USING MM5/SMOKE/CAMx MODELLING SYSTEM TO EVALUATE EMISSIONS CONTROL STRATEGIES IN TEMUCO CITY – CHILE

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1. INTRODUCTION

The city of Temuco, located 800 km to the south of Santiago - Chile (38.5ºS) suffers from severe particulate pollution events during the period from April to September (fall and winter) each year. The records from monitoring show high levels of PM_{10} concentration with a 24-h 98 percentile from 188 µg/m^3 in 2001 to 172 µg/m^3 in 2002. For this reason it was declared as non-attainment area for PM10 in 2005 (CONAMA-a, 2005). The deleterious effects of PM_{10} on human health have been extensively studied in many cities of several countries with different weather conditions and sources (Sanhueza et al, 1999, 2006, Katsouyanni et al 1995). Temuco has a population of 300,000 and 55,000 houses that use mainly wood burning appliances for heating and cooking.

The MM5 model was chosen for modeling the meteorological fields. SMOKE was selected to process the emission inventory, and CAMx was the chemical and transport model to simulate different control scenarios to reduce the PM10 impact over Temuco city. The USEPA Guidance for demonstrating attainment of air quality goals for PM2.5 and regional haze was used as modeling protocol.

1.2 Objectives

The main goal of this study was to apply a dispersion model to determine the PM_{10} emission-concentration relationship that allows to understand the behavior of the air pollution and to evaluate control strategies in the city of Temuco.

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2. MODELLING DOMAIN

The modeling domain has been selected in order to considers the regional and urban influence but at the same time to provide detailed representation of the emissions, wind fields, and the pattern of PM_{10} concentration in the area of interest. The modeling domain consists in an area of 50x50 km that covers the two counties declared non-attainment and other sources such as agricultural burning and forest fires. The horizontal resolution considers a grid of 25 cells of 2x2 km and a nested domain of 26 cells each one of 1x1 km (see Figure 2.1).

The vertical resolution considers 8 layers as shows Figure 2.2.

The meteorological domain considers an outer grid of 1350x1620 km with cells of 54 km, and three sub-domains of 558x558 km – 18 km cells, 294x276 km – 6 km cells, and 158x128 km – 2km cells.

