Impact assessment of PM and BC emissions from residential wood combustión in Osorno, Chile

report elaborated by

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prepared for

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CONTENT

1 Executive summary

Residential wood combustion for cooking and heating constitutes a dominant source for particles and soot in ambient air. Except for a strong health impact, soot is also an important short-lived climate pollutant (SLCP). There are strong synergy effects to be gained by reducing PM and soot emissions from wood combustion. Cities in Southern Chile have a critical problem with high pollution levels caused by residential wood combustion and the Chilean Ministry of the Environment (MMA) have been taken actions to reduce the impact through improved combustion technique and a better handling of the fuel.

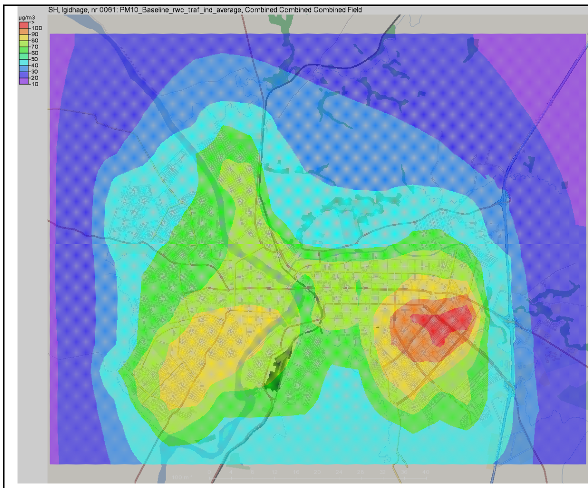
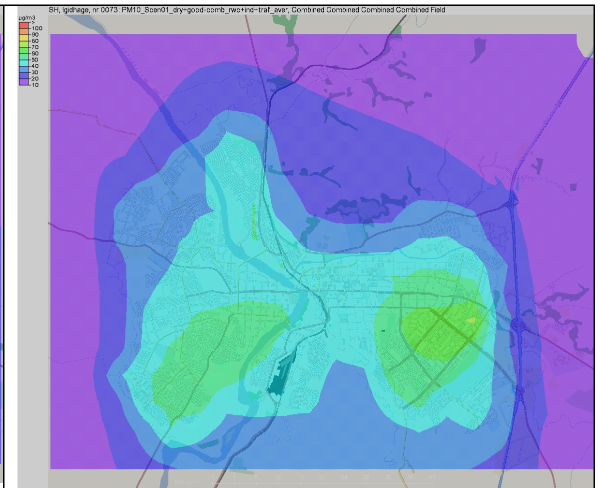
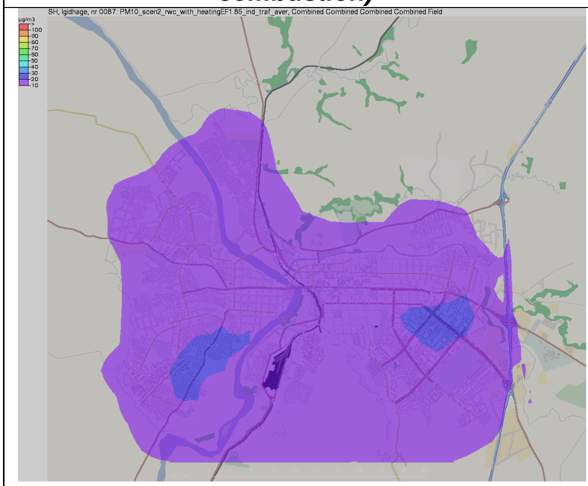
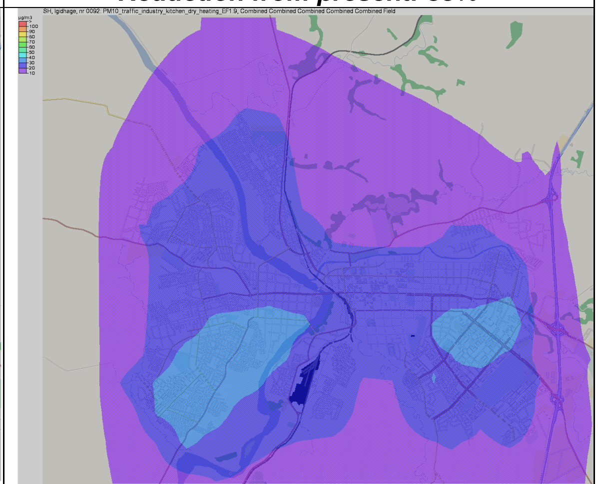
SMHI has achieved for 2013-2014 a Swedish funding for bilateral cooperation with MMA to assess and support the problem of high particle pollution in Southern Chile. The Swedish work with emissions and dispersion modeling has been linked to a monitoring campaign in Osorno performed by Centro Mario Molina Chile.

The general objective of the bilateral cooperation is to transfer a methodology for quantification of emissions and impact of particles (PM2.5 and BC) from residential wood combustion in cities of Southern Chile. The method should also allow the evaluation of different actions that can be taken to reduce the impact on health and climate. During 2013 the work was focused on Osorno, while during 2014 there will be other assessments in other cities with similar problems.

The present study has used existing information on traffic and industrial PM emissions, together with a newly elaborated study of wood consumption, to develop an emission inventory useful for dispersion modeling in Osorno. In terms of emissions, the residentatial wood combustion is the dominating source, contributing to 90-95% of the PM10 emissions.

By comparing modeling results with measured PM10 data at the El Alba monitoring station, it was found that emission factors for residential wood combustion taken from the literature yielded much too high impact. The strong overestimation – 5 times higher simulated PM10 levels as compared to the measured levels - can be caused by either overestimated wood combustion or too high emission factors, most likely a combination. By lowering all emission factors, i.e. all rwc emissions with a factor 0.17, simulated and measured PM10 time series showed good resemblance during the period March to September 2013. From this we estimate that PM10 emissions form residential wood combustion in Osorno sums up to 1 275 tons/year. By using ratios based on measurements at the El Alba station, the emissions of PM2.5 and black carbon were estimated to 1 020 and 31 tons/year, respectively.

The dispersion model has been used to determine the expected impact of two types of actions aimed at reducing the pollution levels in Osorno. The first scenario was assuming that all wood used for heating and cooking was dry (humidity <20%). This reduced the annual PM10 levels by approximately one third. The second and third scenario were based on the new Chilean regulation that puts an upper limit of 2.5 g/hour for wood combustion fireplaces. The second scenario assumed that all fireplaces, both for cooking and heating purposes, had emissions which never exceeded 2.5 g/hour. The model result shows that with such actions taken, there are good possibilities to comply with both PM10 and PM2.5 limit values. If cooking stoves are, as is the case in the current Chilean legislation, the average levels will most likely be exceeding the PM2.5 limit value.

	
Baseline scenario (present situation due to impact from traffic, industry and wood combustion)	***Scenario 1: only using dry wood*** ***Reduction from present: 35%***
	
Scenario 2: emission limit of 2.5 g/hour applied to all fireplaces ***Reduction from present: 78%***	***Scenario 3: emission limit of 2.5 g/hour applied to heating fireplaces, with cooking fireplaces only using dry wood*** ***Reduction from present: 66%***

The overall conclusion from this assessment is that PM10 and PM2.5 levels are today much too high, exceeding the standards, almost entirely due to the impact of residential wood combustion. Only with a strong control, including the use of dry wood and replacing old wood stoves with new modern fireplaces, there will be a possibility to reduce PM pollution levels below the Chilean air quality standards. The current emission regulation which excludes fireplaces used for cooking, will thus not be sufficient even if all heating fireplaces are equipped with new and modern technology.

The evaluation of the WRF model output against meteorological surface information has just been initiated in Osorno. After just a few weeks of comparisons, the results are promising and will be further evaluated in a future 2014 report. The objective is to use the WRF model data as input to urban dispersion models in cities where there are no meteorological surface data available.

2 Introduction

Residential wood combustion (rwc) for cooking and heating constitutes a dominant source for particles and soot in ambient air. Except for a strong health impact, soot is also an important short-lived climate pollutant (SLCP). There are strong synergy effects by reducing PM and soot emissions from wood combustion. Cities in Southern Chile have a critical problem with high pollution levels caused by residential wood combustion (rwc) and actions have been taken to reduce the impact through improved combustion technique and a better handling of the fuel. During a meeting with a SMHI delegation on January 8, 2013, the Ministry of Environment (MMA) expressed their need of assessments and methods to quantify emissions and follow-up the effects of different actions that may reduce the impact.

SMHI has achieved a Swedish funding for bilateral cooperation during 2013 and 2014 with MMA to assess and support the problem of high particle pollution in Southern Chile. The Swedish work with emissions and dispersion modeling has been linked to a monitoring campaign in Osorno performed by Centro Mario Molina Chile (CMM). The present report does include results from both SMHI and CMM during 2013, although CMM also delivers a separate report [1].

The monitoring campaign was executed during the period August 16 to September 02, 2013. Although work has been ongoing continuously at CMM and SMHI since May 2013, the following specific events can be listed:

- August 21-22, 2013: Visit to Osorno for site inspection and participation in a seminar on residential wood combustion (MMA, CMM, SMHI)
- September 7-29, 2013: Gabriel Silva from MMA visiting SMHI for capacity training and work with Osorno project.
- October 10-16, 2013: SMHI in Santiago for capacity training at the Chilean Meteorology Department (DMC) and for Osorno project work with MMA and CMM.
- November 7-22, 2013: Matías Tagle from CMM at SMHI for capacity training and work with Osorno project.

Model simulations, analysis and documentation have been performed during the period December 2013 – January 2014. The results will be presented in more detail for MMA during a SMHI visit to Santiago in March 2014.

General objectives

Transfer of methodology for quantification of emissions and impact of particles (PM2.5 and BC) from residential wood combustion and evaluation in Chilean cities. Support Chilean authorities in their effort to comply with PM2.5 regulation and to adhere to the CCAC initiative “Reducing short-lived climate pollutant emissions from household cooking and domestic heating”.

Specific objectives

Through the use of dispersion models assess quantitatively the effects of actions taken to reduce emissions from wood combustion, illustrating both the emissions reductions and their impacts on air quality, allowing prioritization. Model concepts applied in various cities in Southern Chile. Chilean and Swedish experts are also expected to contribute to actions and impact/follow-up studies in other countries in the region.

Overview of reported tasks

The report includes a method section where most of the background information is given. We also describe the monitoring performed during the campaign and how the emission inventory was established. The result section includes three major parts:

- A model evaluation part (comparison of model results against monitor data), also including a description of the current (winter 2013) impact of the residential wood combustion in Osorno. The comparison between model and monitor output is used to evaluate the quality of both the model concept as well as the input data used (mainly emissions).
- A scenario part where we evaluate the consequences on air quality levels of three different scenarios, defined by MMA and relevant for actions that MMA is trying to achieve.
- A preliminar evaluation of meteorological information generated by DMC modeling, aimed to be used for urban scale dispersion modeling in Southern Chile (a more complete evaluation will come during 2014).

3 Methods and meteorological background conditions

This section describes the methods used for monitoring, the build-up of an emission inventory and the dispersion model system used, however starting with a background description of the meteorological conditions in Osorno.

3.1 Meteorological information

Meteorological data have been taken from the El Alba station, the same station as is measuring PM10. Dominating wind directions during the period March to September 2013 are from NNW and SSE (Fig.3.1.1). Wind speed is usually low, on average 1.6 m/s with maximum during early afternoon and minimum during the night.

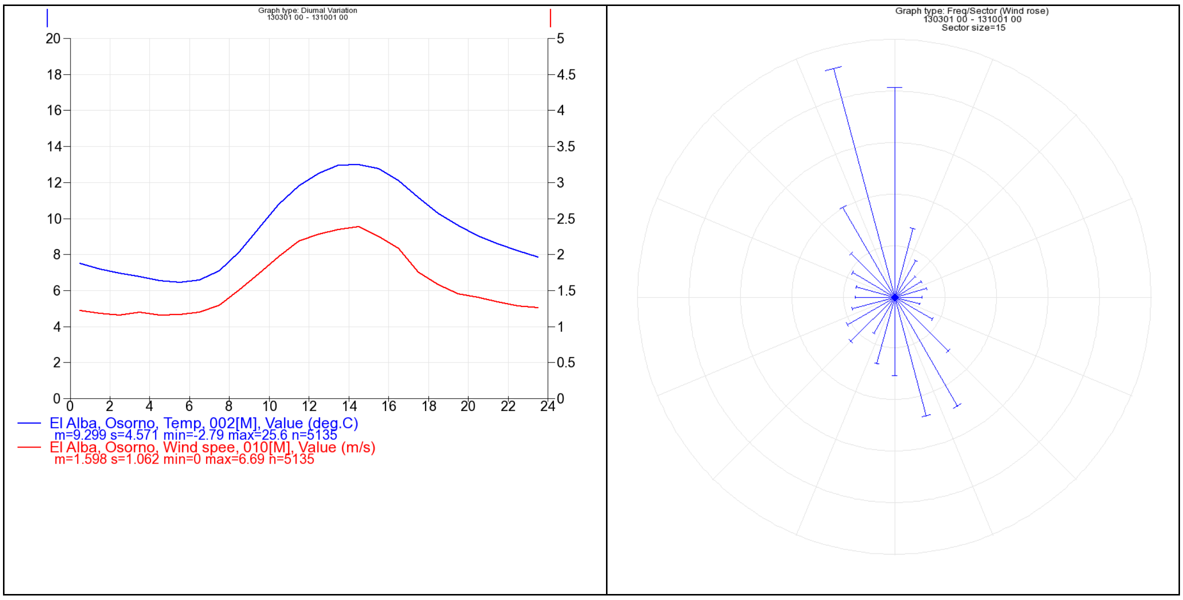


Figure 3.1.1: Daily variation in temperature and wind speed (left) and wind rose (right) at the El Alba station. Results based on the period 2013-03-01 to 2013-09-30.

A procedure to generate meteorological input data for whatever city in Southern Chile has been elaborated. The procedure is based on output from a meteorological forecasting model (DMC:s WRF model), stored at the location of a virtual meteorological tower located in a particular city. A comparison between WRF output and registered meteorological data is presented in the Result section of the report.

3.2 Air quality data

El Alba station (659255 E, 5505711 S, 18G) is located in a residential neighborhood where nearest rwc sources are located some 25-50 meters away (Figure 3.2.1).

Figure 3.2.1 El Alba Station surrounded with local sources of residential wood combustion.

PM10 concentrations measured from 2008 to 2013 at El Alba/ Osorno are shown in Fig. 3.2.2 (BAM1020, Met One). In this report data from the period 2013-03-01 to 2013-09-30 are used for evaluating the model calculations.

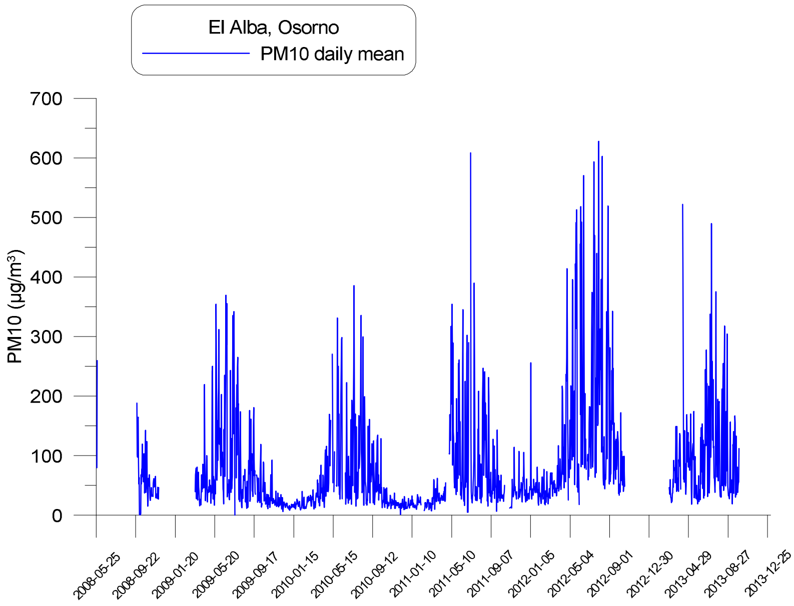


Figure 3.2.2: Daily mean PM10 (µg/m3) concentrations at El Alba in Osorno.

