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Improvements in Emissions and Air Quality Modeling System applied to Rio de Janeiro – Brazil

Santolim, L. C. D; Curbani, F.; Albuquerque, T. T. A; Morais, T. J.; Cavassani, K. N.; F. Frizzera, A. B.; Scardini, C.; Silva, M. L. B.; Vieira, M. R; Kohler, L. A; Oliveira, A. M. P; Gonsalves, T. B.

EcoSoft – Consultoria e Softwares Ambientais Ltda: Consulting, Softwares and Monitoring (www.ecosoft.com.br)

1. INTRODUCTION

It was developed an alternative tool to build a spatially (3D geo-referenced framework) and temporally resolved emissions inventory called SIA-ATMOS. All kind of sources arising from the study area are included in the software, i.e. mobile sources, industrial and commercial emissions, open burning, dust resuspension and stack releases. Input data to feed the software include geo-referenced location for all the considered sources, traffic patterns, integrated emission factors for mobile sources, fleet composition, energy generation at local power plants, natural gas burning in residential and commercial places and trash and vegetation burning rates, among others information. Additional to that, an interesting aspect of this work is the CMAQ coupling into this package tool, which allows users without Linux knowledge to work with these types of models. Thus in the course of this work, it was introduced a routine into SIA-ATMOS which modifies the time independent sparse gridding matrix (GRDMAT) depending on meteorological values. This modified gridding matrix is calculated for each hour of the year, and therefore enhances the spatial as well as the temporal resolution for certain source sectors. Additionally a vertical distribution using Plume Rise was also introduced. The newly created emissions inventory was used as input for CMAQv4.6. This paper presents a package tool to quantify and evaluate the local air quality. The main aim of the work is to implement a calculation tool to predict air pollutant concentrations and the impact of potential mitigation measures on the local air quality. An emission inventory was created to the Metropolitan Area of Rio de Janeiro (MARJ) based on 2008 year as well as mitigation scenarios.

2. MODELING APPROACH

The modeling system of this study consists of a meteorological model, an air quality model and an emission inventory database and all these modeling tools were integrated into a general framework to simulate the local and regional atmospheric circulation and predict the pollutant concentrations in MARJ. Details of each component are described in following subsections.

SIA is an Environmental Information System which was developed by EcoSoft Consulting Company to control in an integrated form, multi-user, multi-company, the most variety of activities related with environmental system, including quality of assurance, environmental

**Corresponding author:* Taciana T. A. Albuquerque
Department of Atmospheric Sciences.
Astronomy, Geophysics and Atmospheric Sciences Institute
University of São Paulo, São Paulo, Brazil.
e-mail: taciana@model.iag.usp.br

monitoring plan, solid waste and management of sub products.

2.1 Functions of the System

The system supports a high volume of data and provides statistical and graphical tools. Advanced features of GIS, reports, inventories, and atmospheric modeling formulations are also integrated in the system.

Besides that, the integrated system allows:

- ✓ To integrate air resources: emission inventory, air pollution prediction and control;
- ✓ The online monitoring of the meteorological parameters, concentrations and emissions pollutants;
- ✓ To link Air Quality and Meteorological Numerical models: CMAQ, WRF, AERMOD, CALPUFF, ISC3, and others;
- ✓ To provide an “on line link” with the enterprises, allowing, for example, to follow the emitted concentration of one or more pollutant in multiple chimneys in each hour or minute.
- ✓ It is also available the exchange of data in many formats allowing the integration with other systems.

2.2 Speciation of NO_X, VOC, PM

The following chemical classifications were added into the system:

- ✓ Carbon Bond Chemical Mechanism with 51 chemical species;
- ✓ The EPA SCC (Source Classification Code);
- ✓ California Air Resources Board (CARB);
- ✓ EPA SPECIATE;
- ✓ Using these sources, it was created more than 4,000 speciation profiles

2.3 Meteorological Model

The meteorological model was selected in this study to provide the meteorological fields required for chemical-transport model and the emission processing system was the Weather Research and Forecasting (WRF) modeling system version 3.1 (Skamarock and Klemp, 2008).

2.4 Air Quality Model

The Community Multiscale Air Quality Model (CMAQ) (Byun and Ching, 1999) has been widely applied to various air quality issues all over the world (Albuquerque et al., 2010; Chen et al., 2007). In this study CMAQ version 4.6 was used to simulate local and regional air quality of Rio de Janeiro.

