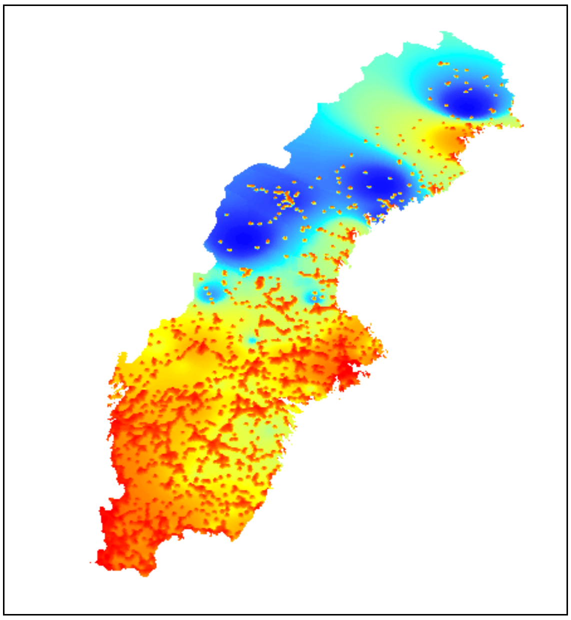
IVL report

IVL Swedish Environmental Research Institute

Quantification of general population exposure to nitrogen dioxide in Sweden



Karin Sjöberg Marie Haeger-Eugensson Marcus Liljeberg Håkan Blomgren
Bertil Forsberg

B 1579
September 2004

IVL

Organisation/Organization

IVL Svenska Miljöinstitutet AB
IVL Swedish Environmental Research Institute Ltd.

Adress/address

Box 5302
400 14 Göteborg

Telefonnr/Telephone

+46 31 725 62 00

RAPPORTSAMMANFATTNING
Report Summary

Projekttitel/Project title

Quantification of general population exposure to nitrogen dioxide in Sweden

Anslagsgivare för projektet/ Project sponsor

Socialstyrelsen

Rapportförfattare/author

Karin Sjöberg Marie Haeger-Eugensson Marcus Liljeberg Håkan Blomgren, Bertil Forsberg (Umeå Universitet)

Rapportens titel och undertitel/Title and subtitle of the report

Quantification of general population exposure to nitrogen dioxide in Sweden

Sammanfattning/Summary

Based on an empirical statistical calculation method for air quality assessment, the URBAN model, a method for quantifying the general population exposure of different ambient air pollutants on a national level has been developed. However, this study has focused on NO_2, a pollutant closely related to traffic emissions and hence to the exposure of air pollution in cities.

The advanced numerical model, TAPM (The Air Pollution Model) was used to improve the ventilation factor by using the output parameters mixing height and wind-speed respectively, for calculating new ventilation parameters with high time and spatial resolution (1 month and 1x1 km (2x2 km for the northern inland)). A comparison between monthly averages of measured and calculated NO_2 concentrations shows a fair accordance.

The results from the urban modelling show that in 1999 the majority of people in Sweden, 40%, were exposed to yearly mean concentrations of NO_2 between 10-15 $\mu g/m^3$. Another 40% were exposed to less than 10 μg NO_2/m^3, and only about 5% of the Swedish inhabitants experienced exposure levels of NO_2 above 20 $\mu g/m^3$.

Nyckelord samt ev. anknytning till geografiskt område eller näringsgren /Keywords

nitrogen dioxide, population exposure, Urban model, TAPM

Bibliografiska uppgifter/Bibliographic data

IVL Rapport/report B1579

Rapporten beställs via /The report can be ordered by

Hemsida: www.ivl.se, e-mail: publicationservice@ivl.se, fax: 08-598 563 90 eller IVL, Box 210 60, 100 31 Stockholm

Abstract

Experience from many years of measurements in urban areas in Sweden shows that high concentrations of various air pollutant components occur not only in large cities but also in small towns. One possible reason is variation in the local meteorological conditions causing poor ventilation facilities.

Some years ago IVL developed the so-called URBAN model, an empirical statistical calculation method for air quality assessment. The model has mainly been used as a screening method for estimating the general risk of exceeding different national standard values for air quality in small and medium sized towns in Sweden.

Based on the URBAN model the aims of this project have mainly been to:

- provide a model for quantifying the general population exposure of different ambient air pollutants on a national level;

- develop a tool useful for exposure assessment in epidemiological air pollution studies as well as trend and prediction studies.

However, this study has focused on NO_2, a pollutant closely related to traffic emissions and hence to the exposure of air pollution in cities.

This was achieved by reproducing the local meteorological variations in a new ventilation index and a dispersion-adjusting constant as well as better temporal and spatial resolution of the parameters. The advanced numerical model, TAPM (The Air Pollution Model) was used to improve the old ventilation factor by using the output parameters mixing height and wind-speed respectively, for calculating new ventilation parameters with high time and spatial resolution (1 month and 1x1 km (2x2 km for the northern inland)). The results were then included in an improved calculation routine/model implemented into the URBAN model.

A comparison between monthly averages of measured and calculated NO_2 concentrations (with the new model) shows a fair accordance. When comparing NO_2 calculated with the old and the new URBAN-model and NO_2 measurements, the new model shows a much better agreement with measured data. Consequently, the need of evaluation of the air quality in communities and small cities can be better met by using this improved URBAN model. Since the time consuming and complicated meteorological modelling is only used to generate the new ventilation parameters, the actual NO_2 calculations with the new URBAN model can still remain rather simple compare to other dispersion models.

The results from the urban modelling show that in 1999 most of the country had rather low NO_2 urban background concentrations, compared to the environmental standard for the yearly mean (40 $\mu g/m^3$). Most of the small to medium sized cities has a NO_2 concentration of 10-15 $\mu g/m^3$. In the large cities and along the Skåne West Coast the concentration is around 20 $\mu g/m^3$. The majority of people in Sweden, 40%, were exposed to yearly mean concentrations of NO_2 between 10-15 $\mu g/m^3$. Another 40% were exposed to less than 10 μg NO_2/m^3, and only about 5% of the Swedish inhabitants experienced exposure levels of NO_2 above 20 $\mu g/m^3$.

Contents

Quantification of general population exposure to nitrogen dioxide in Sweden

1 Introduction

The outdoor air quality situation in Sweden has improved dramatically during the last decades, due to the control measures adopted, both at national and international levels, and due to local infrastructure planning. The concentrations of sulphur dioxide has for example decreased more than 90% since the early 1970's and also the concentration levels of nitrogen dioxide and soot show a decreasing trend (Sjöberg et al., 2004; Frisk luft, 2003). Despite the successful work to reduce emissions from both stationary sources (industries, energy production) and mobile sources (traffic), health impact of exposure to ambient air pollution is still an important issue.

Ambient air includes many different components, e.g. particles, ozone, and nitrogen dioxide, which may contribute to a variety of health effects. In many areas the air pollution levels of specific compounds still exceed the health related air quality guidelines and health effects of exposure to air pollutants, even at moderate levels, have been shown in many studies during recent years (Forsberg et al., 2003; APHEIS, 2003; Miljöhälsorapport 2001). Consequently, there is an increasing need of tools to estimate the magnitude of the health effects in order to evaluate the number of people exposed to harmful pollution levels and hence to improve the basis for decisions on air pollution control strategies.

Based on air quality monitoring data and improved local, meteorological ventilation adjusting factors the Swedish Environmental Research Institute (IVL) has developed a model for quantification of general population exposure to nitrogen dioxide in Sweden. The work has been funded by the National Board on Health and Welfare (Social-styrelsen).

Furthermore, the project has been performed in close connection to another research project at IVL within the Swedish National Air Pollution and Health Effects Program (SNAP), financed by the Swedish Environmental Protection Agency. The SNAP part of the project focuses on benzene and particles and a final report will be published by the end of 2004.

2 Background and aims

For more than fifteen years air pollution levels related to health effects have been studied in small to medium sized cities in Sweden within the framework of the urban air quality network, a co-operation between local authorities and IVL. This work has provided important input to assess trends of public exposure to several critical air pollutants, such as nitrogen dioxide, benzene and soot. During recent years also measurements of additional pollutants, such as PM_{10}, $PM_{2.5}$, PM_1 and polyaromatic hydrocarbons have been included.

The Swedish Urban Air Quality Network was established in 1986 as a joint project between IVL and the local health departments in Swedish towns. Since then measurements have been performed every winter season (October-March) in approximately 40 towns each year. Altogether, around 100 towns, one third of the Swedish communities, have participated for one or several years. The main purpose of the project is to enable municipal authorities to evaluate and describe the air quality situation in their own town and to compare measurements between towns.

The measurements are mainly carried out at one site in the centre of each of the participating urban areas, as an urban background station about 4-8 meters above ground level, without direct influence from local sources. The program began with measurements of SO_2, soot (black smoke) and NO_2, taken as daily means. The program was later expanded to include volatile organic compounds (VOC) as weekly means, and SO_2 and NO_2 at two places in the countryside nearby some of the towns, taken as monthly means. Monthly ozone measurements began in summer 1996 and daily measurements of PM_{10} began in 2000.

Experience e.g. from the urban air quality network shows that high concentrations of various air pollutants occur not only in large cities but also in small towns. One possible reason is that the local meteorological conditions cause poor ventilation. According to the investigation performed by The Parliament Committee on Environmental Objectives (Miljömålskommittén) about 10% of the communities in the country are going to exceed the threshold values of NO_2 even if proposed reductions of emissions are being carried through. In areas where no information is available about the air quality or meteorology, it is a very expensive and time-consuming procedure to obtain reliable data from either long-term measurements or advanced modelling. Thus, there will be a continuous need of reliable, cost-effective and rapid calculations of the air quality in the future, in order to meet the EU air quality directives as well as the Swedish national standards in both small and medium sized towns.

Based on the results achieved within the urban air quality network the so-called “Urban model” has been developed. The Urban model is a useful tool to assess the risk for exceedances of Environmental air quality standards in urban environments in Sweden by applying air monitoring data (diurnal resolution) from around 100 towns of different sizes and location in the country and relations between rural/urban background/street level concentrations of NO_2, benzene and particles (soot, PM_{10}) respectively (see further Chapter 3.1). In order to achieve a better quantification of the air quality situation in areas where no monitoring data is available the local meteorological variations need to be better represented in a new improved calculation routine.

