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ASSESSING ATMOSPHERIC ASSIMILATIVE CAPACITY TO AIR POLLUTANTS EMITTED FROM COAL POWER PLANTS IN THE SOUTH OF BRAZIL: USING CALPUFF AS A DECISION SUPPORT TOOL IN THE ENVIRONMENTAL PERMITTING PROCESS

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Abstract: The Brazilian law establishes that the federal environmental agency (IBAMA) it's responsible for the permitting process of thermal power plants (TPP) with nominal power over 300 MW. In far south of Brazil, close to the Uruguayan border, the coal deposit of Candiota has been exploited for power generation since 1970. Nowadays a 796 MW nominal capacity complex it's under operation with older and newly units; a 350 MW new complex it's under construction; and others 2,477 MW TPP projects are in different phases of planing. Concerned to develop prevent deterioration indexes and to avoid transboundary pollution, IBAMA, EPE and UFRGS developed an atmospheric dispersion modeling study using CALPUFF coupled with 2011 to 2015 WRF and local meteorological and air quality monitoring data to assess assimilative capacity to SO_2, PM and NOx air pollutants from currently and new projects. Conclusions revealed that in function of industrial park modernization, the future scenario exerts less pollution saturation of the aerial basin, even with increasingly power generation and more spatial distribution of sources, orienting the environmental permitting processes of planed TPP. Further work also evaluated the urban population exposure using the Intake Fraction (IF). An Environmental Pressure Index (EPI) were developed to evaluate grades of regulatory standard saturation. Well known recommended statistical tests were applied, indicating satisfactory model performance.

Key words: ***Assimilative capacity; CALPUFF; Intake Fraction; Environmental Pressure Index; Candiota/RS.***

INTRODUCTION

Atmospheric dispersion modeling has been used in multiple large-scale studies with the objective of linking source-specific health impacts or environmental externalities (Levy et. al., 2002; Zhou et al., 2003; Ghannam and El-Fadel, 2013).

The municipality of Candiota/RS, located far south of Brazil (54° 10' 58" / 53° 18' 35" W ; 31° 17' 35" / 32° 02' 41" S), about 50 to 60 km from the Uruguayan border, has the largest coal deposit in the country. Within superficial layers, the low calorific and the high contaminants concentrations - about 5,7% of sulfur; 52% of inert minerals; 0,7% of nitrogen – characterizes the mineral which is currently used in "run of mine" thermal power plants (TPP). Between 1970 and 2010, the President Médici TPP (UTPM) complex operated with nominal power of 346 MW, distributed into four pulverized coal units, with obsolete NOx and PM emissions controls and no SO_2 control. A 350 MW pulverized coal TPP with NOx, PM and SO_2 emissions controls started its operation in 2010 in the same complex. Since then, 13 violation episodes of the daily regulatory SO_2 standard were identified in the air quality monitoring network. The federal environmental agency (IBAMA) expressed concerns about how would be air quality deterioration in the region due to new TTP under permiting process. Meanwile others 2,907 MW TPP projects were in different phases of planing and construction, the study nominated Aerial Basin Assimilative Capacity was performed using CALPUFF model coupled with 2011 to 2015 WRF mesoscale meteorological and in situ monitoring data to evaluate present and future scenarios of atmospheric dispersion. The goal of this paper is to present the results of the current and future simulated scenarios for TPP emissions of SO_2, PM and NOx - assuming full transformation to NO_2 - and atmospheric dispersion; model statistics performance tests; and results of further researches to estimate population exposure and development of an aerial basin saturation index.

METHODOLOGY

Study Area

The Figure 01 illustrates the studied area in the state of Rio Grande do Sul/Brazil. The modeling domain (red square) comprises an 100 x 100 km area, where all the TPP sources used in simulations are in the middle (orange square). Vector data from 2010 Brazilian Census was plotted over the modeled domain.