Additionally, ambient levels of pollutants were measured at El Alba station, using PM2.5 filter cascade impactors (HI), for subsequent elemental, mass concentration and EC/OC analysis. The samplers were operating at 25 LPM in a weekly manner, while filters collected material between 10 minutes each hour of day. An extra cascade impactor was measuring in parallel way and besides the first HI. Nevertheless, this instrument was operating at 30 LPM and continuously over all the period. The objective was to determine PM mass concentration in different fractions (10-2.5, 2.5-1.0 and 1.0-0.16 µm of aerodynamic diameter).

Filters were weighed to determine mass concentration, also, were analyzed for EC/OC concentration using NIOSH procedure (thermo-optical analysis) and elemental characterization, by X-RF analysis. The total period of measurements comprised days from 2013-08-16 to 2013-08-30.

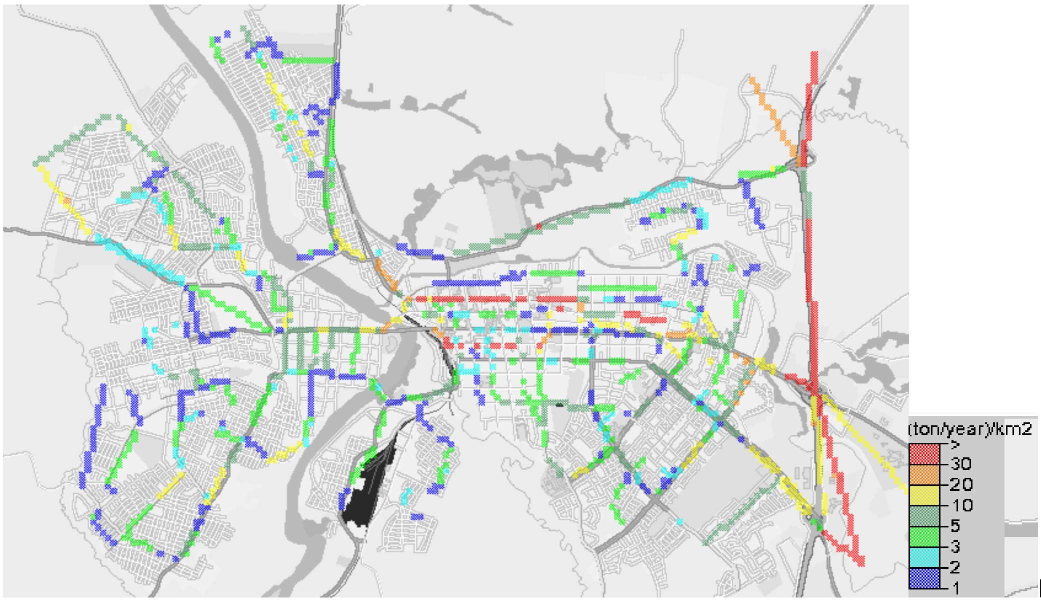
Nevertheless, a few short continuous monitoring, at different points of town, were realized using DustTrack (TSI) and microAeth (AethLabs) instruments, for PM2.5 and BC, respectively. Diffusive samplers were also distributed in a grid of 12 points inside town, to determine gases concentrations of SO_2, NO_2 and NO, during 2.5 weeks

A schematic assembling of the cascade impactors and installation of diffusive samplers are shown in the Figure 3.3.3.

Figure 3.3.3. Impactors (left) and diffusive samplers (right) used to monitor PM and gas concentrations.

3.3 Emission inventory

The emission inventory used for modelling includes three types of sources: Traffic exhaust emissions, larger point sources and residential wood combustion. Traffic emissions were taken from a traffic model simulation [2] and entered as a grid source (Fig. 3.3.1)



Figure

Figure 3.3.1: PM10 emissions from traffic exhaust, as an average 35 tons/year.

Point source emissions have been described as stacks according to data reported to authorities [3] (Fig. 3.3.2).

Figure 3.3.2: PM10 emissions from larger point source, as an average 28 tons/year.

Emissions from residential wood combustion (rwc) are given as grid sources separated in districts (Fig. 3.3.3, taken from [4]). More details of the rwc emissions are given below.

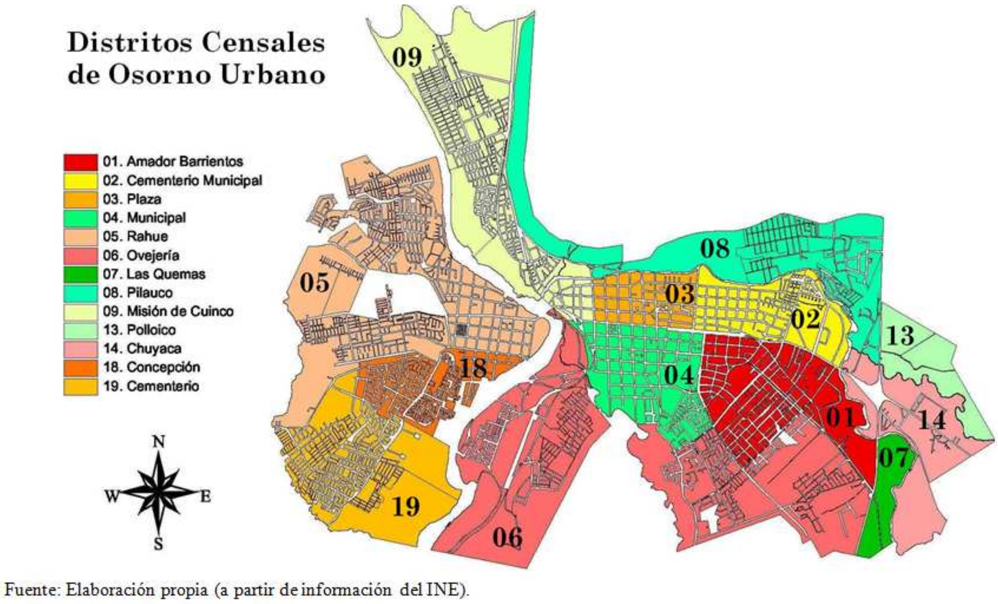


Figure 3.3.3: Distritos Censales (administrative districts) within Osorno.

Wood consumption

The wood consumption has been estimated in a separate study [4], summarized in Table 3.3.1.

Table 3.3.1 Number of houses and wood consumption in different districts in Osorno.

District	Number of houses	Wood consumption per house (m^3/year)	Total wood consumption (m^3/year)
1	3356	18.5	62 153
2	2398	11.7	28 105
3	1032	15.7	16 223
4	2115	15.7	33 248
5	7682	11.2	86 269
6	4946	11.8	58 511
8	1020	15.6	15 871
9	5827	11.8	68 700
18	3150	11.2	35 375
19	4939	11.2	55 465
Total			***459 920***

The use of eight different types of wood stove devices are listed in Table 3.3.2. We have for each district a distribution profile determined from questionnaires [see 4 for details]. Within each district we have no further information, except that we assume that rwc emissions take place in areas mapped as residential (i.e. we exclude open fields, parks, river banks etc). We do not have, as would have been ideal, information on individual houses and their type of wood stoves. Therefore the eight types of wood stoves have been homogeneously distributed over each district (see Fig. 3.3.5-6 below). The distribution of different types of stoves and the estimated wood consumption in each district are listed in Table 3.3.3.

Table 3.3.2 Different types of fire places used in this study.

	Description
1	wood stoves in kitchen
2	Salamandra (old Chilean wood stove)
3	wood stove with templator bad wood combustion
4	wood stoves with templator good wood combustion
5	wood stove without templator bad wood combustion
6	wood stoves without templator good wood combustion
7	open fire place
8	others

Table 3.3.3 Wood consumption for different districts and fire types (wood density 0.5 ton/m^3)

District	Total wood consumption (ton/year)	Fire type/ arte facto (%)							
		1	2	3	4	5	6	7	8
1	31 077	37.2	4.1	9.9	17.4	6.7	11.9	11.6	1.2
2	14 052	48.6	2.7	6.4	7.1	7.3	8.1	0.9	18.9
3	8 112	52.9	0.0	11.8	5.9	15.7	7.8	5.9	0.0
4	16 624	40.0	2.9	23.8	11.9	6.7	3.3	7.1	4.3
5	43 134	51.0	5.2	18.9	14.1	5.9	4.4	0.0	0.5
6	29 256	42.6	1.1	32.5	18.0	3.7	2.1	0.0	0.0
8	7 936	43.9	2.4	7.3	12.2	11.9	19.8	0.0	2.4
9	34 350	51.1	3.8	29.7	8.4	3.4	1.0	0.0	2.7
18	17 687	56.9	3.8	18.1	13.4	4.0	2.9	0.0	0.8
19	27 732	69.8	5.8	7.3	5.4	5.0	3.7	0.0	2.9

Emission factors

The emission factors for PM10 in table 3.3.4 have been taken from a study by CENMA [5]. The factors, as well as the corrections made for wet wood, are based on literature values from different studies. The assumption used for the reference case (present conditions winter 2013) was 90% wet wood. We separate emissions from stoves with and without templators, assuming that the emission factors from stoves with templators are 50% lower compared to stoves without templators (private communication MMA).

In [4] the estimated emission of PM10 from wood combustion in Osorno is 9180.1 ton/year. In our calculation the emission is about 18 % lower i.e. 7501.0 ton/year, this due to the assumption of lower emission factors for stoves with templators and the assumption that some of the wood used (about 10%) is dry.

In Table 3.3.5 and Figure 3.3.4 we compare the emission factors with those that are used in Sweden, showing much lower values.

Table 3.3.4 Emissionfactors (g/kg) for PM10 from wood combustion based on information's from ref [5] and assuming that the emission factors for stoves with templators is 50% of the emission factor for stoves without templators (private communication).

Type	Emissionfactor (g/kg)		
	dry wood	wet wood	90% wet wood
wood stove kitchen	19.2	30.9	29.7
stoves with templator bad combustion	40.5	40.5	40.5
stoves with templator good combustion	8.0	12.9	12.4
stoves without templator bad combustion	76.0	76.0	76.0
stoves without templator good combustion	15.0	24.2	23.3
Salamanders and others	17.3	27.9	26.8

Table 3.3.5 Emission factors for PM10 used in Sweden for different types of fire places

Type	Emission factor (mg/MJ)	Emission factor (g/kg)*
Old-type wood boilers with poor combustion	2190	30.2
Old-type wood boilers with good combustion	1148	15.9
Old-type wood boilers with accumulation tank	190	2.6
Modern boilers without accumulation tank	120	1.7
Modern boilers with accumulation tank	52	0.72
Boilers using pellets	34	0.47
Stoves	400	5.5

* assuming an effective heat value of 13.8 MJ/kg

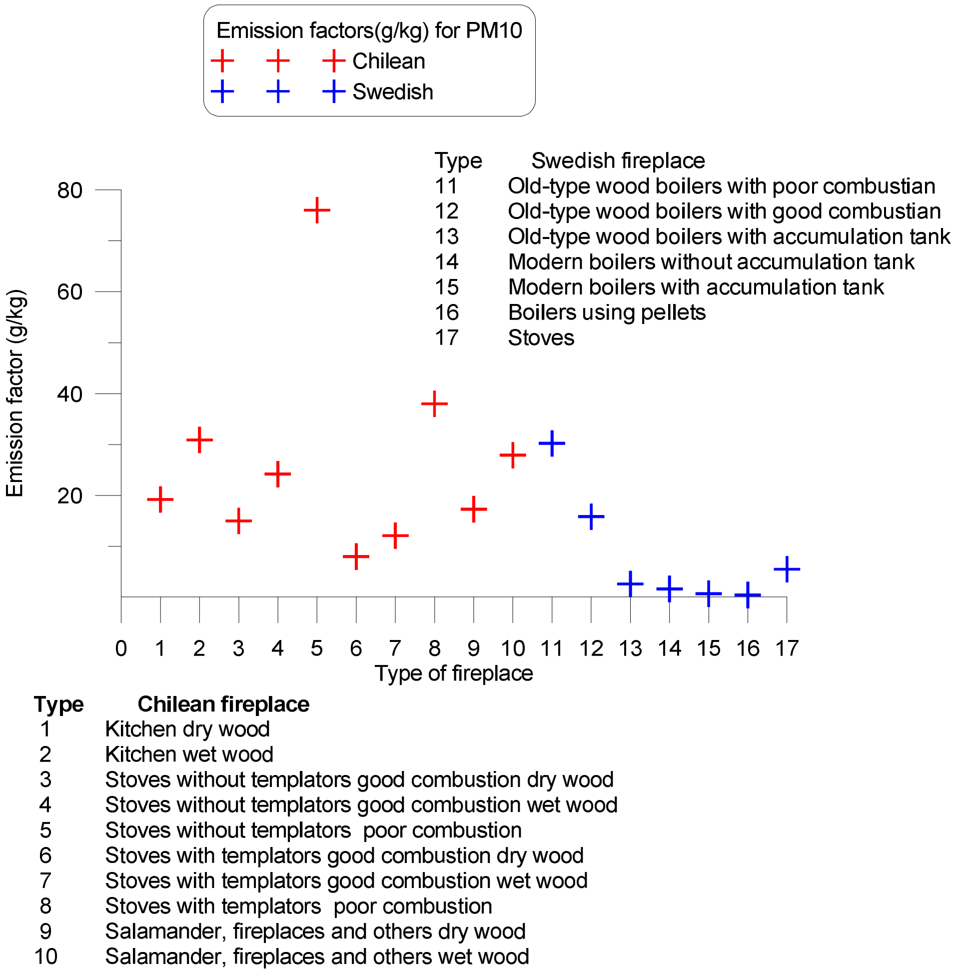


Figure 3.3.4 Comparison between emission factors (g/kg) for PM10 from different fire places used in Chile and Sweden.

Spatial distribution of rwc sources

The number of houses that use wood in Osorno is 36 465 and several of them uses more than one fireplace for i.e. cooking and heating. The exact location is not known, only the number of houses and the frequencies of different fireplaces in different districts. We therefore need to do some simplifications. For the modelling of concentrations around the measuring station El Alba, where we will evaluate the simulated concentrations, a dense spatial resolution of rwc sources are used. The reason for this is that the impact of sources close to El Alba will affect the monitor location with high concentrations in narrow plumes. With too long distance between the sources, the impact will be highly irregular and not representative for the impact expected from many houses located much more densely. For rwc sources located far away from El Alba we can use a coarser distribution of rwc sources.

The first high-resolution distribution uses a dense and rather realistic (i.e. comparable to simulating 1-2 sources from each house) distribution of sources around El Alba (Figure 3.3.5). The second (Fig. 3.3.6) uses a more coarse and simplified distribution for all wood smoke sources located outside the area with the first and dense distribution. Calculations are performed separately for the two source configurations and the total impact can later be summed together to allow a comparison with monitored PM concentrations at El Alba monitor station.

