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NERI Technical Report No. 623, 2007

The Danish Air Quality Monitoring Programme

Annual Summary for 2006

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Data sheet

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Abstract: The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring (LMP) network. The aim has been to monitor the levels of toxic pollutants in the urban atmosphere and to provide the necessary knowledge to assess the concentration trends, to perform source apportionment, and to evaluate the chemical reactions and the dispersion of the pollutants in the atmosphere. In 2006 the air quality was measured in four Danish cities and at two background sites. Besides this model calculations were carried out to supplement the measurements. NO_2 and PM_{10} were at several stations found in concentrations above EU limit values, which the Member States have to comply 2005 and in 2010. While the concentrations for most other pollutants have been strongly decreasing since 1982, only a minor decrease has been observed for NO_2 and O_3.

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Summary and Conclusion

The Danish Air Quality Monitoring Programme (LMP IV) has been revised and is still under revision in accordance with the EU Frame-work Directive and the four daughter directives of SO_2, NO_x/NO_2, PM_{10}, lead, benzene, CO, ozone, arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons. The data sets for year 2006 are almost complete for most stations. The monitoring programme consists in total of in total 10 stations. Also results from one station under the Municipality of Copenhagen are included in this report.

The concentrations in 2006 were almost the same as in 2005. Changes may mainly be due to meteorological conditions. Several exceedances of the limit value occurred for PM_{10}, while 2 exceedances of the limit value + plus margin of tolerance were measured for NO_2.

The limit value + the margin of tolerance for the annual average of NO_2 (48 µg/m^3 in 2006) was exceeded in Copenhagen at the street stations on H.C. Andersens Boulevard and Jagtvej. The limit value (to be complied with in 2010) of the annual average of NO_2, was in 2006 exceeded at four out of five street stations. The NO_2 concentrations seem to have been almost unchanged during the last ten years. Model calculations at selected streets in Copenhagen and Aalborg showed that the limit value + margin of tolerance were exceeded on a large number of streets in central Copenhagen while the concentrations in Aalborg were slightly below this value.

The ozone level was in 2006 slightly higher than in 2005 at all rural and urban background stations but no clear trend was observed. The information threshold on 180 µg/m^3 was exceeded two times. The target values were not exceeded, but the long-term objectives for both the max 8 hours on 120 µg/m^3 and the AOT40 on 6000 µg/m^3·h were exceeded at all non-traffic stations. The relative high values in 2006 are probably a result of the warm and sunny summer in Europe 2006. The O_3 pollution in Denmark is to a large extent caused by emissions in other European countries.

The limit value for the 35th highest daily average value for PM_{10} (50 µg/m^3) was in 2006 exceeded at 4 stations. The limit value for the yearly average (40 µg/m^3) was exceeded at one out of four stations (the margin of tolerance is = 0 from 2005). Emission in other European countries contributes significantly to the PM_{10} levels in Denmark.

The SO_2 and lead levels have been decreasing for more than two decades and are far below the limit values. The limit values for benzene and CO are not exceeded and the levels have been decreasing for the last decade.

Current data, quarterly reports, annual and multi-annual summaries are available at the website of NERI (http://www.dmu.dk/-International/-Air).

Danish summary - Dansk resumé

Rapporten præsenterer resultaterne fra overvågningsprogrammet for luftkvalitet i danske byer (LMP IV) for 2006. Formålet med programmet er at fastlægge koncentrationer af skadelige stoffer i luften i danske byer, følge udviklingen af koncentrationerne og vurdere kilderne til de enkelte stoffer. Målingerne bruges til at vurdere effekten af allerede gennemførte tiltag og beregne virkningen af mulige fremtidige tiltag. Desuden tjener resultaterne som videnbasis for en række videnskabelige undersøgelser, fx vurdering af små partiklers effekt på sundheden.

Der er fastsat grænse- og målværdier for flere af de målte stoffer. Grænseværdierne skal overholdes i 2005 eller 2010. Det er dog tilladt at overskride disse grænseværdier indenfor en fastsat tolerancemargin, som løbende reduceres. En detaljeret beskrivelse af gældende mål- og grænseværdier og deres gennemførelse findes i en bekendtgørelse fra Miljøministeriet (Miljøministeriet 2007). Bekendtgørelsen er baseret på EU-direktiverne (EC 1996, 1999, 2000, 2003 og 2005).

De væsentligste konklusioner fra overvågningsprogrammet i 2006 er følgende:

- Generelt var niveauerne i 2006 på samme eller lidt højere niveau end i 2005. Ændringer kan for en stor del skyldes meteorologiske forhold, bl.a. den varme sommer i 2006.
- Indholdet af kvælstofdioxid (NO_2) overskred i 2006 grænseværdierne, som skal overholdes fra 2010 på flere målestationer. Grænseværdien + tilladte margin (i 2006: 48 µg/m^3) blev i 2006 overskredet på de Københavnske gadestationer. Ligeledes viste modelberegninger at grænseværdi + tilladte margin var overskredet på et stort antal gadestrækninger i centrum af København. Tilsvarende modelberegninger for Aalborg viste et koncentrationsniveau lige under grænseværdi + tilladte margin.
- Indholdet af partikler mindre end 10 µm (PM_{10}) overskrider grænseværdierne som skal overholdes fra 2005 på 4 ud af 5 gadestationer.
- Der er ikke fastsat egentlige grænseværdier for ozon (O_3), men kun "målværdier" og "langsigtede mål" (hensigtsværdier). De langsigtede mål blev overskredet på alle ikke gadestationer.
- De øvrige målte stoffer findes i koncentrationer under grænseværdierne, og for flere stoffer (fx svovldioxid og bly) er indholdet faldet kraftigt siden målingernes start.

1 Introduction

The fourth Danish Air Quality Monitoring Programme (LMP IV) was started in 2000. The programme comprises an urban monitoring network with stations in the four largest Danish cities (fig. 2.1). The results are used for assessment of the air pollution in urban areas. The programme is carried out in a co-operation between the National Environmental Research Institute (NERI), the Danish Environmental Protection Agency, the Municipalities of Copenhagen, Aarhus and Aalborg and County of Funen. NERI is responsible for the practical programme. The results are currently published in quarterly reports in Danish and they are summarised in annual reports in English with a Danish summary (e.g. last years report Kemp et al. 2006). This report includes results from the LMP network and a station in Greater Copenhagen organised by the Environmental Protection Agency of the Municipality in Copenhagen. Statistical parameters and actual data are accessible at the website: http://www.dmu.dk/International/Air. Selected actual data are also available at tele-text, Danish National Television. Moreover, this report presents results from model calculation of air quality in Denmark carried out as supplement to the measurements in LMP.