2.5 Domain and Model Setup

The modeling domains in this study for WRF model are shown in Fig. 1. The coarse domain (D1) covers most of the southeast area of Brazil. Coarse domain (D1) was set in such a way that intended to capture synoptic features and general circulation patterns. The nested domain (D2) comprises part of the four states of the southeast region. D3 covers the whole Rio de Janeiro State. D4 covers only the Metropolitan Area of Rio de Janeiro and its surrounding. The horizontal grid spacing of D1, D2, D3 and D4 were set as 27 km, 9 km, 3 km and 1km respectively. D1, D2, D3 and D4 consist of 56×56, 81×81, 126x126, 156x123 horizontal grids respectively and all domains have 21 vertical layers. Only the inner domain (D4) was used by the CMAQ model (Fig. 2). The horizontal coordinate is based on the Lambert conformal projection for both models with vertical coordinate based on the sigma-p coordinate.

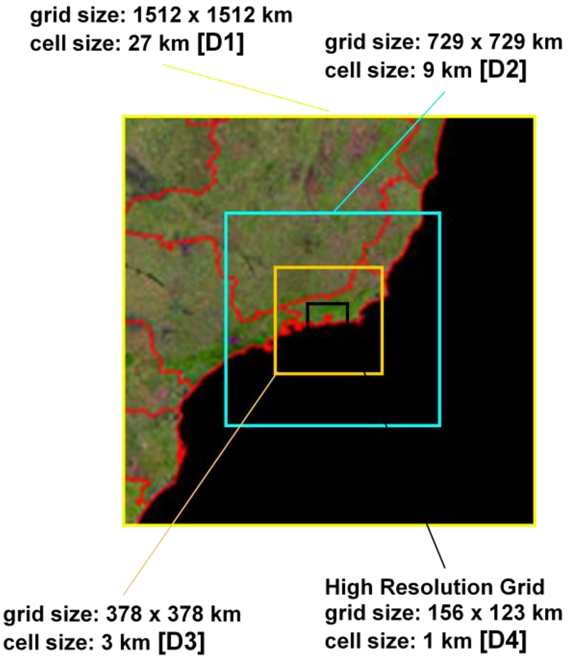

Fig. 1. Modeling domains for the application of WRF.

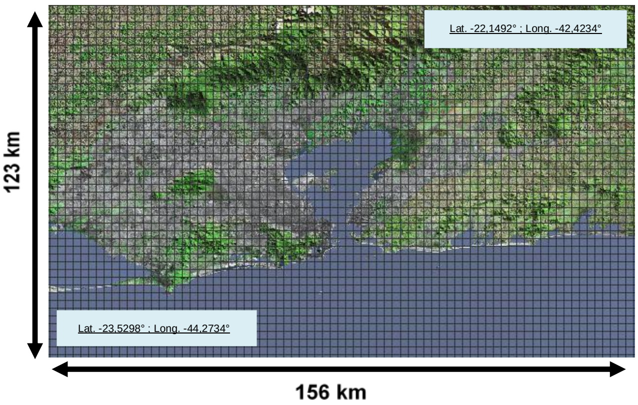

Fig. 2. The inner modeling domain for the application of WRF and CMAQ models.

The WRF simulations were driven by GFS data with 1°×1° spatial resolution and 6h temporal resolution to generate the required initial and boundary conditions. The WRF output files were processed with the Meteorology-Chemistry Interface Processor (MCIP) version 3.4 which create the required meteorological input data to run CMAQ. The Carbon Bond Five mechanism (CB05) was used as chemical mechanism for CMAQ simulation. Averages concentrations from the MARJ were used for initial conditions (ICONs) and boundary conditions (BCONs) for the inner domain (D4).

2.6 Episode Selection

In this study, the year of 2008 was simulated and it was chosen four month episode for the simulations to represent a typical seasonal peak pollution episode in Rio de Janeiro Metropolitan Area. The calculated air concentrations were then compared with measurements from the monitoring stations. Afterwards, it was simulated the air quality impact by reducing industrial emissions, decreasing the SO_2, VOC, NO_X, PM_{10} emissions.