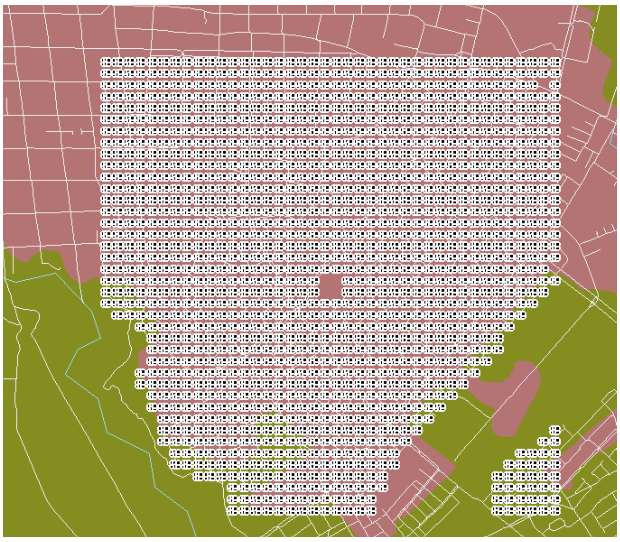


Figure 3.3.5 The distribution of wood smoke sources close to El Alba using a dence distribution within +/- 1000 meter from El Alba. The spatial resolution is 50 metres distance between a group of sources representing the six different types of fireplaces (Table 3.3.4) used in this study. The distance between different fireplaces is 12.5 m. Sources within +/- 50 m from El Alba are excluded. The number of sources in district 1 is 4 164 which can be compared with the number of houses in district 1 which is 3356 with an average of about 1.8 fireplaces in each house.

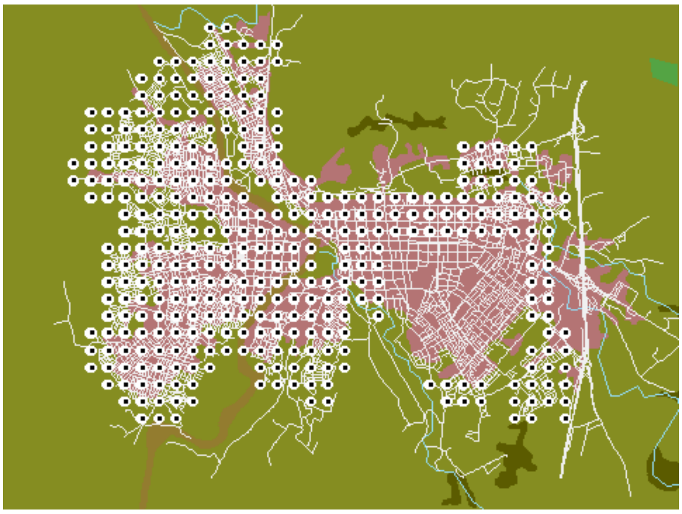


Figure 3.3.6 The second coarse distribution of wood smoke sources in Osorno

3.5 Dispersion modeling

In this study the SIMAIRrwc model system [6] has been used where rwc stands for residential wood combustion. It is an updated Gaussian plume model, wind and dispersion parameters are calculated using basic boundary layer parameters such as friction velocity, sensible heat flux and boundary layer height. It includes an emission model for residential wood combustions. The following components are included: emission types, emission factors, start and running phases, accumulation tank and size. The time variations of emissions are described as a function of social factors or as a function of fuel consumption; for the latter, a method using heating degree-days is used. This model is part of the Airviro system, which means that it can be operated as part of the SINCA tool.

The simulations of traffic and industrial sources have been made with the standard Airviro Gaussian model. Model output from SIMAIRrwc and AIRVIRO Gauss have the same format, so AIRVIRO tools have been used to sum the impact together.

4 Results: Impact during present conditions

4.1 Air Quality monitoring

The continuous PM2.5 mass values registered operationally at the El Alba station were compared to the discret values measured on filters during the campaign. Both instruments showed similar values for PM2.5 mass concentration, but slightly higher for HI in the first period of measurement (Fig. 4.1.1, left).

The right part of Fig. 4.1.1 shows that the decreased PM2.5 concentrations during the second period was mainly explained by lower concentrations of particles in the size range 2.5 to 1.0 µm, a size range where we expect accumulation of secondary particles. The local rwc emission we expect to be in the sub-micrometer range. Thus there is no good explanation to his reduction in the 2.5 to 1.0 µm size range. The HI measurement indicate a PM2.5 to PM10 ratio of about 80%, being 82% during period 1 and 78% during period 2.

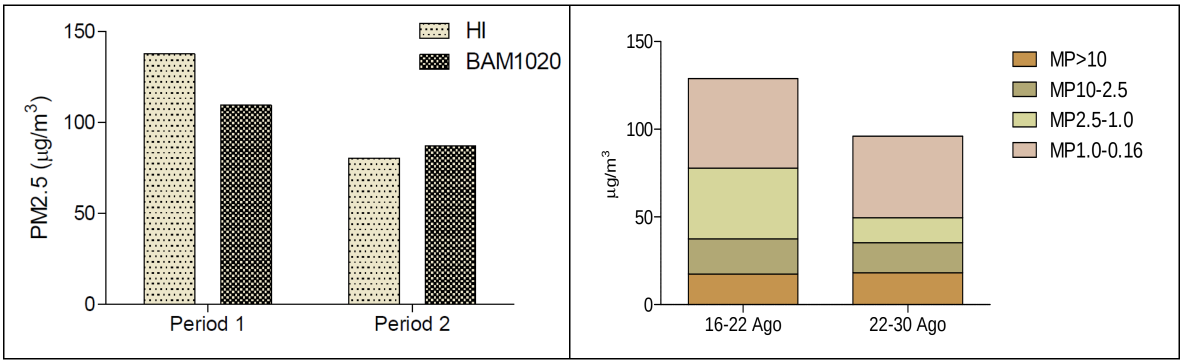


Figure 4.1.1 Comparision of gravimetric and continuous measurments of PM2.5 (left). Separation of PM mass in four size ranges (right) at the El Alba station.

During the winter period May to August the PM2.5 to PM10 ratio is, as an average of the BAM1020 data, around 65-66%, during both night and day (Figure 4.1.2). Absolute levels are considerably higher during nighttime, 144 as compared to 84 µ/m^3 for PM10 and 95 as compared to 55 µg/m^3 for PM2.5.

The BAM1020 data gives for the two shorter periods with parallel measurements (Fig. 4.1.1) a PM2.5 to PM10 ratio of 69 and 74%, respectively. Considering the domination of wood combustion sources in Osorno, a PM2.5 to PM10 ratio around 65-66% (entire winter period) or 69 to 74% (August 16-30) as indicated by the BAM1020 data, is unexpectedly low. Earlier monitoring campaigns in rwc-dominated areas in Sweden have revealed ratios of 80-90%, with most of the combustion particles being smaller than 1 µm, i.e. a ratio more in line with the two HI measurements (Fig. 4.1.1). Although uncertain which monitoring technique to trust, we choose to use for further calculations the 80% value as representative for the PM2.5 to PM10 ratio in Osorno.

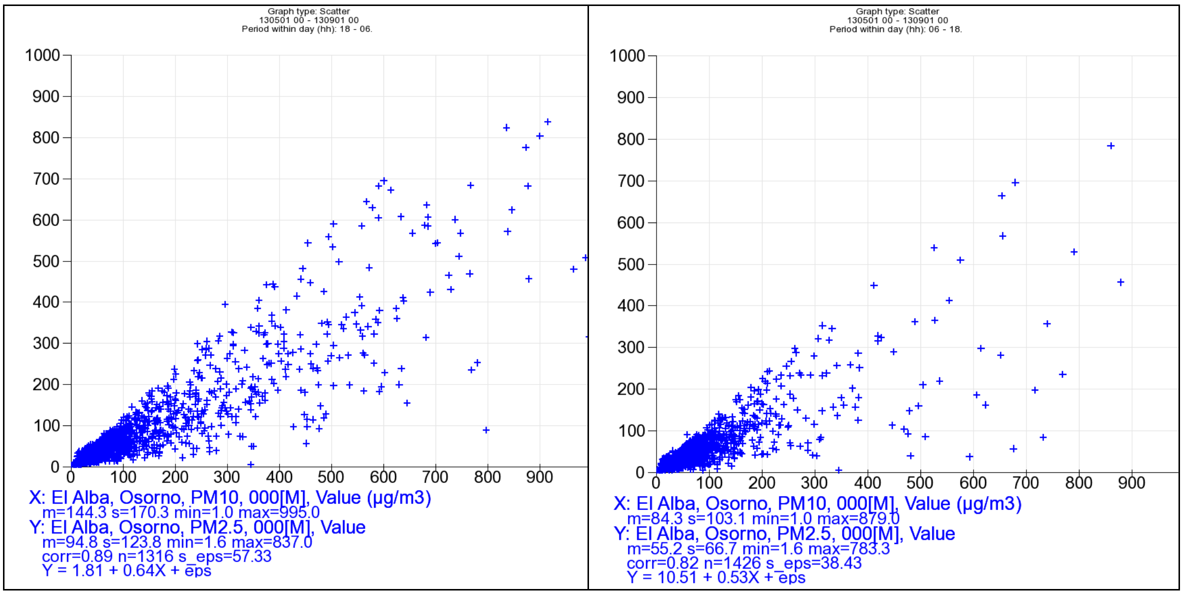


Figure 4.1.2 Scatter plot of PM10 and PM2.5 during night hours (left) and day hours (right). Period: May – August 2013.

The time series graphs for May-August values are shown in Figure 4.1.3. Two observed peaks can be seen during the day, one at 08-09 hours and another with the highest maximum levels at 22-23 hours. Both peaks are associated with the use of wood stoves. The nighttime peak is higher due to a larger number of wood heaters in operation, in combination with meteorological conditions that are unfavourable for dilution. The time series for weekly variation indicated similar values inside de week, with a smaller rise in the weekend days.

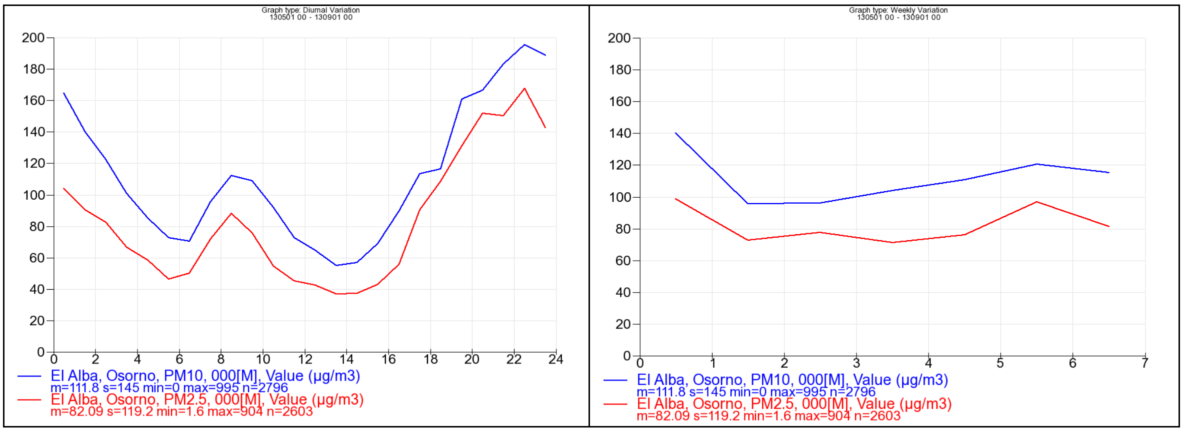


Figure 4.1.3 Diurnal (left) and weekly (right) variation om PM10 (blue) and PM2.5 (red) levels. Period: May – August 2013.

Very high PM levels can occur with almost all wind directions (Fig. 4.1.4) while mean PM levels are highest for winds in the sector NE – E and the sector SW – W (fig. 4.1.5).

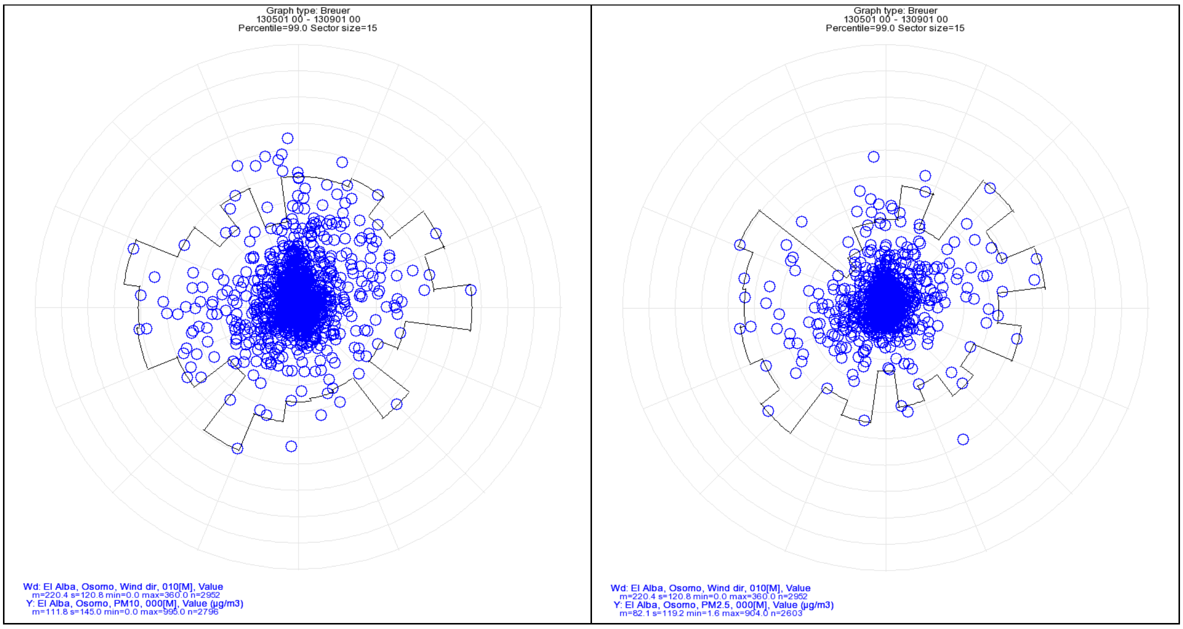


Figure 4.1.4 Breuer diagram of PM10 (left) and PM2.5 (right) with maximum hourly concentration levels of 995 µg/m^3 for PM10 and 904 µg/m^3 for PM2.5. Period: May – August 2013.

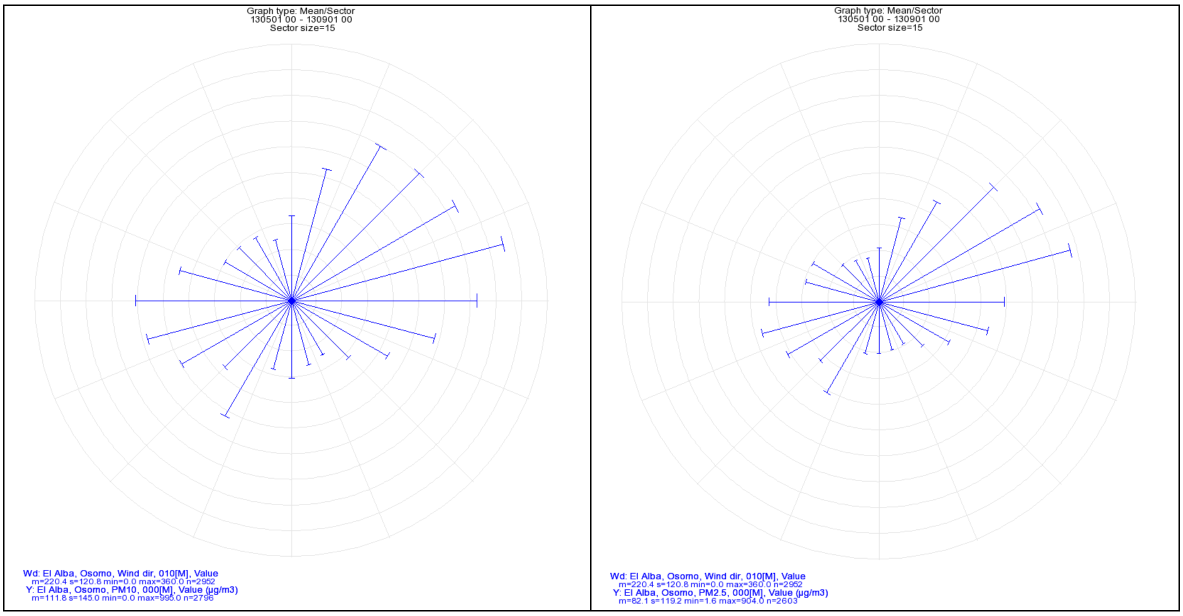
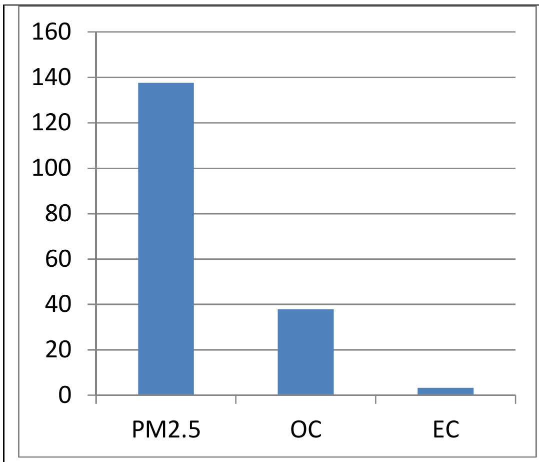


Figure 4.1.5 Mean values for different wind sectors, PM10 (left) and PM2.5 (right). Highest mean concentration levels are registered with winds from ENE, being 255 µg/m^3 for PM10 and 231 g/m^3 for PM2.5. Period: May – August 2013.