A number of studies have been performed regarding individual exposure measurements and ambient air quality related to morbidity/mortality in the most populated parts of Sweden, which also are assumed to be the generally most polluted areas. Within this project the Urban model has been further developed to work as a basis for quantifying the general population exposure of different ambient air pollutants on a national level, where e.g. the number of people exposed to a specific concentration level of a certain air pollutant can be estimated and geographically distributed exposure patterns can be achieved. Based on exposure-response relationships it will also be possible to estimate health impact due to air pollution.

The aims of the project have mainly been to:

- provide a model for quantifying the general population exposure of different ambient air pollutants on a national level;
- develop a tool useful for exposure assessment in epidemiological air pollution studies as well as trend and prediction studies.

The model will be applicable to different air pollution compounds as long as relevant input data are available. However, this study has focused on NO_2, a pollutant closely related to traffic emissions and hence to the exposure of air pollution in cities.

3 Models and methods used

In order to improve the calculations of air pollution concentrations in small/medium sized cities used in the URBAN model, the local meteorological variations needed to be represented better in a new improved calculation routine. Therefore, improved mixing parameters were developed, later used to improve the calculations of the air pollution concentrations in the URBAN model. For calculation of meteorological parameters the advanced numerical model, TAPM, was used.

The distributions of NO_2 concentrations within cities were estimated assuming a decreasing gradient towards the rural background areas. The calculated NO_2 concentrations are valid for the similar height above ground level as the input data (4-8 m) in order to describe the relevant concentrations for exposure. The exposure calculation was based on a comparison between the NO_2 concentration and the population density. The population density was developed by using either the parish- or the community population.

3.1 The original URBAN model

The URBAN model, an empirical statistical calculation method, has earlier been developed by IVL (Persson et al., 1999). The model has mainly been used as a screening method for estimating the general risk of exceeding different national standard values for air quality in small and medium sized towns in Sweden. The dispersion possibility in the model is based on a ventilation index calculated from the mixing height and wind speed (Holzworth, 1972 and Krieg and Olsson, 1977). Similar methods have recently been used in the United States, especially in determining the ventilation potential for smoke from wildland fires (Hardy et al., 2003), with a further development by adding a locally developed inversion potential (Fergeson, 2002 and Fergeson et al., 2003).

The model is based on a logarithmic function, assuming that the emission of air pollutants in a region is proportional to the population in the area. Even though this method of calculating the emissions are rather rough there is a clear connection between the two parameters. This can be explained by assuming that the activity of each person produces a certain amount of air pollution (traffic, heating etc.) which is distributed over the city area. The relation between NO_X emission and population from 35 different communities in Sweden from 1995 is shown in Figure 1. The logarithmic correlation is valid for small to medium sized communities (straight line in a logarithmic scale) but for larger cities (Stockholm, Göteborg and Malmö) the relation is no longer linear, instead it seems to be exponential. However, for the largest cities air quality monitoring data is available for all months, why the model is only going to be used for calculation of the concentration in small to medium sized cities.

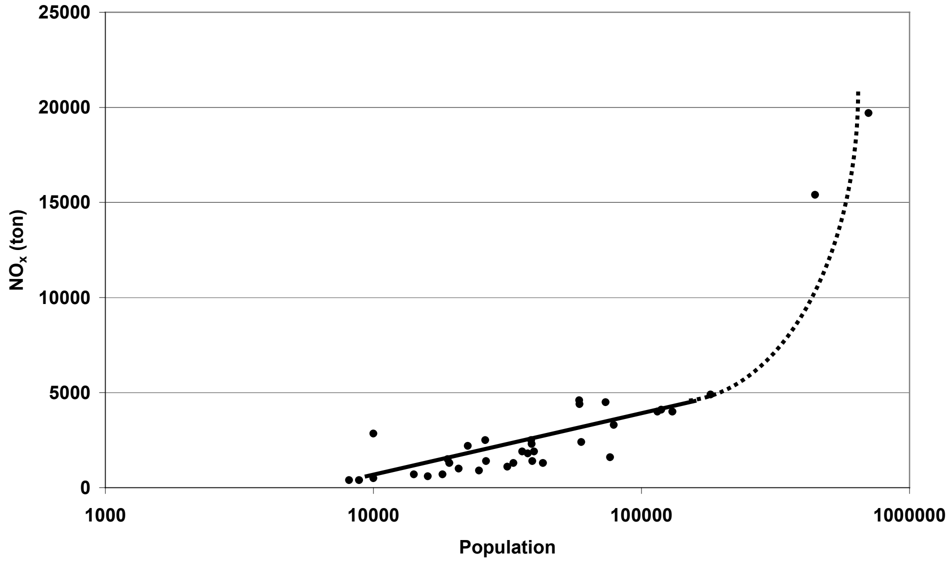


Figure 1 Relation between population (logarithmic scale) and emission of NO_X (linear scale).

Sensitivity tests of the model have shown a very good agreement between calculated results and independent measurement data (Haeger-Eugensson et al, 2002).

The scale of the calculation area in the model is 2x2 km, which is about a Swedish medium sized town. Percentile calculations and street level concentrations are estimated from the urban background concentrations with a statistical relationship based on measurement data. The rural background air concentrations are also taken into account, where available data has been interpolated over non-urban areas (Pihl Karlsson et al., 2003; Persson et al., 2003; Hallgren-Larsson et al., 2003)).

The original URBAN model is based on measured air pollution concentrations in urban background, C_t, collected in the national URBAN Air Quality network (Persson 2003), minus rural background concentration, C_b, and a ventilation factor, F_V.

$$C_t - C_b = \log(\text{population}) * F_V \qquad (1)$$

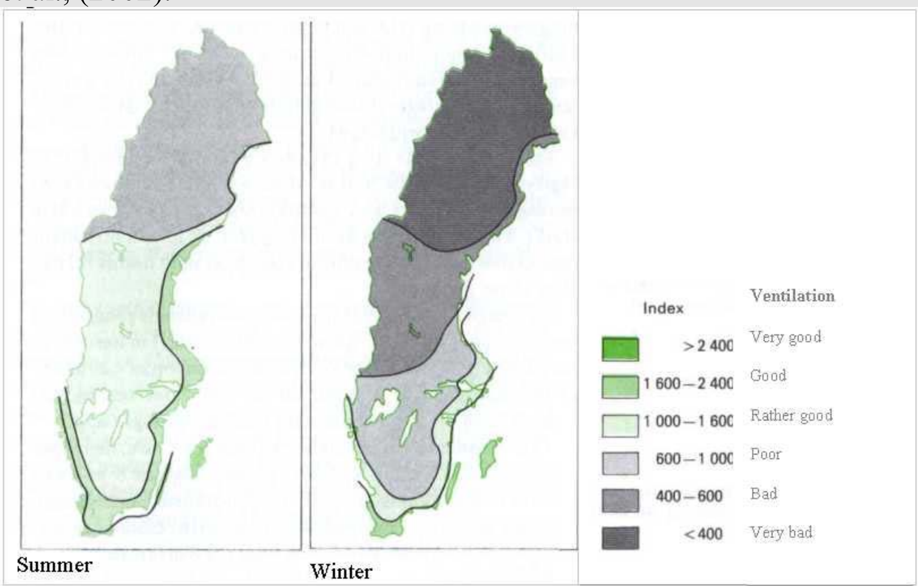
The determination of a meteorological ventilation index in Sweden was developed by SMHI (Krieg and Olsson. 1977) and is derived from calculations of the mixing height[1] (H) and the ground level wind speed (U).

$$V = U * H \qquad (2)$$

For the calculation of H the vertical temperature from balloon soundings is used. The wind profile is thus not taken into consideration. Since there are very few radio soundings in the country, both in time (at 00 and 12 GMT) and place, these calculations only show a mixing height that is assumed to represent large areas. The partition of Sweden into zones with different ventilation indexes is therefore very approximate without consideration of local variations (SOU, 1979), see Figure below. This is also true for the calculated ventilation factor, F_v.

From the calculated F_v (Equation 1) it is possible to derive air pollution concentrations in towns without measurements (of air quality and/or meteorology), by first determine in which zone of ventilation index the town is located (see Figure below) and then use the calculated F_v for that region. The background concentrations for all regions are already specified in the model.

The theory behind the Urban model is described in further detail in Haeger-Eugensson et al., (2002).



[1] *The mixing height is defined as that level where the temperature of the adiabatically lifted parcel becomes less than the measured ambient temperature. This means that the mixing height is the height from ground to the top of the mixing layer. In the mixing layer the turbulence is rather uniform, resulting in fairly good dispersion of air pollutants. However, at the mixing height the turbulence is suppressed causing difficulties for pollutants to penetrate. The vertical limitation can be caused by for example an inversion layer.*

3.2 The TAPM model

3.2.1 Model description

TAPM (The Air Pollution Model) is an advanced numerical model developed by Australian CSIRO Atmospheric Research Division which integrates meteorology, air dispersion and air chemistry (Hurley, 1999b). Air pollution models typically use either observed data from a surface based meteorological station or a diagnostic wind field model based on available observations. TAPM is different from these approaches in that it solves the fundamental fluid dynamics and scalar transport equations to predict meteorology and pollutant concentration for a range of pollutants important for air pollution applications. It eliminates the need of site-specific meteorological observations. Instead, the model predicts the flows important to local-scale air pollution transport, such as sea breezes and terrain induced flows, against a background of larger-scale meteorology provided by synoptic analyses. It predicts meteorological and pollution parameters directly on local, city or inter-regional scales.

