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URBAN AIR POLLUTION OF NITROGEN OXIDES FROM TRAFFIC

Ole Hertel, Ruwim Berkowicz, Elisabetta Vignati and Finn Palmgren
National Environmental Research Institute, Department of Atmospheric Environment
Frederiksborgvej 399, 4000 Roskilde, Denmark

Abstract

Traffic is a major source of nitrogen oxides, especially in urban areas where the traffic density is high. Dispersion of nitrogen oxides in urban areas is governed mainly by wind conditions. In a street canyon the wind generates a vortex, which leads to considerable differences in concentration levels on the two sides of the street.

Nitrogen dioxide can cause problems for people suffering from respiratory diseases, especially asthma patients are sensitive to high concentrations. The introduction of catalytic converters has decreased the nitrogen oxide concentrations, and the levels are expected to decrease further in the coming years. However, the catalytic technique is today limited to petrol driven vehicles. Since heavy vehicles, e.g. buses and trucks, contribute significantly to the NO_x emission, this will limit the reduction in many urban streets. At the same time the traffic is increasing in many streets. The nitrogen oxide emission from traffic contains only 5 to 20% nitrogen dioxide, the remaining 80 to 95% is in the form of nitrogen monoxide, which is thought to be harmless. In the presence of ozone, NO is quickly chemically transformed to NO_2. Due to the increasing pollution in Europe, levels of tropospheric ozone (ozone in the lower part of the atmosphere) has increased. In Danish urban streets ozone is the limiting factor for the NO_2 levels. Ozone is photo-chemically produced due to emissions of NO_x and hydrocarbons on a European scale. The ozone concentrations in Denmark are governed by large scale processes and can therefore only be reduced by reduction of emissions on European scale.

Introduction

Air pollution levels depend highly on meteorological conditions. For ground level sources, like traffic, the highest concentrations occur at low wind speeds. Comparison of the air quality in two similar streets of Copenhagen and Milan (*Vignati et al.*, 1995), with respect to the climatological conditions show that the much higher frequency of low wind speed conditions is responsible for considerably higher pollution levels in Milan than in Copenhagen. An additional factor was shown to be the domestic heating contributing substantially to NO_x levels in Milan, especially in the Winter months.

Due to the low frequency of calm wind conditions, Copenhagen is a relatively clean city with respect to air pollution.

Measurements of urban air pollution are usually confined to a few locations in the city area. Monitoring stations are often situated in streets with significant traffic or in places where severe pollution problems are expected. Such measurements are naturally influenced by the very local conditions and care must be taken in interpretation of the results. *Berkowicz et al.*

(1995a) described how measurements of air pollution in streets can be used for evaluation of urban air quality by means of meteorological analyses and model calculations. A model for air pollution in urban streets - the Operational Street Pollution Model (OSPM) was developed at the Danish National Environmental Research Institute (*Hertel, Berkowicz,* 1989; *Berkowicz et al.,* 1995b). This model can be used for urban traffic planning and for policy assessment. Only a brief description of the model will be given here, however some examples of implementation of the OSPM will be given later in the paper.

Dispersion in urban streets

The dispersion of traffic emissions in urban areas is highly influence by the presence of buildings. The main properties of the wind flow in a street canyon are well known. When the wind direction is perpendicular to the street direction, a vortex is generated in the street canyon, whereby the wind flow at street level is opposite to the flow above roof level (Figure 1).

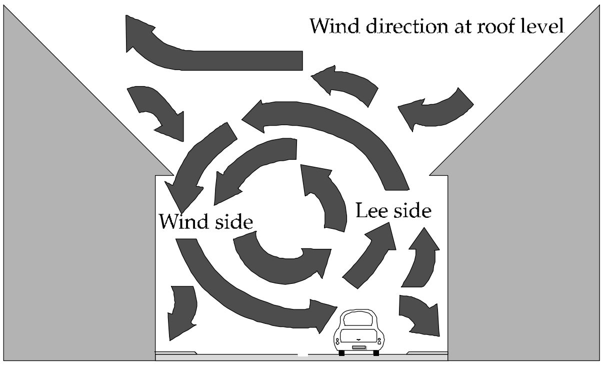

Figure 1. *Schematic illustration of wind circulation in a street canyon. Windward and leeward sides are defined with respect to wind direction at roof level.*

This phenomenon was already taken into account in one of the first street pollution models: the STREET model (*Johnson et al.*, 1973). A much more advanced approach was introduced by *Yamartino and Wiegand* (1986) in the Canyon Plume Box Model (CPBM). Results of the test of this model showed significant improvement in predictive ability compared to the simple STREET-model. A similar concept to the CPB-model is implemented in OSPM.