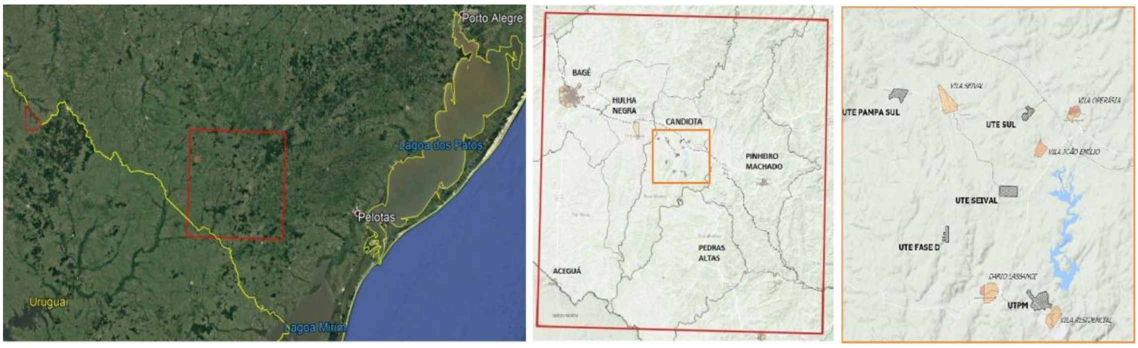

Figure 1. Model domais; spatial distribution of TPPs simulated and urban nucleis in the study area. [Images generated in Google Earth and Google Physical]

Scenarios and Sources Characterization

Simulations to prognostic air quality impacts where performed in two different scenarios, using data from 2011 to 2015. The current scenario considered only UTPM operational TPP, representing a total of 796 MW, five point sources with heights between 150 and 200m and total emission rates of 3,266.1 $g \cdot s^{-1}$ SO_2; 696.3 $g \cdot s^{-1}$ PM; 375.9 $g \cdot s^{-1}$ NOx. Only the newest 350 MW power plant have full emissions control systems, while older ones controls only MP and NOx with obsolete systems. The future scenario represents the modernization of the industrial park. We simulated the decommissioning and retrofiting of older plants and the inclusion of planned and in construction TPPs, representing a total of 3,581 MW, divided into eleven sources with predominant heights of 200m and a total emission rates of 2,707.9 $g \cdot s^{-1}$ SO_2; 383.7 $g \cdot s^{-1}$ PM; 1,823.9 $g \cdot s^{-1}$ NOx.

Geophysical and Meteorological Data Processing

For the model domain, the Digital Elevation Model (DEM) was processed into CALMET using the SRTM3 data, with a 90m spatial resolution. Aerial images captured by drones where also used to validate topography and to develop building 3d model as CALPUFF input to simulate downwash conditions, mainly due to hyperbolic refrigeration tower, as seen in Figure 2. For land cover characterization the GLCC data was used with a 1,0 x 1,0 km resolution. Current Landsat 5 TM and 7 ETM+ where also used to refine the model. The terrain grid was set for 10.000 discrete receptors (1,0 x 1,0km).

Data from six National Meteorological Institute (INMET) automated monitoring stations distributed into the model domain and outside, along an UTPM on-site station, where used to configure CALMET surface grid alongside WRF meteorological mesoscale model data. For each modeled year, the WRF grid was set for the state of Rio Grande do Sul with horizontal resolution of 10 km, as seen in Figure 2, totaling 115x115 grid cells with 28 vertical levels and temporal resolution of 60s. Further grid processing was performed to refine and configure upper air and prognostic wind field to the receptors of the model domain grid using CALWRF to process data to input into the CALMET. Upper air simulations was compared to radiosonde data for sensitivity analysis.

CALPUFF Simulations

CALPUF View ver. 8.5 Lagrangian Dispersion Model was used to perform air quality prognosis for each selected scenario and year. Computational domain is similar to those used in the meteorological and geophysical processing. In preference, setup default options was used in the model. No chemical transformation or wet and dry deposition was considered. CALPOST module was used to generate hourly, daily and yearly mean concentration isolines. Hourly and daily SO_2 means was used to the model performance test, evaluating the response of the model in comparison to real emissions and air quality monitored data. All annual mean results was compared to standard regulatory values. Concentric radius of mean Environmental Pressure Index (EPI) was used to evaluate aerial basin saturation due to the spatial distribution of those pollutants. Also, annual means was plotted over each census vectors to perform consequence analysis using the Intake Fraction (IF) index.

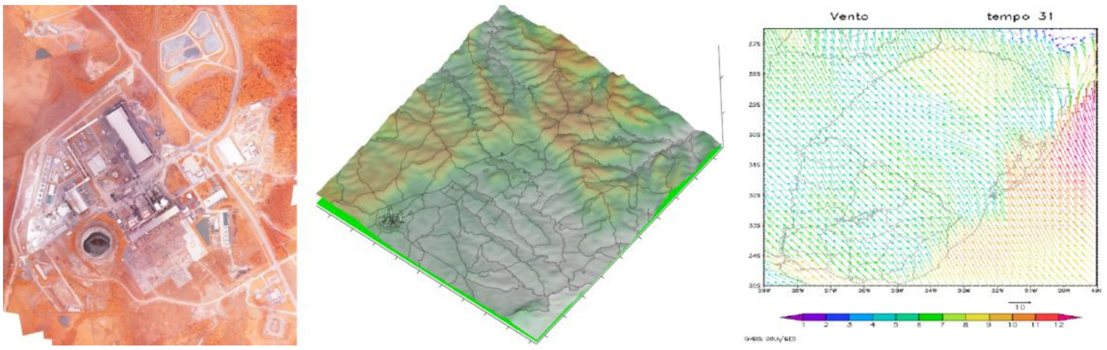

Figure 2. Aerial image of UTPM. DEM of themodel domain. WRF wind field grid.