Two national air quality monitoring networks are in operation in Denmark. Beside the LMP programme, a network in rural areas (the Danish Background Monitoring Program) was established in 1978 (fig. 2.1). NERI runs both programmes. At present gas and aerosol measurements are performed at six stations, and various ions are determined in precipitation collected at 9 sites. The Environmental Protection Agency of the Municipality in Copenhagen is responsible for a street station in the central part of Copenhagen (www. miljoe.kk.dk). The site (H.C. Andersens Boulevard) is operated by NERI and is under the same quality control/quality assurance as the other measurement stations in LMP IV. The whole program is from 2007 fusioned under the auspices of NERI.

The present Danish limit values are identical with the limit values laid down in the EU directives. The new EU legislation consists of the framework directive (EC, 1996), giving general rules for network design and limit value strategies, and a number of daughter directives giving limit values, target values, alert thresholds, reference methods and monitoring strategies for specific pollutants. The limit values are close to the recommendations (WHO, 2000) based on the known health effects of the pollutants. The limit values must in most cases be attained in 2005 or 2010. Until then a so-called margin of tolerance are added to the limit values. The margin of tolerance is gradually reduced to zero at the date of compliance. Daughter Directives for NO_2, SO_2, particulate matter (PM_{10}) and Pb (EC, 1999), CO and benzene (EC, 2000) and O_3 (EC, 2002) are adopted. Most recently a daughter Directive for Cr, As, Cd, Hg and PAH (EC, 2005) have been adopted. In the following chapters the results from measurements and model calculations are compared to limit and threshold values. Please refer to the Directives for a detailed description of the exact definitions of the limit values, margin of tolerance, target values and alert thresholds.

2 Measurements and model calculations

The measuring strategy is in short to place one or more pairs of stations in each city. One of the stations is located close (at the sidewalk) to a street lane with a high traffic density. The other is located within a few hundred meters from the street station, and is representative for the urban background pollution; it is not influenced by a single or a few streets or other nearby sources. In most cases the background stations are placed on rooftops. In addition, two rural stations monitor the pollution outside city areas. Further information about the program and results is found at the website: http://www.dmu.dk/International/Air.

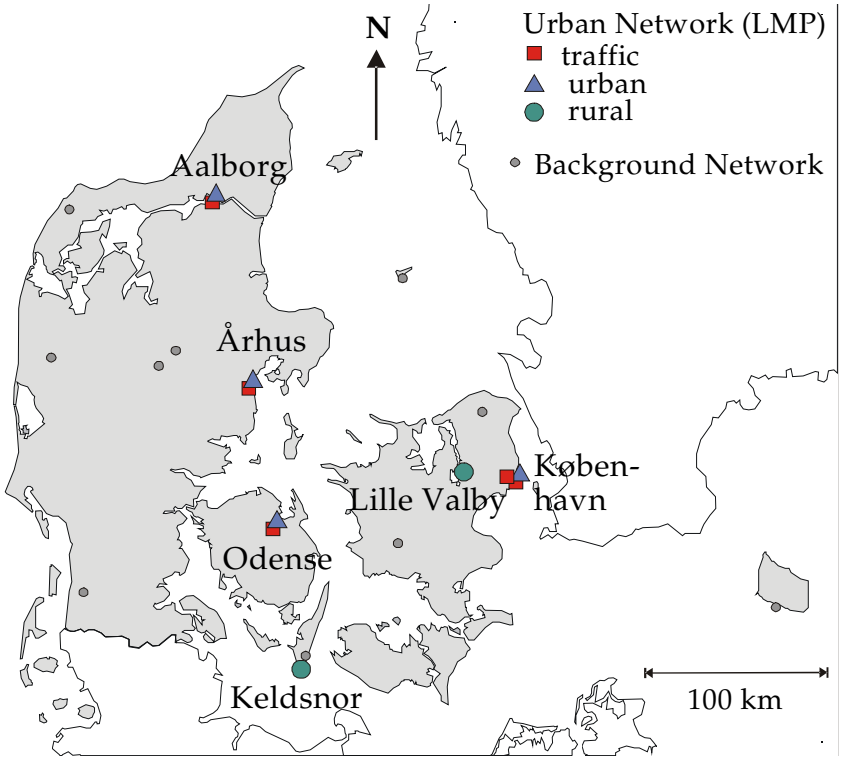


Figure 2.1 Monitoring stations in the two nation-wide air quality networks (including the Copenhagen Municipality Station).

Table 2.1 Stations in the LMP IV network and the Copenhagen Municipality included in this report for 2006

Name	Street/location	Type	Remarks
Copenhagen/1257	Jagtvej	Street	
Copenhagen/1259	H.C. Ørsted Institute	Urban background	
Copenhagen/1103	H.C. Andersens Boulevard	Street	Copenhagen Municipality
Århus/6153	Banegårdsgade	Street	
Århus/6159	Valdemarsgade	Urban Background	
Odense/9155	Albanigade	Street	
Odense/9159	Town hall in Odense	Urban background	
Aalborg/8151	Vesterbro	Street	
Aalborg/8158	Østerbro	Urban background	
Lille Valby/2090	-	Rural	CO measurements startet February 2005
Keldsnor/9055	-	Rural	

The following compounds were measured:

- NO, NO_x (including NO_2=NO_x-NO), PM_{10} and elements (heavy metals) in PM_{10} were measured at all stations. PM_{10} was measured by means of β-absorption.
- PM_{10} was measured at Copenhagen/1103, -/1257 and -/1259 by means of TEOM.
- $PM_{2.5}$ was measured at Copenhagen/1103, -/1259 and Lille Valby/2090 by means of TEOM.
- O_3 was measured at all urban background and rural stations, Copenhagen/1257 and Copenhagen/1103
- CO was measured at all street stations, the urban background station, Copenhagen/1259 and the rural site Lille Valby /2090.
- Benzene and Toluene were measured at Copenhagen/1103 and Copenhagen/1257
- SO_2 was measured at Aalborg/8151 and at Copenhagen/1103. The main purpose was to monitor episodic high concentrations.
- The meteorological parameters - temperature, wind speed and direction, relative humidity and global radiation - were measured at all urban background stations.

The pollutants are described in the appendix.

Apart from measurements of PM_{10} all parameters were recorded as ½-hour averages. PM_{10} and elements in the particles were measured as 24 hour averages. TEOM results are recorded as ½-hour averages for PM_{10} and $PM_{2.5}$.

Short descriptions of the measured pollutants are given in the appendix. The actually applied measurement methods are listed at the website: http://www.dmu.dk/International/Air.