The OSPM calculates street concentrations as the sum of three contributions: the direct contribution from the traffic to the receptor point at the pavement on one side of the street, the contribution from recirculation inside the street and finally the contribution from the city background. The direct contribution is calculated applying a plume formula and the recirculation is simulated by a simple box model. The city background is the contribution from long range transport and from other sources inside the urban area i.a. traffic in other streets.

In *Berkowicz et al.* (1995) OSPM calculations were compared to measurements from three streets in Copenhagen: H.C. Andersens Boulevard, Bredgade and Jagtvej. The first two stations are operated under the Great Copenhagen Air Pollution Monitoring Programme (HLU) and the last is operated under the National Air Quality Monitoring Programme (LMP III). The OSPM was shown to reproduce the observed dependency of the observed concentrations versus wind speed and wind direction.

For a long time there has been a need for improving the model in order to describe streets that can not be categorized as street canyons. In *Berkowicz et al.* (1995) the first step in this direction was made by allowing the specification of wind sectors in which there are openings between buildings along the street. By this modification, it is now possible to simulate dispersion in streets with different configurations.

Model calculations were performed for the street Vesterbro in Aalborg. The monitoring station at Vesterbro in Aalborg is placed on the first part of the Limfjord bridge between Aalborg and Nørresundby. The monitoring site has a complex configuration. The street is orientated close to north-south with the monitoring station placed on the east side. At the station the street width is about 42 m. On the east side of the street the building height is about 11 m, while on the opposite side a 38 m high building is situated. Large part of the street is open.

Figures 2 and 3 show the observed and calculated hourly mean NO_x concentrations versus wind speed and wind direction for 1994 at Vesterbro. It appears from the figures that even with this very complex street configuration, the model is able to reproduce the observed dependency on wind speed and wind direction. Figure 4 shows a scatter plot of computed versus measured concentrations. In general the results are in good aggrement with the observed concentrations, albeit with a slight tendency for overestimation of the low concentrations and underestimation of the high concentrations.

Some of the scatter in Figure 4 may be due to the uncertainties in traffic data. The traffic data used for the calculations are rather uncertain, especially with respect to fraction of the heavy traffic.

For the shown calculations, meteorological data and city background concentrations are obtained from a monitoring site located on a roof of a nearby building.

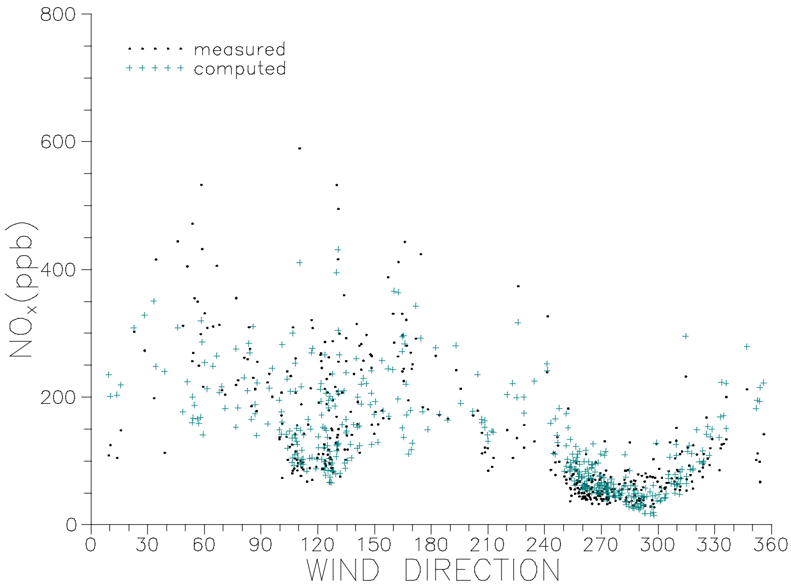

Figure 2. *Measured and computed NO_x concentrations verus wind direction for 1994 at the east side of Vesterbro in Aalborg.*