Intake Fraction

The intake fraction is defined as the fraction of material released from a source that is eventually inhaled or ingested by a population (Bennett et al., 2002). It's only directly relevant for human health risk assessment if risk is proportional to ambient concentration, without any strong non-linearities or thresholds. By definition, in this work we used the IF formulation presented by Zhou et al., 2003.

Environmental Pressure Index

The environmental pressure index is widely used in life cycle analysis as a tool to evaluate the environmental performance of industrial processes (Seppälä, 1999). The EPI used in the present work reflects the summation of the impact that the three pollutants studied exerts over an area by means of how much each one saturates the annual regulatory standard. The EPI can be calculated as:

$$EPI = \sum \left(\sum reg.stand \Big/ reg.stand.i \right) \cdot \sum \left(xi \Big/ reg.stand.i \right) \cdot radius \qquad (1)$$

Where the relationship of the summation of all values of regulatory standard concentrations of SO_2, PM and NO_2 divided by the value of the regulatory standard concentration of "*i*" pollutant gives it's relative grade in terms of significance in the saturation level; and the "*xi*" mean concentration value modeled of the pollutant divided by it's regulatory standard concentration and then multiplied by the radius of the influence of the mean concentration gives the current impact of the pollutant "*i*" to the saturation level. In other words, the weights reflects how lower the is the standard concentration and how higher the pollutant impacts the environment and public health.

RESULTS

The assimilative capacity of the aerial basin of Candiota/RS were evaluated by the spatial distribution of pollutants. For five concentric radius of influence from the center of the grid [1,0; 5,0; 10,0; 20,0; 40,0 km], using results for each discrete receptor in the circular polygon, either the average concentration and the EPI were calculated for the purpose of measuring the grade of the aerial basin saturation due to each and all pollutants studied. Using a relative difference analysis between scenarios (Figure 3), we observed that spatial distribution of SO_2 and PM are very similar in the computational grid and the saturation of the regulatory standard for future scenario was lowered in the range of 9,5% - 17,6% for SO_2 and 28,3% - 34,2% for PM, with higher peak at the 5,0 km radius; drop till the 20,km radius and slightly elevation till the end of the computational grid. Relative difference analysis for NO_2 distribution had an opposite behavior, where future scenario exerts more saturation of the regulatory standard in the range of 54,2 to

73,4%, with lower peak at the 5,0 km radius; elevation till the 10,0km radius and steady ongoing till the end of the computational grid.

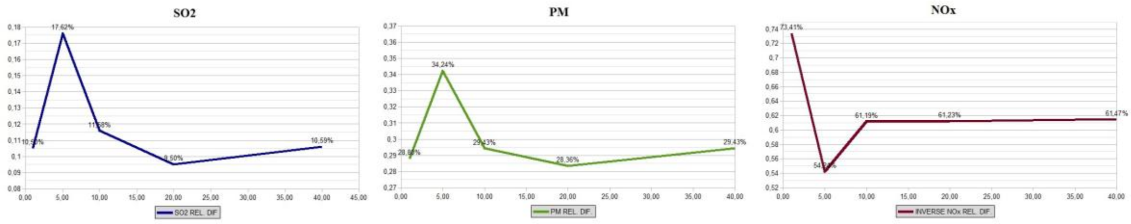

Figura 3. Relative difference analysis for spatial pollutant distribution between scenarios

Comparing the simulation results with the regulatory standard, absolute saturation for the current scenario was in the range of 3,9% - 16,47% for SO_2 and 0,67% - 2,77% for PM; and for the future scenario was in the range of 0,75% - 3,14% for NO_2. As a function of how meaningful is the shift between grades of regulatory standard saturation when comparing current and future scenarios, once SO_2 and PM are reduced and NO_2 is amplified, we assume that the parameter for the decision making should reflect the contribution of all pollutants studied in one index. Applying Equation 1 we calculated the EPI for each concentric radius confirming that current scenario imposes higher saturation of the index. In terms of cumulative saturation of the EPI, considering that pollutants are equivalent distributed into the circular polygon formed by each concentric radius adopted, we estimated that between 70 to 80% of the pollutants are within the 10,0km radius circular area and that future scenario represents 77% of currents cumulative EPI, as show in Figure 4.

