7.12 EVALUATING THE IMPACTS OF POWER PLANT EMISSIONS IN MEXICO

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INTRODUCTION

Mexican electricity generation has proven to be a large source of air pollution nationwide. According to the Energy Secretariat, electricity generation in Mexico accounts for 68% of SO_2 emissions, 24% of PM_{10} emissions and 20% of NO_x emissions nationwide (SENER, 2001). The country's total effective installed capacity is 42,067 MW, of which 67% corresponds to thermoelectric power plants. Heavy fuel oil, known as 'combustóleo', is used in many thermoelectric plants primarily for regular operation. The typical sulphur content of 'combustóleo' is approximately 2.5 to 4% (SENER, 2003).

As a first step to determine the potential impacts of Mexican power plants on regional air pollution and health, we conducted a case study on the Adolfo López Mateos power plant, located in the town of Tuxpan in the eastern state of Veracruz. The plant is located on the northern coast of the Gulf of Mexico; therefore greatly influenced by the weather of the region.

We used the CALPUFF Lagrangian puff model (Earth Tech, Concord, MA) to simulate the dispersion of SO_2, NO_x and primary PM_{10} emissions from the power plant stacks and the formation of secondary particulate matter. We considered a 120km × 120km grid, with a resolution of 2km × 2km and height of 2500 km. This area comprises approximately 791,000 inhabitants, including rural and urban populations (figure 1).

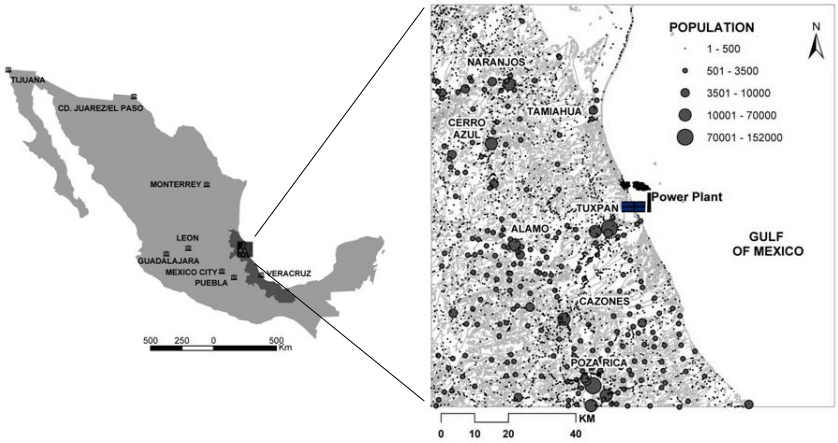


Figure 1. Modelling domain with population centres

Total annual emissions from this plant amount to approximately 257,000 tons of SO_2, 22,000 tons of NO_x and 17,000 tons of PM_{10}, which are released through three stacks. Emissions information and stack properties were provided by the Secretariat of the Environment and Natural Resources (SEMARNAT, 2003) for the year 2001, and were obtained from annual operations reports of fuel consumption and calculated using standard emissions factors for oil combustion (EPA, 1995).

METHODOLOGY

Many studies have run air quality models to simulate conditions for an entire year to determine impacts from power plant emissions (Levy et al., 2002), Due to the intensive computational and data requirements necessary to run the MM5-CALMET-CALPUFF modelling framework for 365 days, however, we were unable to simulate air quality conditions for an entire year. We therefore selected representative periods which would characterize the most frequent meteorological conditions over the course of a year. The model year 2001 was selected because of its high data quality relative to other years and availability (SMN, 2003, personal communication). Information from these periods along with their representativeness was then combined to estimate annual average conditions (Physick and Goudey, 2001) using equation 1 (Nevers, 1998):

$$C_{annual} = \sum c_i \times f_i \qquad (1)$$

Where c_i is the average concentration of period i and f_i is the frequency of that period. Using this technique we assume that there are certain meteorological patterns that repeat throughout the year, which can be characterized in terms of observable meteorological parameters (wind speed, temperature, etc.), and that air pollution conditions are similar during these periods (Samson et al., 1990).

