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The urban air quality forecast system for Norway

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THE URBAN AIR QUALITY FORECAST SYSTEM FOR NORWAY

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ABSTRACT
For the past 6 years the Norwegian Institute for Air Research, the Norwegian Meteorological Institute and the Norwegian Public Road Administration have been producing air quality forecasts for a number of Norwegian cities. The forecast meteorology is based on ECMWF forecasts, which serve as input for the limited area model HIRLAM, which in turn supplies boundary conditions for MM5. Air quality forecasts, based on the MM5 meteorology, are then carried out using the AirQUIS modelling system. This paper describes the forecast system and presents an analysis of the forecast quality for the city of Oslo during the 2003/2004-winter period.

1. INTRODUCTION
High levels of PM_{10}, $PM_{2.5}$, and NO_2 occur every winter in Norwegian cities during temperature inversions and weak winds. High levels of PM_{10} also occur during dry weather conditions, in particular during spring when snow melts and particulate matter accumulated along the roads due to traffic and usage of studded tyres is released. These pollutants cause health effects to people, especially to asthmatics, allergy sufferers and those who live close to hotspots. Local authorities require a forecast system to help deal with these public health issues.

As a result, an operational Urban Air Quality Information and Forecasting System (UAQIFS) has been developed. The first version of this system was used for the winter season 1999/2000 in Oslo and Bergen. Today this UAQIFS is applied in six Norwegian cities including Oslo, Bergen, Trondheim Drammen, Stavanger, and Grenland. The meteorological part of the model is based on the nonhydrostatic version of the MM5-model (Grell et al., 1994). The MM5 forecast is used as input to the urban air quality model, AirQUIS-2003, developed by the Norwegian Institute for Air Research (AirQUIS, 2004).

Each day the results from MM5 and AirQUIS are published on password protected web pages. The local authorities use this information to give their recommendations to the public. The recommendations are published in local newspapers and also on an official web page (http://www.luftkvalitet.info). A service has also been developed for the distribution of the forecast via SMS. The public are warned about high concentrations of pollutants and the road authorities may use the results to execute abatement measures, for instance reducing speed limits on roads with large emission of PM_{10}.

2. FORECAST SYSTEM
The forecast meteorology is based on ECMWF forecasts, which serve as input for the limited area model HIRLAM (Undén, 2002). HIRLAM starts at 00 UTC and runs for a 48-hour prognosis. This model in turn supplies boundary conditions for MM5, which is nested down from a resolution of 3 km to a resolution of 1 km.

The meteorological data is then used as input data to the AirQUIS modelling system. The emission inventory database in AirQUIS consists of a set of area sources from domestic heating, line sources from roads, and point sources from industrial emissions. AirQUIS couples these emissions to the EPISODE dispersion model (Slørdal et al., 2003), which consists of a standard Eulerian transport model combined with the line source model HIWAY2 (Peterson, 1980) and the point source model INPUFF (Petersen and Lavdas, 1986). All compounds, except NO_2, are considered to be passive. NO_2 chemistry is based on the photo-stationary assumption for NO, NO_2 and O_3. Background concentrations are specified as climatological mean values, based on values from nearby regional background measurement sites.

The results of the forecasts are split into 4 different classes described as ‘little’, ‘some’, ‘much’ and ‘very much’ pollution. Each city forecast is based on concentration levels and how many people who are exposed to this concentration. This index is made publicly available through a web portal via the Public Road Administration and is displayed for the coming day for every 4 hours, figure 1. The forecasts are used for health warnings and to plan immediate measures, such as reduction of speed limits, when episodes are predicted. In addition to the forecast information, monitoring data from all stations for up to 30 days can be accessed and viewed.

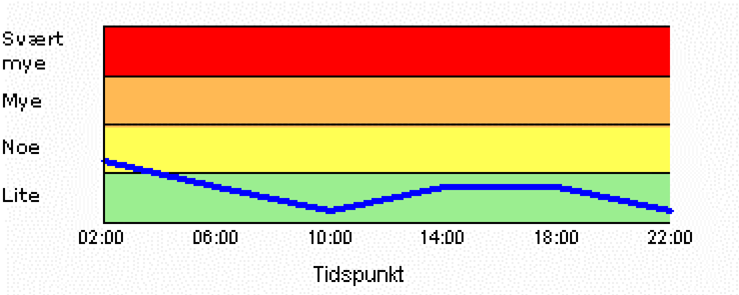

Figure 1. Example of the 24 hour forecast displayed on the public web page for Oslo from 5 February 2005. Forecasts are only available in Norwegian.