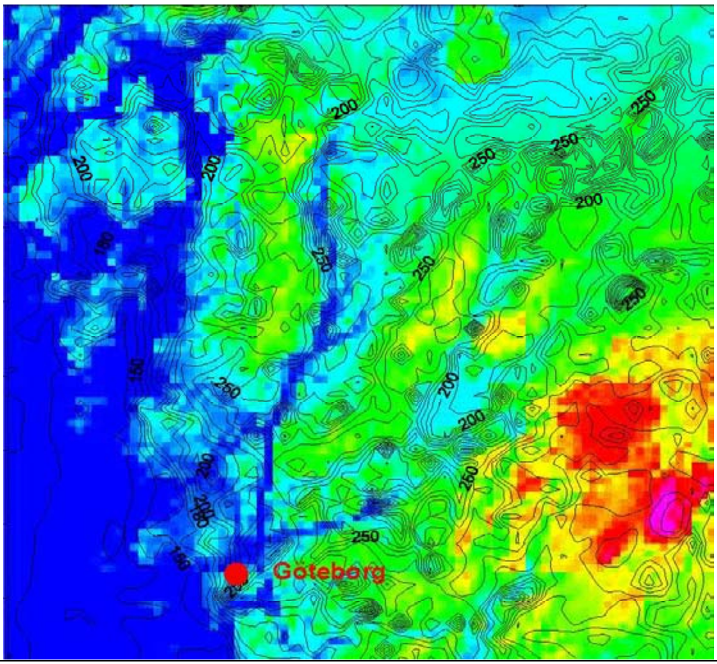
The model is designed to be run in a nestable way and the spatial resolution can be as fine as around 100 meters. In addition, it can be run for one year or longer, which provides a means to deal with statistics of meteorological and pollutant variables.

3.2.2 Validation of the model

TAPM has previously been used and verified for regions in Australia and in different parts of Asia (e.g. Hurley, 1999a). However, since the circumstances are rather different in northern Europe (rain, soil moisture, day length etc.) the model's performance on meteorology modelling was verified before using the output of the model in calculating a new ventilation index (Chen et al., 2002). For this purpose, TAPM was run with three nestings that have spatial resolution of 9, 3 and 1 km respectively, with 90*90 grid points in horizontal and 20 levels in vertical (from 10 to 8000 meters) dimensions.

A very important feature of TAPM is its ability to explicitly deal with surface energy budget and temperature, which allows simulation of thermally driven wind systems and also a properly modelled mixing height. The distribution of mixing height (H) is closely linked to surface characteristics and topography. This is visualised in Figure 2, where the mixing height increases rapidly along the coastline mainly due to very different surface parameters between sea and land. Further away from the cost H continues to slowly increase primarily due to topography, however, in valleys H is usually low because of local climatological effects (shelter from wind and cool air lakes).

Based on the comparisons between the TAPM output from two years run (1999 and 2000) and the surface/profile measurements on air temperature and wind speed, it was found that TAPM performs well in simulating air temperature and wind for Swedish conditions. These parameters are the two most important fields to drive the air pollution modelling. In addition, TAPM has strong ability in modelling sea-land breeze and urban heat island effect. As such, it was concluded that TAPM with confidence could be applied in meteorological modelling and environmental impact assessment in Sweden.



Colour	**altitude (m)**
Dark blue	0
Light blue	10-40
Turquoise	40-70
Green	70-100
Green-yellow	100-170
Yellow	170-190
Orange	190-220
Red	220-280
Pink	>280

Figure 2 The distribution of mixing height overlaid the topography in south-western Sweden.

3.2.3 Calculation of new mixing parameters

The new mixing parameters calculated are an improved ventilation index (V) and a dispersion-adjusting constant (C_d) which are substituting F_v from the old URBAN-model (C_d*V=F_v).

The calculation of the ***ventilation index*** (V) is based on equation 2, but includes calculation of ***wind speed*** (U) and a new type of ***mixing height*** (H) calculation, both performed with TAPM in a grid resolution of 1x1 km.

To determine the ***dispersion-adjusting constant*** (C_d), measurements of monthly average of NO_2 minus the background concentration and the monthly average of V (or H*U) are used. C_d is thus calculated according to

C_t-C_b=log(population)* V*C_d

At all sites and times where measurements of NO_2 concentrations (C_t) exist, C_d has been calculated separately at each site and months for the two years. Those calculations have then been used to determine the NO_2 concentration in cities where no measurement data is available, by assuming that C_d is similar for towns with similar V's.

3.3 Concentration distribution within cities

The distribution of air pollution concentrations in cities depends on the structure of the city such as street width, building height, green areas, the size of the city and, of course, the distribution of the emission sources. A schematic distribution is illustrated in Figure 3.

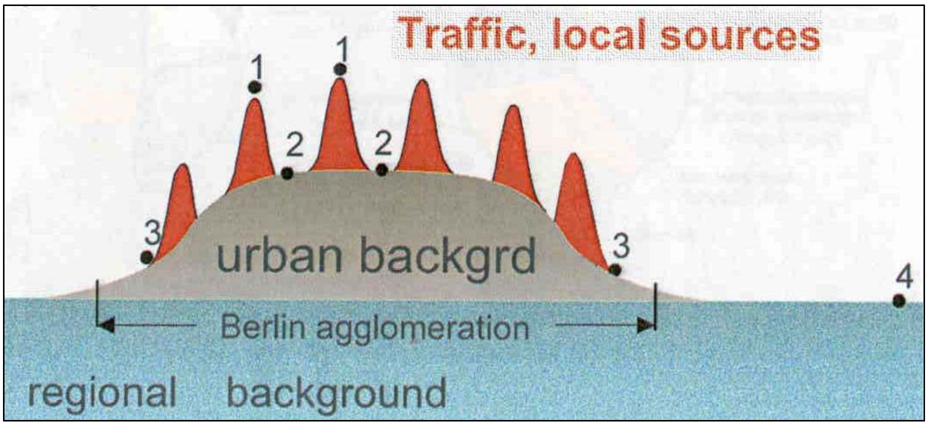


Figure 3 A schematic picture of air pollution distribution in cities (Lutz, 2002).

Usually it is the urban background air concentration that is being used in exposure studies since this value can be assumed to represent the general exposure level in a city. However, the urban background concentration varies depending on the size and location of the city.

3.3.1 Concentration distribution by the New Urban model

In this study the calculated urban background concentrations of NO_2 has been regarded as representative for the city centre. The decrease of this concentration towards the rural area surrounding the city has been calculated by using a generalised decrease based on the range of the city plume, windward to the city, recommended by SMHI (IVL 1995). This generalised distance (table 1) is calculated from dispersion modelling of various cities, and are in this study used symmetrically around the cities.

The concentrations from the urban plumes are thus decreasing differently depending on the city size, down to the closest interpolated background concentration of each city respectively. However, in many areas in Sweden the cities lay close to one another, causing interaction of the urban plumes. Consequently, before the regional background concentration is reached an increase of the concentration, due to a plume from a city close by, can be the result.

Table 1 A generalised dispersion of air pollution plumes from various sized cities based on recommendation in (IVL 1995).

Number of citizens	Distance of the city plume (km)
≥ 500 000	25
40 000 - 499 000	10
< 40 000	5

Examples of the calculated concentration decrease for some cities using the New Urban model are shown in figure 4. The main part of the concentration from urban plumes decreases to various extents depending on the size of the city and closeness to other cities. The above mentioned increase is visible in the example for Jönköping, where the concentrations increase again after some kilometres due to the urban plume from Huskvarna.

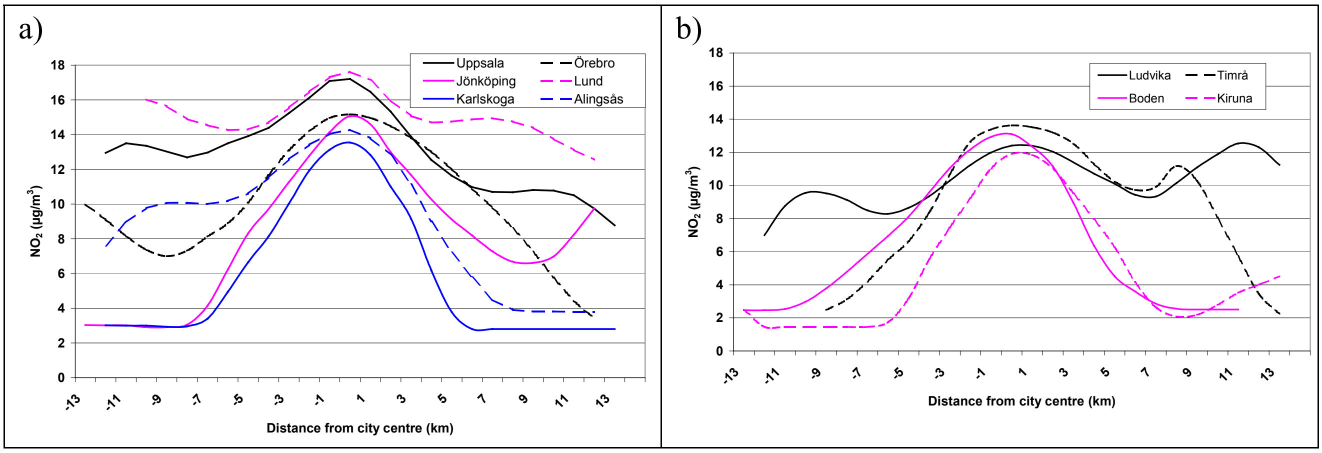


Figure 4 Examples of the decrease in the NO_2 concentration in (a) large to medium and (b) small sized Swedish cities of at different locations based on the calculations by the New Urban model.

The generalised decrease of the urban background concentration is used in 110 of the large, medium and small cities according to table 1. Outside the city areas, and the areas influenced by the city plume, the interpolated rural background concentration is used.

3.4 Exposure analysis

3.4.1 Calculations of population density

Using either the parish- or the community population a calculation of the population density was conducted in a 1*1 km grid for Sweden. For some parts of the country information about the population, evenly spread out over a parish area, was available. For the rest of the country there was only information of the number of people in a community (figure 5).