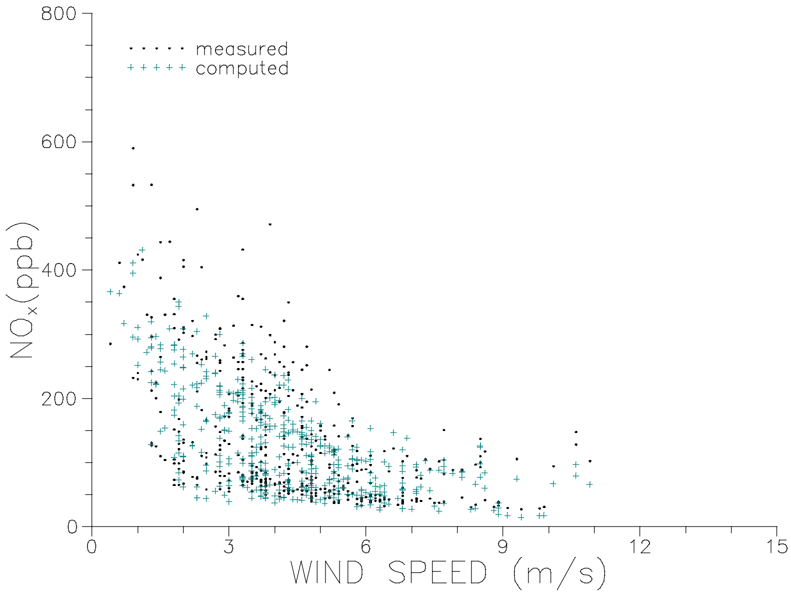

Figure 3. *Measured and computed NO_x concentrations versus wind speed for 1994 at the east side of Vesterbro in Aalborg.*

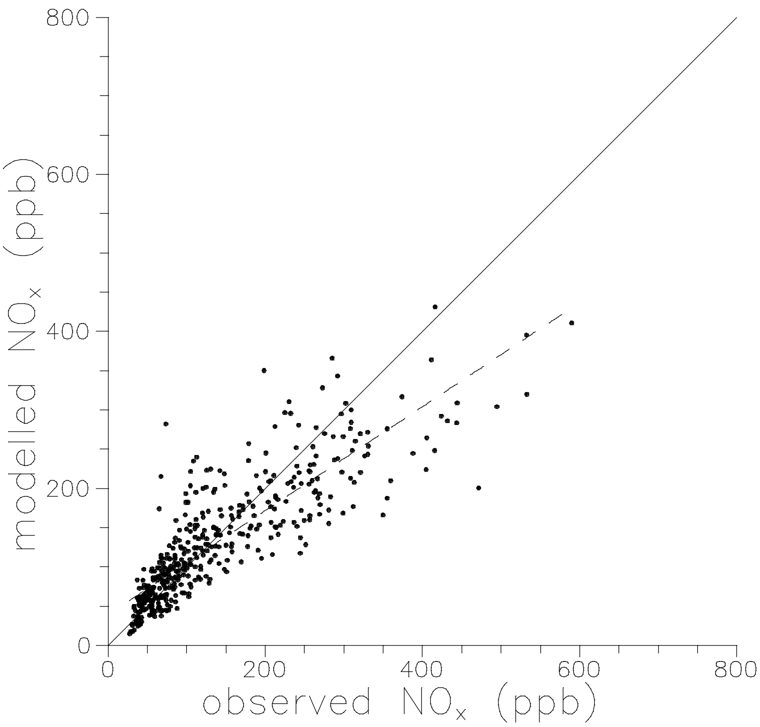

Figure 4. *Computed versus measured NO_x concentrations for 1994 at the east side of Vesterbro in Aalborg.*

Chemical formation of nitrogen dioxide

Between 80 and 95% of the nitrogen oxides are emitted as NO, which is believed to be harmless in the actual concentrations, even in heavily polluted cities. This fraction is generally lowest for diesel engines. The remaining part is mainly NO_2. NO will be oxidized in the atmosphere to NO_2, mainly by ozone (O_3), and eventually to other nitrogen compounds by different chemical processes.

Characteristic for the urban area is the high degree of mixing and the dominance of few chemical reactions. Due to the short residence time, nitrogen oxide chemistry in Danish urban areas can roughly be simplified by only two reactions: transformation of NO to NO_2 by reaction with ozone and photo-dissociation of NO_2. *Palmgren et al.* (1995) have shown that a simple box-model containing only these two reactions can reproduce well the observed nitrogen dioxide concentrations. An example is given in Figure 5, that shows the modelled versus observed NO_2 concentrations - including urban background - for Jagtvej, Copenhagen. It is seen from the figure that there is an excellent agreement between the computed and the measured concentrations.