3. FORECAST ASSESSMENT

Assessment methodology

In an evaluation of any forecast performance, the simplest way of evaluating the result is to state that it is right or wrong and judge its quality on how often it is right. To simplify the comparisons the results have been classified into two classes, poor and non-poor air quality. This is determined by defining the air quality to be poor if it is above the lowest national limits, e.g. 100 µg NO_2 /m^3 per hour, 50 µg PM_{10} /m^3 per hour, and 25 µg $PM_{2.5}$ /m^3 per hour. Receptor point forecasts, which represent monitoring stations in the cities, are then compared to the actual monitoring data.

The US Environmental Protection Agency (EPA) have given recommendations for forecast evaluation (EPA, 2003), which is suitable for the "Index Class" forecast type. The key parameters for calculating performance of a forecast classified as an event or a non-event (i.e. poor air quality or non-poor air-quality) are shown in Table 1 and 2.

Table 1: Key numbers (a, b, c, d) for quantification of events.

	forecast not poor	forecast poor
observed not poor	a	b
observed poor	c	d

Table 2: Evaluation parameters and how they are calculated.

Accuracy (A)	The percentage of forecasts that correctly predicted the event or non-event. A= (a+d)/(a+b+c+d)*100
Bias (B)	Indicates, on average, if the forecasts are underpredicted (false negatives) or overpredicted (false positives) B = (b+d)/(c+d)
False alarm rate (FAR)	Percent of times a forecast of poor air quality did not occur FAR = b / (b + d) *100
Critical success index (CSI)	How well the poor air quality events were predicted CSI = d / (b +c +d) *100
Probability of detection (POD)	Ability to predict poor air quality POD = d / (c + d) *100

Assessment results

Three locations in Oslo for the winter season 2003/2004 have been analysed and the results are given in Table 3. In addition the yearly average of the observed and predicted values along with the correlation between observations and prognosis have been analysed and are given in Table 4.

Table 3: Comparison of key quantification parameters of different forecasts.

Forecast Winter 2003 – 2004	Accuracy	Bias	False Alarm	Critical Success	Probability of detection
PM_{10} Kirkev.	72	1.1	74	16	29
$PM_{2.5}$ Kirkev.	77	2.7	77	20	61
NO_2 Løren	86	0.4	73	8	10
PM_{10} Løren	72	0.9	59	24	37
$PM_{2.5}$ Løren	77	1.1	66	21	36
NO_2 Alnabru	91	0.4	93	2	3
PM_{10} Alnabru	66	1.3	70	21	38

Table 4: Comparison of observed and predicted average and correlation coefficient.

Forecast Winter 2003 – 2004	Average Observation	Average Prediction	Correlation
NO_2 Kirkev.	45.9	50.0	0.41
PM_{10} Kirkev.	32.7	32.9	0.15
$PM_{2.5}$ Kirkev.	13.9	20.4	0.33
NO_2 Løren	54.0	46.7	0.44
PM_{10} Løren	45.2	37.9	0.22
$PM_{2.5}$ Løren	15.5	16.2	0.27
NO_2 Alnabru	50.3	57.2	0.34
PM_{10} Alnabru	37.9	40.9	0.19

4. RESULTS AND DISCUSSION

The results of the forecast analysis for Oslo 2003/2004 show reasonable forecast quality in regard to accuracy, ranging from 66% to 91%. The EPA reports accuracies in the range of 85% to 90% to be typical of forecast systems. The bias parameter indicates that the number of NO_2 episodes is under predicted while the number of PM_{10} predictions is quite good. The number of false alarms however is quite high for all pollutants, between 59% and 93% though the EPA reports false alarm rates between 27% and 79%. The critical success, which is an evaluation of how well the poor air quality events are predicted, is quite low, between 2% and 24% where EPA results range from 15% to 44%. The probability of detection ranges from 3% to 61%, with the lowest values occurring for NO_2. EPA results range from 30% to 50% for this parameter.