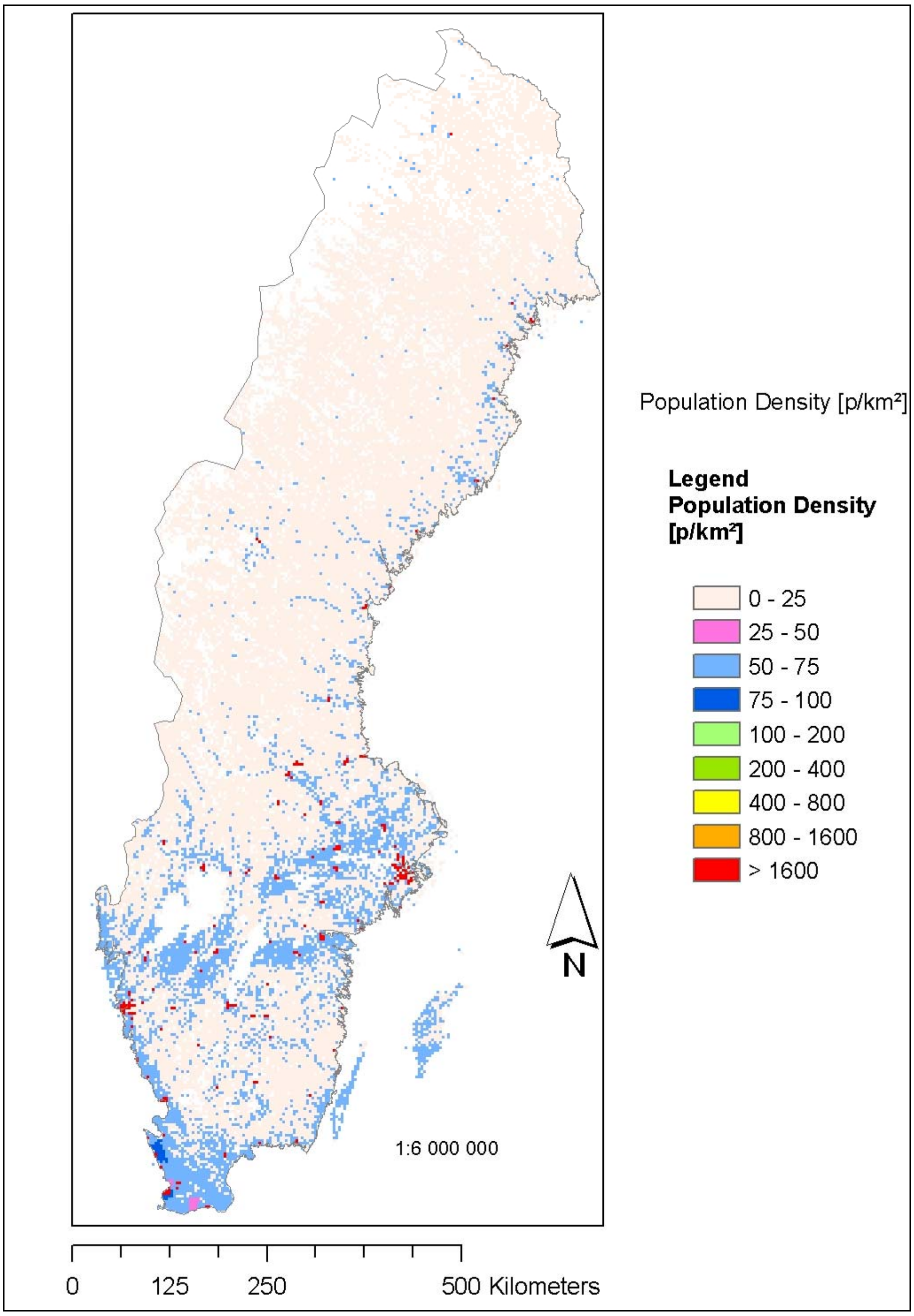


Figure 5 Interpolated population density from parish and community population.

Hence, an improved distribution of the population density was developed by using a differentiated allocation of the population based on large-scale statistical connections and land-use information. The statistical connection gives that 35 % of the population lives in areas with open ground such as farmland, 5% in the woods and 60 % of the population in city areas. Within a city the population is allocated to built-up areas. Furthermore, the population density distribution within a city is assumed to decrease from the city centre to the city limit.

The population density is, as expected, highest in the large city areas. However, along the West Coast of Skåne there are also some spots of high population density.

3.4.2 Exposure study

The exposure study is based on a comparison between concentration and the population density in each grid. By over-laying the population density grid to the air pollution grid completes this.

3.5 Air quality standards for NO_2

The environmental quality standards (EQS) in Sweden are legally binding limits for an environmental status, which may not be infringed after a specific date. The ordinance (2001:527) on environmental quality standards for ambient air contains standards issued for nitrogen dioxide, oxides of nitrogen, sulphur dioxide, carbon monoxide, lead, benzene and particulate matter (PM_{10}) in ambient air.

The EQS for NO_2 as a yearly mean is 40 $\mu g/m^3$ and should not be exceeded after 31 December 2005. The upper and lower assessment thresholds, which define the requirements of methods used for assessment the ambient air quality, are 32 and 26 $\mu g/m^3$ respectively.

The quantification of the general exposure of nitrogen dioxide in different concentration intervals has been based on the EQS and connected assessment thresholds.

4 Results

The meteorology output parameters from TAPM used here are mixing height (H) and wind speed (U) with a resolution of 2x2 km for southern Sweden and along the northern coastline and 5x5 km for the northern inland. Both parameters are calculated for each hour. TAPM uses boundary layer variables including temperature and wind profile to calculated H. Two-monthly means of H are then calculated for the whole Sweden by integrating the hourly values. The pollution grid was however calculated with a better resolution, 1x1 km and 2x2 km for the above mentioned areas respectively. The year used for the calculations was 1999.

4.1 Improved ventilation indexes

Improved meteorological mixing parameters were developed in order to enhance the calculations of the concentration of air pollutants in small to medium sized cities where no air quality data is available. The mixing parameters are a new ventilation index (V) combined with a dispersion-adjusting constant (C_d). V_i is based on method earlier used by SMHI (see Chapter 3.1), but with higher time and spatial resolution, since the circumstances for ventilation differs rather much during different seasons, especially in northern Sweden.

4.1.1 Calculation for Västra Götaland

In a pilot research project, funded by the Swedish National Road Administration, improved ventilation indices, with a resolution of 2x2 km, was developed for the western part of Sweden, in order to give a better description of the local situation (Haeger-Eugensson et al., 2002).

The investigated area was southwestern Sweden including 6 urban areas; Alingsås, Borås, Göteborg, Kungälv, Vänersborg and Trollhättan. The mixing height was calculated for each site as monthly means for 1999 and 2000. The results showed two different developments of the mixing height, divided as coastal and inland location. Since there was a rather large difference between the inland and the coastal sites in terms of mixing height (H) and thus the new calculated ventilation index (V), the calculation of the dispersion-adjusting constant (C_d) was also separated into inland and coastal respectively.

For calculating the concentration of NO_2 $C_{d\text{-inland}}$ or $C_{d\text{-coastal}}$ was used, depending on the location of the city. As can be seen in Figure 6 a comparison between measured and calculated monthly means of NO_2 showed a quite good correlation (n=68, R^2=0.6). Between 17-27 µg/m^3 the calculated NO_2 values were approximately in a ratio of 1, with an accuracy of ±0.2 µg/m^3, and hence the concentrations are well modelled in this interval. For concentrations higher that about 27 µg/m^3 the ratio was about 0.8, indicating a slight underestimation. However, in this range there were a few observations and thus the results become more uncertain. For concentrations lower than 17 µg/m^3 the ratio was 1.3, resulting in somewhat overestimating of the modelled concentrations.

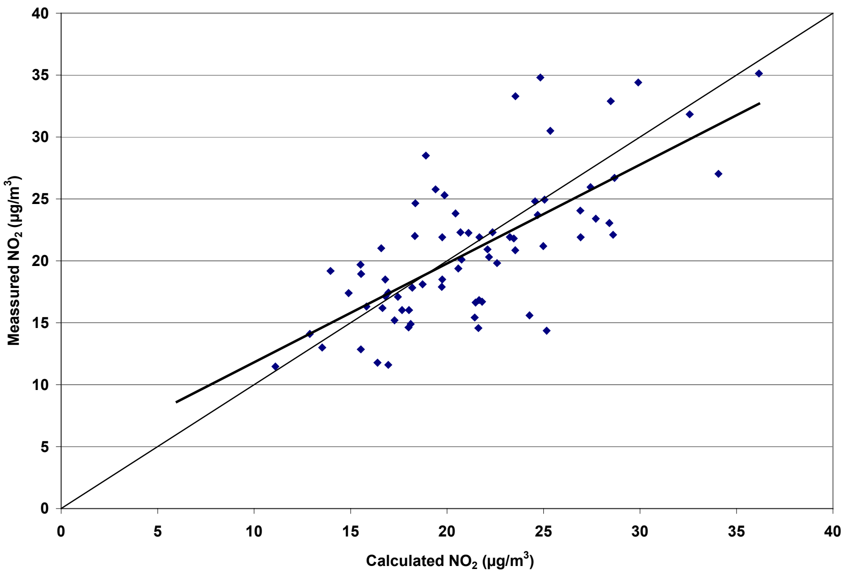


Figure 6 Comparison between monthly means of measured and calculated concentrations of NO_2.

The original URBAN model only calculates mean concentration over six months during the wintertime. The monthly mean concentration calculated by the new URBAN model was thus converted into half-year means and then compared with the calculations by the original URBAN model for the same period. The result of that comparison is presented in Figure 7 together with measurement data for the same period.