Ozone is formed photo-chemically from emitted NO_x and hydrocarbons during long range transport. The highest ozone concentrations in Denmark appear when a high pressure system over central Europe lead to transport from south. In order to reduce the tropospheric ozone concentrations emission of NO_x and hydrocarbons needs to be reduced on a European scale.

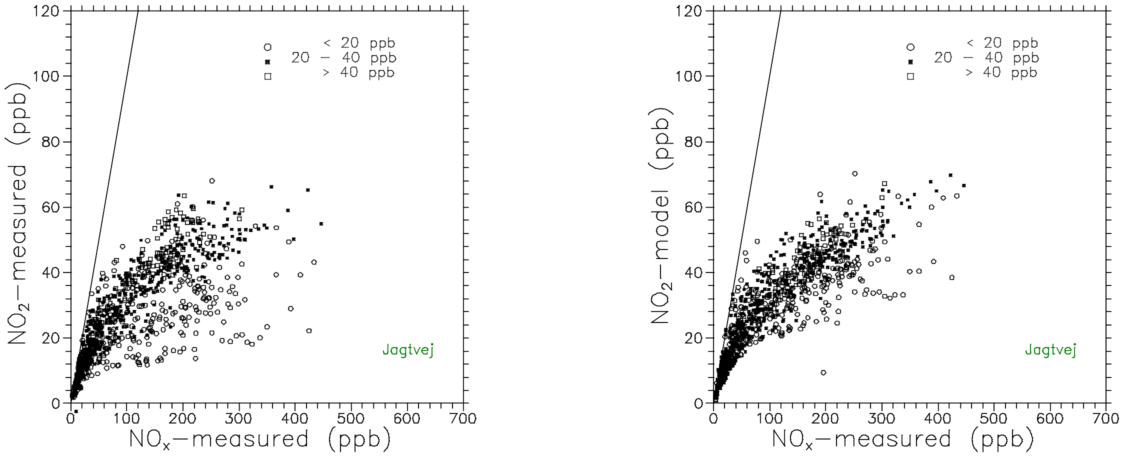

Figure 5. *Measured and computed hourly mean concentrations of NO_2 versus measured NO_x for Jagtvej, Copenhagen 1993. The relation between NO_2 and NO_x is shown for different levels of urban background ozone. The full line represents the 1 to 1 relation.*

Examples of model scenarios

The simplified chemistry for nitrogen dioxide in urban streets, described in the previous section, is implemented in OSPM. One of the main advantanges of such a model is that it can be used for prediction of future concentrations under different conditions. In *Fenger et al.* (1995) the OSPM was used for scenario calculations for the future Øresund link between Denmark and Sweden. These scenarios were based on an estimated diurnal traffic of 8 to 10,000 vehicles across the link. Calculations were performed for the traffic amount as in year 1992 and for two future situations around year 2000 assuming that 40 or 60% of the Danish cars have been equipped with catalytic converters. It was further assumed that the background pollution levels are unchanged. Calculations were performed for three different streets on Amager island, where the link will be established in order to study the effect on pollution levels from the change in traffic amounts. The three streets were:

- Amagerbrogade with a present daily traffic of 30,000 vehicles and an assumed decrease of 22% in year 2000, when the link is established

- Vejlands Alle with a present traffic of 38,000 and an assumed decrease of 62%

- Peder Lykkes Vej with a present traffic of 10,000 and an assumed increase of 60%

The traffic data were distributed over 24 h and split into two groups: below and above 2,5 tons, respectively.