In general the forecast analysis indicates some poor results, e.g. NO_2 at Alnabru, but some quite reasonable results, e.g. particulates at Løren and mean concentrations at all stations. When compared to the quoted EPA results the Oslo forecast is of average or below average quality, however, the quality of forecasting is strongly dependent on the local situation and on the scale at which forecasts are made. For Oslo forecast results are compared directly to measurements at traffic stations where concentration gradients in both time and space are large. Moreover, concentrations at these stations are strongly dependent on both wind speed and direction. Small errors in the forecasted wind direction can lead to significant errors in the modelling of near road concentrations. Since poor air quality is often linked to weak winds, which have poorly defined directional components, the largest errors occur exactly during the periods when poor air quality episodes are likely. EPA forecasts are generally made on a regional basis and are less demanding in this regard.

Statistically the yearly mean concentrations are well described, Table 4. The correlation between model and measurements is generally low with the best correlation occurring for NO_2 and the worst for PM_{10}. This is expected because the concentration of NO_2 is limited by the background concentration of ozone. For forecasts, the ozone concentration is given by climatological measurement data (historical measurements) and is assumed to have the same hourly variation each day of the season. The correlation is better for $PM_{2.5}$ than for PM_{10}. This is probably because there are more emission sources with different time variations for PM_{10} than for $PM_{2.5}$. In addition, the effect of stored road dust strongly influences the concentration of PM_{10} (dust from resuspension by studded tires).

There is any number of reasons for a poor forecast but the most important two factors determining forecast quality are the meteorological prognosis and the quality of the emission data. For Oslo, MM5 results are verified with measurements at 3 locations, one outside the city and two locations inside the city. The evaluation of the wind speed in the 2 locations inside Oslo shows that MM5 underestimates the wind speed by ~ 1 ms^{-1} for the winter 2003/2004 (standard deviation ~ 2 ms^{-1}). The temperature is also slightly underestimated, ~ 1 ^{o}C, on the two locations inside Oslo (standard deviation ~ 2 ^{o}C). More detailed studies have revealed that MM5 tend to overestimate both the surface wind speed and the surface inversion during pollution episodes (Berge et al. 2002).

The other major contributor to forecast errors comes from emissions. These can be spit into three main categories: Area sources, traffic sources, and point sources. Emission from point sources, e.g. industrial emission, is much less than the other two sources in Oslo. Traffic related emissions come from both exhaust and by resuspension of dust. During winter large amounts of PM_{10} are stored along the roads. This dust is covered by snow and hence not a emission source until the snow melts in spring. When the snow disappears leading to dry conditions this causes a very significant source of PM_{10}. This is one of the most difficult emissions to forecast under Norwegian conditions.

The most important area emission is domestic heating by wood burning. One weakness of the emission data of wood burning is that it is not a function of the temperature prognosis generated by MM5. Instead it is regulated only by a given weekly, daily, and hourly time variation. Because of this approximation any temperature deviation that may cause more or less wood burning than the average is neglected in the forecast calculations.

In addition to the emission and meteorological errors in the forecast, approximations made in model formulations can be influential under particular conditions. Examples of this are the HIWAY2 Gaussian line source model that by necessity requires a minimum wind speed to avoid a singularity in the calculations. This is set to 1 ms^{-1} which tends to preclude some of the lower wind events, which are related to poor air quality. Another problem lies with the limited area of the dispersion calculations. Once pollutants leave the grid they do not return, though the basin topography of Oslo can lead to recirculation through drainage winds. During poor air quality events observations regularly show a build up of pollutants in Oslo, a phenomenon that is not reflected in the model calculations.

5. CONCLUSIONS

The Norwegian air quality forecast system has been described and an analysis has been carried out for the winter season 2003/2004 in Oslo. The analysis shows reasonable accuracy of the forecasts but low success in predicting poor air quality events. The analysis is made by comparison with 3 traffic stations in the Oslo region. Such an analysis is very demanding on the forecast system.

There are several reasons for the deviation of the forecast system. There are some weaknesses in the emission data, especially the lack of dependence of domestic heating on temperature, which causes a significant mismatch between measurements and forecasts on days where the actual temperature deviates from the normal temperature. There is also the problem of stored road dust along the roads, which needs to be described by improved algorithms. This is a typical source of error that occurs under conditions where snow cover is involved. In addition, the meteorological input data can introduce serious problems. Situations regularly occur where the input from MM5 is not adequate to produce correct forecasts, especially in situations with low wind speeds.

6. ACKNOWLEDGEMENTS

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