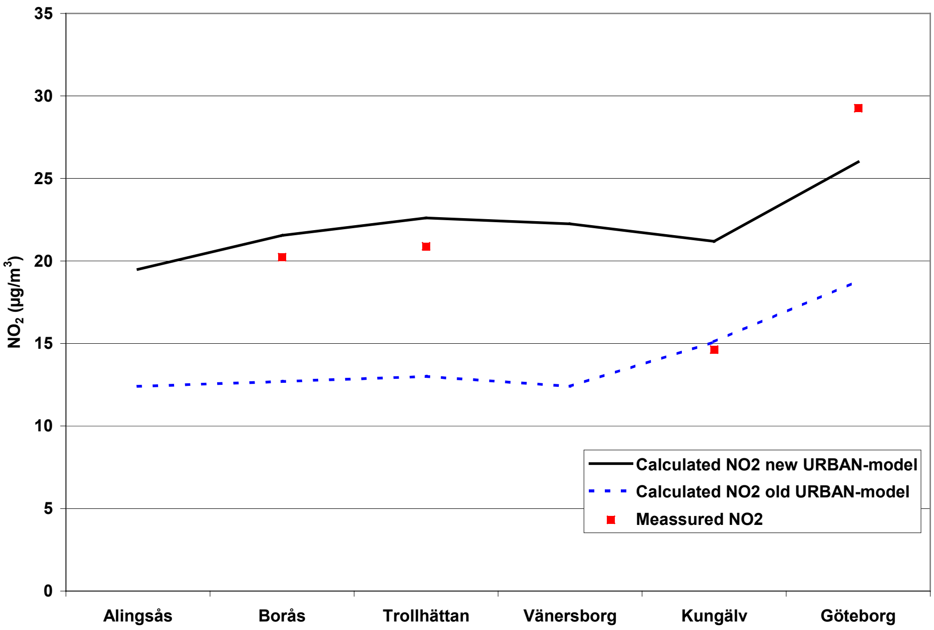


Figure 7 Comparison between winter half-year means of NO_2 concentrations by measurements (red squares) and calculation made by the old (dotted line) and the new (black line) URBAN model respectively at each site.

The comparison between NO_2 calculations by the old and the new URBAN model shows that the new model calculates NO_2 concentrations with a much better accuracy in all cases but one (Kungälv), according to the measured concentration. The monitoring point in Kungälv is suspected not to be located in a representative urban background spot. Thus, this might be one reason why the calculated NO_2 concentration in Kungälv is not performing a fit as good as for the others sites.

4.1.2 The whole of Sweden

In order to obtain ventilation indexes for the whole of Sweden the TAPM model was used. The reason why a finer grid was chosen for the southern part of the country was that the morphology has finer structures (topography, valley width m.m) in southern Sweden why the effect of the local climate was assumed to be reduce if a coarser grid would have been used. The time resolution of the calculations here is two-monthly means, January-February, March-April etc for 1999. All indexes for each two months period are presented in Figure 8.

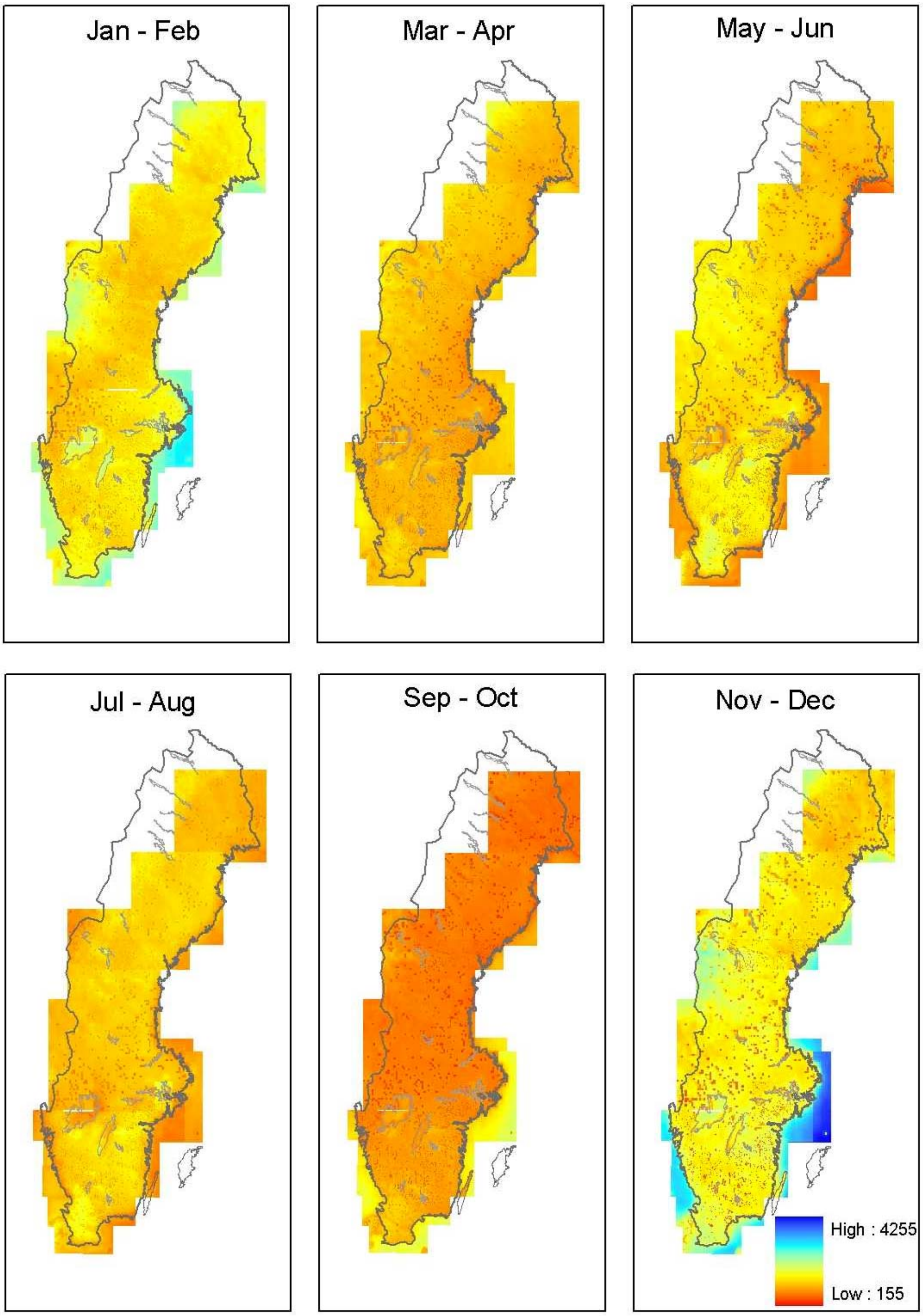


Figure 8 The variation of mixing index (V) during a year (1999) for two months periods Jan-Feb, Mar-Apr, May-Jun, Jul-Aug, Sep-Oct and Nov-Dec for Sweden, calculated with the TAPM model.

The mixing height (H) usually decrease from coastal areas and inland. It is also lower in valleys than at higher altitudes. The wind speed also decreases in a similar way as the mixing height. This usually results in larger mixing indexes along coasts and on top of mountains. However, this is not the case during the coastlines in May and June when V is lower along coasts than in the inland. The reason for this is that land areas are strongly heated during the long, and usually sunny, days while the water is still rather cool. This induces convection over land and therefore vertical movement is suppressed over water and thus along the coastal areas. Hence, the possibility of mixing differs very much depending on the location in the country. For example, Värmland has worse mixing conditions than Skåne. This is mainly due to the topography and the inland location.

Within an area V can also differ during the year. For example in parts of Småland V can be rather good during summer, but rather poor in the winter due to local climatological effects (e.g. inversions in valleys) (see Figure 6f).

From the mixing index calculations (Figure 6) various dispersion adjusting constants, C_d, were calculated by using the urban background concentrations from about 60 urban areas for all months. All C_d's are then grouped according to V in a span of 200 in each group. The means of C_d is the calculated in each group. In figure 9 both the original and the means of C_d is presented.

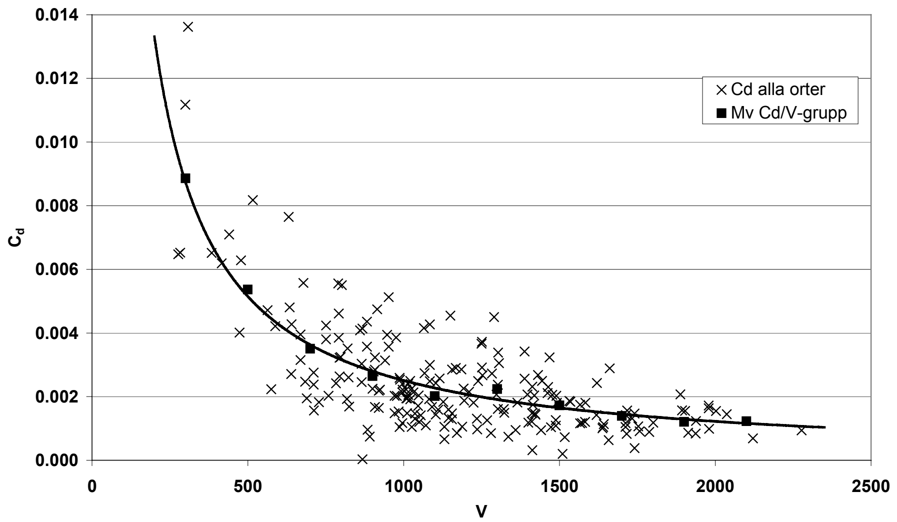


Figure 9 The means and the original values of C_d for all cities with measurements and for all months.

The result presented in figure 9 above illustrates that the constant C_d well describes that a compensation of the urban concentration interacts with the mixing possibility described in V. It is also shown that C_d does not vary with city size or time of the year. C_d can thus be used to better calculate the urban background concentration in cities where no measurements have been performed. In the calculations of urban background concentrations the new improved Urban model uses a C_d which is related to the calculated V for the location of the city and the time of the year.