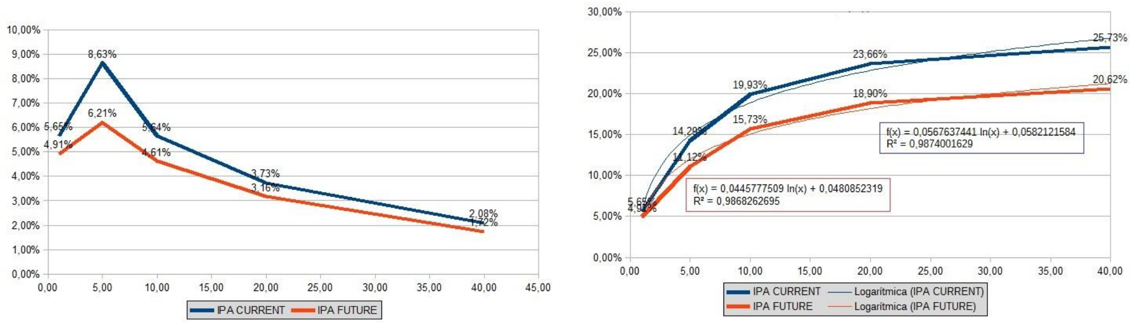

Figure 4. EPI for each concentric radius; cumulative saturation of the EPI

Figure 5 presents the 2012 future scenario concentration isolines for all pollutants as an example of spatial distribution over the 20,0km radius within the studied area. By a grouping analysis of pollutants concentration over urban nucleus vector and population density, we estimated the year average IF as being $1,4 \times 10^{-8}$ for SO_2; $9,2 \times 10^{-9}$ for PM; and $8,4 \times 10^{-8}$ for NO_2..

Figure 5. Isolines of SO_2, PM and NO_2 concentration over a 20,0 km area within the model domain

Model performance was evaluated for 13 daily episodes of SO_2 violation of the regulatory standard by using statistical indicators (FB, NMSE, MG and FAC2) and data plots correlating model predictions with measured emission rates as inputs and air quality field measurements, exemplified by Figure 6. For all episodes the plume spatial distribution predicted by the model was in good agreement over the air quality station influence zone. Statistical results revealed satisfactory model performance (FB = 0,35; NMSE = 0,39; MG = 1,62; FAC = 0,77).

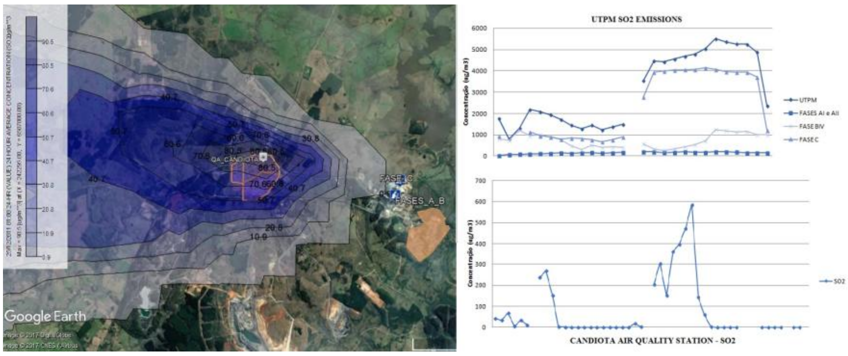

Figure 6: Model performance evaluation

CONCLUSIONS

The UTPM complex exerts high influence in the 5,0km SO_2 and PM saturation zone, even with complex adaptability evaluated in the future scenario. Another important factor is that new TPP planned are at distances about 5,0, 10,0 and 15 km from the center of the grid and besides their sources configuration that promotes better plume elevation favoring dispersion, alongside lower emission rates, it's upstream location influences the center of the grid as predominant wind directions are from north and northeast. That is also observed by the lower relative difference values between 5,0,0 to 20,0 km radius. Otherwise, NO_2 relative differences between 10.0 and 40.0 km radius are more constant, thus representing long range influence of new TPPs due to higher NOx emission rates. It's also true that future UTPM configuration contributes both for long range and for the 5,0 km saturation zone, observing the lower relative difference at that radius. Comparing the calculated IF with results presented by Zhou et al., 2003, we can conclude that either the low population density and reduced covered area studied were significant variables for lower results. Environmental permitting processes and analysis are now oriented by this assimilative capacity study supporting institutional decision for planned coal TPP in Candiota/RS region.

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