1.04 EVALUATION OF MODELLING RESULTS FOR URBAN AREAS IN TERMS OF APPLICATION FOR AIR POLLUTION MANAGEMENT

Ruwim Berkowicz, Jørgen Brandt, Jesper H. Christensen and Steen S. Jensen
National Environmental Research Institute, Frederiksborgvej 399, 4000 Roskilde, Denmark

INTRODUCTION

An important criterion for model application for air pollution management is a detailed evaluation of its performance and especially of the model responses to the driving parameters. An European wide model inter-comparison exercise, the CITY-DELTA exercise, was launched as a contribution to the modelling activities in the CAFE programme (http://rea.ei.jrc.it/netshare/thunis/citydelta). The aim of the project is to explore the changes in urban air quality predicted by different atmospheric chemistry-transport dispersion models in response to changes in urban emissions. Although, the main focus of CITY-DELTA is on particulate matter, ozone and NO_2 pollution, which to large extend are governed by large scale processes, the urban aspect leads also to the question how well the different models can deal with the pollutants emitted directly within the urban areas. This question is especially of relevance taking into account the need of evaluation of the effectiveness of local measures to reduce the impact of air pollution on human exposure and its other adverse effects.
The extensive CITY-DELTA database covering urban scale emissions and monitoring data provided an unique opportunity for detailed evaluation of performance of the models and to draw the conclusions on the aspects of the necessary model elements.
The Danish Air Pollution Management and Forecast System, THOR (*Brandt et al., 2001*), was applied within the CITY-DELTA exercise for such cities as Copenhagen, Berlin and London. Using results from this modelling system, discussion and some conclusions on the requirements of model performance in terms of its application for air pollution management, are provided in this paper.

URBAN SCALE MODELLING

THOR model system includes several separate meteorological and air pollution models capable of operating for different applications and different scales, ranging from regional down to a single street location. Each of the models is especially adapted to describe properly the processes most important for the particular application. Coupling models over different scales makes it possible to efficiently account for contributions from local, near-local as well as remote emission sources in order to describe the air quality at a specific location. The need of using a “model cascade” when dealing with urban scale modelling is elucidated with an example of emission data for the city of Berlin and the surrounding area. *Figure 1* shows the annual traffic emissions of NO_X on a grid net of approximately 2x2 km^2 and additionally a cross-section of this emission field along an East-West going line crossing the centre of the city. It’s seen that the urban emissions constitute almost a “singularity” comparing with the rural areas. Because the urban emissions are nowadays strongly dominated by ground level sources with the main contribution from road traffic this situation is typical for majority of European cities. This implies that appropriate description of dispersion and dilution of emissions from urban sources on a very short spatial scale is crucial. On the other hand, the relatively short transport time implies less importance of the chemical reactions, such as those leading to formation of ozone or secondary aerosols. These processes are to a large extent taken into account by the large-scale models.