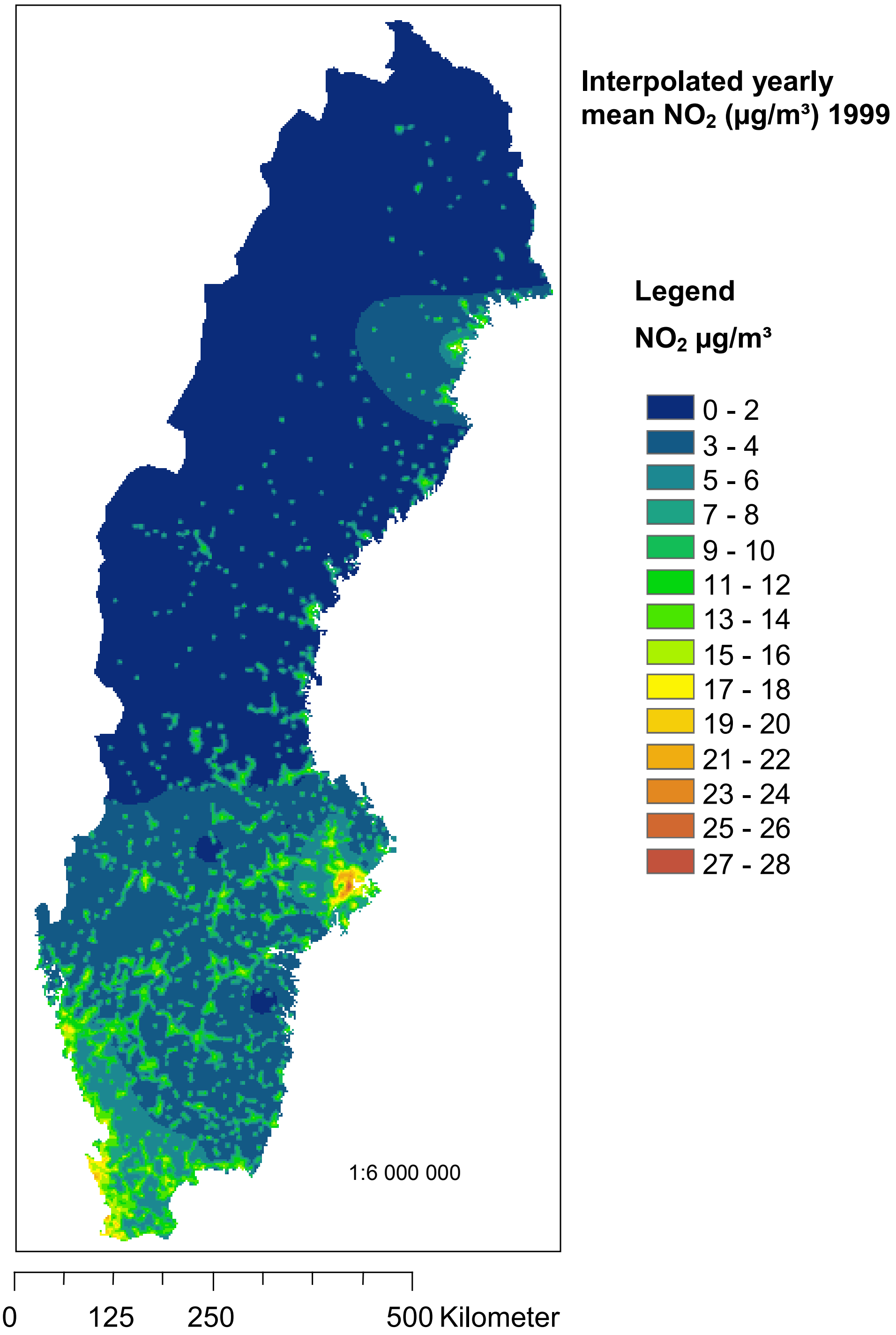


Figure 10 Interpolated yearly mean NO_2 concentration calculated with the New Urban Model.

4.2 Concentration calculations

For the calculation of the air pollution concentrations in urban areas in Sweden the new improved Urban model have been used. Since the calculation were based on gridded data information the over-lay analysis was performed in the GIS-system (ArcView).

4.2.1 NO_2 concentrations in Sweden

The yearly mean concentration of NO_2 calculated with the new urban model is presented in figure 10. This result is based of calculated two-monthly means in order to capture the seasonal variation, where higher concentrations usually appear during the winter. The calculated two-monthly means are presented is Appendix 1.

The input data used for the concentration calculations for the year 1999 comprised about

* 900 daily and 450 monthly means in rural/regional background air

* 10 000 daily and 350 monthly means in urban background air

In figure 10 it is visible that most of the country has rather low NO_2 urban background concentrations calculated for 1999, compared to the environmental standard for the yearly mean (40 $\mu g/m^3$). Most of the small to medium sized cities has a NO_2 concentration of 10-15 $\mu g/m^3$. In the large cities and along the Skåne West Coast the concentration is around 20.

There is an observable partition of Sweden north of Stockholm, possibly due to both a decreasing density of cities and meteorological factors. The locations of cities are giving the pattern of the concentrations, while the city size and the meteorological mixing parameters determine the levels. Thus, even in a small town high NO_2 concentrations can occur due to location in an area with bad ventilation.

According to the calculated results, there are no exceedances of the annual air quality standards in Sweden. However, since the standards are also valid for concentrations in street canyons which normally is 1.5 times higher than the urban background (Persson and Haeger-Eugensson, 2001), there may be exceedances at some “hot spots” in the country.

4.3 Population exposure

As mentioned above the highest NO_2 concentration levels normally will be found in street canyons. However, for studies of population exposure to air pollution it is costume to use the urban background air concentration levels, since this type of air quality data is used in dose-response relationship studies and health consequence calculations.

The number of people in Sweden exposed to certain levels of NO_2 in 1999 is shown in figure 10. From the figure it becomes obvious that the majority of people in Sweden, 40%, were exposed to yearly mean concentrations of NO_2 between 10-15 µg/m^3. Another 40% were exposed to less than 10 µg NO_2/m^3, and only about 5% of the Swedish inhabitants experienced exposure levels of NO_2 above 20 µg/m^3. The geographical distribution of the population exposure can be seen in figure 11 and 12.

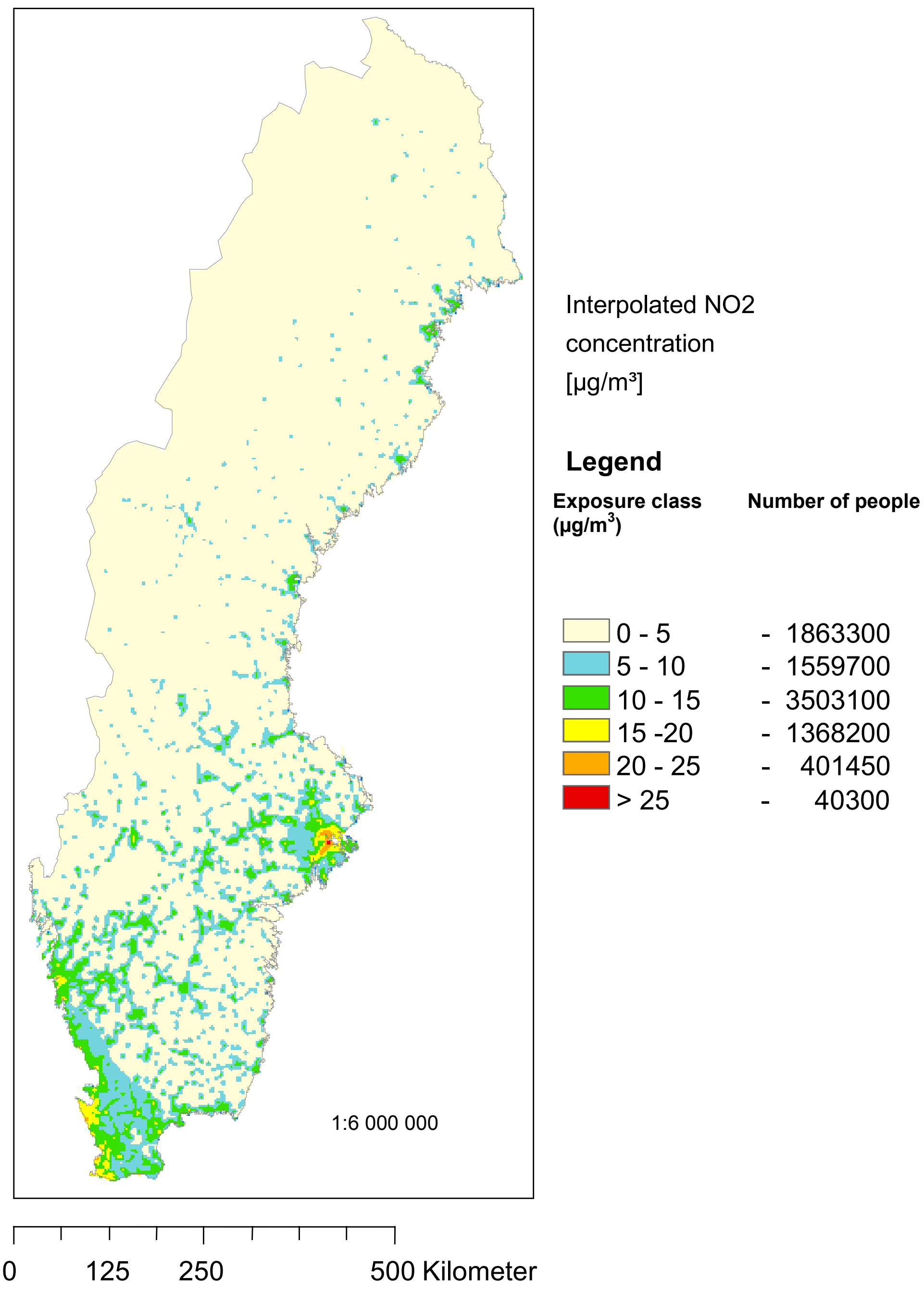


Figure 11 The number of people being exposed to different levels of NO_2 concentrations.

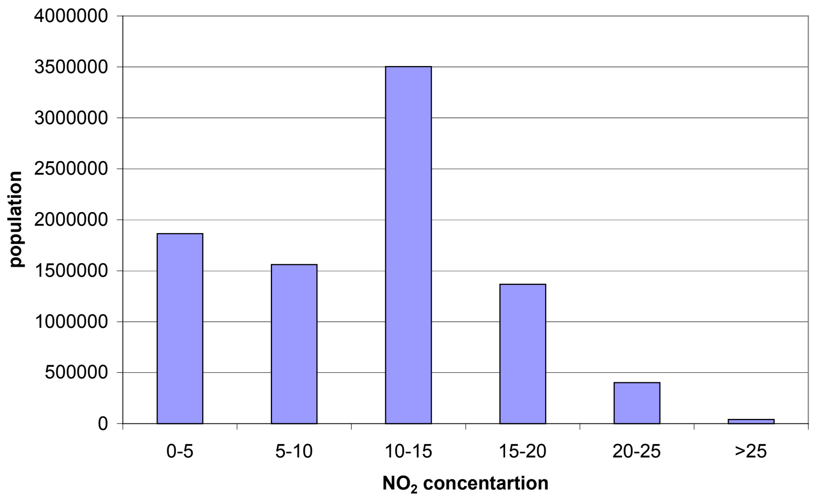


Figure 12 Number of people exposed to different levels of NO_2 in 1999 (based on figure 11).