In LMP the measurements at fixed measurement stations are supplemented with model calculations using the following models:

- The Danish Eulerian Hemispheric Model (DEHM)
- The Danish Eulerian Operational Model (DEOM)
- The Urban Background Model (UBM)
- The Operational Street Pollution Model (OSPM)

Model calculations of air quality on national scale is carried out using DEHM, which is an Eulerian model where emissions, transport, chemical reactions, physical transformations, and depositions of air pollutants are calculated in a three dimensional net of grid cells covering the northern hemisphere. The transport of air pollutants is calculated on the basis of meteorological data from a weather forecast model and takes place in and out of the individual grid cells in both horizontal and vertical directions. The calculations of air quality in Denmark are carried out with a geographical resolution of 16.67 km x 16.67 km in the horizontal plane. In the vertical direction the model is divided into 20 layers covering the lowest 15 km of the atmosphere. Of these the lowest layers are relatively thin (60 m) while the upper layers are relatively thick (2000 m). The model includes a comprehensive chemical scheme for calculation of the chemical reactions in the bottom part of the atmosphere. The model calculations for 2006 are carried out using meteorological data from the meteorological model MM5v3 (Grell et al., 1995). The emission inventories used in DEHM have a geographical resolution on 16.67 km x 16.67 km for Europe and are based on Danish national emission inventories for the year 2005 made by NERI (www.dmu.dk) and international emission inventories for the year 2004 collected and distributed by EMEP (www.emep.int).

Model calculations for Aalborg are carried out using the Thor system, which is an integrated model system, capable of performing model calculations at regional scale over urban background scale and down to individual street canyons in cities – on both sides of the streets (thor.dmu.dk). At present the system includes global meteorological data from National Centres for Environmental Prediction, United States, which is used as initial and boundary conditions for the numerical weather forecast model Eta (Janjié, 1994). The weather data from Eta is used to drive the air pollution models, including the Danish Eulerian Operational Model, DEOM (Brandt et al., 2001), the Urban Background Model, UBM (Berkowicz, 1999b) and the Operational Street Pollution Model, OSPM (Berkowicz (1999a). DEOM is providing air pollution input data for UBM which again is again is providing air pollution input data to OSPM. Further details about the system can be found in Brandt et al. 2001 and 2003.

DEOM is a long-range chemical transport model. The model is similar to DEHM, however less comprehensive and it is planned to substitute DEOM with DEHM in the Thor system in the near future. DEOM is applied at a resolution of 50 km x 50 km covering Europe and has three vertical layers up to 3 km. Emissions from EMEP have been implemented in the model. The model includes 35 chemical species based on the CBM-IV chemical scheme.

Meteorological data from the meteorological model Eta and air pollution concentrations from DEOM are used as input to the Urban Background Model, UBM, calculating the urban background air pollution based on emission inventories with a spatial resolution down to 1 km x 1 km. UBM is suitable for calculations of urban background concentrations when the dominating source is the road traffic. The model includes a simple scheme for calculation of the dispersion and transport of the air pollutants and a simple chemical model accounting for oxidation of nitrogen monoxide by ozone based on an assumption of photochemical equilibrium on the time scale of the pollution transport across the city area. The model is described in detail in Berkowicz (1999b).

Finally, the street canyon model OSPM is used to calculate the air pollution at 2 m height at the side walks of the 10 selected streets in Aalborg. Meteorological data from the meteorological model Eta and air pollution concentrations from UBM are used as input to the model. The model includes emissions from traffic, simple chemical reactions describing the reactions of air pollutants in the street canyons and the dispersion of the air pollution in the street canyon (due to meteorological conditions and the moving traffic). The traffic emission data used for the calculation with OSPM is based on traffic information from 1999 provided by the Municipality of Aalborg.

The calculations of the NO_2 concentration in 138 selected streets in Copenhagen are also carried out using OSPM. However, the urban background concentration is in this case taken from the measurements at the urban background measurement station in Copenhagen at the H. C. Ørsted Institute. Meteorological data are also based on the measurements at this site. The traffic emission data used for the calculations in Copenhagen are based on NERI's traffic database for 2003 and emission factors are from the latest version of the COPERT IV emissions model.

The model calculations for 2006 are carried out using the existing models and the best available emission data. In order to improve and streamline the model calculations carried out in LMP work has been initiated to harmonize and update the models and the emission data.

3 Nitrogen oxides

3.1 Yearly Statistics

Table 3.1 Nitrogen dioxide (NO_2) in 2006. All parameters are calculated with hourly averages.

Unit: µg/m^3	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	8616	53*)	48	124	159
Copenhagen/1103	8579	53*)	51	104	131
Århus/6153	8242	45	42	103	132
Odense/9155	8671	34	28	96	120
Aalborg/8151	8671	43	37	111	141
Urban Background:					
Copenhagen/1259	8420	25	21	65	90
Århus/6159	8697	21	17	57	74
Odense/9159	8693	18	15	52	71
Aalborg/8158	8458	19	15	58	84
Rural:					
Lille Valby/2090	8615	12	9	42	65
Keldsnor/9055	8215	10	7	36	53
Limit values/limit value + margin of tolerance for 2006	>7884	40/48			200/240

*) Limit value + margin of tolerance exceeded.

Table 3.2 Nitrogen oxides (NO_x=NO+NO_2) 2006. All parameters are calculated with hourly averages.

Unit: µg/m^3 (as NO_2)	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	8616	110	91	347	515
Copenhagen/1103	8579	114	97	326	531
Århus/6153	8242	100	81	331	540
Odense/9155	8671	71	48	288	468
Aalborg/8151	8671	105	78	382	607
Urban Background:					
Copenhagen/1259	8420	33	26	109	193
Århus/6159	8697	31	23	115	237
Odense/9159	8693	25	20	88	152
Aalborg/8158	8458	29	20	108	267
Rural:					
Lille Valby/2090	8616	16	11	58	108
Keldsnor/9055	8392	13	10	47	72

The limit values are based on EU Council Directive 1999/30/1999 (EC 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

3.2 Episodes

Table 3.3 Episodic results for Nitrogen dioxide (NO_2) in 2006. All parameters are calculated with hourly averages.

Unit: µg/m^3	Max. 3 hours	Date:hour	Max. hour	Date:hour
Traffic:				
Copenhagen/1257	166	060421: 6	212	060421: 6
Copenhagen/1103	135	060817: 6	158	060825: 5
Århus/6153	144	060301: 6	219	060301: 6
Odense/9155	133	060517: 6	177	060508: 6
Aalborg/8151	135	060317:15	169	060421: 7
Urban Background:				
Copenhagen/1259	93	61220:16	105	061220:17
Århus/6159	71	060426:16	110	060509:22
Odense/9159	79	060314: 6	108	060314: 8
Aalborg/8158	100	061110: 8	111	061110: 9
Rural:				
Lille Valby/2090	71	060307:22	76	060307:23
Keldsnor/9055	71	060502:20	84	060618:20
Alert threshold	400	-	-	-

Table 3.4 Episodic results for Nitrogen oxides (NOx=NO+NO_2) 2006. All parameters are calculated with hourly averages.