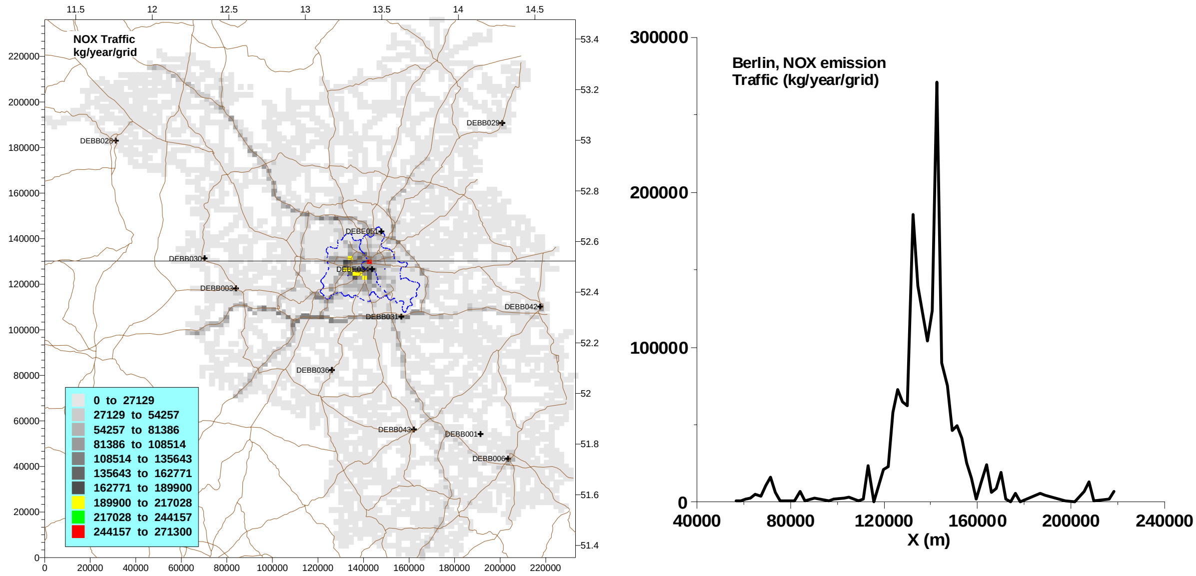

Figure 1. Annual traffic emissions of NO_x for the domain covering the city of Berlin. Very large increase of emissions within the urban area is illustrated in the right pane, where the emissions are plotted along an East-West line crossing the city centre. The emission data are shown only for the city of Berlin and the Federal State of Brandenburg.

An Eulerian 3-layer model with a grid resolution of 50x50 km^2 and with a chemical reaction scheme based on the condensed CBM IV scheme is used for modelling of the regional background levels (*Brandt et al., 2001*). A simple urban background model (*Berkowicz, 2000*) is applied for urban scale, covering an area of typically 40-50 km and with the horizontal resolution limited only by the resolution of the emission data. Because the urban model (UBM) makes use of the continuous plume concept, there is no limitation on the vertical resolution, which is important for appropriate description of the dilution processes on the local scale. Superposition of the contributions from the regional and urban scale models provide pollution levels within the urban environment. UBM contains also a simplified chemical module describing formation of NO_2 due to oxidation of NO by ozone, which in turn is provided by the large-scale regional model.
The meteorological data are provided by the Eta Model, which was developed originally at the University of Belgrade (Mesinger et al., 1988). It is a limited area grid-point model with a comprehensive physics package added then at the U. S. National Meteorological Center (NMC).

MODEL EVALUATION

Dilution of the urban emissions depends strongly on the meteorological conditions. The most important parameter is the wind speed but for larger urban areas the influence of mixing height can also be critical. Reliable emission data and realistic description of the dispersion conditions on the urban scale are not only important for a correct modelling of pollution levels within the urban areas but they are also crucial for interpretation of emission reduction scenarios. Because one of the goals of the CITY-DELTA project is to assist air-quality managers in quantifying the contribution of regional versus local sources and in identifying and assessing the most effective emission controls, these model performance criteria must be considered as being important.
In the following, using the Berlin domain as an example, a critical evaluation of the modelling results is provided focusing on the model response to the most important forcing parameters, i.e. the emission data and the meteorological conditions. Although, the meteorological

conditions are not really within the scope of air pollution management, the appropriate model response to these parameters determines the level of confidence of the model predictions.