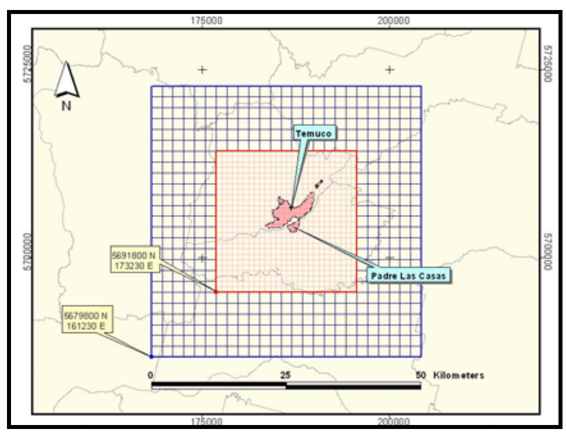

Figure 2.1 Modeling domain

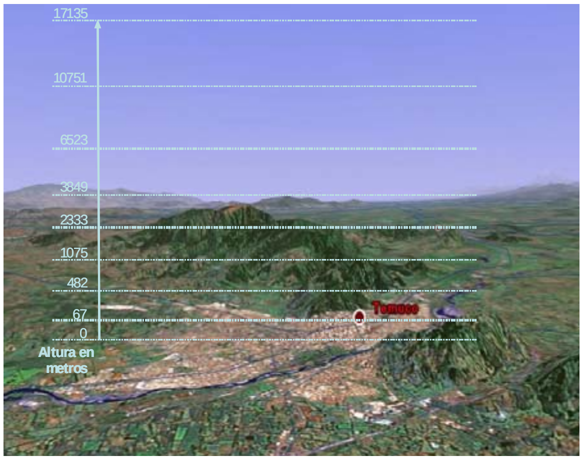

Figure 2.2 Vertical resolution

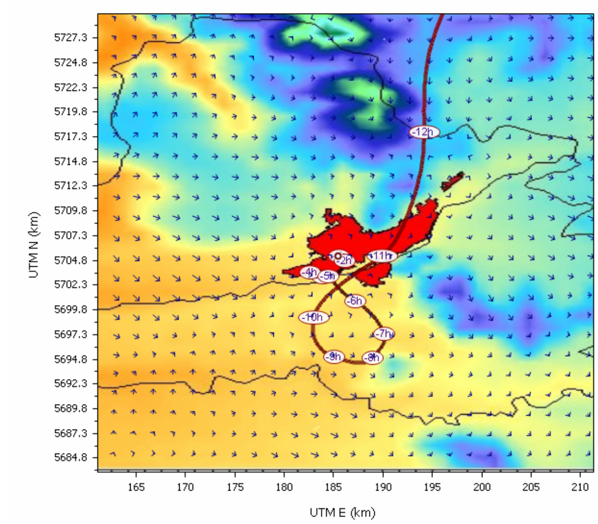

Figure 3.1 Back-trajectory 20 UTC May 15 2004

3. EPISODE SELECTION

To determine the episodic periods, the air quality data along with the meteorological data were analyzed. The analysis consisted of selecting periods of two or more consecutive days with high PM_{10} concentrations (greater than 120 ug/m^3). From 2001 to 2004, eleven episodic periods were selected and out of them, the period from May 13 to May 18 was chosen. This was the larger period with PM_{10} concentration ranged from 144 to 229 ug/m^3 and was consisted in both monitoring stations.

The synoptic regimes showed the prevalence of anticyclonic conditions during the episode period which is typically associated with severe air pollution events in Temuco. The high pressure system persisted over the region for several days, with meteorological conditions conductive to an extended smog episode.

During the event, the sky was predominately clear and no precipitation was recorded. Surface winds were generally light, especially during evening and early morning periods when calms were frequently observed.

Figure 3.1 shows a back-trajectory at 20 UTC May 15 2004 were the air mass came from the north, passing for Temuco city and recycling on the city.

4. EMISSION INVENTORY

The emission inventory in Temuco considered sources such as industrial, home heating and cooking, building heating, mobile, agricultural burning, and forest fire (CONAF, 2005, CONAMA-b 2001, CONAMA-c 2004, Dennis et al 2002).

The estimated total mass of PM_{10} emitted on a typical winter day into the Temuco airshed was 26,0 ton/d, and the majority of these emissions were from domestic heating and cooking appliances (88%). The industries were responsible of 6.4% of the emissions, the agriculture burning accounted for 2.6%, mobile for 1.4% and building for 0.6%.

5. MODEL PERFORMANCE EVALUATION

To accurately simulate PM_{10} dispersion, the model must be able to reproduce the wind and temperature structure within the airshed, and this is especially important with regard to the nocturnal boundary layer. Thus, the outputs from the MM5 model were evaluated by comparing it with observation registered in two surface monitoring stations and one upper air station. Using statistics metrics (MBE, MAE, RMSE) and graphical time-series comparison is shown that in general the agreement in wind speed and direction was good but less in temperature.

Figure 5.1 shows the time-series of temperature observed and predicted for the episodic period.

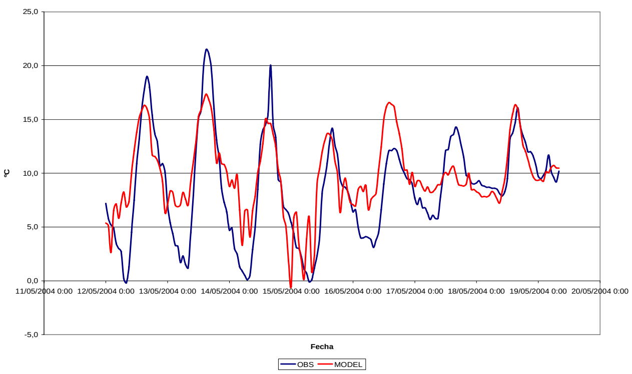

Figure 5.1 Observed and predicted temperature

Table V.1 shows the concentrations observed and predicted for each day of the episodic period. In general the model under and over predict PM_{10} concentrations. The average observed level was 187 ug/m^3 and the predicted value was 181 ug/m^3.

