LOCAL AND REGIONAL CONTRIBUTIONS TO AMBIENT PARTICUlATE MATTER IN OSLO, NORWAY

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INTRODUCTION

The harmful effects of air pollution on human health have raised a series of concerns in recent years and resulted in revisions of environmental protection actions. This focus on human health imposes further needs for accurate descriptions of air pollution levels in urban areas and improved understanding of their origin. Exposure to particulate matter (PM) in ambient air has been linked to a wide range of adverse health effects, from transient changes in the respiratory tract to increased risk of death from cardiovascular and respiratory diseases or lung cancer.

PM has a significant long-range transported component and a similarly relevant local contribution. Thus, traditional environmental protection actions focusing on either urban scale exposure analysis or long-range regional transport need now to be coupled in order to include the control of the relevant sources both from local and regional sources. This implies that the tools used up to now to support national pollution control and planning need to be further developed to describe the influence of long-range transport in urban areas.

Aware of the need for further development of the traditional air pollution modelling tools, the Norwegian authorities initiated a project in 2001 to allow the use of a flexible modelling system capable of describing air pollution transport at different scales in their national policy planning. The resulting modelling system is based on the coupling and further development of two existing models: the regional scale EMEP Unified Eulerian model (EMEP, Report 1/2003, Berge and Jakobsen, 1998; Olendrzynski et al, 2000) developed by the Norwegian Meteorological Institute (met.no) and the urban scale modelling system, AirQUIS (AirQUIS, 2005; Slørdal et al., 2003; Laupsa et al., 2005), developed by the Norwegian Institute for Air Research (NILU). AirQUIS has been implemented in Oslo, and contains a detailed emission database for the city. Within this system, subgrid line- and point source models can be applied, thereby allowing a more detailed description of the concentration distribution close to important sources. The reader is referred to Wind et al. (2002, 2003) and Slørdal et al. (2005) for a more detailed description of the applied modelling system.

In the present study this coupled modelling system has been applied to investigate the origin of particulate matter in Oslo. The study distinguishes the contribution of long-range transported particulate matter and the influence of local sources to PM levels. The results are based on calculations where output from the regional scale EMEP model has been applied as boundary conditions for AirQUIS. An initial comparison of local vs. long-range transported PM in Oslo is presented for the two months of November and December 2003. The period was selected to illustrate the importance of local sources during periods with high PM levels. Hourly measurement data of both PM_{10} and $PM_{2.5}$ exist for this period, allowing validation of model performance.

COMPARISON OF MODEL RESULTS WITH OBSERVATIONS

In order to gain confidence in the modelling tools, and to help interpreting the model output, a comparison of measured and calculated $PM_{2.5}$ and PM_{10} values has been performed. For PM_{10} measurements both from an urban background station and from two street stations were available, one within the central city area (Kirkeveien, annual daily traffic (ADT) of 20 000 vehicles) and another, a thoroughfare, at the outskirt of the city centre (Løren, ADT of 80 000 vehicles). Unfortunately, for $PM_{2.5}$ only observations from the street stations were available. An illustration of observed (thin solid line) and predicted (thin broken line) hourly $PM_{2.5}$ levels is presented, for the thoroughfare street station Løren, in Figure 1 below. In addition the regional contribution estimated by the EMEP model is depicted in this Figure (thick dotted line). As seen in this plot, the background level calculated by the EMEP model rather closely follows the baseline (i.e. day to day minimum values) of the observations. Moreover, the regional background episodically reach rather high values, as see for instance during the period from the 5th to the 7th of November.

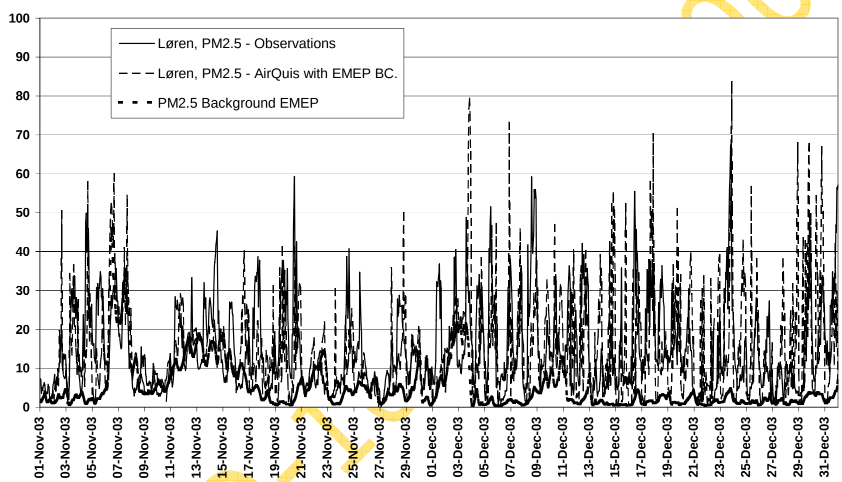

Fig. 1; Hourly values of $PM_{2.5}$ ($\mu g\ m^{-3}$) at the street station Løren (ADT 80 000) for the calculation period November – December 2003.

