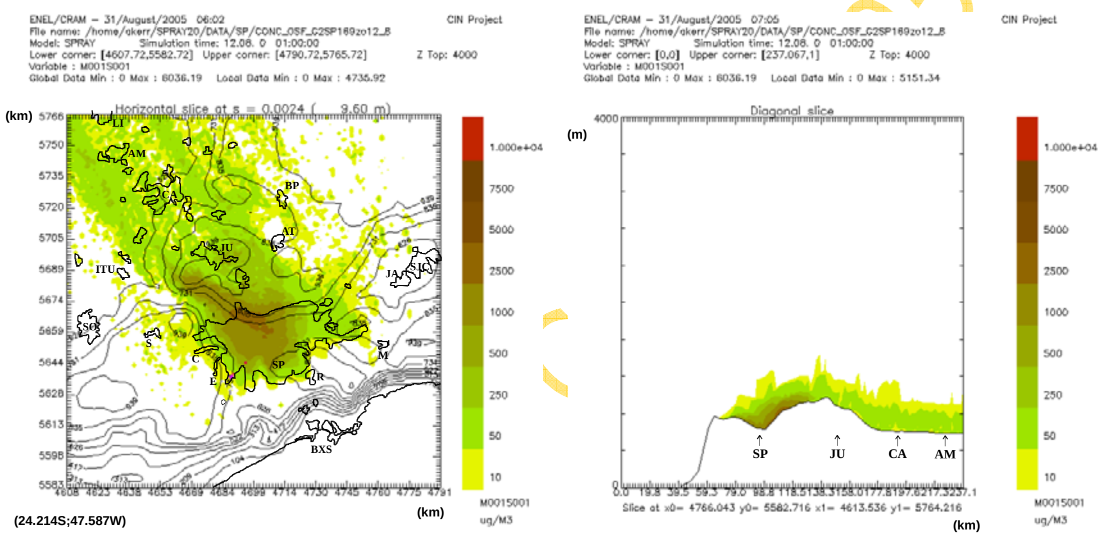

(4.a) *(4.b)*

Figure 4 - Simulations at 12 August 2000, 01UTC. (a) Concentration field in the first 10 m; (b) vertical slice at the signed point. Name of urban centres are abridged, some of them are SP= RMSP; JU= Jundiai; CA= Campinas; AM= Americana; SO= Sorocaba; SJC= São José dos Campos; BXS= Baixada Santista Metropolitan Region.