Fig. 4.1.6 shows measured fractions of PM2.5 characterised as OC (27.5 and 34.4%) and as EC (2.4 and 3.6%), respectively for two week-long periods. The two data sets indicate that we can expect some 3% of PM2.5 to be EC (EC should be about the same as black carbon, BC).



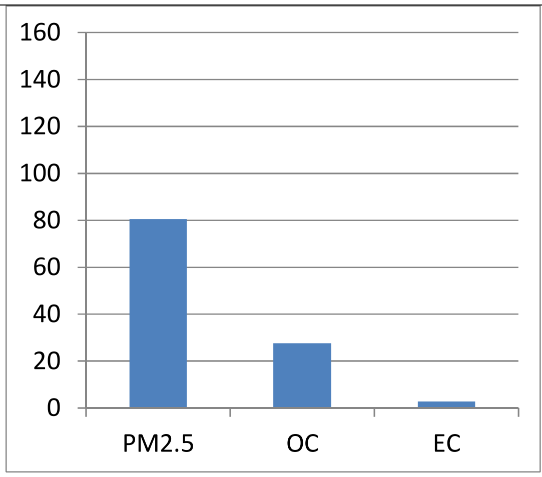
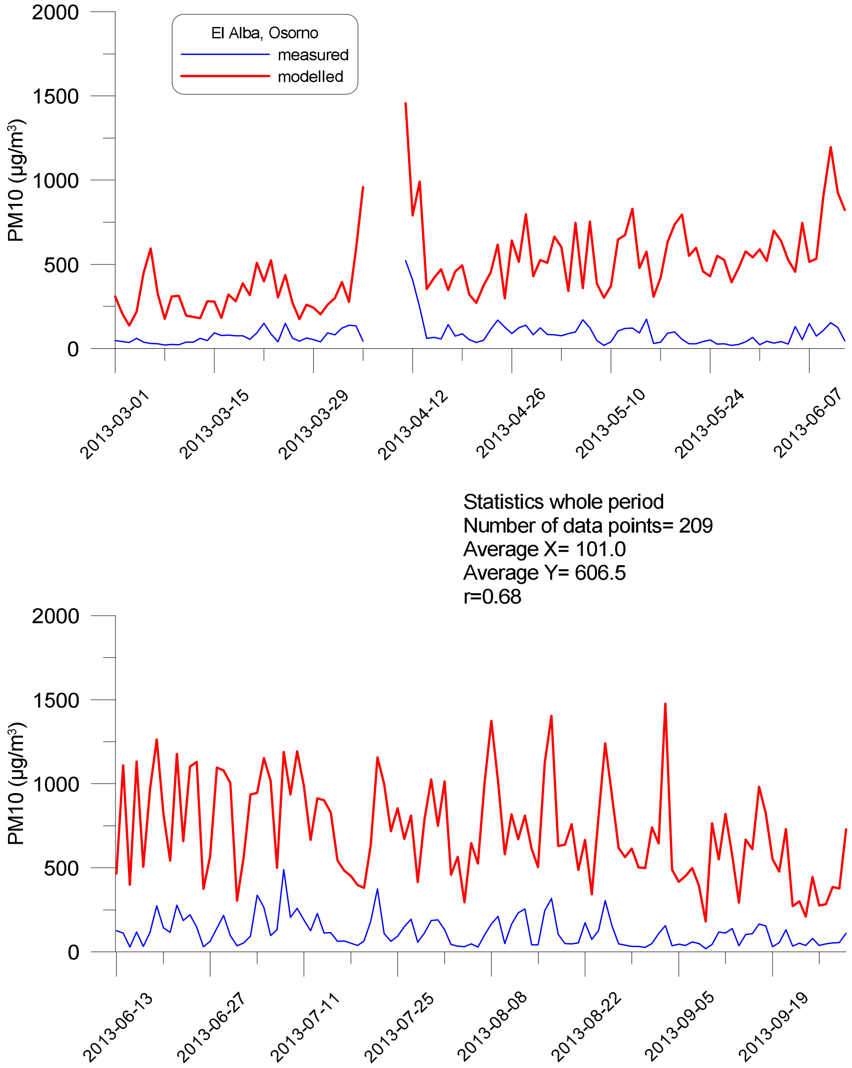


Figure 4.1.6 Mean values of measured PM2.5, organic carbon (OC) and elemental carbon (EC) during the period 16-22 August (left) and 22-30 August (right), station El Alba.

4.2 Air Quality modeling

Model results in the form of daily averages of PM10 have been compared to monitor values at the El Alba station (Figure 4.2.1). During the winter period, when rwc starts to be more frequently used, the simulated levels become much higher than the monitored values. For the 7 months long period March-September 2013 the simulated average PM10 mean concentration is about a factor of six higher than the measured one. Such a large discrepancy can’t be attributed to model imperfections and uncertainties in meteorological forcing. It is clear that emissions have been overestimated.

The emission data are uncertain due to several reasons. The amount of wood consumed for rwc purposes is, for example, not easy to estimate. It is expressed in m^3/year and the weight is calculated using a density value of 0.5 ton/year. In fact the wood density is dependent on how the logs are stacked and the type of woods. If the amount of wood given in [4] is based on information of stacked wood logs, the value 0.5 ton/year might be too high. Also the levels of the emission factors are highly uncertain and, as seen in the Table 3.3.4 and 3.3.5 comparison with Swedish emission factors, there is a possibility that they are much lower than what is suggested in [5]. More attention to these issues are therefore needed.



Figur 4.2.1 Comparison between measured and modelled daily PM10 (µg/m^3) concentrations at El Alba, Osorno using emission factors according to Table 3.3.4 (90% wet wood). r is the correlation coefficient.

When emissions are lowered with a factor 0.17 from the theoretical values, we get a good resemblance between model simulations and measured PM10 concentrations (Figures 4.2.2. and 4.2.3). The original emission overestimation can be explained by too high emission factors in [5] or overestimated wood consumption in [4], perhaps more likely a combination of both. With the information we have at hand, it is not possible to give a more precise explication to the overestimation. In continuation we will refer to this % reduction of the emissions by the factor 0.17 as a 83% lowering of the emission factors given in Table 3.3.4 for 90% wet wood, leaving wood consumption as it is in Table 3.3.1.

The validated PM10 emissions are, after the % reduction of the emission factors by the factor 0.17, 1275 tons/year. Using an averaged PM2.5 to PM10 ratio of 80% and a 3%

fraction of PM2.5 being BC, we get an annual PM2.5 emission of 1 020 tons/year and a BC emission of about 31 tons/year from the Osorno rwc sources.

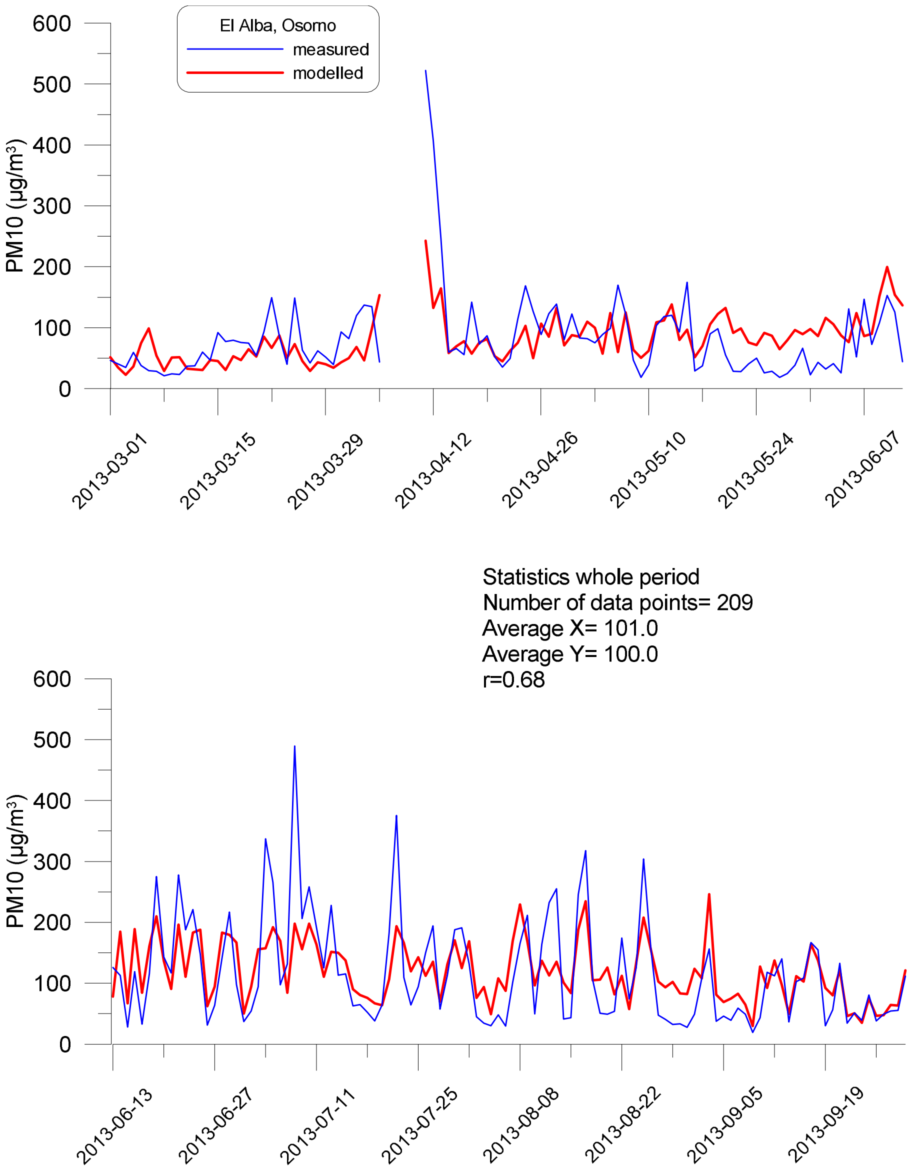


Figure 4.2.2 Comparison between measured and modelled PM10 (µg/m^3) concentrations at El Alba, Osorno assuming a factor of 0.17 lower emission factors than given in Table 3.3.4 (90% wet wood). r is the correlation coefficient.

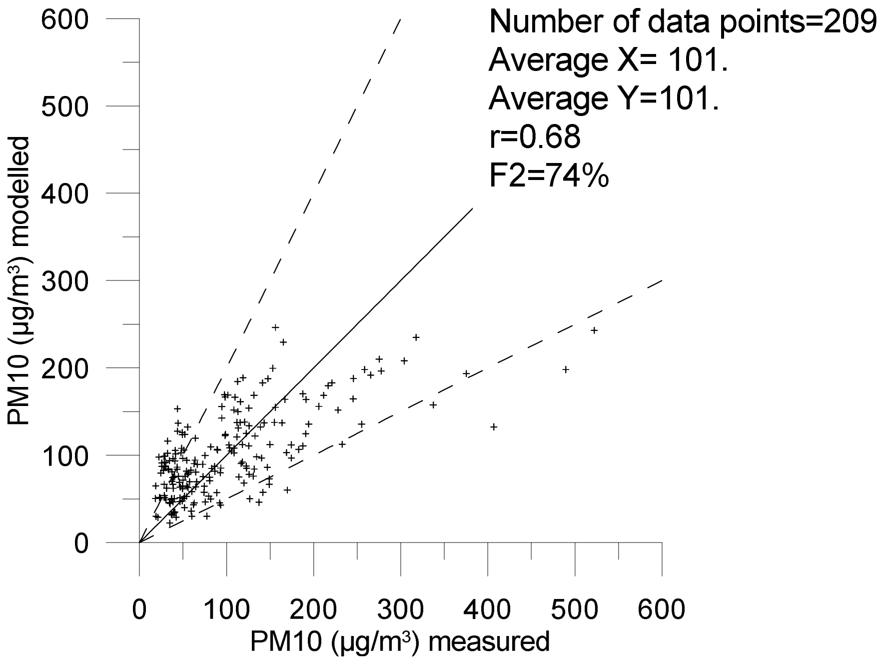


Figure 4.2.3 Comparison between measured and modelled PM10 (µg/m^3) concentrations at El Alba, Osorno assuming a factor of 0.17 lower emission factors than given in Table 3.3.4 (90% wet wood). r is the correlation coefficient and F2(%) denotes the number of modelled data that are within a factor of two compare to measured data.

Figure 4.2.4 shows that simulated and measured PM10 concentrations have a similar dependency to ambient temperature, likely reflecting the intensity of wood combustion plus a minor effect of meteorology (lower wind speeds and less mixing during cold days).

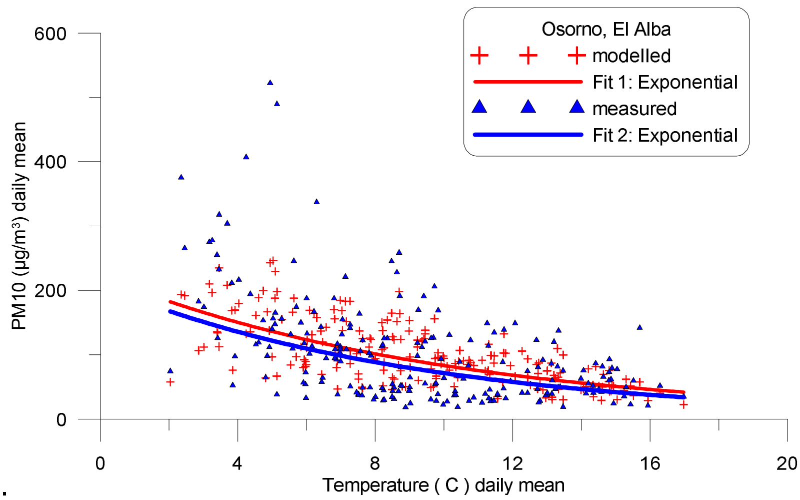


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Figure 4.2.4 Comparisons between PM10 concentration (measured and modelled) and temperature, daily mean values assuming a factor of 0.17 lower emission factors than given I Table 3.3.4.

Model simulations are made hour by hour. Figure 4.2.5 shows that simulated and measured PM10 concentrations have a similar variation during the day. Wood stove combustion is more intense during a shorter period in the morning and then again during the evening and early night.