2.7 Emission Database

EcoSoft Environmental Consulting Company was contracted to develop an emission inventory to the MARJ with the resolution of 1 x 1 km for the whole D4 domain in order to understand the role of trace constitutes in the atmosphere. After that, it was developed a regulatory control of O_3 precursor emissions from industrial sources to formulate ozone abatement strategies in this region. The local emission inventory data were used in this study as emission input file required for the CMAQ model.

3. RESULTS: APPLICATION TO RIO DE JANEIRO METROPOLITAN AREA

3.1 CMAQ Sensitivity Analysis

A good agreement between predicted concentrations and monitoring campaigns was found. The results showed a stronger contribution in O_3 formation around the petrochemical complex influence area into the MARJ. Due to this response, a sensitivity analyses with SIA-Emissions/CMAQ modeling system were performed in this study in order to check its applicability in the Petrochemical Industrial area located into MARJ.

Figure 3 shows a base case emissions (blue columns) from the Petrochemical Industries Group and a Benchmarking Scenario (red columns) after this group of industries decrease their emissions.

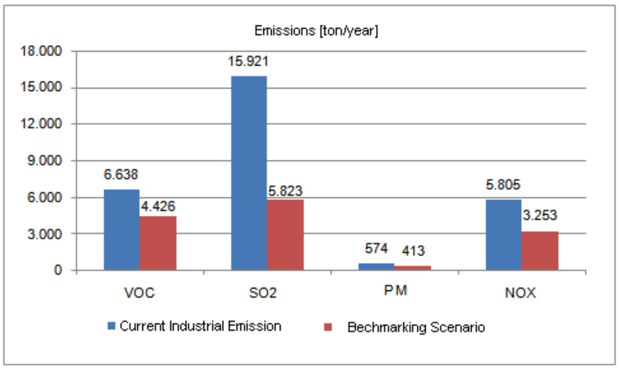

Fig. 3. The Percentages Reductions Scenarios Applied by the Petrochemical Industries from Rio de Janeiro Area.

Afterwards, it was simulated the air quality impact using CMAQ model by reducing these industrial emissions, decreasing the SO_2, VOC, NO_X, PM_{10} emissions (Fig. 3).

After reducing the Industrial emissions, the air quality may have an improvement such as showed on table 1:

Pollutant	Maximum Average Reduction Obtained in the Air Quality[%]		
	Petrochemical Complex Surroundings	Duque de Caxias City	MARJ
PM_{10}	3	2	1
SO_2	41	36	22
NO_x	12	8	3
VOC	43	32	7
O_3[a]	2	1	Irrelevant

The results showed that an average the O_3 concentrations decrease in a maximum of 10% at the industrial area, after reducing the industries emissions (Fig. 4). By the other hand, the NO_X, PM_{10}, VOC and SO_2 concentrations decrease 20%, 10%, 50% and 50%, respectively. The results indicated the CMAQ model can be an effective tool to reproduce the atmosphere behavior and mainly to simulate scenarios to improve the air quality in a complex Mega City like Rio de Janeiro.