To select the representative periods, we used surface meteorological information for wind direction (°N) and speed (m/s), barometric pressure (mb), temperature (°C), relative humidity (%) and precipitation (mm) from the Tuxpan, Veracruz station operated by the National Meteorological Service (SMN). We applied cluster analysis to this data to determine representative groups (Samson, et al., 1990; Physick and Goudey, 2001). Cluster analysis is an explicit way of identifying groups in raw data, involving a number of techniques whose primary purpose is to group objects according to similarity criteria established by the user. The theory behind this way of clustering is that large differences should prevail over the less important smaller differences: the global structure of a group should determine the subgroups.

After determining the representative groups, we selected specific weeks to model from each of these three groups, by comparing the weekly averaged values of the meteorological parameters with the average values for the entire period of the group. We then applied the CALPUFF-CALMET-MM5 system to estimate pollutant concentrations for the selected representative weeks. CALPUFF, a non-steady-state Lagrangian Gaussian puff model (Scire et al., 2000a), was run for the three selected weeks to determine concentrations of primary PM_{10}, SO_2, and NO_x distributed in the selected domain for every hour. To calculate the formation of secondary particulate matter species SO_4^{2-} and NO_3^- we used the MESOPUFFII mechanism, a simple chemical transformation model, included in the CALPUFF model the (Finlayson-Pitts and Pitts, 2000). CALPUFF default assumptions were used for wet and dry deposition parameters and background concentrations of ammonia and ozone.

The CALMET model is used to calculate surface wind structures and micrometeorological variables (Scire et al., 2000b). Topographical data required by CALMET was generated by analyzing satellite images (LAN), whereas land use data was obtained from the National Forest Inventory (SARH, 1994). Surface meteorological data was processed from SMN station. Finally, data from radiosondes from the city of Veracruz, the closest available data to the study region (365 km from Tuxpan), were used to provide vertical profiles of meteorological and thermodynamic parameters

The MM5 model was applied to improve the description of the vertical wind structure (Robe and Scire, 1996). This model is capable of predicting mesoscale flows by incorporating global NCEP (National Centre for Environmental Prediction) data. To model prevailing meteorological conditions during the selected weeks, we used a 6 km × 6 km resolution grid larger than our domain, which was then incorporated into the CALMET model, in order to interpolate from a lower to a higher resolution grid (2 X 2 km).

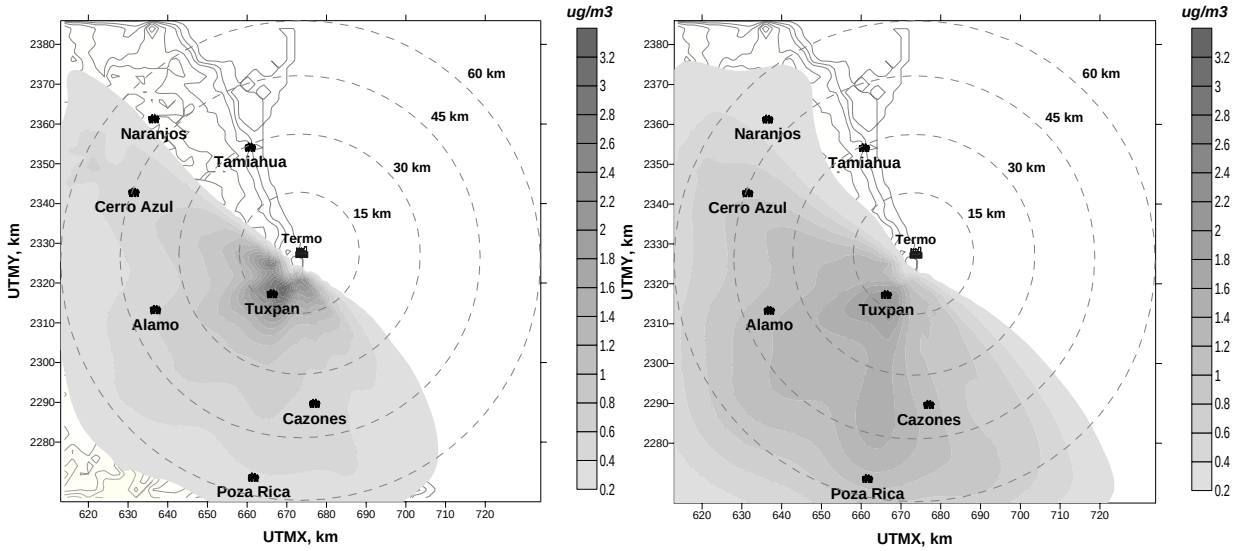
The MM5 model output was used as an "initial guess field" and then adjusted for kinematical effects of terrain, slope flows, and terrain blocking by CALMET, to produce the initial wind fields. These fields were further adjusted by interpolation methods with surface observations and the vertical profile data. In addition to reproducing the wind fields of the region, CALMET uses a micro-meteorological module to describe characteristics of the mixing layer, three-dimensional fields of temperature and other parameters that CALPUFF uses in its calculation of dispersion.