Unit: µg/m^3 (as NO_2)	Max. 3 hours	Date:hour	Max. hour	Date:hour
Traffic:				
Copenhagen/1257	313	061018:11	762	061018: 7
Copenhagen/1103	291	060127:15	814	60127:11
Århus/6153	403	061018:13	920	061018: 8
Odense/9155	296	060104:13	705	060104: 8
Aalborg/8151	369	060127:17	749	060118:15
Urban Background:				
Copenhagen/1259	127	061220:32	291	061018: 7
Århus/6159	200	061018:15	557	061018: 9
Odense/9159	126	060314:11	371	060314: 8
Aalborg/8158	217	061110:15	498	061110: 9
Rural:				
Lille Valby/2090	86	060307:43	211	060307:23
Keldsnor/9055	40	060502:37	114	060214: 6

The Alert threshold is given in EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The "Max 3. hour" values are defined and calculated in the following way: First find the lowest one hour value for all consecutive three-hours periods. Second find the highest of these lowest one hour values which is defined as the "Max 3. hours" values, which is listed in table 3-3 and 3-4.

3.3 Trends

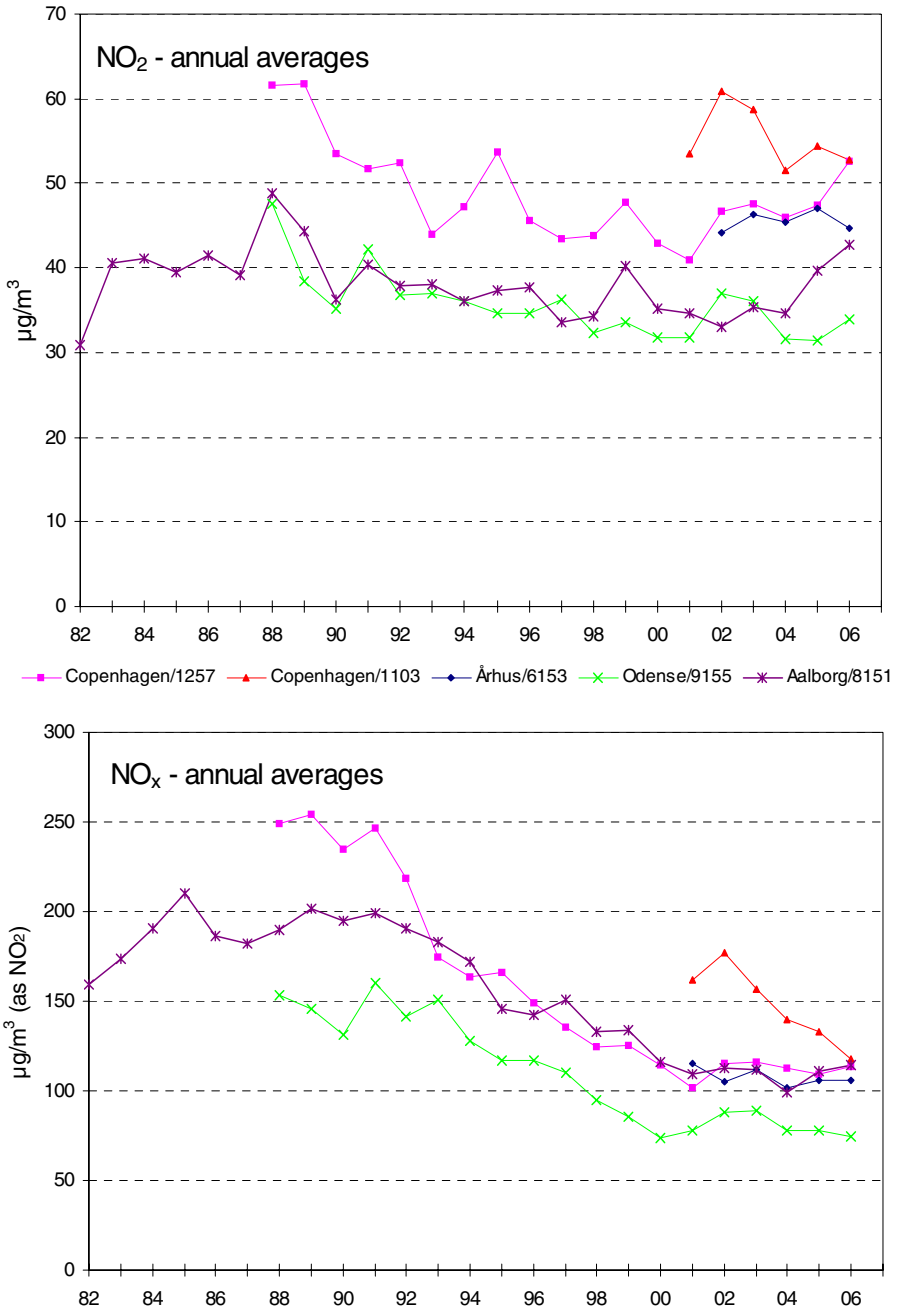


Figure 3.1 The graphs show the time series for the annual average values measured at street stations. Previous results from Copenhagen/1103 can be found at the homepage of Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk)