Table V.1 Observed and predicted PM_{10} concentrations

Days	$[PM_{10}]$ ug/m^3	
	Observed	Predicted
12/05/04	N/A	**112**
13/05/04	151	**115**
14/05/04	144	**173**
15/05/04	229	**261**
16/05/04	215	**183**
17/05/04	183	**174**
18/05/04	201	**180**

Figure 5.2 shows the time-series of PM_{10} observed and predicted during the episodic event selected. It is observed that the model fits fairly well in reproducing the real data even the peaks and minimums. Some shift in the model seems to occur between May 15th and 17th.

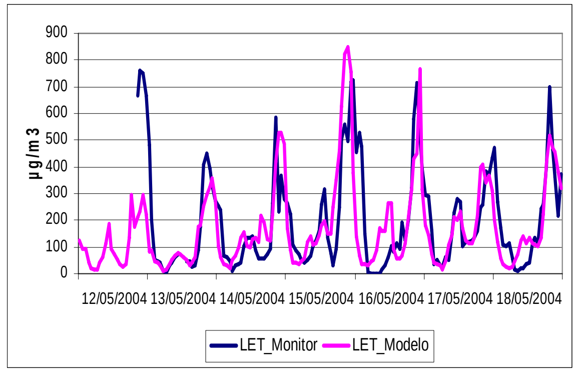

Figure 5.2 Observed and predicted PM_{10} time-series

5.1 Source contribution

With the model was possible to determine the source contribution to the PM_{10} concentrations measured in the monitoring station during each day of the episode selected. Table V.2 summarize the information and it is clear that the residential sources are responsible for the 98% of the PM_{10} concentrations, been the kitchen the first single source with 52% and the simple stove the second source in importance with 30% of the PM_{10} concentration.

Table V.2 PM_{10} - Source contribution (ug/m^3)

Days of May	Buildings	Fire forest	Industries	Burning	Vehícles	Kitchens	Masonry	Conventional Wood stove	Non catalytic stoves	Open fires	No Residential	Residential	Total Sources
13	0.2	0.2	1.1	0.2	0.5	61	8	35	4	6	2	113	**115**
14	0.2	0.2	2.3	0.1	0.6	86	14	53	7	10	3	170	**173**
15	0.1	0.2	2.1	0.1	0.7	137	20	77	9	14	3	257	**261**
16	0.2	0.3	2.1	0.3	0.5	89	14	58	7	10	3	179	**183**
17	0.3	0.4	1.6	0.3	0.8	92	14	50	6	8	3	170	**174**
18	0.2	0.4	1.8	0.3	0.7	95	14	51	6	10	3	177	**180**
Average	**0.2**	**0.3**	**1.8**	**0.2**	**0.6**	**93**	**14**	**54**	**7**	**10**	**3**	**178**	**181**

The maximum contribution of each source anywhere in the modeling domain indicates that 137 ug/m^3 are due kitchens, 81 ug/m^3 are due to conventionalstove, 17 ug/m^3 due to open fires, and just 2 ug/m^3 are due to vehicles. These maximum concentrations of course occur in different times and places. Figure 5.3 shows the spatial distribution and the maximum cell attributable to the apportionment of kitchens to the PM_{10}.

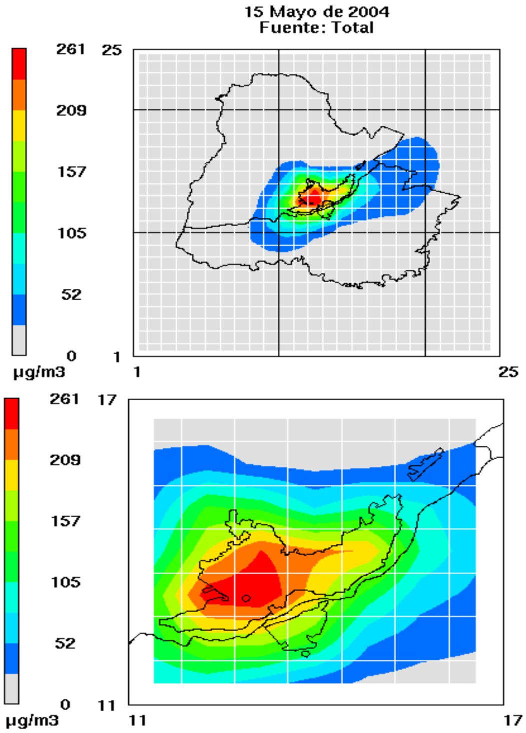

Figure 5.3 Distribution of PM_{10} due to kitchens

6. CONTROL STRATEGIES

In order to use the modeling results in control strategies, the Relative Reduction Factor (RRF) was calculated using equation (1).