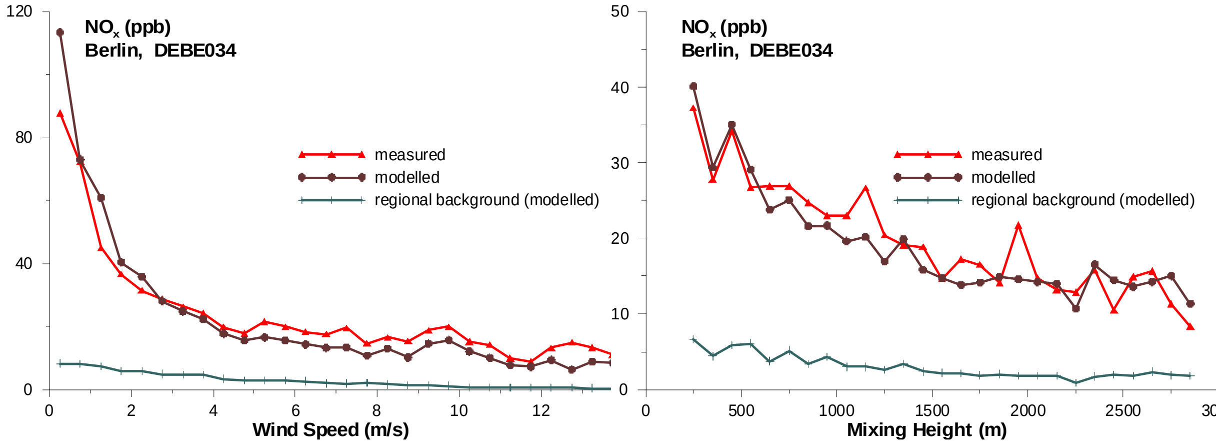

Figure 2. Variation of the measured and modelled NO_x concentrations with wind speed and mixing height. Results are shown for the Berlin monitoring station DEBE034 (city centre). The modelled regional background contribution is shown too.

In *Figure 2* the variation of the measured and modelled NO_x concentrations with wind speed and mixing height is shown for the monitoring station DEBE034. This station is situated in the centre of Berlin (see also *Figure 1*) and exhibits the highest concentrations within the domain. The results presented in *Figure 2* are average values over the whole year 1999 but only for working days. The averaging interval for wind speed is 0.5 m/s, while for mixing height it is 100 m.

The behaviour shown in the figure is typical for a situation when the pollution levels are determined by emissions from low-level local sources. The concentrations are increasing with decreasing wind speed and decreasing mixing height. The model predictions seem to reproduce this behaviour quite well. The regional background contribution calculated with the large-scale regional model using the 50x50 km^2 emission grid, is shown too. It's evident that this regional background contribution to concentrations in the city is quite marginal. The contribution from the local sources is totally dominating.

The variation of pollution levels in response to emissions cannot be evaluated directly, but some information can be gained by examining the dependence between the concentrations and some parameters, which have influence on emissions. One of the possibilities is evaluation of the variation of pollution concentrations with wind direction. Air masses arriving at a measuring location from different directions are affected by varying emissions, and this variation will indirectly be depicted in pollution levels variation with wind direction. Such an evaluation is shown in *Figure 3* for all the three stations located within the urban area of Berlin. The monitoring station DEBE034 is in the city centre, DEBE051 is at the north suburb of the city, while DEBB031 is actually located to south of the city but very close to the city border. As expected, the variation of concentrations with wind direction is less pronounced at the city centre location than at the two other locations. The DEBE051 stations exhibits the highest pollution levels with southerly winds, while the northerly winds result in the highest concentrations at the DEBB031 station, which is located south of the city. Although the model results show a similar behaviour, some stringent differences are evident. Most pronounced is the underestimation of the concentrations for south- southeasterly winds (winds directions from about 120 to 180 degree). Because this effect is observed for all the three locations, it's not likely that it is due to underestimation of local city emissions.