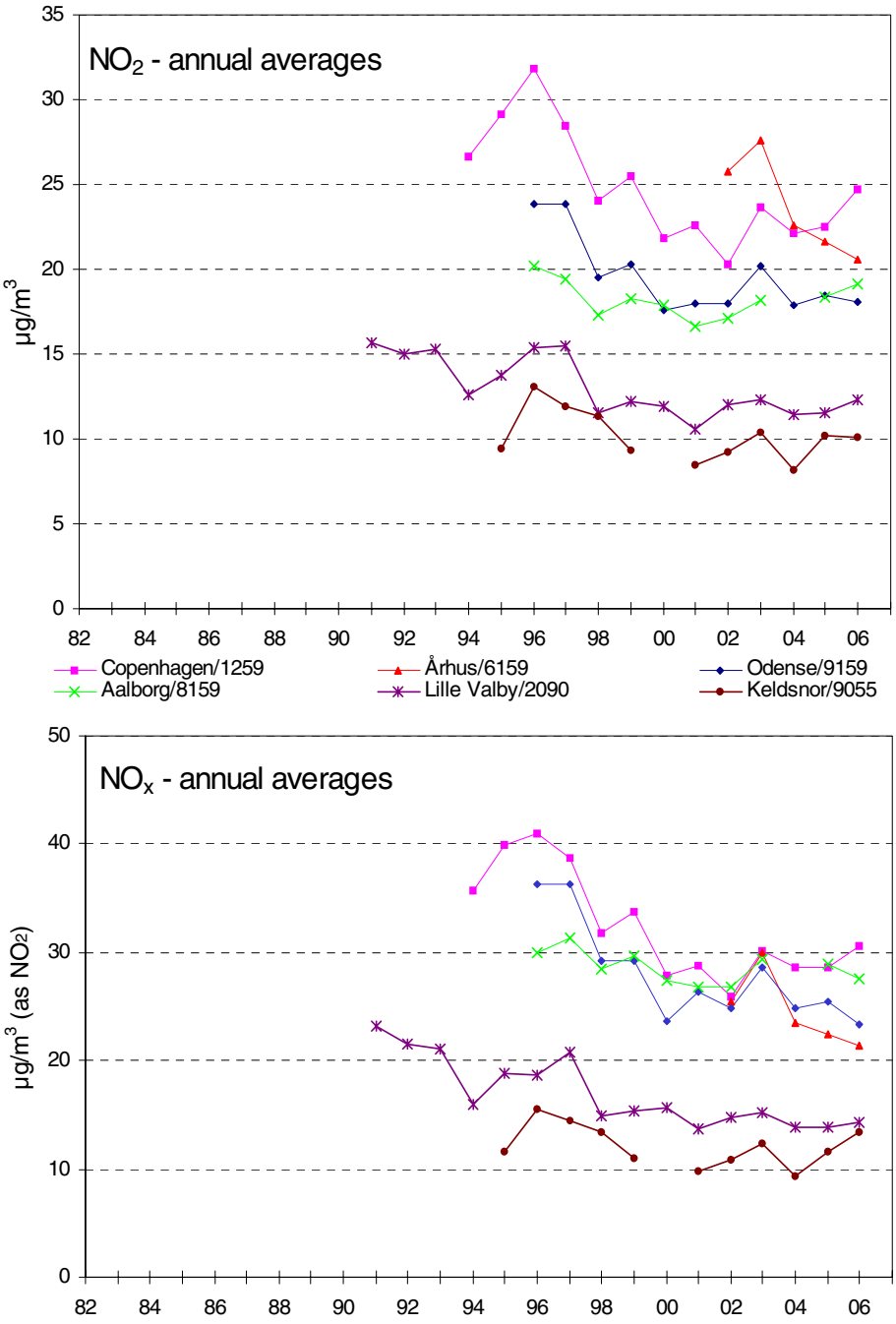


Figure 3.2 The graphs show the time series for the annual average values measured at urban background and rural stations.

3.4 Results from model calculations

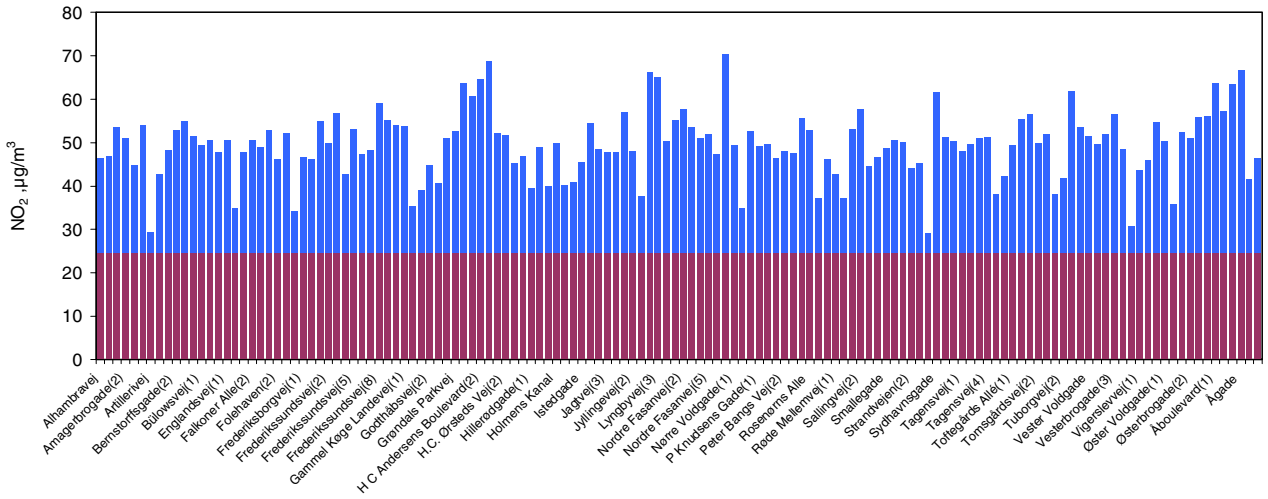


Figure 3.3 Annual mean concentrations of NO_2 for 2006 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with OSPM. The urban background (dark red colour) is obtained from measurements at the H.C. Ørsted Institute. This might lead to minor errors (estimated to ± 1-2 µg/ m^3) in the calculations. Further details on the calculation can be found in Jensen et al., 2005). The value for a street is for the kerb side with the highest annual mean concentration.

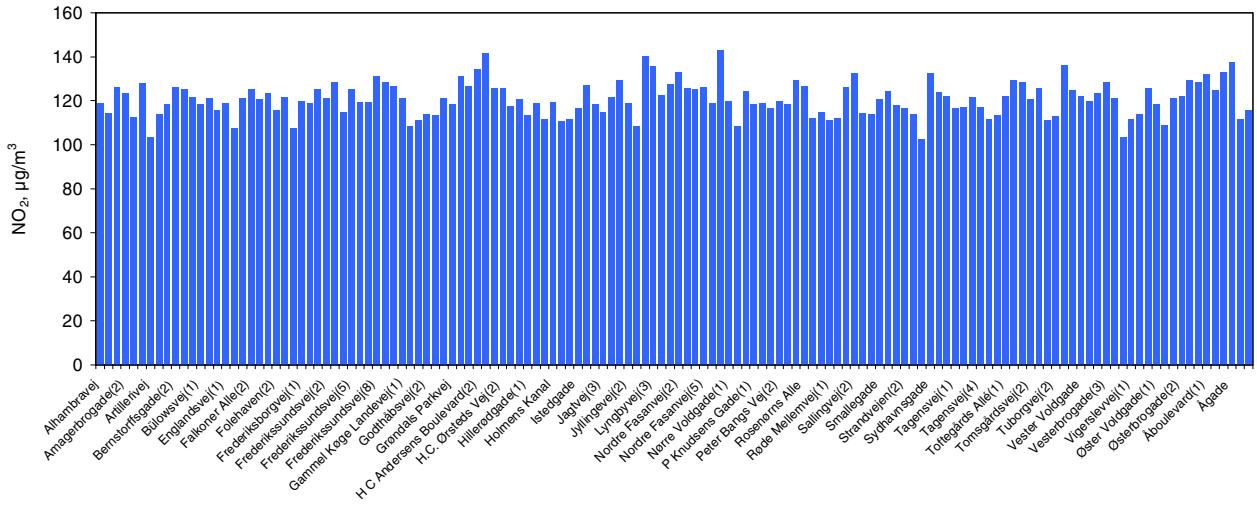


Figure 3.4 The 19th highest concentration of NO_2 in 2006 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with OSPM, while the contribution from urban background is obtained from measurements at the H.C. Ørsted Institute. The value for a street is for the kerb side with the highest concentration.