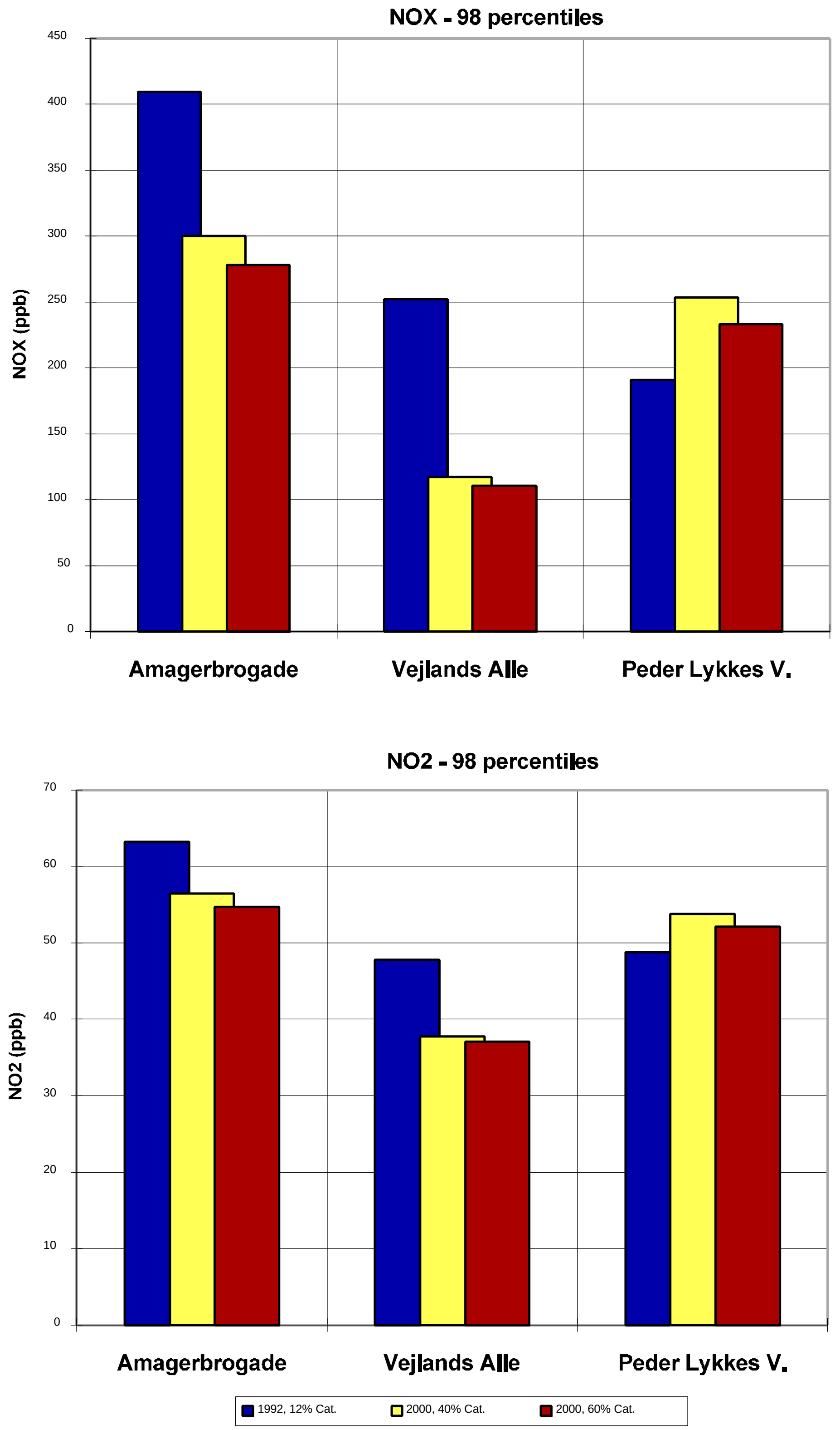

Figure 6. *98 percentiles of 1 h mean nitrogen oxide concentrations at the south side of the three streets for the three scenarios.*