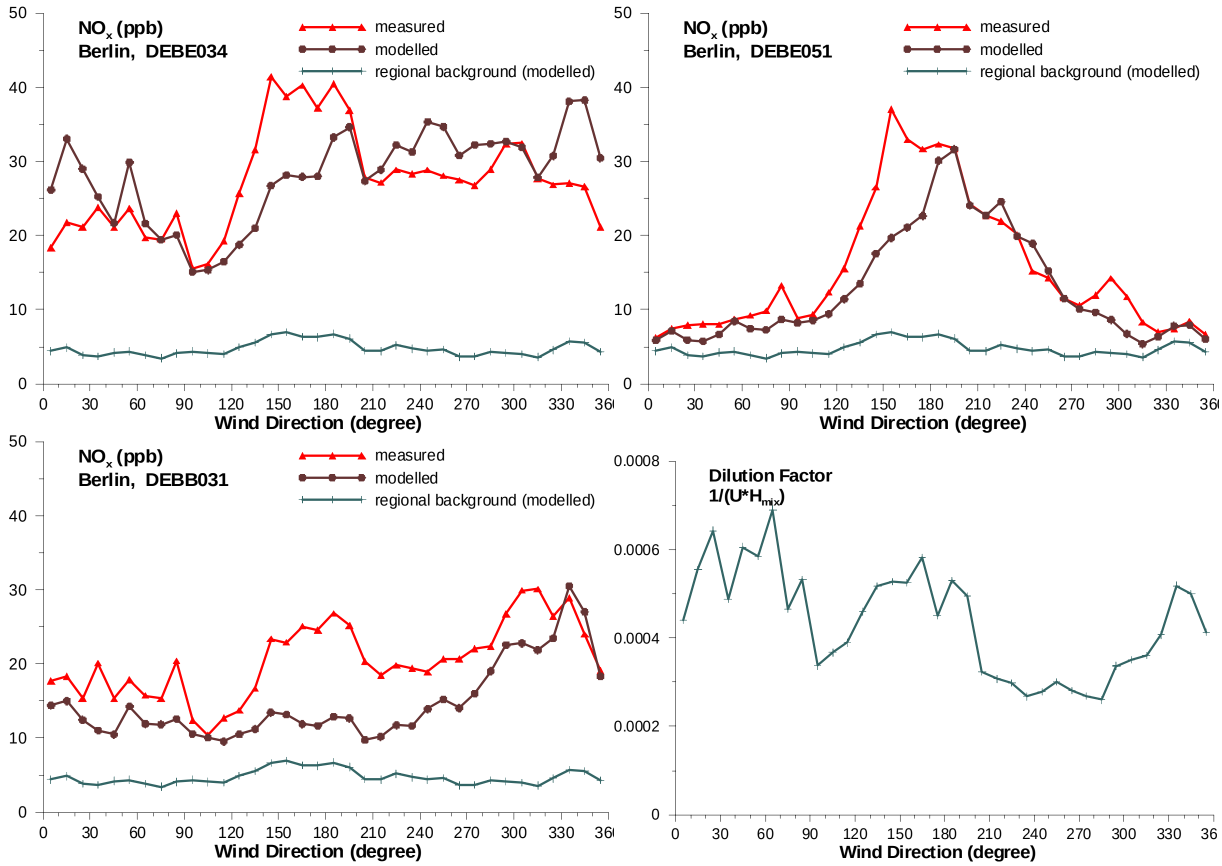

Figure 3. Variation of the measured and modelled NO_x concentrations with wind direction. Results are shown for 3 monitoring stations: DEBE034 - city centre, DEBE051 – north suburb, DEBB031 – south of the city border. The modelled regional background contribution is shown too. Additionally, the effective dilution factor defined as the inverse of the product of wind speed and mixing height, is shown as well.

Some indication of the possible reason for the observed phenomena is provided in the plot of the effective dilution factor defined as the inverse of the product of wind speed and mixing height. With this definition, the larger is this factor the higher are expected the pollution levels to be. Ended, a quite pronounced maximum in this factor is evident for the same wind direction sector where the measured NO_x concentrations exhibit higher concentrations at all the three mentioned locations. Increased frequency of low mixing heights (inversion conditions) and low wind speeds within this wind sector results in the elevated concentration levels, and this behaviour is not well reproduced by the model. However, a weak maximum is also visible in the modelled urban concentrations, and even in the modelled regional background contribution.