RESULTS

Based on our statistical analysis of meteorological parameters, we identify 3 main groups. Group 1 consists of 16 weeks (November to February) with winter season characteristics of low temperature, high relative humidity, high surface pressure and medium precipitation, with a representativeness of 31% of the year. The second group includes 23 weeks (March to June), with average conditions of high temperature, low relative humidity, low surface pressure and zero precipitation, which represents conditions for 44% of the year. Finally, group three which comprises 12 weeks (August to October) is dominated by high precipitation, coinciding with the Atlantic hurricane season in 2001 (Gray W. M. et al., 2001), representing 23% of the year's conditions.

For Group One, we identified the most representative week in terms of its meteorological conditions (Sverre-Petterssen,1976) to be the period from the 5th to the 11th of November (Week 1), 1st to the 7^{h} of June (Week 2) for Group Two, and 10th to the 16th of September (Week 3) for Group Three.

Model simulations show that emissions from the power plant result in annual population weighted average concentrations of 0.65 μg/m^3 for primary PM_{10}, 1.45 μg/m^3 for ammonium sulphate, 0.14 μg/m^3 for nitric acid and 0.11 μg/m^3 for ammonium nitrate. The plumes of the primary particles and sulphate concentrations reach beyond the modelling domain (figures 2a and 2b).



(a) (b)

Figure2. (a) Annual average primary PM10 concentrations; (b) Annual average ammonia sulphate concentrations

The concentrations tend to peak within 20 km range of the power plant. The highest concentrations for primary particulate matter were observed near Tuxpan, with a value of 1.81 $\mu g/m^3$, seven times greater than the annual average. Sulphate concentrations appear to have a much larger impact in terms of concentration and spatial coverage. The greatest impacts were observed southeast and southwest of the power plant.

DISCUSSION AND CONCLUSIONS

The cluster analysis proved to be a very effective statistical tool to select the three representative groups of meteorological conditions, since 98% of the weeks in 2001 were included in these clusters. Only the week of September 24th did not fall into any group, as its conditions were dominated by hurricane Humberto from the 21st to the 27th of September, which influenced the rise in precipitation on the Gulf of Mexico (Gray W.M. et al., 2001).

Results show that simulated concentrations for the week in June (representative of Group 2) were higher for all pollutants. This was expected due to unfavourable meteorological conditions for pollutant dispersion. November (Group 1) and September (Group 3) followed in concentration levels, respectively. This was also expected, due to the heavy rains characteristic of Group 3.

For all three periods, modelling results show that SO_2, PM_{10} and $(NH_4)_2SO_4$, NH_4NO_3 and nitric acid emissions disperse mainly to the South of the power plant, primarily affecting the towns of Tuxpan, Alamo, Cazones and Poza Rica. However, Tuxpan is evidently more affected than the other communities due to SO_2, PM_{10}, sulphate and nitric acid formation. With specific regard for SO_2 and secondary particles, the 120 km X 120 km grid appears to be too small to display the full extension of pollutant dispersion from this single source. It is also interesting to note that in none of the three modelled time periods does the plume disperse over the ocean.

Future analyses should include expansion of the modelling domain, simulation over an entire year, incorporation of other relevant sources in the area, and further validation of the air quality model.

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