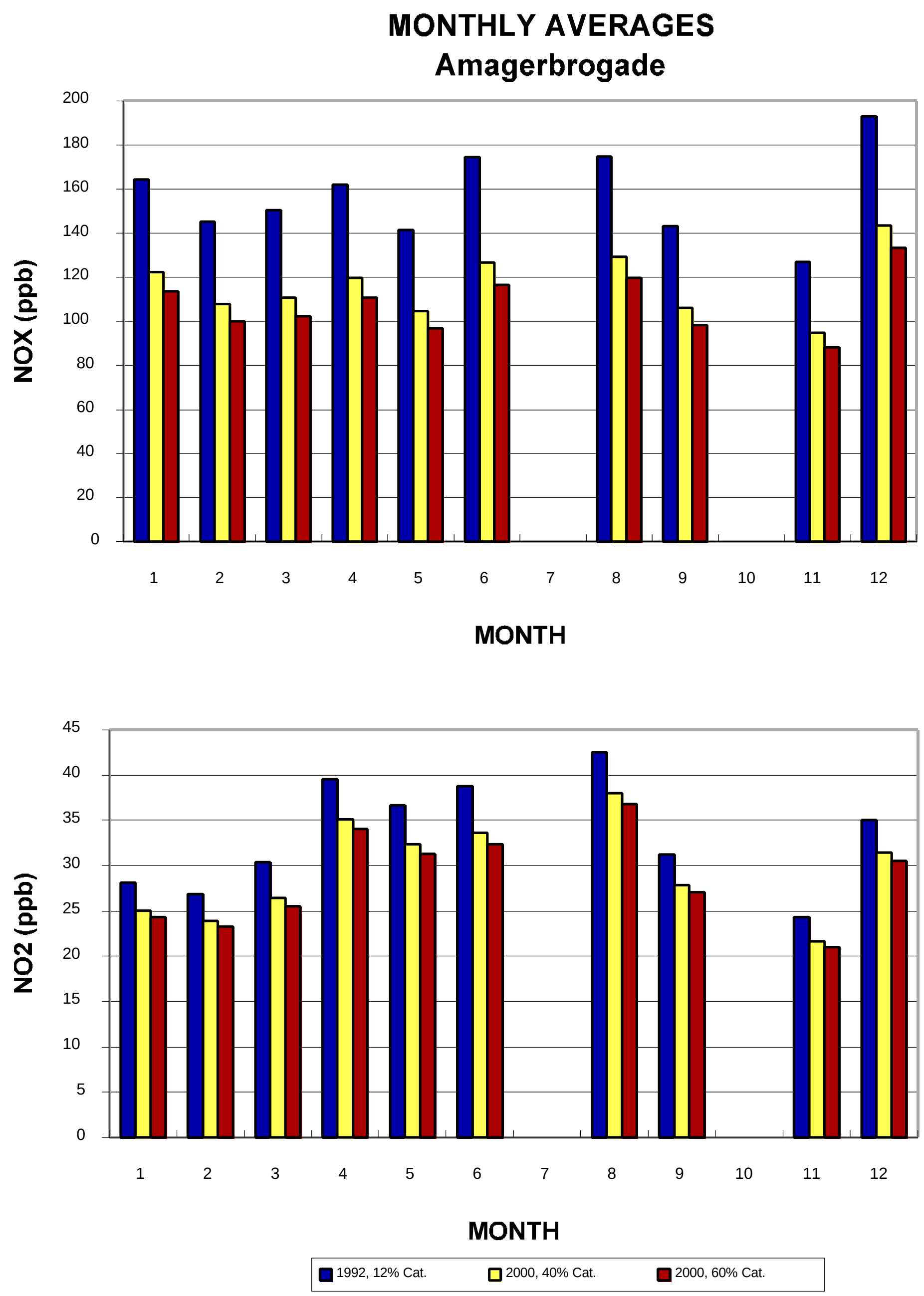

Figure 7. *Monthly averages of pollution levels on the south side of Amagerbrogade at present and in the two year 2000 scenarios.*

Figure 6 shows the computed 98 percentiles for the present and the two scenarios year 2000. Also in this case it can be observed that NO_2 is considerable less affected than the NO_x concentrations by the increase in catalytic converters.

Figure 7 shows computed monthly averages of NO_x and NO_x for Amagerbrogade for 1992 and for year 2000 assuming 40 and 60% catalytic converters. It is seen that even though a substantial reduction in NO_x concentrations is obtained, the NO_2 levels are only little effected even in the case of 60% catalytic converters.

Discussion and conclusions

The concentrations levels in urban streets are generally governed by the wind flows. Due to the low frequency of calm wind speed conditions, Danish urban streets are less polluted than streets in many other European cities. Only 5 to 20% of the NO_x emission from traffic is NO_2, wheras the remaining (95 to 80%) is emitted as the harmless NO. Nitrogen dioxide is then formed in the street by oxidation of NO by reaction with ozone. The nitrogen dioxide levels in Danish urban streets are in many cases limited, not by the NO_x emission and dispersion conditions in the considered street, but by the city background ozone level. The future reductions in NO_2 levels are expected to be much smaller than the reductions in NO_x pollution.

The coarse geographical resolution of monitoring networks gives substantial need for model tools for estimation of concentration levels in urban areas. Simple models, which can be run on PC's, can be developed when the physical and chemical processes are well understood. Some implementations of such a model - the Operational Street Pollution Model (OSPM) - was presented in this paper.

Scenario calculations for the future Øresund link between Denmark and Sweden confirm that the NO_2 concentrations can not be expected to be considerably lowered, even though NO_x concentrations are expected to decrease due to the introduction of catalytic converters for the gasoline vehicles.

Acknowledgements

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