The validation was performed using traditional statistical parameters (Wilmott, 1982), i.e. maximum, average and standard deviation (σ) of the observed and predicted values, and the combinational measures: index of agreement (IoA), correlation coefficient (r), root mean square error (RMSE), normalized mean square error (NMSE), fractional bias (FB), and fraction of data within a factor of 2 (F2). The statistical evaluation was performed both for the hourly values (presented in Table 1A) and for the running daily averages (presented in Table 1B). These results show that the agreement between the observed and predicted mean values and standard deviations are good, but there are still some discrepancies between the position and magnitude of the peaks. However, F2 is for all stations 50 % or better, and for the daily running $PM_{2.5}$ averages F2 is 90 % and 93 % for the two street stations. The agreement between observed and calculated values is somewhat better for $PM_{2.5}$ than for PM_{10}. The main reason for this is, in our opinion, linked to the uncertainties in the estimated particle emissions emanating from re-suspended road dust. As expected the statistical parameters are systematically better for the running daily averages than for the hourly values. The general impression from the validation exercise is that the model system performs reasonably well and that it therefore can be applied in a further assessment of the most important source contributors to the ambient PM_{10} and $PM_{2.5}$ concentrations in Oslo.

Table 1. Statistical parameters PM_{10} and $PM_{2.5}$ for Oslo. The values are based on comparison during November-December 2003. The evaluation is based on hourly values in Table 1 A, and on running daily averages in Table 1 B.

A) Hourly values Conc unit: µg/m3	PM10 (Iladalen, urban background station)		PM10 (Kirkeveien, urban street station)		PM10 (Løren, thoroughfare street station)		PM2.5 (Kirkeveien, urban street station)		PM2.5 (Løren, thoroughfare street station)	
	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Max. value:	200.6	120.7	231.7	139.8	391.7	435.6	73.3	75.2	67.4	83.7
Mean value:	25.7	27.3	32.2	30.4	42.6	42.4	13.9	15.0	15.3	14.4
σ :	25.0	23.6	33.8	24.9	57.7	55.3	9.2	12.7	11.1	12.5
IoA :	0.59		0.58		0.56		0.62		0.65	
r :	0.36		0.35		0.35		0.42		0.42	
RMSE:	27.5		34.2		65.4		12.2		12.8	
NMSE:	1.08		1.19		2.37		0.72		0.75	
FB:	0.062		-0.057		-0.003		0.078		-0.064	
F2 :	0.53		0.52		0.50		0.60		0.60	

B) Daily values Conc unit: µg/m3	PM10 (Iladalen, urban background station)		PM10 (Kirkeveien, urban street station)		PM10 (Løren, thoroughfare street station)		PM2.5 (Kirkeveien, urban street station)		PM2.5 (Løren, thoroughfare street station)	
	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Max. value:	68.6	58.9	118.9	61.0	169.0	112.6	35.3	35.7	33.8	35.7
Mean value:	25.7	27.3	32.2	30.4	42.6	42.4	13.9	15.0	15.3	14.4
σ :	14.2	11.4	21.6	11.6	34.1	23.9	5.6	6.2	6.8	5.9
IoA :	0.66		0.53		0.65		0.66		0.73	
r :	0.48		0.33		0.46		0.45		0.54	
RMSE:	13.5		20.9		38.3		6.3		6.2	
NMSE:	0.26		0.44		0.55		0.19		0.18	
FB:	0.062		-0.057		-0.003		0.078		-0.064	
F2 :	0.79		0.71		0.57		0.93		0.90	

ESTIMATION OF SOURCE CONTRIBUTORS

On the regional scale the $PM_{2.5}$ concentrations levels can be viewed as a sum of a large number of smaller contributions from individual countries. More than 10 countries have contributions larger than 2% to background PM concentrations in Oslo. Norway is, as expected, the largest single contributor country (38%). The fine particulates are composed of primary particulate matter (33%), nitrates (29%), sulphates (19%), ammonium (15%) and sea salt (4%). An analysis of the relative importance of different emission sectors shows that agriculture is the most important source for background $PM_{2.5}$ in Oslo (35%). Agriculture is a large emitter of NH_3, which can condensate into particles ($(NH_4)_xSO_4$ and NH_4NO_3). These particles can be transported over long distances and are therefore relatively important in areas far from the main sources.