$$RRF = Cm_f/Cm_a \quad (1)$$

Where:

- FRR: Relative reduction factor
- Cm_f: Predicted future concentration
- Cm_a : Predicted actual concentration

The 98 percentile will be:

$$P98_f = P98_a * RRF \quad (2)$$

Where:

- $P98_f$: Future 98 Percentile
- $P98_a$: Actual 98 Percentile (base year 2004 = 172 µg/m^3)

If no measures for reducing emissions are taking in Temuco city, it is expected to get 180 ug/m^3 as 98 percentile in 2016. This is called the BAU (Business as usual) scenario.

6.1 Reduction needed to attain PM_{10} standard

In order to meet the PM_{10} standard (150 ug/m^3), it is necessary to reduce the emissions by 13% and by 31% to leave the latency. Figure 6.1 shows the reduction required in each year of analysis along with the 98 percentile expected to occur in each year.

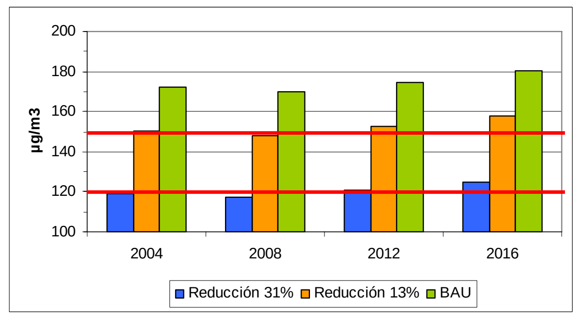

Figure 6.1 Trend in PM_{10} 98 percentile

Various management options were evaluated in order to estimate its reduction in the 98 percentile of PM_{10}. The policy options included 15 strategies focused mainly in residential heating and cooking appliances as hey are the largest contributors to the PM_{10} problem in Temuco. Some of them are banning the use of open fires, improving in the fuels (drying wood and use of natural gas), PM_{10} standard for wood appliances, and combination of them.

It was found that banning the open fires and improving the wood stoves, produces the highest reduction in PM_{10} emissions, between 35% and 51% at the beginning and the end of the evaluation period, respectively.

7. CONCLUSIONS

This work represents the application of a three dimensional model system to evaluate control strategies in reducing the PM_{10} concentration in Temuco city which has been declared non-attainment area in 2005. According to the emission inventory, the main source of particulates is the use of wood for heating and cooking, with old appliances and bad operation conditions.

The use of MM5/SMOKE/CAMx modelling system was found adequate to simulate the transport, dispersion, and chemical transformation of the pollutants emitted to the airshed in Temuco.

The modelling system allowed the assessment of the contribution of each group of sources to the PM_{10} in the city. That is important because it is not just the emission but also the spatial distribution of the sources and the temporal rate of emission the elements that are important in order to evaluate different control strategies to solve the problem.

The modelling of secondary particulate shows very low values as contributions of sulphur dioxide, nitrogen oxides, and volatile organic compounds (less than 1 ug/m^3). This low contribution is mainly due to that during the winter small solar radiation is expected in Temuco. Nevertheless the PM_{10} measured in the city shows that the $PM_{2.5}$ particles account for the 93% of the primary particulates.

From the modeling it was shown that the use of wood in kitchens is the most important single source of PM_{10} concentrations in the city followed by the stoves. Even though the banning of open fires and improving the technology in stoves allow to meet the 150 ug/m^3 of PM_{10} in the city. That because the use of wood in kitchens presents a negative trends due to the change of natural gas in these appliances but nor in stoves where the use of wood is increasing.

The solution in Temuco is not easy because the social problem associated with the banning of using wood in stove and kitchens appliances. This is a typical practice and form part of the culture of the population. Instead of banning, other measures have to be evaluated, for example setting new standard for appliances, developing educational program on good operational practices for using wood stoves, or even setting incentives for changing to natural gas or electricity.

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