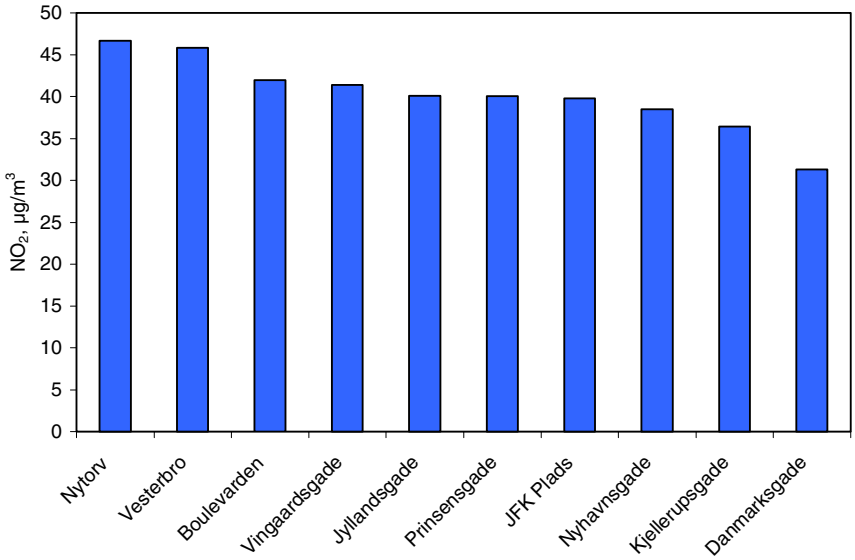


Figure 3.5 Annual mean concentrations of NO_2 in 2006 for 10 selected streets in Aalborg. The contribution from traffic in the street canyons is calculated with OSPM, while the contribution from urban background is calculated using UBM. The value for a street is for the kerb side with the highest concentration.

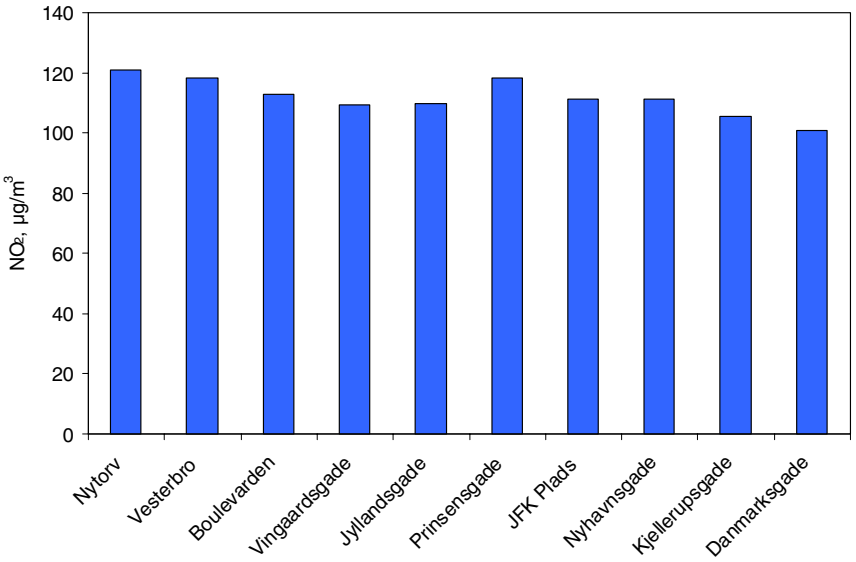


Figure 3.6 The 19th highest concentration of NO_2 in 2006 for 10 streets in Aalborg. The contribution from traffic in the street canyons is calculated with OSPM while the contribution from urban background is calculated using UBM. The value for a street is for the kerb side with the highest concentration.

In 2006 the limit value plus margin of tolerance for protection of human health is 48 µg/m^3 for the annual mean concentration and 240 µg/m^3 for the 19th highest concentration of NO_2. The limit values are based on EU Council Directive 1999/30/1999 (EC 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The results from the model calculations for 2006 show that the limit value plus margin of tolerance for the annual mean concentration was exceeded in 87 of the 138 selected streets in Copenhagen (figure 3.3). The limit value plus margin of tolerance for the 19th highest concentration is not exceeded at any of the selected streets (figure 3.4).

The results from the model calculation show that the limit value for the annual mean concentration and for the 19th highest concentration was not exceeded in Aalborg (figure 3.5 and 3.6).

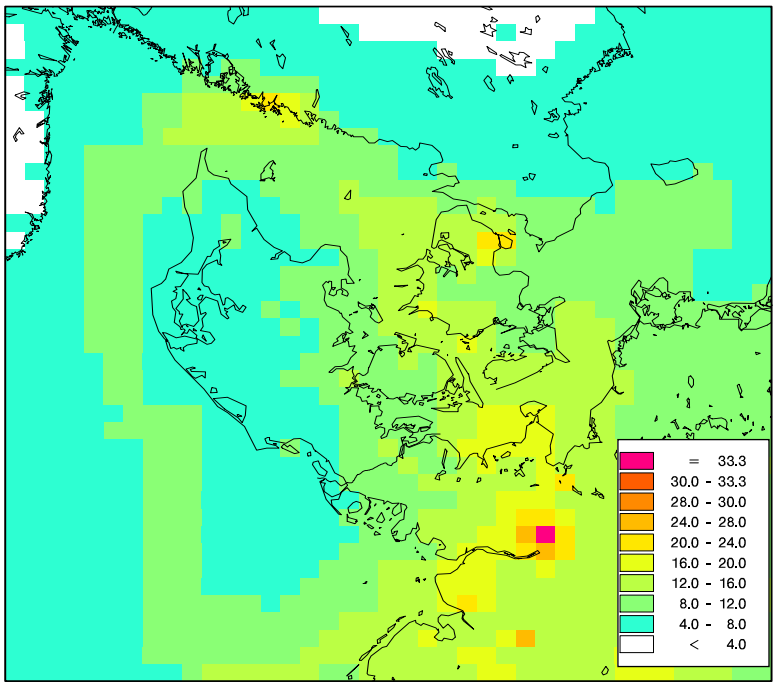


Figure 3.7 Annual mean concentrations of NO_x for 2006 calculated with DEHM given as µg/m^3, when all NO_x is calculated as NO_2. The figure shows the average concentrations for the 16,67 x 16,67 km grit cells used in the model. The high concentrations calculated for the inner Danish waters are due to emissions from ships.

The limit value for protection of ecosystems is 30 µg/m^3 NO_x calculated for the calendar year. The limit value is based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations show (figure 3.7) that the annual mean concentrations of NO_x were below the limit value in 2006.

4 Ozone

4.1 Annual statistics

Table 4.1 *Ozone* (O_3) 2006. All parameters are calculated with one-hour average values. The eight hour values are calculated as a moving average based on hourly measurements. For the "26. highest 8 hour" value is used the highest daily 8 hour average values calculated as described in the EU Directive 2002/3/EC.