The urban emissions exhibit typical diurnal variation, which is mainly due to the variation in the traffic intensity during a day. The measured and modelled diurnal variation of NO_x at the city centre station DEBE034 is shown in *Figure 4.* The time variation during the working days (from Monday to Friday) is reproduced reasonable well but it's totally out of the scope for the weekends. The reason for this is that the same hourly variation of emissions is applied for all days of the week in the model. Only the average daily traffic intensity is reduced for the weekends, resulting only in reduction of the average levels but wrong diurnal pattern.

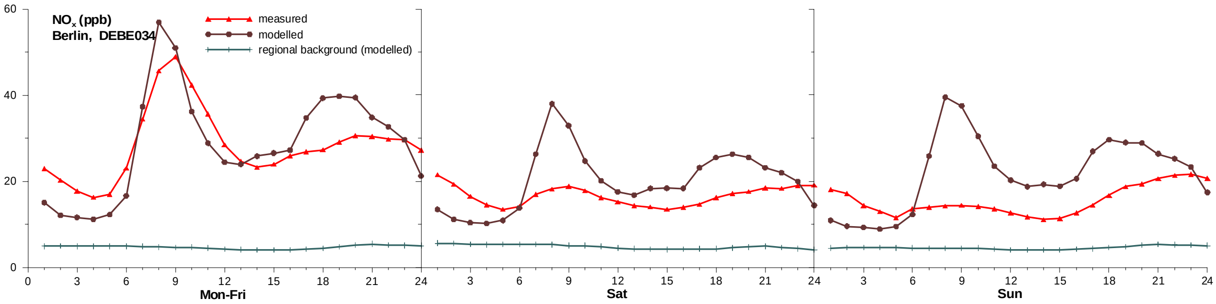

Figure 4. Hourly variation of measured and modelled NO_x concentrations at the station DEBE034. The time variation of emissions implemented in the model doesn't reproduce the time variation observed during the weekends.

In *Figure 5* is shown the monthly variation of NO_x at the three urban stations. This variation is mainly due to seasonal variation in meteorological conditions. Most striking is the maximum observed and predicted for November. few days with bad dilution conditions resulted in this maximum, which is also observed in the modelled regional background concentrations.

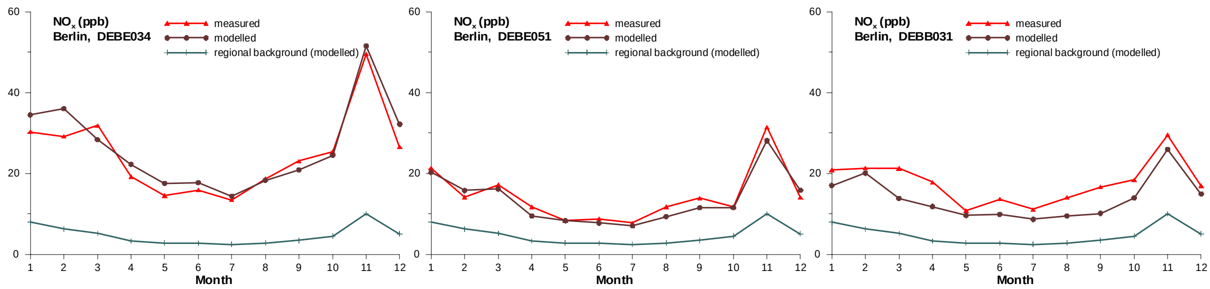

Figure 5. Monthly variation of measured and modelled NO_x concentrations at the Berlin stations.

ACKNOWLEDGEMENTS

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REFERENCES

Brandt, J., J.H. Christensen, L.M. Frohn, F. Palmgren, R. Berkowicz and Z. Zlatev, 2001: Operational air pollution forecasts from European to local scale. *Atmospheric Environment*, **35**, Sup. No. 1, S91-S98.

Berkowicz, R, 2000: A simple model for urban background pollution. *Environmental Modelling and Assessment,* **65**, 259-267.

Mesinger, F., Z.I. Janjic, S. Nickovic, D. Gavrilov, D. Deaven, 1988: The step-mountain coordinate: Model description and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment. *Mon. Wea. Rev.*, **116**, 1493-1518