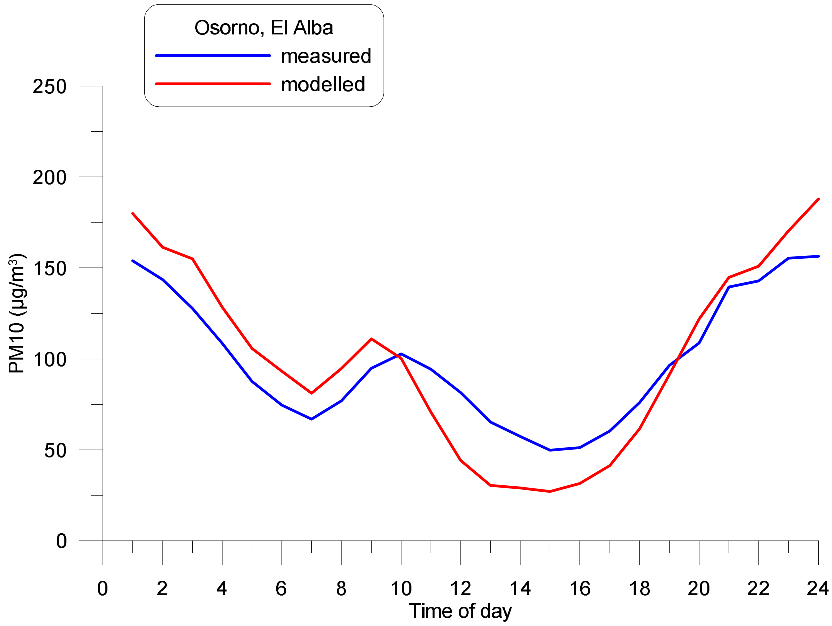


Figure 4.2.5. Comparison between measured and modelled PM10 concentrations as function of time of the day during the whole period assuming a factor of 0.17 lower emission factors than given I Table 3.3.4 (90% wet wood).

Model simulations also permit the separation of impact of different types of wood stoves, see Table 4.2.1 and Figures 4.2.6 and 4.2.7. An important source for PM10 is wood burning for cooking, about 31 % of PM10 is due to this source and it uses about 50% of the total wood consumption. The PM10 contributions from stoves with templator and without templator are large, about 25 and 29%, respectively. The use of stoves with templator, as quantified by wood consumption, is however a factor of 2.8 higher as compared to stoves without templator.

Table 4.2.1 Contribution of PM10 concentrations and wood consumption from different type of fireplaces in Osorno.

Type of fireplace	PM10 (µg/m^3)	PM10 (%)	Wood consumption (%)
wood stove kitchen	31.2	30.9	49.7
stoves with templator	25.4	25.1	30.7
stoves without templator	29.3	29.0	11.0
salamanders and others	15.1	15.0	8.6

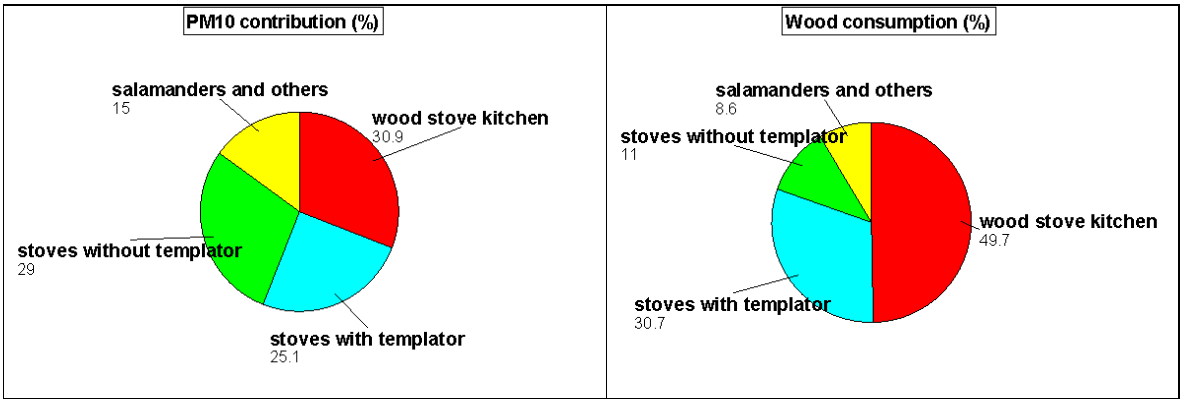


Figure 4.2.6 Contribution of PM10 concentrations and the use of different types of fireplaces (as quantified by wood consumption) in Osorno, based on data from Table 4.2.1.

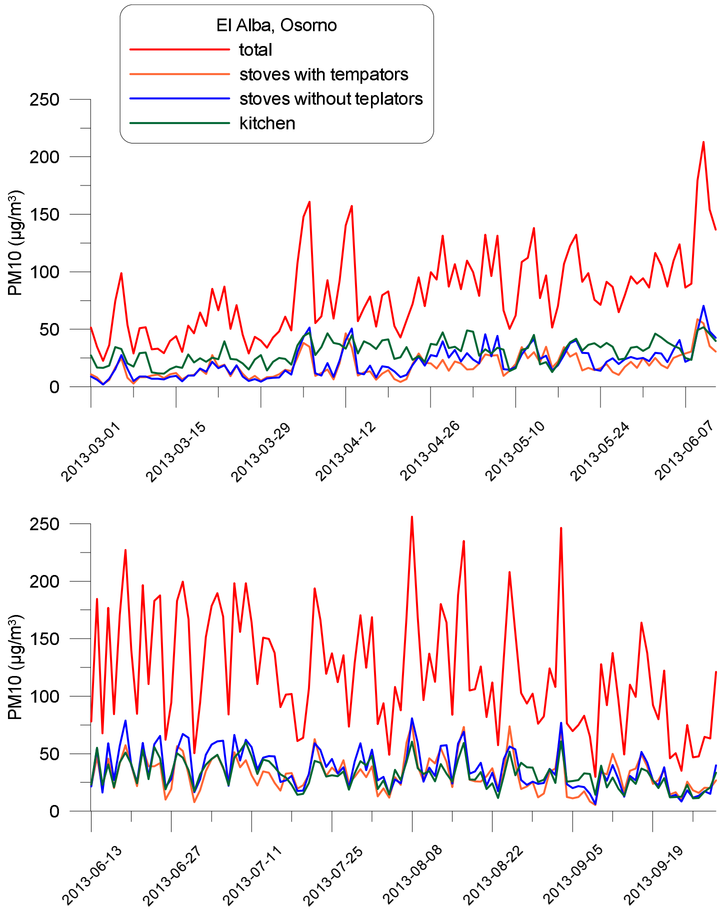
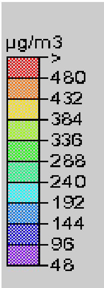


Figure 4.2.7 Modelled PM10 ($\mu g/m^3$) at El Alba, Osorno for different source types.

Characteristics of rwc impact with realistic emissions

The comparison between simulated and measured PM10 levels at the El Alba station has shown that the emission factors found in the literature are not realistic, giving far too high impact as compared to measured pollution levels. In order to discuss the true impact of the wood combustion source in Osorno, we will therefore in what follows use emissions for the present situation (2013) that are 17% of the factors of Table 3.3.4 (all emission factors lowered the same percentage). The huge difference is illustrated in Figure 4.2.8.

Figure 4.2.8a
Modelled annual PM10 concentrations for 2013 with only residential wood combustion sources (emission factors as of Table 3.3.4).



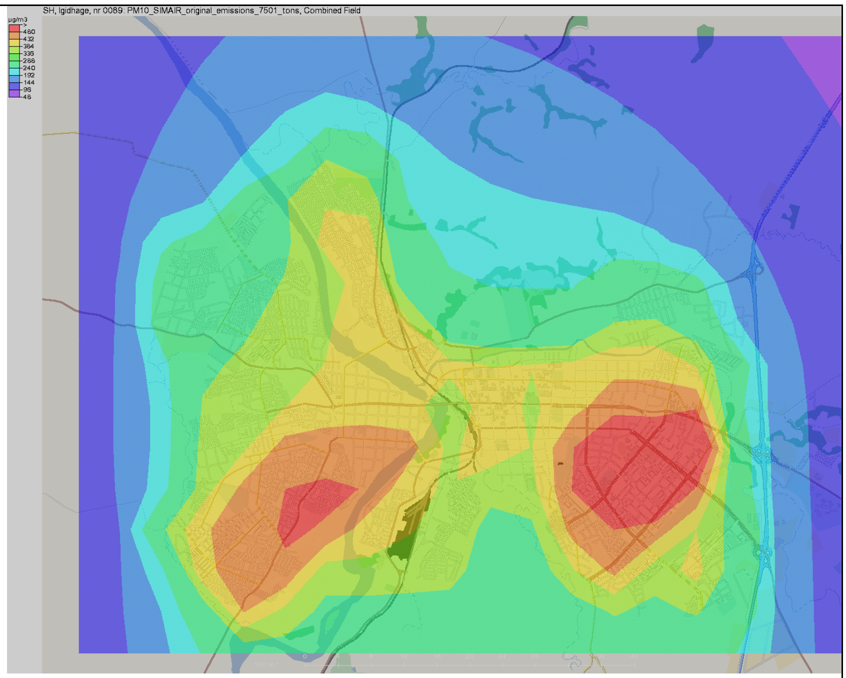
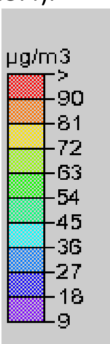
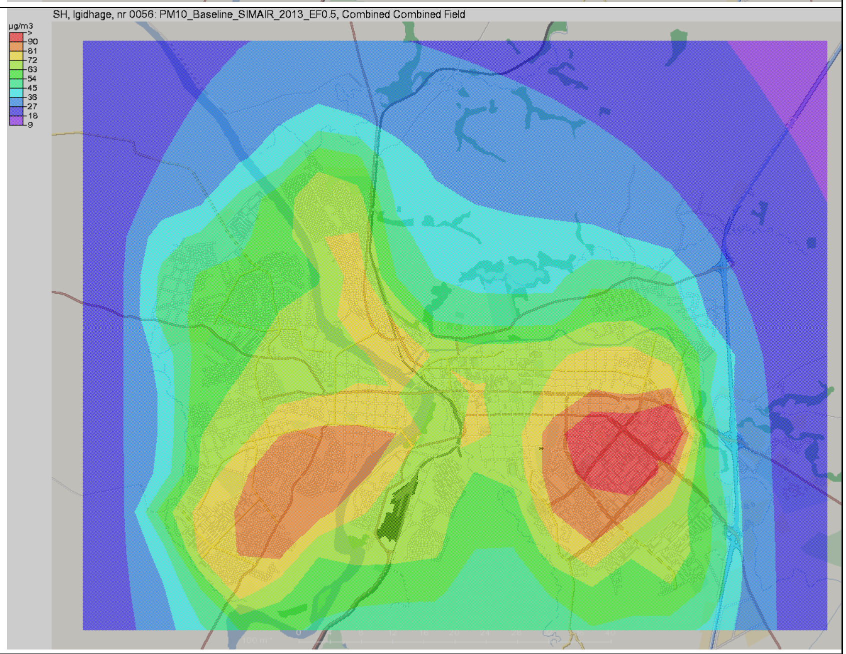


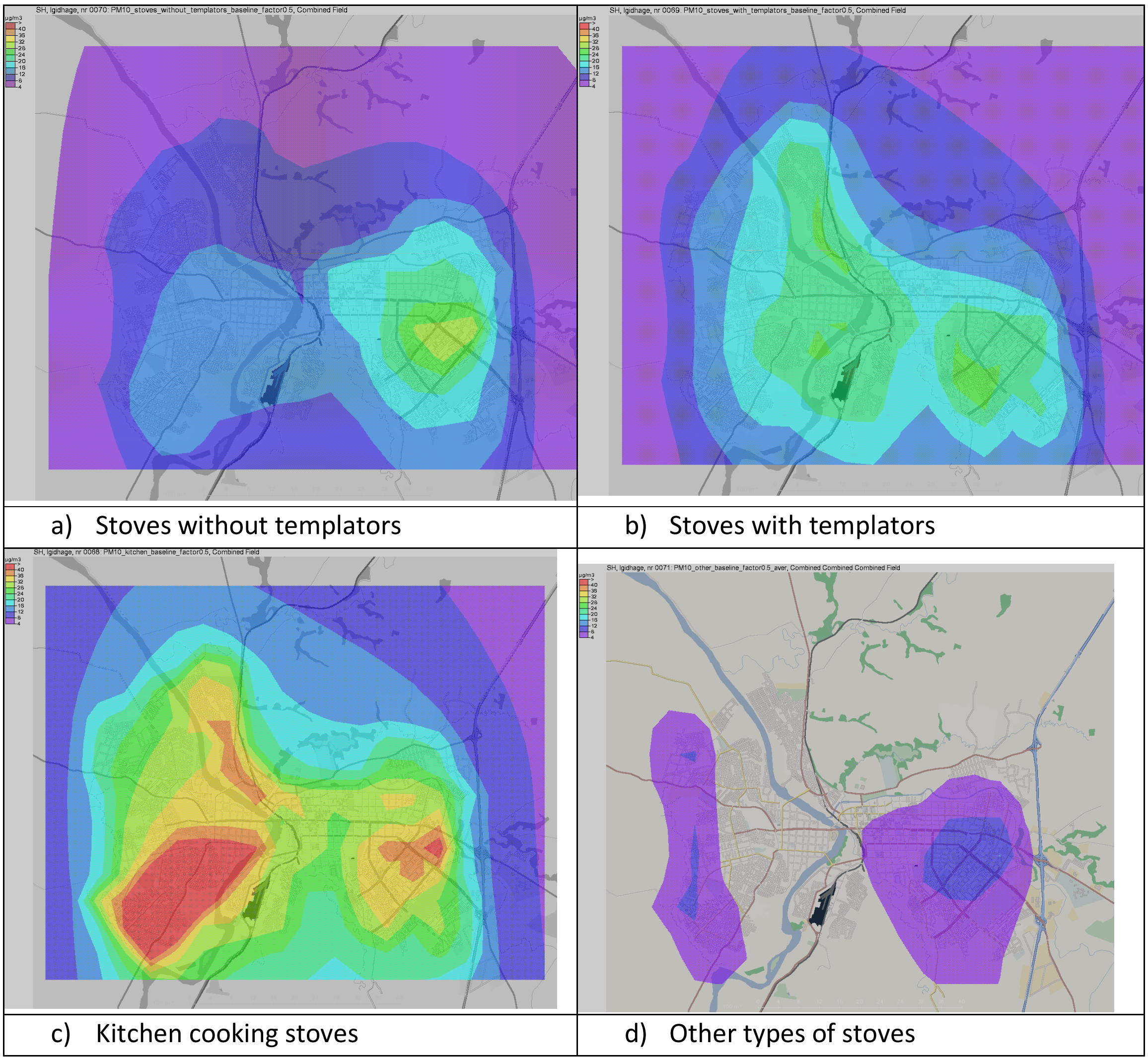
Figure 4.2.8b
Modelled annual PM10 concentrations for 2013 with only residential wood combustion sources (emission factors 17% of those in Table 3.3.4).





Model simulations does also show the spatial distribution of the rwc impact, based on the spatial distribution of wood consumption and use of different type of wood stove. The final (corrected) impact illustrated in Figure 4.2.8b shows the highest long-term impact in the eastern part of the city with annual mean PM10 levels above 80 µg/m^3.

Figure 4.2.9 shows the averaged impact of different rwc artefacts used in Osorno. The high PM10 levels simulated in the eastern part of the city seems to be a consequence of a higher fraction of stoves without templators, as compared to other parts of the city.



a) Stoves without templators

b) Stoves with templators

c) Kitchen cooking stoves

d) Other types of stoves

Figure 4.2.9 Contributions to annual PM10 concentrations from different types of wood stoves.