Unit: µg/m^3	Number of results	Average	Median	Max. 8 hours	26. highest 8 hour	Max. 1 hour	AOT40 µg/m^3.h
Urban Background:							
Copenhagen/1259	8699	54	54	154	52	164	13640
Århus/6159	8692	50	52	148	97	166	8249
Odense/9159	8678	54	53	153	111	167	14179
Aalborg/8158	8297	58	60	162	104	179	13973
Rural							
Lille Valby/2090	7902	61	62	163	113	181	17899
Keldsnor/9055	8576	60	60	149	80	179	11065
Traffic							
Copenhagen/1257	8491	37	36	119	81	128	2750
Copenhagen/1103	8683	34	33	112	59	121	1955
Target value	>7884	-	-	-	120	-	18 000
Long term objective	>7884	-	-	120	-	-	6 000

The target values and long term objectives are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Number of information to the public due to exceedance of the information threshold (180 µg/m^3) in 2006: 2.

Number of information to the public due to exceedance of the alert threshold (240 µg/m^3) in 2006: 0.

4.2 Trends

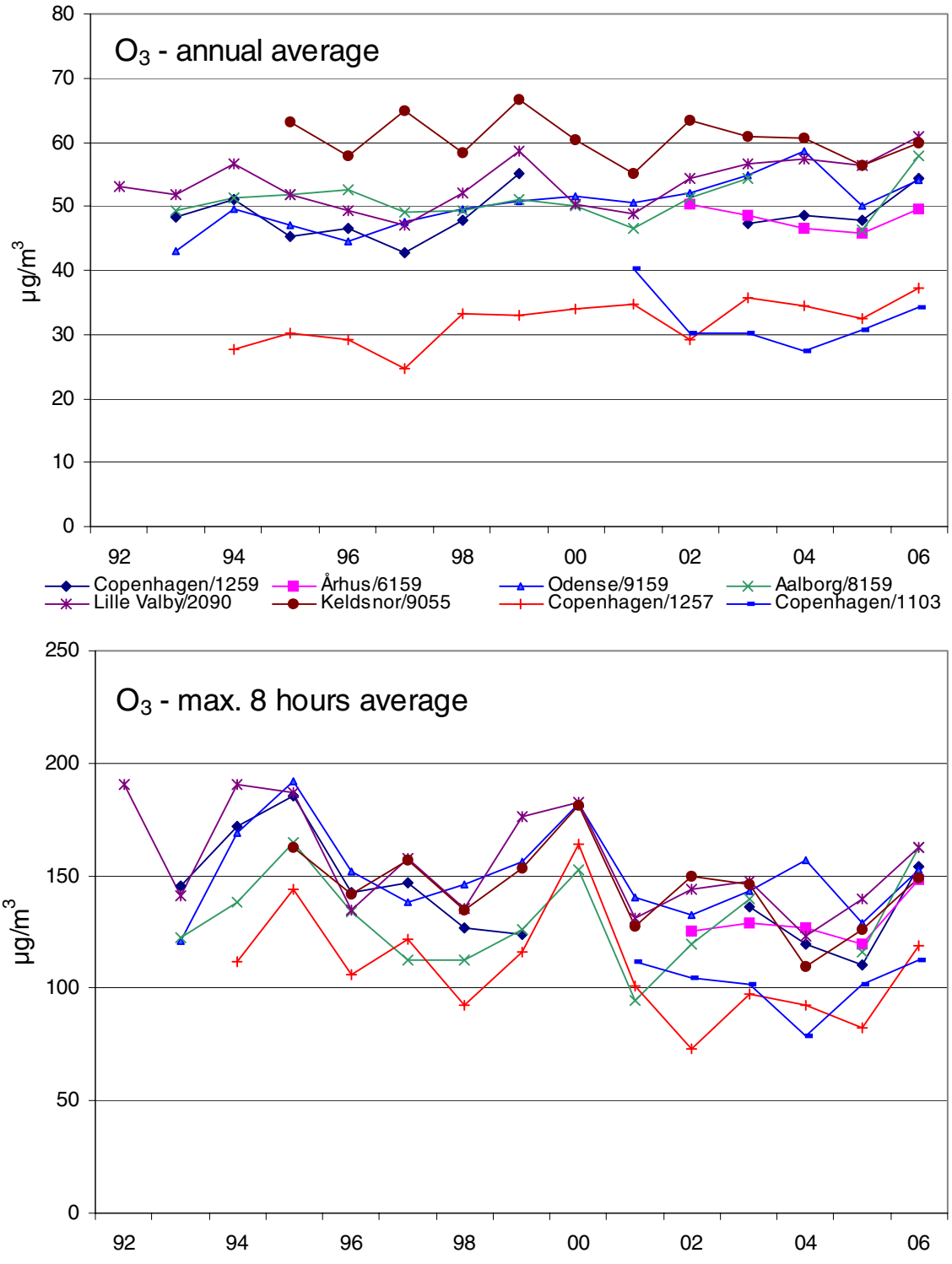


Figure 4.1 Annual average values and the max. 8 hour average value. The latter is calculated as hourly 8 hour running averages according to the provisions in the EU Council Directive (EC, 2002). Previous results from Copenhagen/1103 can be found at the Website of the Copenhagen Environmental Protection Agency (www. Miljoe.kk.dk).

4.3 Results from model calculations

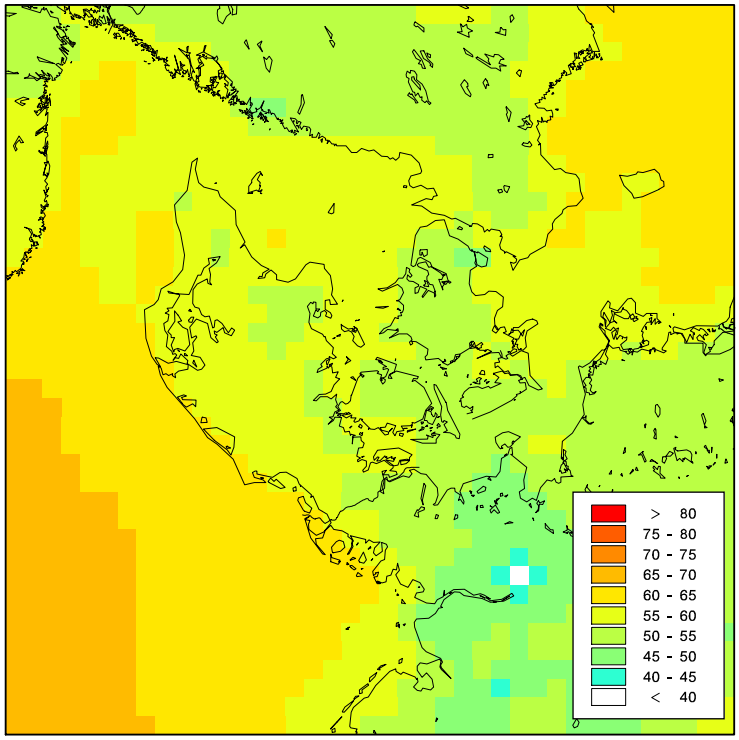


Figure 4.2 Annual mean concentrations of O_3 (µg/m^3) for 2006 calculated using DEHM. The figure shows the average concentrations for the 16,67 x 16,67 km grit cells used in the model.