The population weighted mean values for each exposure class are presented in table 2.

Table 2 Population weighted NO_2 mean value for each exposure class

Exposure class (µg/m^3)	Population weighted mean value (µg/m^3)
0 – 5	2.3
5 – 10	7.1
10 – 15	12.2
15 – 20	16.4
20 – 25	21.2
> 25	25.5

Figure 13 illustrates the total land area covered by certain NO_2 concentration levels in 1999. Over most of the Swedish land area (> 80%) the annual mean of NO_2 was less than 5 µg/m^3. NO_2 concentrations higher than 15 µg/m^3 were only found over less than 1% of the area.

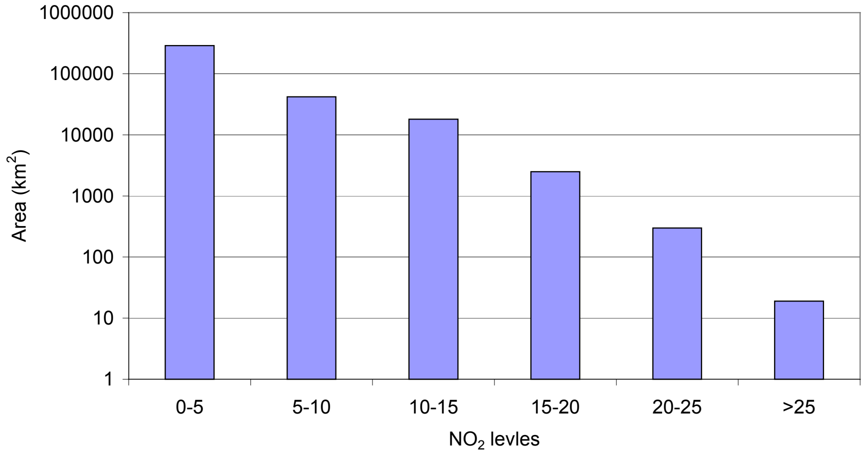


Figure 13 The area over which the different levels of air pollutants are spread over in logarithmic scale.

5 Discussion and conclusions

The results from the urban modelling show that in 1999 most of the country had rather low NO_2 urban background concentrations, compared to the environmental standard for the yearly mean (40 µg/m^3). Most of the small to medium sized cities has a NO_2 concentration of 10-15 µg/m^3. In the large cities and along the Skåne West Coast the concentration is around 20.

The results show that the majority of people in Sweden, 40%, in 1999 were exposed to yearly mean concentrations of NO_2 between 10-15 µg/m^3. Another 40% were exposed to less than 10 µg NO_2/m^3, and only about 5% of the Swedish inhabitants experienced exposure levels of NO_2 above 20 µg/m^3.

The improvement of the original URBAN model to achieve more accurate estimations has resulted in:

- a dispersion-related constant, C_b, calculated from measurements of monthly means of concentration of NO_2 at different geographical locations;
- a better description of the meteorological site-specific dispersion processes, described in the new ventilation index, V, including mixing height, wind speed in combination with the dispersion-adjusting constant C_b. All parameters are calculated with better time and geographical resolution than for the old ventilation factor F_v;
- the emissions are, like in the old model, still derived from the amount of the population in the communities, but its accordance has been verified.

The problem with dispersion modelling of today is that if all the important processes should be included into the calculation, the model becomes complex (a decent knowledge in meteorology is required to run the models properly) and often a long computation time is required. By calculating some of the main parameters for dispersion (H and U) with the advanced model TAPM and using this result in a simple model, some of these problems are solved. Consequently, the high demands of the simple model being able to reproduce a site specific climatology is thus being fulfilled, by the calculation of V (H*U) in the high resolution and in combination with the dispersion-adjusting constant, C_b. This is thus resulting in improved calculations compared to the performance of the original URBAN model. The urban background concentration is appropriate to use when calculating the C_b, since the result of all dispersion processes in an area (in combination with the regional background concentration) is representing a relevant situation, provided that the measurements are located at comparable urban background sites.

The connection between population and NO_2 emissions is a relevant approach, at least for air pollutants mainly generated from local sources. A further improvement of the emission calculations in the new URBAN model could possibly be a separate calculation for each town and city, instead of the whole community. As the new URBAN model calculations are done in a much higher geographical resolution than in the old version, this change would be relevant to perform. However, further investigations are required to test if the connection is as good between population and other pollutants as it is for NO_2.

A brief comparison between NO_2 concentrations calculated for the same area with the new Urban model, the TAPM model and a micro-scale model called Miskam shows that the results achieved by the different models are comparable. The NO_2 concentrations calculated by the Urban model is thus assumed to be reliable to use for the exposure studies on a national level. In order to validate the accuracy and sensitivity of this model for exposure assessment the relevant parts of the resulting population exposure levels will be compare to the outcome of the exposure model, with i.a. a higher geographical resolution, planned to be developed for the Scania Region within the SNAP programme. The model has the potential to be used for exposure estimates in small and medium sized towns. However, in the largest Swedish cities more sophisticated models might have to be used to achieve a more detailed picture of the air pollution load, and thus the exposure.

Dispersion models always calculate the concentration at roof top level as the output result. This will give an underestimation of the exposure levels later used for health consequence studies. Hence, the Urban model will give more relevant concentration patterns for estimation of long-term exposure (Forsberg, B. et al., 2004). However, short term variations (hourly) are not possible to calculate.

Latter epidemiological studies has shown that health impact might be better related to the concentration of NO_X than to NO_2. For areas outside cities the NO_X and NO_2

concentration are assumed to be equal. In urban background air the NO_2 part of the total NO_X concentration can vary largely both within a city and between cities, approximately between 50-90%.

Apart from the difficulty to interpret the health impact from a certain pollutant, there is a lot of other complications in population exposure calculations, such as representativity of air quality monitoring data, differences between indoor and outdoor concentrations, population movement etc. The model can provide possibilities to choose different levels of details for exposure estimates, i.e. to calculate the general exposure to air pollution based on assumptions of individual behaviour or only on ambient air concentrations for use in epidemiological studies. As the knowledge about air concentration patterns, personal exposure, indoor/outdoor relationships (concentration levels as well as movement pattern) is improved the input data for model calculations can easily be updated.

In a following project, funded by the Health effects program at the Swedish EPA, the results achieved within this part of the project will be used for estimating health impact due to air pollution.

6 References

APHEIS (2002). Health Impact Assessment of Air Pollution In 26 European Cities, Second-Year Report 2000-2001.

Chen, D., Wang, T., Haeger-Eugensson, M., Ashberger, C. and Borne, K. (2002). Application of TAPM (v.1) in Swedish West Coast: validation during 1999 and 2000. IVL Report L02/51.

Fergeson, S. (2002). Ventilation Climate Information System. USDA Forest Service and FERA- Fire and Environmental Research Applications' (http:// www.fs.fed.us/pnw/fera/vent.html/.

Fergeson, S. (2003). The potential for smoke to ventilate from windland fires in the United States. Pre-prints for the Fourth Symposium on Fire and Forest Meteorology organised by American Meteorological Society in February 2003.

Frisk luft – Underlagsrapport till fördjupad utvärdering av miljömålsarbetet (in Swedish). Naturvårdsverket (2003).

Forsberg, B., Modig, L., Svanberg, P-A., Segerstedt, B. (2003). Hälsokonsekvenser av ozon – en kvantifiering av det marknära ozonets korttidseffekter på antalet sjukhusinläggningar och dödsfall i Sverige (in Swedish). På uppdrag av Statens folkhälsoinstitut.

Forsberg, B., Modig, L., Segerstedt, B, Sjöberg, K., Persson, K., Haeger-Eugensson, M. (2004), Från enkla metoder att beräkna exponering till avancerade skattningar av relaterade hälsokonsekvenser – förslag till metodik i MKB för vägprojekt (in Swedish). Umeå universitet, 2004 (remissversion).

Haeger-Eugensson, M., Borne, K., Chen, D., Persson, K. (2002). Development of a New Meteorological Ventilation Index for Urban Air Quality Studies. IVL Report L02/70.

Hallgren Larsson E., Svensson A., Westling O. (2003). Luftföroreningar i skogliga provytor - Resultat till och med September 2002 (in Swedish). IVL Rapport B 1521.

Hardy, C., Ottmar, R. D., Petersen, J. and Core, J. (2003). Smoke management guide for prescribed and wildland fire. 2000 edition. Bois, ID: National Wildfire Coordinating Group.

Hurley, P.J. (1999a). The Air Pollution Model (TAPM) Version 1: Technical Description and Examples. *CAR Technical Paper No. 43*. 42 p.

Hurley, P.J. (1999b). The air pollution model (TAPM) version 1: User manual. Internal paper 12 of CSIRO Atmospheric Research Division 22 p.

Holzworth, G. C (1972). Mixing heights, wind speeds, and potentials for urban air pollution throughout the contiguous United States. Office of Air Publication No. AP-101. Research Triangular Park, NC US Environmental Protection Agency, Office of Air Programs.

Krieg, R. and Olsson, L. (1977). Undersökning av ventilationsklimatet i Sverige (Investigation of the ventilation climate in Sweden, in Swedish). SMHI.

Miljöhälsorapport 2001 (in Swedish). Socialstyrelsen, Institutet för Miljömedicin, Miljömedicin Stockholms läns landsting. ISBN 91-7201-495-4.

Lutz M. (2002).http://ies.jrc.cec.eu.int/Units/eh/events/EURO5/PROCEEDINGS/Session%20II%20Presentations/EuroV-Lutz-Berlin-fin.pdf Conference paper.