So far all simulations have only shown the impact of the rwc source on PM10 levels. Model simulations were also performed for the traffic and point source emissions described in Section 3. Figur 4.2.10 shows that the rwc impact is completely dominating over other sources.

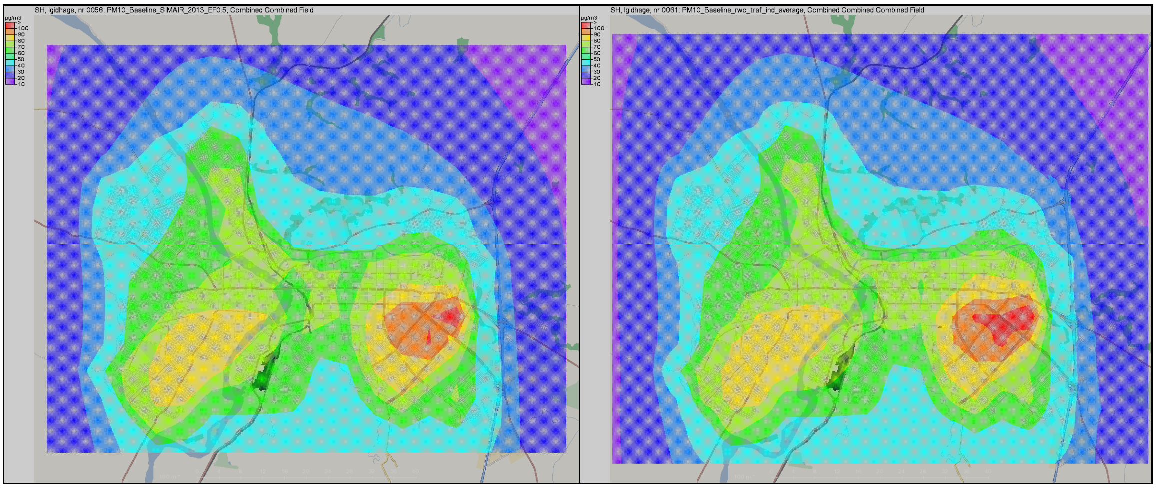


Figure 4.2.10 Modelled average PM10 concentrations with only rwc emissions (left) and total including traffic and industrial sources (right). Note: rwc emission factors 17% of Table 3.3.4.

Figure 4.2.11 show a typical wintertime event with high PM levels in the evening-night time 21:00-24:00 on June 21, 2013. PM2.5 monitoring was performed with a mobile DustTrack monitor which is very efficient to show the spatial distribution of the rwc pollution. Model results show a similar pattern, but with overestimated PM levels in the eastern part. This indicates that emissions are over-estimated in this eastern part of the city, at least during this occasion.

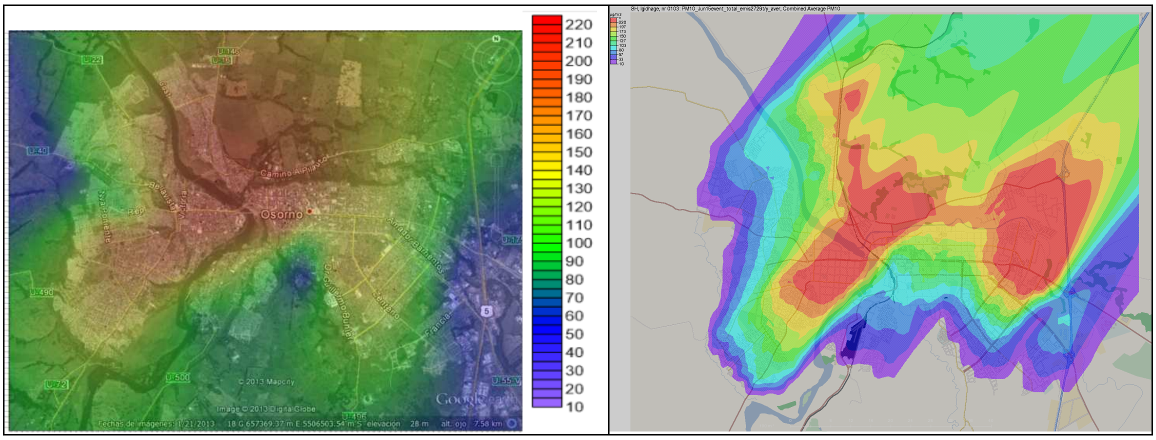


Figure 4.2.11. Monitored PM2.5 concentrations (left) and simulated PM10 (right) during the June 23 21-24 hour event (model results with emission factors 17% of Table 3.3.4, emission during these hours 2 729 tons/year)

The monitored map distribution is based on 10 minutes measurements in 21 locations. Figure 4.2.12 shows a comparison of monitored and model simulated PM2.5

concentrations (the latter calculated as 80% of PM10 concentrations). Also BC was measured and a comparison with simulated BC, assuming 3% BC in PM2.5, is found in Figure 4.2.13.

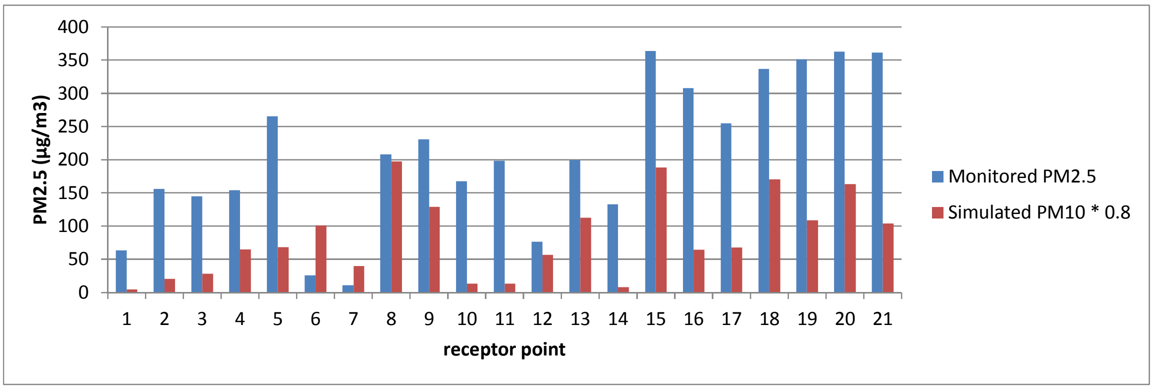


Figure 4.2.12 Monitored and simulated PM2.5 (80% of simulated PM10) for the evening of June 26 21-24 hours, 2013.

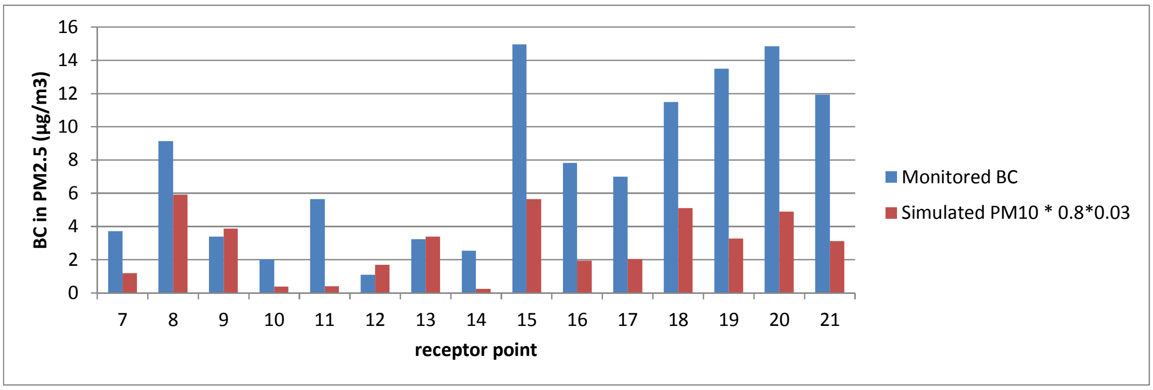


Figure 4.2.13 Monitored and simulated BC (3% of simulated PM2.5) for the evening of June 26 21-24 hours, 2013.

The comparison of PM2.5 and BC shows that the model during this short event and in most of the locations underestimates the high evening concentrations. Ambient temperature was around +6 ℃ with a weak south-west erly wind of about 1 m/s. The similar underestimation of both PM2.5 and BC indicate that the 3% assumption of BC in PM2.5 is reasonable, although the absolute levels are overestimated

This type of mapping was repeated on August 15, 2013, an evening with similar temperature and wind velocity as June 23, however this time the wind was from northwest and it was raining during parts of the 3 hour campaign. The rather few data points, 12 in total makes the interpolation more uncertain and less consistent, see Figure 4.2.14. The point wise comparison in Figure 4.2.15 shows lower monitored PM2.5 levels as compared to the earlier June event, with simulated levels that are about the same magnitude as monitored concentrations.

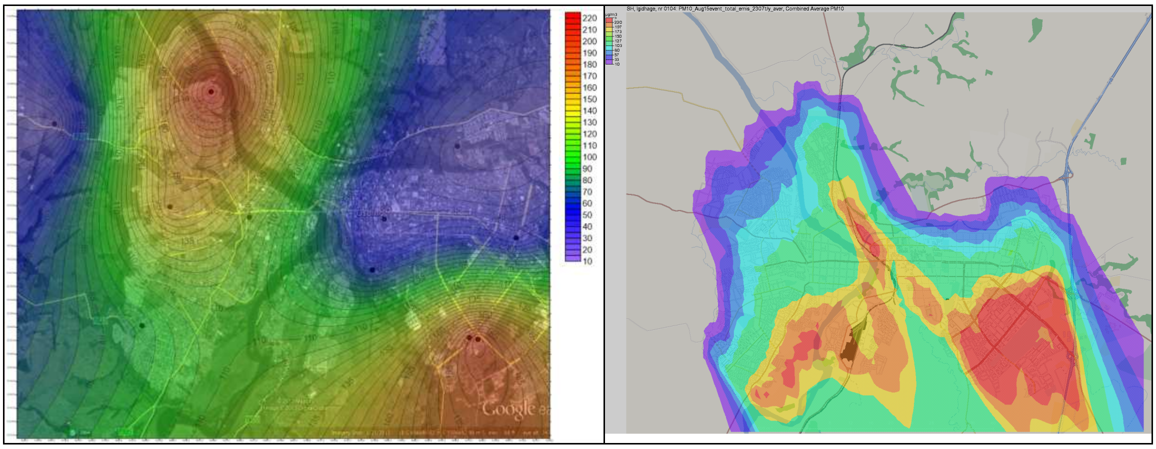


Figure 4.2.14. Monitored PM2.5 concentrations (left) and simulated PM10 (right) during the August 15 21-24 hour event (model results with emission factors 17% of Table 3.3.4, emission during these hours 2 308 tons/year)

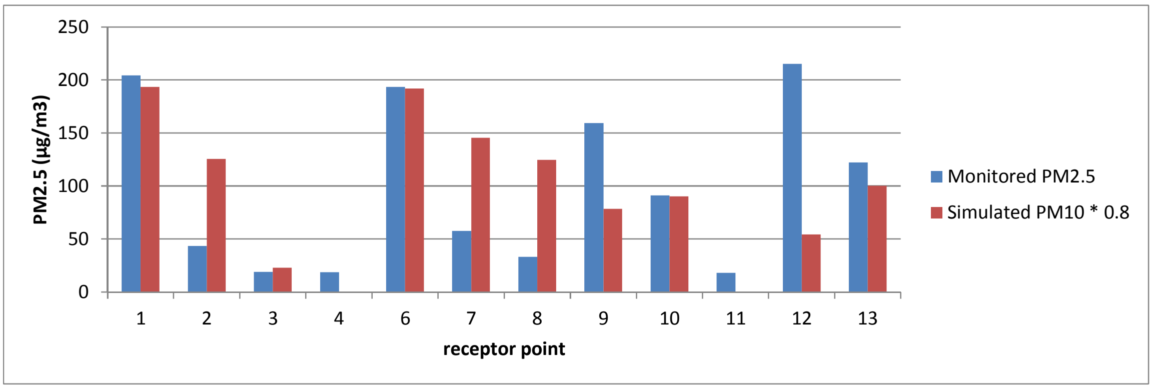


Figure 4.2.15 Monitored and simulated PM2.5 (80% of simulated PM10) for the evening of August 15 at 21-24 hours, 2013.

The spatial PM and BC monitoring in different locations are too few to allow stronger conclusions, but in terms of general PM10 levels they support the evaluation made at the El Alba monitoring station. Some indications can be found in the results:

- The strong impact in the eastern part of the city (Fig. 4.2.8b) may be overestimated, while the impact in the western part is underestimated
- As we have adjusted the emissions to give a similar impact in the only location where long term measurements were made (station El Alba), this would likely imply somewhat higher emission and impact in the western part and a somewhat higher total emission in Osorno as a whole. However, such a modified annual distribution of the rwc impact will not imply emissions that comes in vicinity of the original emission factors in Table 3.3.4.

5 Scenarios

Air quality can be improved by different actions. In this section two different actions will be studied using the dispersion model presented above. The first is assuming that only dry wood will be used and the second assuming that individual wood fireplaces only emit max 2.5 g/hour of PM as suggested as a limit value for Chile [7]. Since the new regulation ([7]) makes an exception for cooking fireplaces, we will look at both the case where all new rwc fireplaces must comply with the limit value and the case – which is in line with the new law – where cooking stoves are excepted from the regulation. It should also be noted that the regulation with a maximum emission limit of 2.5 g/hour only applies to new fireplaces, not existing ones.

5.1 Baseline scenario

The reductions in PM levels will be compared to present conditions, i.e. the emissions and annual average impact during 2013 with all emission sources as illustrated in Fig. 4.2.10 (right). We found that with rwc emission factors from the literature the emission inventory yielded much too high PM10 levels. The reason can be either an overestimated wood consumption and/or too high emission factors. We have selected to keep the wood consumption fixed as given by [4], instead reducing the emission factors by a factor of 0.17. This leads to emission factors according to Table 5.1.1.

Table 5.1.1 Emissionfactors (g/kg) for PM10 from wood combustion used for the simulation of present PM10 levels. These are 17% of Table 3.3.4 factors, taken from [5].

Type	Emissionfactor (g/kg)		
	dry wood	wet wood	90% wet wood
wood stove kitchen	3.3	5.3	5.1
stoves with templator bad combustion	6.9	6.9	6.9
stoves with templator good combustion	1.4	2.2	2.1
stoves without templator bad combustion	12.9	12.9	12.9
stoves without templator good combustion	2.6	4.1	4.0
Salamanders and others	2.9	4.7	4.6

We call the simulation results where we have used the 90% wet wood emission factors of Table 5.1.1 for the “Baseline scenario”. The emissions in Osorno are 1 275 tons/year of PM10 and 31 tons of BC. The PM10 emissions from pure heating constitute 683 tons/year and those from cooking 592 tons/year.

5.2 Dry wood

By using dry wood instead of wet wood the combustion can be more effective, decreasing the emissions of particles, as shown in Table 5.1.1 (using the same percentage reductions as in the original Table 3.3.4). Data from the left column of Table 5.1.1 is used for calculating the effects of using dry wood in combination with good and bad combustion. Calculations are done for the measuring station El Alba and for the time period Mars-September 2013. The results are shown in Table 5.2.1. The first column shows the situation for El Alba/ Osorno today as described by the model calculations shown in Figure 4.2.8b. The second column shows the reduction of PM10 calculated using dry wood according to Table 5.1.1 and permitting both good and bad combustion. The third column shows the same but only using good combustion. Table 5.2.1 shows that a significant improvement of air quality can be obtained if dry wood is used instead of wet wood, the latter being common today in Osorno. The PM10 reduction calculated is about 32 % for dry wood but can be about 36 % if dry wood is used together with good combustion.