The average regional background $PM_{2.5}$ concentrations in Oslo is ~ 5 µg m^{-3} for the period November-December 2003 and corresponds to about 30% of the mean concentrations observed within the Oslo city area. However, the background concentration level can episodically increase to more than 40 µg m^{-3}. This can happen when specific meteorological conditions causes plumes with high concentration levels to be transported from northern Europe towards Norway. This is the case in the model results presented in Figure 1 for the November 5 – 9 episode.

The estimated $PM_{2.5}$ levels in the central and western city area are dominated by emissions from domestic wood burning, being responsible for more than 60 % of the ground level concentrations in some grid cells. Road traffic is the second most important contributor to $PM_{2.5}$ concentrations in Oslo. One should note that the relative influence of this source is stronger close to the main road network than on the urban (or model grid) scale. The regional contribution is quite substantial when considering the average $PM_{2.5}$ levels, contributing about 30 % even in central grid cells with large local emissions.

During winter and spring high levels of coarse particles ($PM_{coarse} = PM_{10} - PM_{2.5}$) are observed in Oslo. The source of these large particles is mainly traffic-induced re-suspension of surface particles caused by extensive use of studded winter tyres on cars. This is especially the case in the areas along the main highways, where dense traffic in combination with high vehicular speed leads to huge concentrations of coarse particles due to traffic-induced re-suspension. Much higher relative contributions to the PM_{10} levels are also found from road traffic at individual receptor points close to the roads, higher than those estimated from the grid cell values (which normally are interpreted as urban background values). In central and western city grid cells without direct contributions from the main road network, domestic wood burning typically dominate the estimated PM_{10} levels. The regional background contributes less to PM_{10} than to $PM_{2.5}$, and is on average responsible for less than 20 % of the average PM_{10} concentration in urban grid cells.

DISCUSSION AND CONCLUSION

The results from the two-month simulation performed in this study, lasting from the 1st of November until the end of December 2003, show that the highest concentration peaks in Oslo are caused by local sources. The urban scale model system applied in this study, AirQUIS, takes into account the most important local sources and is therefore, in combination with a grid resolution of 1 x 1 km^2 and application of a sub-grid line source model, able to reproduce the high observed particle levels (reaching about 73 $\mu g\ m^{-3}$ for $PM_{2.5}$ and about 400 $\mu g\ m^{-3}$ for PM_{10}) in Oslo during the simulation period. The results from this study reveal that the various sources contribute differently depending both on location and on whether we consider $PM_{2.5}$ or PM_{10}. In areas with no local emissions, i.e. over the fjord or in the forests surrounding the city, the regional background will naturally dominate the concentration levels.

The highest peaks caused by local sources need not, and in most cases will not, coincide with the highest peaks of regional origin. High concentration levels due to local sources typically appear under high-pressure conditions, with low wind speed and near surface temperature inversions, resulting in low mixing of the pollutant emissions. These conditions differ markedly from the cases when regional air masses with high concentration of pollutants are transported over large distances. To properly model the observed concentration levels within Oslo during such episodes, application of high quality data from regional models like the EMEP model at the fine scale model boundaries is of vital importance.

The regional background and the urban pollution of local origin are two different and complementary descriptions of the total air pollution. The regional background model will capture episodes of long-range transported pollutants, which during regularly occurring episodes contribute significantly to the urban air pollution. However, during periods in which local sources are dominant, large variability in concentration levels are observed over small distances, and consequently the regional model, with its emissions distributed in a coarse grid system, gives a poor representation of the actual air pollution levels within the urban area. This is especially the case in Oslo where the total city area is effectively about 1/6 of the regional grid size of $50x50km^2$. Therefore, in order to describe the PM levels inside the city area properly, the use of a nested model, like the one applied in this study, is required.

This study has only given preliminary answers to important questions. One important limitation of the simulations performed in this project is the lack of an emission inventory at the intermediate resolution (~5 km) around Oslo that would allow a more accurate identification of the relative importance of regional vs. local sources. Although the comparison is presently hampered by large uncertainties especially when regarding the emissions, the calculated PM levels are considered to be indicative of the observed PM levels and the estimation of the source contributions to be representative for winter months.

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