Persson, K and Haeger-Eugensson, M (2001). Luftkvalitetsituationen i svenska tätorter till år 2020 (in Swedish). IVL rapport L01/61.

Persson, K., Sjöberg, K., Svanberg, P-A., and Blomgren, H. (1999). Dokumentation av URBAN-modellen (Documentation of the URBAN model, in Swedish). IVL rapport L99/7.

Persson, K., Haeger-Eugensson, M., Brorström-Lundén, E. and Sjöberg, K. (2003). Luftkvaliteten i Sverige sommaren 2002 och vintern 2002/2003 (Air quality in Sweden summer 2002 and winter 2002/2003, in Swedish). IVL Report B 1535.

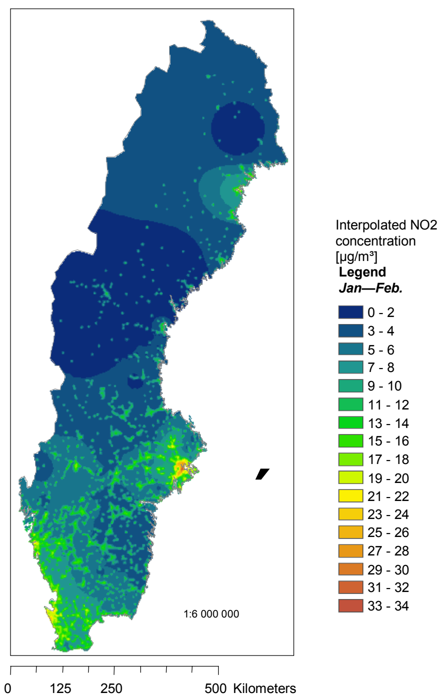
Pihl Karlsson, G., Blomgren, H., Peterson, K., Svensson, A., Sjöberg, K. (2003). Nationell miljöövervakning av luft- och nederbördskemi 2002 (National monitoring of air and precipitation chemistry 2002, in Swedish). For the Swedish Environmental Protection Agency. IVL Report U 852.

Sjöberg, K., Persson, K, Lagerström, M., Brodin, Y. (2004), Luftkvalitet i tätorter (Air quality in urban areas, in Swedish). IVL Report B 1553.

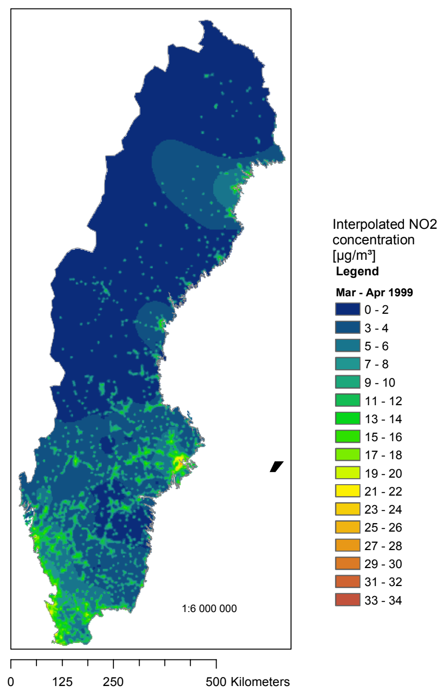
SOU (1979), Hushållning mark och vatten, del 2 (in Swedish). Statens Offentliga Utredningar. SOU Report 1979:55.

Appendix 1 Two month means of the NO_2 concentration

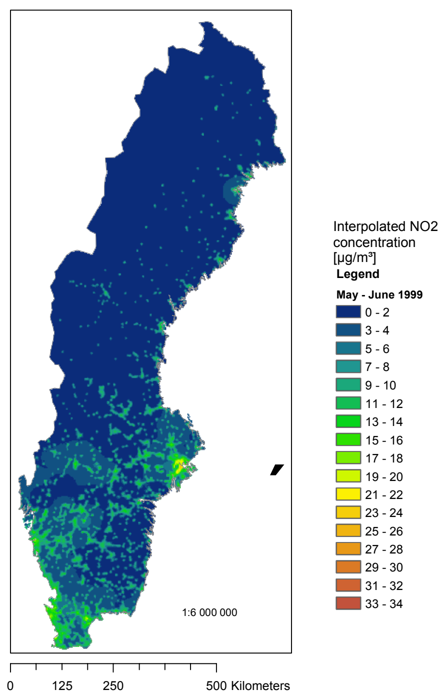
Two month means of NO_2 are presented in figure a-f.



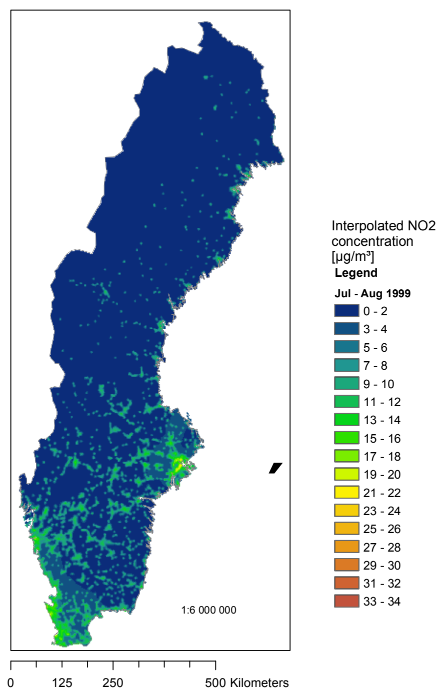
a)



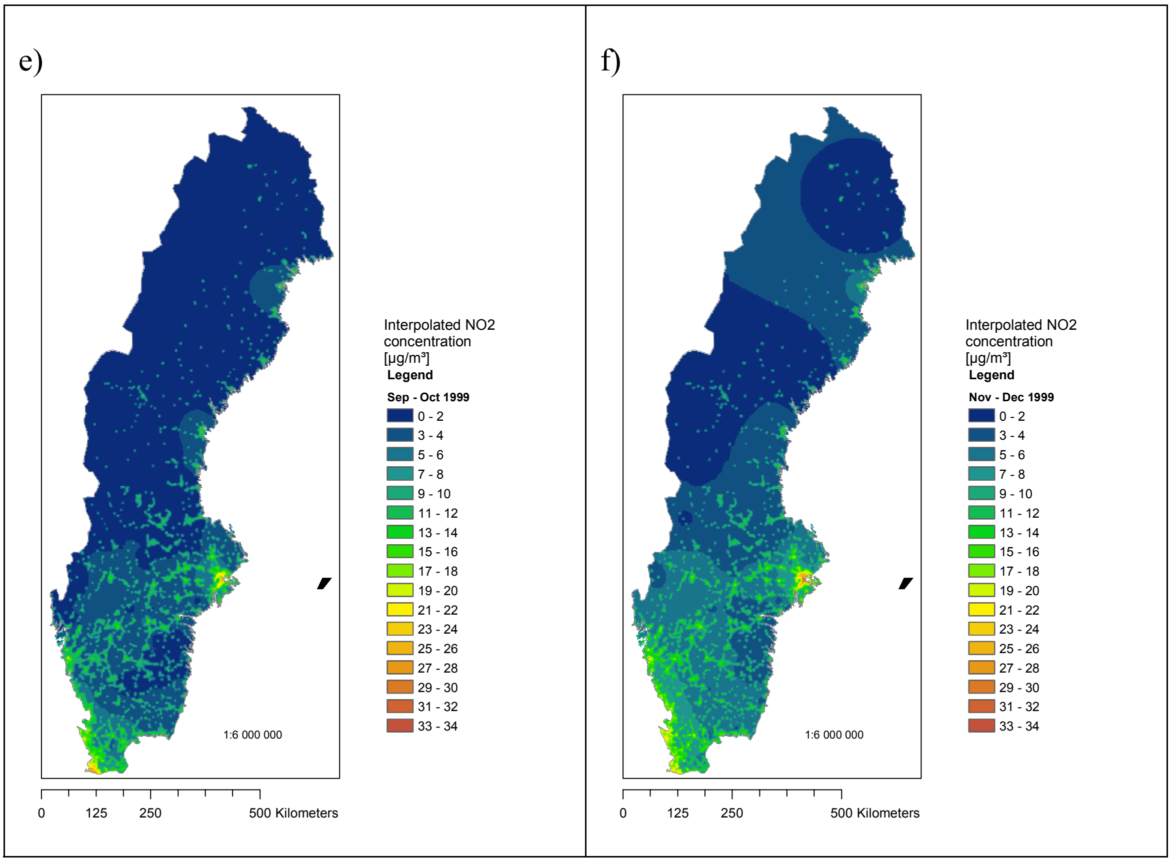
b)



c)



d)


e)
Interpolated NO2
concentration
[µg/m³]
Legend
Sep - Oct 1999
0 - 2
3 - 4
5 - 6
7 - 8
9 - 10
11 - 12
13 - 14
15 - 16
17 - 18
19 - 20
21 - 22
23 - 24
25 - 26
27 - 28
29 - 30
31 - 32
33 - 34
1:6 000 000
0
125
250
500 Kilometers
f)
Interpolated NO2
concentration
[µg/m³]
Legend
Nov - Dec 1999
0 - 2
3 - 4
5 - 6
7 - 8
9 - 10
11 - 12
13 - 14
15 - 16
17 - 18
19 - 20
21 - 22
23 - 24
25 - 26
27 - 28
29 - 30
31 - 32
33 - 34
1:6 000 000
0
125
250
500 Kilometers

IVL Svenska Miljöinstitutet AB

IVL Swedish Environmental Research Institute Ltd

P.O. Box 210 60, SE-100 31 Stockholm
Visit: Hälsingegatan 43, Stockholm
Phone: +46 8 598 563 00
Fax: +46 8 598 563 90

P.O. Box 5302, SE-400 14 Göteborg
Visit: Aschebergsgatan 44
Phone: +46 31 725 62 00
Fax: +46 31 725 62 90

Aneboda, SE-360 30 Lammhult
Aneboda, Lammhult
Phone: +46 0472 26 77 80
Fax: +46 472 26 77 90

www.ivl.se