Table 5.2.1 Calculated reduction of PM10 (µg/m^3) if only dry wood is used with and without good combustion (Table 2.). Calculation period Mars-September 2013.

	PM10(µg/m^3) Osorno today	%-reduction dry wood	%-reduction dry wood and good combustion
total	101.7	31.6	35.7
kitchen	31.4	35.4	35.4
stoves with templators	25.5	23.9	36.3
stoves without templators	29.4	32.0	35.6
others	15.3	35.5	35.5

By only using dry wood, the maximum PM10 average levels for March to September will reduce from >100 µgm^{-3} to 70 µgm^{-3}. The general improvement on the annual averaged PM10 concentrations by using dry wood and good combustion is illustrated in Figure 5.2.1.

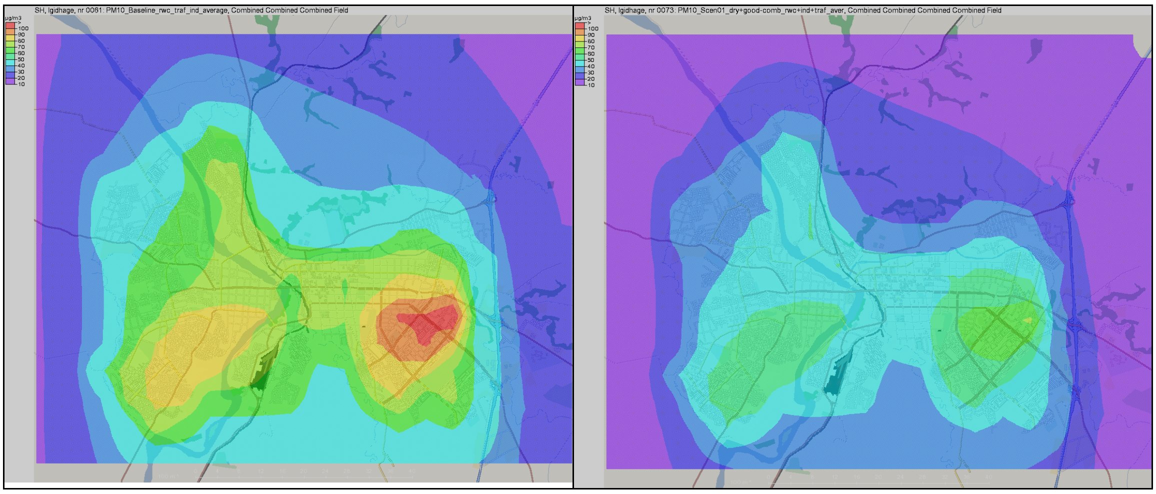


Figure 5.2.1 Modelled annual average PM10 concentrations responding to all sources including rwc, traffic and industrial sources, for present conditions (left) and for a scenario where all houses

use dry wood and good combustion. The reduction of the rwc impact is approximately 36% (see Table 5.2.1).

5.3 Limit emission of 2.5 g/h

The emission from an individual wood fireplace depend on the amount of wood used and the emission factor which is related to type of fireplace, if the wood is dry or wet, if the combustion is good or bad etc. According to Table 3.3.1 the typical wood consumption for a house in Osorno is 11.2-18.5 m^3/year. In a house several different fireplaces and types can be used for cooking and heating, each with different emission factors and different time variations. In this study we separate between stoves for heating and stoves in kitchens for cooking purposes (the latter also heating, but not as its principal purpose). We use the model to calculate the maximal hourly emission rate for PM (g/hour) as a function of yearly wood consumption and emission factors, i.e. responding to the question which emission factors (g/kg wood) are required to fulfill the new limit ([7]) of 2.5 g/hour. The results are shown in Table 5.3.1 and Table 5.3.2. As an example, Table 5.3.1 shows that if an individual fireplace for heating purposes uses a wood consumption of 4 ton/year, the emission factor should be less or equal to 2.5 g/kg in order to not exceed the limit value of 2.5 g/h at any hour of the year. Corresponding emission factor for individual fireplaces for cooking purposes (Table 5.3.2) is about 5 g/kg. The reason for heating to have a lower emission factor is because it is operated more intensively in the morning and afternoon/ late evening, while cooking has a more homogeneously distributed operation during the day and also during the year (cooking is taking place also when ambient temperature does not require heating). The emission factors required to avoid exceedances of the limit value are therefore lower than the emission factors used in the Baseline scenario (Table 5.1.1).

In order to translate these maximum emission factors to expected reductions in PM10 levels, we assume that the wood consumption in Osorno is the same as shown in Table 3.3.1.The wood consumption varies dependent on district and type of fireplace. The maximum wood consumption used in a house for heating purposes, based on data from Table 3.3.1 and Table 3.3.3, is about 11.6 m^3/year. Corresponding value for wood stoves used for food cooking is about 8.3 m^3/year. Assuming a density of wood of 0.5 ton/m^3, we can through Table 5.3.1 and 5.3.2 estimate the maximum emission factors that can be used for reaching the limited emission level of 2.5 g/h. These are about 1.9 g/kg for heating purpose and 5.0 g/kg for cooking purposes.

Table 5.3.1 Calculated maximal PM emissions (g/hour) in Osorno from an individual stove for heating purpose as function of yearly wood consumptions and emission factors. Red values denotes PM emissions above 2.5 g/hour, green values PM emissions below 2.5 g/hour. The calculation period is Mars-September 2013.

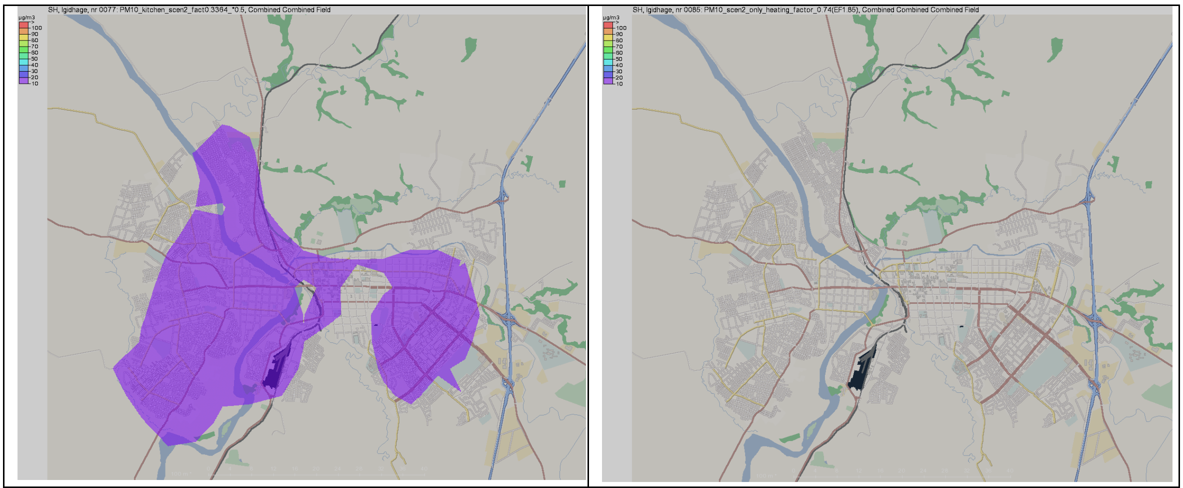
			Max emission of PM10 during one hour (g/hour)					
	emission factor (g/kg)							
wood consumption (ton/year)	0.5	1	2.5	5	7.5	10	15	20
0.5	0.06	0.12	0.29	0.58	0.87	1.16	1.74	2.32
1	0.12	0.23	0.58	1.16	1.74	2.32	3.48	4.64
2	0.23	0.46	1.16	2.32	3.48	4.64	6.96	9.28
3	0.35	0.70	1.74	3.48	5.22	6.96	10.44	13.92
4	0.46	0.93	2.32	4.64	6.96	9.28	13.92	18.56
5	0.58	1.16	2.90	5.80	8.70	11.60	17.40	23.20
6	0.70	1.39	3.48	6.96	10.44	13.92	20.88	27.83
7	0.81	1.62	4.06	8.12	12.18	16.24	24.36	32.47
8	0.93	1.86	4.64	9.28	13.92	18.56	27.83	37.11

Table 5.3.2 Calculated maximal PM emission(g/hour) in Osorno from an individual stove for cooking purposes as function of yearly wood consumptions and emission factors. Red values denotes PM emissions above 2.5 g/hour, green values PM emissions below 2.5 g/hour. The calculation period is Mars-September 2013.

			Max emission of PM10 during one hour (g/hour)					
	emission factor (g/kg)							
wood consumption (ton/year)	0.5	1	2.5	5	7.5	10	15	20
0.5	0.03	0.06	0.15	0.29	0.44	0.59	0.88	1.18
1	0.06	0.12	0.29	0.59	0.88	1.18	1.77	2.35
2	0.12	0.24	0.59	1.18	1.77	2.35	3.53	4.71
3	0.18	0.35	0.88	1.77	2.65	3.53	5.30	7.06
4	0.24	0.47	1.18	2.35	3.53	4.71	7.06	9.42
5	0.29	0.59	1.47	2.94	4.41	5.89	8.83	11.77
6	0.35	0.71	1.77	3.53	5.30	7.06	10.59	14.13
7	0.41	0.82	2.06	4.12	6.18	8.24	12.36	16.48
8	0.47	0.94	2.35	4.71	7.06	9.42	14.13	18.83

Model simulation of the expected impact for the case where heating stoves of all types have an emission factor of 1.9 g/kg and those for cooking all have an emission factor of 5.0 g/kg are shown in Figure 5.3.1 (please note that the impact of heating will be less than 10 $\mu g/m^3$ everywhere). For this scenario the heating contributes with 75 tons/year of PM10 and cooking 210 tons/year.

Figure 5.3.2 shows the considerable reduction in PM10 levels obtained by the 2.5 g/hour limit value applied for all rwc fireplaces, in comparison to present conditions.



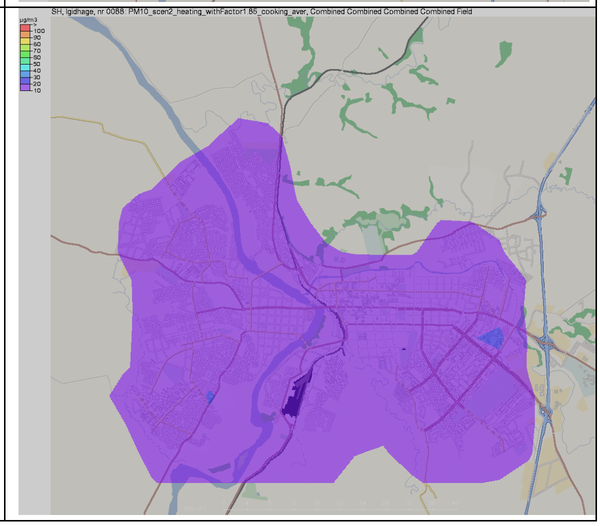


Figure 5.3.1 Modelled average PM10 concentrations 2013 with a maximum emission limit of 2.5 g/h valid for all rwc sources: impact of only kitchen cooking stoves (top left), only heating stoves (top right) and summed rwc impact (bottom right)

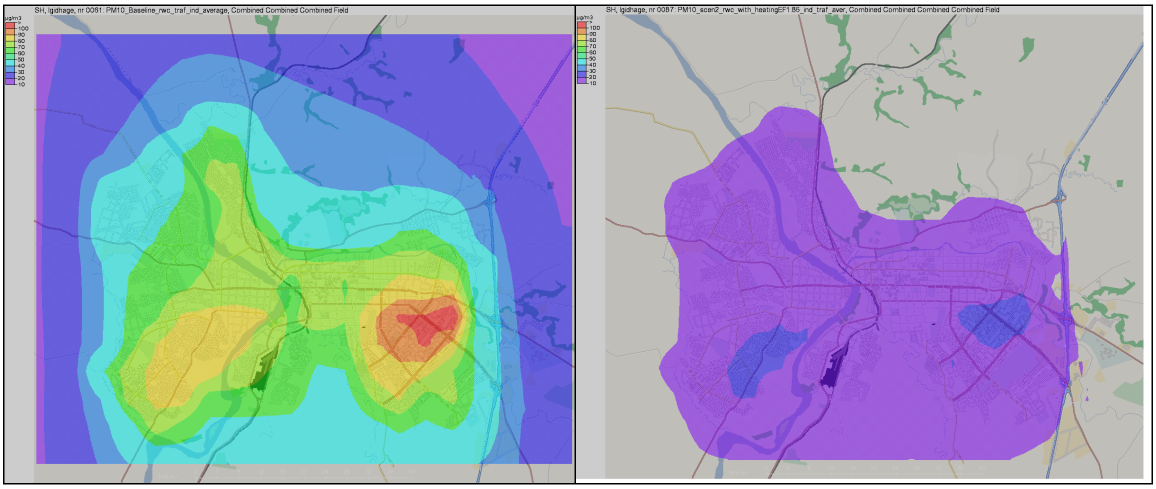
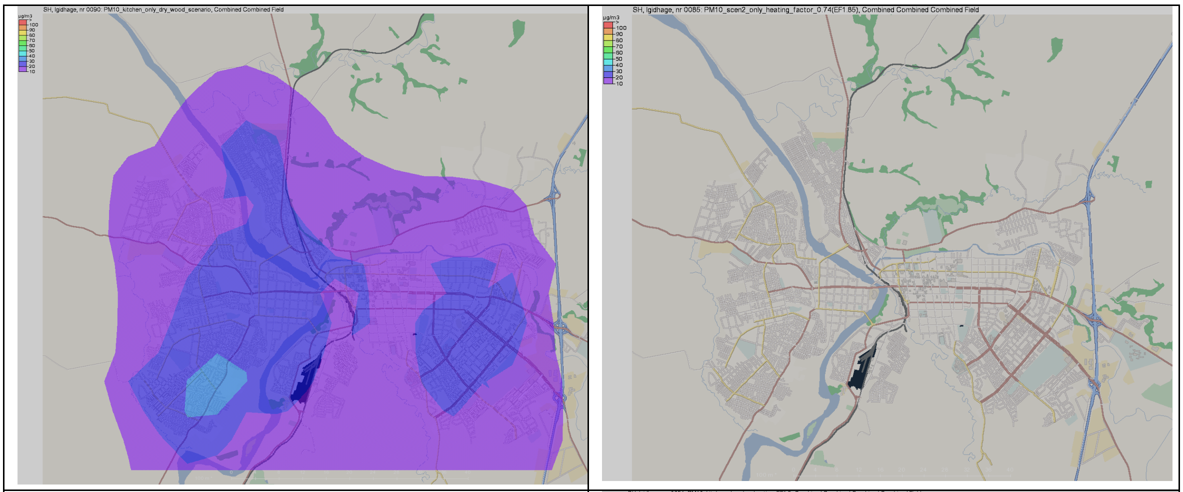
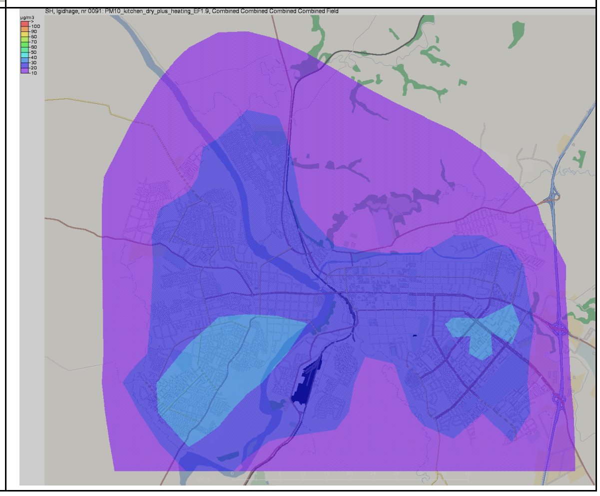