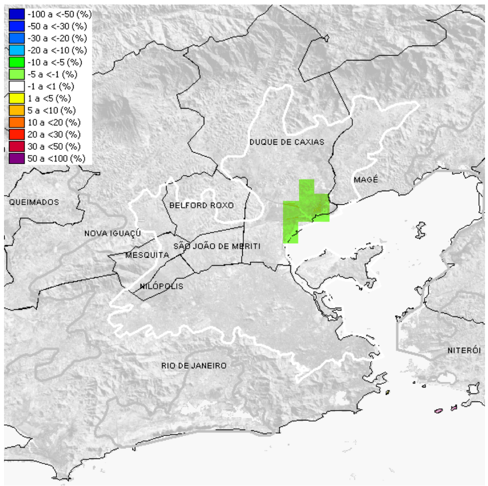

Fig. 4: Average of O_3 Hourly Concentrations Variability

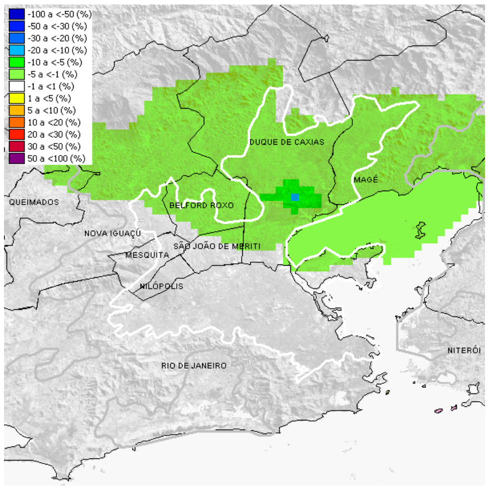

Fig. 5: Average of NO_x Hourly Concentrations Variability

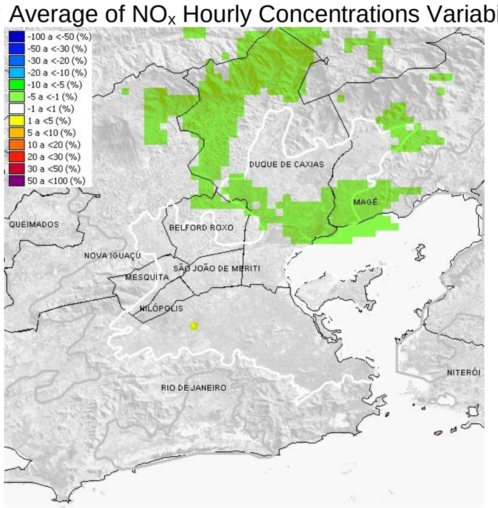

Fig. 6: Average of PM_{10} Hourly Concentrations Variability

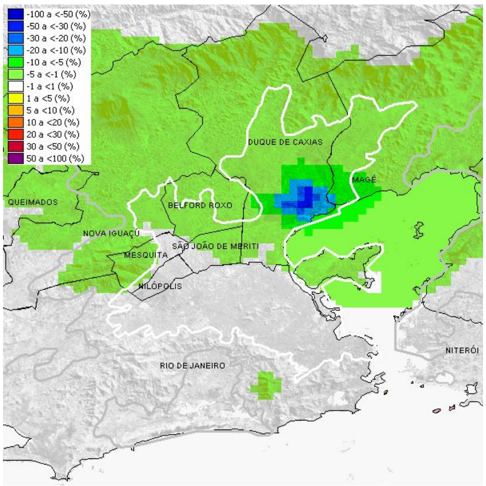

Fig. 7: Average of VOC Hourly Concentrations Variability

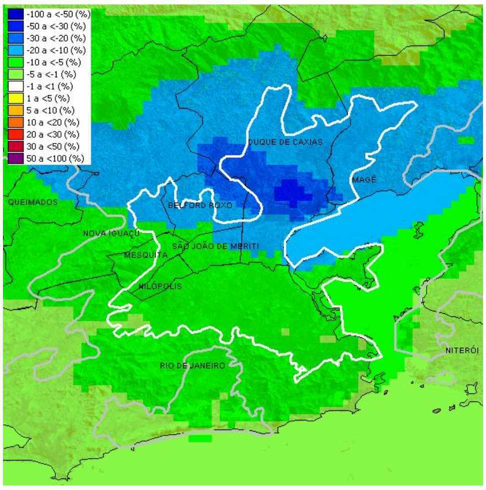

Fig. 8: Average of SO_2 Hourly Concentrations Variability

4. SUMMARY

Since 1995, EcoSoft develops services related to Air Resources and Environmental Management, integrated air resources management: emission inventory, air pollution prevention and control; mathematical models for air quality and meteorology; Softwares for environmental management; Air resources monitoring: network project and monitoring plan for air quality, atmospheric emission sources and meteorology.

This paper presented a package tool to quantify and evaluate the local air quality, which is able to predict the air pollutant concentrations and the impact of potential mitigation measures on the local air quality.

Through this system it was able to develop a detailed emission inventory to the Metropolitan Area of Rio de Janeiro, Brazil. The emission inventory file was applied into CMAQ model as the input file. The results indicated that CMAQ model can be an effective tool to simulate scenarios to improve the air quality in a complex Mega City like Rio de Janeiro. Despite of the higher industrial emissions reductions, the results did not show a direct response in the Ozone and PM_{10} concentrations. To improve the MARJ air quality, we suggest including the vehicle sources in this regulatory control program to give improvements in the ozone abatement strategies.

5. ACKNOWLEGMENTS

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