Figure 5.3.2 Modelled average PM10 concentrations including all sources today (left) and with a maximum emission limit of 2.5 g/h valid for both heating and cooking rwc sources (right).





igure 5.3.3 Modelled average PM10 concentrations 2013 with a maximum emission limit of 2.5 g/h valid for all heating fireplaces only, with cooking stoves of today but only using dry wood:
impact of only kitchen cooking stoves (top left), only heating stoves (top right) and summed rwc impact (bottom right)

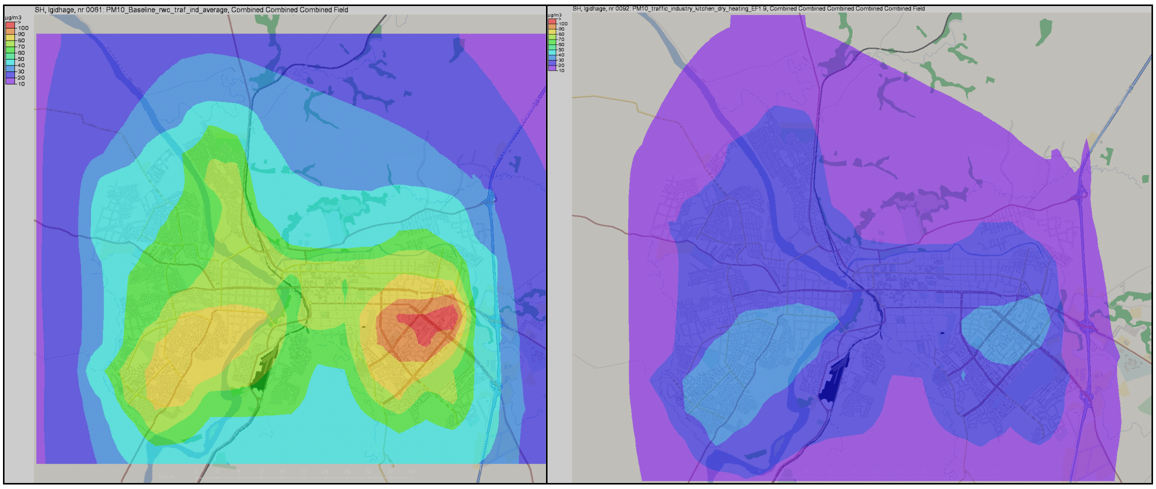


Figure 5.3.4 Modelled average PM10 concentrations including all sources today (left) and with a maximum emission limit of 2.5 g/h valid for heating fireplaces and with cooking rwc sources using only dry wood (right).

As stated earlier, the current regulation does exclude fireplaces used for cooking purposes. Figure 5.3.3 and 5.3.4 show that leaving cooking stoves without emission limit standards implies a much lower effect of the regulation [7], even if we here have assumed that all cooking stoves uses dry wood in line with the first scenario.

5.4 Summing up the scenario simulations and discussion

The simulated PM10 concentration distributions have been illustrated for present conditions, as well as for three scenarios where actions to reduce emissions have been taken for all rwc sources. Scenario 1 assumes that all wood used for rwc is completely dry. The scenario 2 reflects a 100% fulfilment of a newly introduced Chilean emission limit (2.5 g/h), to be applied for all rwc stoves. The final scenario 3 is giving the expected impact if all heating fireplaces are complying with the emission limit of 2.5 g/hour, while cooking devices are excluded (this is how the regulation [7] is defined). In order to have a realistic third scenario, showing the fulfilment of the new legislation, we can expect that this takes time to achieve (wood stoves have a long life-time). Considering a certain time span, it seems more realistic to use, for cooking fireplaces, only dry wood to be used. Authorities have been active during the last years to reduce wet wood by promoting a dry wood license labelling.

In order to have a simpler measure of how the three different scenarios reduce air pollution as compared to the present situation, Fig. 5.4.1 shows the spatial average and the local maximum level of annually averaged PM10 concentrations in Osorno. As we can see the reductions caused by improved wood quality - scenario 1 - gives a reduction of one third (65% of Baseline concentrations) while a general fulfillment of an emission limit of 2.5 g/hours applied to both heating and cooking stoves – scenario 2 - will reduce more than three quarters (22% of Baseline concentrations). The third scenario is a mixture of 1 and 2.

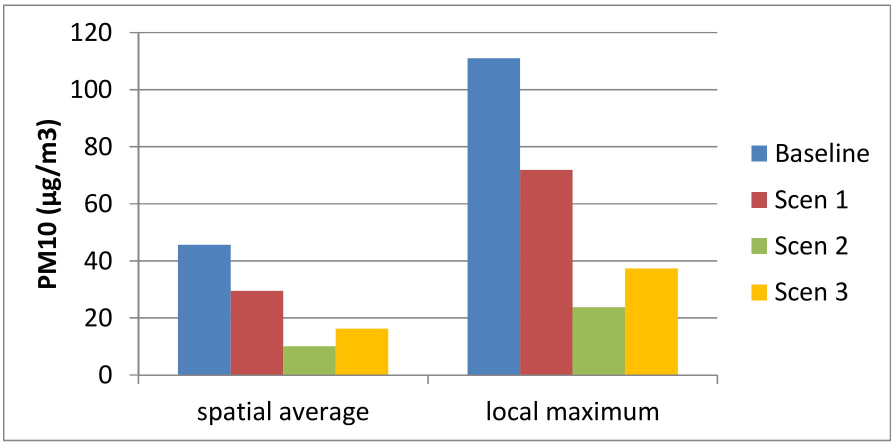


Figure 5.4.1 Spatial average and local maximum PM10 concentrations over the Osorno model domain for present conditions (blue), for scen 1 with a use of 100% dry wood, for scen 2 with <2.5 g/hour emissions from all rwc sources and a scen 3 where heating stoves are regulated but cooking fireplaces not (however used with only dry wood) (yellow).

It is obvious that also EC/BC emissions will be reduced with the three scenarios, but it is not possible to assume that the reduction will follow in proportion to the PM mass reduction. Especially for the scenarios with an upper emission limit, the EC/BC reduction will depend on the technical solution chosen to obtain the required emission factor reduction.

The second and third scenario shows the impact of regulating new residential combustion devices. The time to achieve new and low-emitting stoves in all Osorno residencesn can be long, since heating and cooking stoves have a long lifetime. Authorities may think of ways – subsidies, extending legislation to existing residential wood combustion devices – to speed up the change to new and environmentally more friendly techniques.

The switch from using wet to dry wood can be made in a much shorter time lap, therefore it is absolutely recommended to work in parallel with improving wood quality and introducing new stove technologies.

It is interesting to see that both Europe and USA are working in the same direction as Chile, concerning a regulation for residential wood combustion devices. In Europe the residential wood combustion devices will be regulated under the Eco-design directive. There are also EU member states and environmental agencies that propose a more strict legislation (Table 5.4.1). The suggested levels from Denmark and EEB are comparable to the scenario 2 calculation for Osorno, while the EU proposal is much higher.

Table 5.4.1 Suggested standard for emission factors for new wood stoves (note that all limit values include condensates, i.e. monitoring should follow the Norwegian standard NS 3058-2).

	Emission limit (g PM/kg wood)	**Introduced**
Denmark	5	2013
Denmark	4	2016
European Commission	18	2015
European Commission	9	2017
European Commission	5	2019
European Environmental Bureau	3.1	2015
European Environmental Bureau	1.6	2018
European Environmental Bureau	0.8	2020

Also US-EPA proposes emission factor limits on new heaters and stoves, starting at 4.5 g/h and with successive lowering to 2.5 g/h after 3 years and to 1.3 g/h after 8 years.

With modern technology and good wood quality it possible for both heating and cooking stoves to comply with the 2.5 g/h emission limit.The scenario simulations, as summarized in Figure 5.4.1, shows that if the emission limit is applied to all rwc devices, there is a good chance to also fulfill the annual air quality standards for PM10 (50 µg/m^3) and PM2.5 (20 μg/m^3) everywhere in Osorno, i.e. open a possibility for Osorno to continue the use of residential wood combustion and still achieve an acceptable air quality. Excluding the cooking fireplaces from this upper emission limit (scenario 3) put this at risk. It should also be noted that Figure 5.4.1 only refers to expected annual averages, not the maximum levels that may occur during cold winter evenings and nights.

6 Work with DMC to provide meteorological information

The Osorno modeling activities, as outlined above, are based on the Airviro databases and tools that MMA uses on a national scale. For dispersion modeling, emissions and meteorological information are required as input. For the Osorno case study earlier described, meteorological data of good quality was available from the monitor station El Alba. However, the assessment of air quality is also required for cities where no meteorological towers are available. SMHI have worked with its Chilean counterpart, Departamento Meteorológico de Chile (DMC), to find ways to generate meteorological information, useful for urban dispersion modeling, all over the Chilean territory.

In Sweden SMHI generates, as part of its weather forecasting services, gridded meteorological information that are stored and can be re-used also for historical periods. The gridded data are based on all available modeling and monitoring information, including satellite data. With DMC SMHI has agreed to evaluate if the DMC model forecasts can be used to extract the data required for urban dispersion modeling. The first step has been to extract from each weather forecast produced with the WRF model an output a the location of the El Alba station. By comparing the measured data with WRF output, we will be able to see if model output can be used as it is for repeating the Osorno modeling exercise in cities without a meteorological tower.

The comparison has just begun and the first data used for comparison purposes are given in Figure 6.1. Although there are only a few weeks of data, the comparison looks promising. During the first days there was an error in the time stamp, but this was corrected after a few days. Simulated temperature is very similar to measurements, while wind speed is somewhat higher in the model. The variations in simulated wind direction also follow well the measured one. However, a longer data set is needed before we can draw more detailed conclusions.

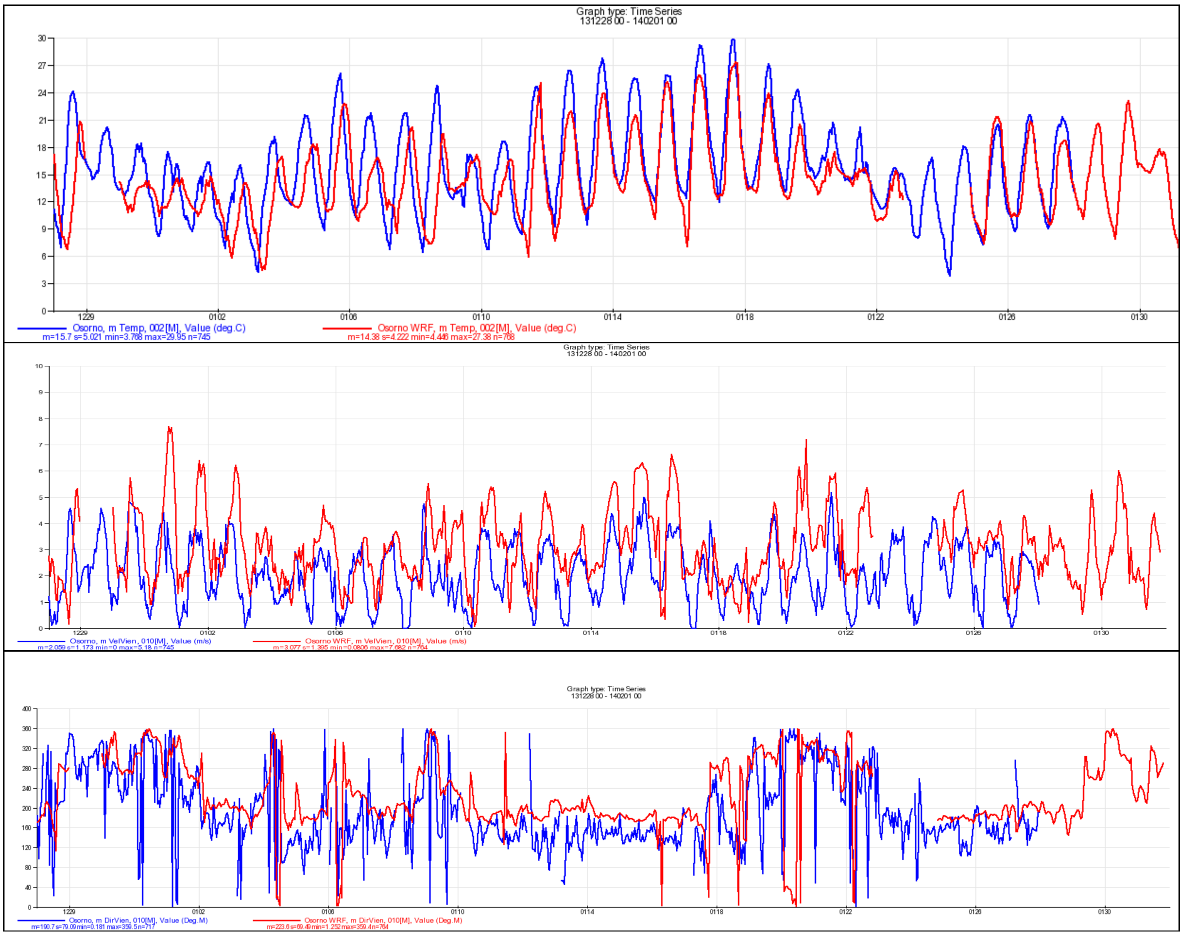


Figure 6.1 Hourly data of WRF simulated (in red) temperature (top), wind speed (middle) and wind direction (bottom), as compared to measured meteorology at the El Alba station in Osorno (blue).

7 Conclusions

The present study has used existing information on traffic and industrial PM emissions, together with a newly elaborated study of wood consumption, to develop an emission inventory useful for dispersion modeling in Osorno. In terms of emissions, the residentatial wood combustion is the dominating source, contributing to 90-95% of the PM10 emissions.

By comparing modeling results with measured PM10 data at the El Alba monitoring station, it was found that emission factors for residential wood combustion taken from the literature yielded much too high impact. The strong overestimation – 5 times higher simulated PM10 levels as compared to the measured levels - can be caused by either overestimated wood combustion or too high emission factors, most likely a combination. By lowering all emission factors, i.e. all rwc emissions with a factor 0.17, simulated and measured PM10 time series showed good resemblance during the period March to September 2013. From this we estimate that PM10 emissions form residential wood combustion in Osorno sums up to 1 275 tons/year. By using ratios based on measurements at the El Alba station, the emissions of PM2.5 and black carbon were estimated to 1 020 and 31 tons/year, respectively.

The dispersion model has been used to determine the expected impact of two types of actions aimed at reducing the pollution levels in Osorno. The first scenario was assuming that all wood used for heating and cooking was dry (humidity <20%). This reduced the annual PM10 levels by approximately one third. The second and third scenario were based on the new Chilean regulation that puts an upper limit of 2.5 g/hour for wood combustion fireplaces. The second scenario assumed that all fireplaces, both for cooking and heating purposes, had emissions which never exceeded 2.5 g/hour. The model result shows that with such actions taken, there are good possibilities to comply with both PM10 and PM2.5 limit values. If cooking stoves are, as is the case in the current Chilean legislation, the average levels will most likely be exceeding the PM2.5 limit value.

The overall conclusion from this assessment is that PM10 and PM2.5 levels are today much too high, exceeding the standards, almost entirely due to the impact of residential wood combustion. Only with a strong control, including the use of dry wood and replacing old wood stoves with new modern fireplaces, will there be a possibility to come down under the Chilean air quality standards. The current emission regulation which excludes fireplaces used for cooking, will thus not be sufficient, even if all heating fireplaces are equipped with new and modern technology.

The evaluation of the WRF model output against meteorological surface information has just been initiated in Osorno. After just a few weeks of comparisons, the results are promising and will be further evaluated in a future 2014 report.

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