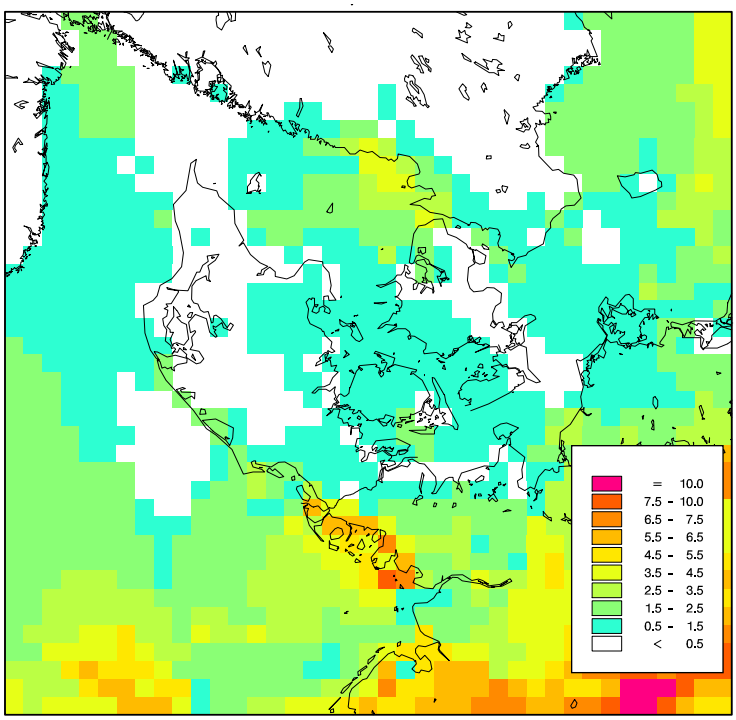


Figure 4.3 Number of exceedances of 120 µg/m^3 for 8-hour running mean concentrations of ozone in 2006. The calculations were carried out using DEHM.

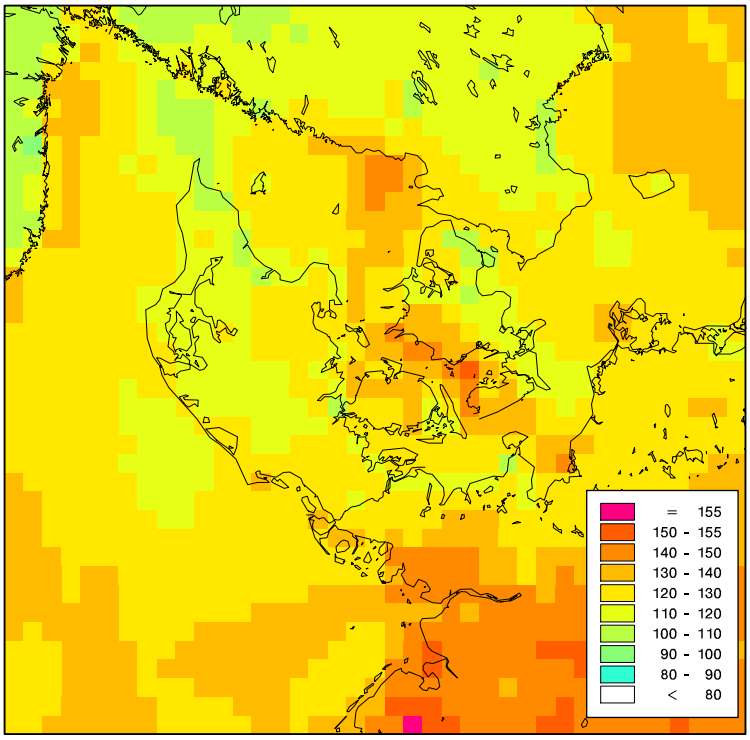


Figure 4.4 Maximum 8 hour running mean concentration (µg/m^3) of ozone in 2006 calculated using DEHM.

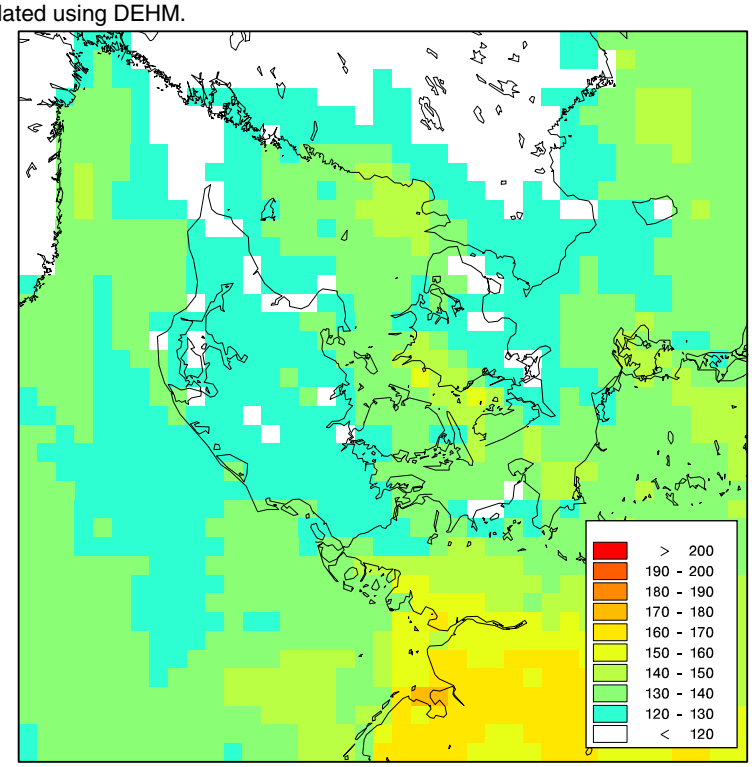


Figure 4.5 Maximum one hour mean concentration of ozone (µg/m3) in 2006 calculated using DEHM.

The target value for protection of human health is that the running 8 hour mean concentration of ozone must not exceed 120 µg/m^3 more than 25 times a calendar year. The long term objectives are that the running 8 hour mean concentration of ozone must not exceed 120 µg/m^3. The target value and long term objective are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). Results from the model calculations show that the target value was not exceeded (figure 4.3) but that the long term objective was exceeded for large parts of the country (figure 4.4).

According to the directive (EC, 2002) the public has to be informed if the one hour mean concentration exceed the information threshold of 180 µg/m^3. Based on measurements this was done twice in 2006. However, the model calculations show that the one hour mean concentration did not exceed 180 µg/m^3 in 2006. The reason for this discrepancy is most likely that the model does not include emissions from wild fires. Large wild fires are known to increase episodic ozone concentrations. Work has been initiated to include emissions from wild fires in the model. Inclusion of emissions of wild fires in the model calculations may also increase the area where the long term objective for ozone was exceeded in 2006.

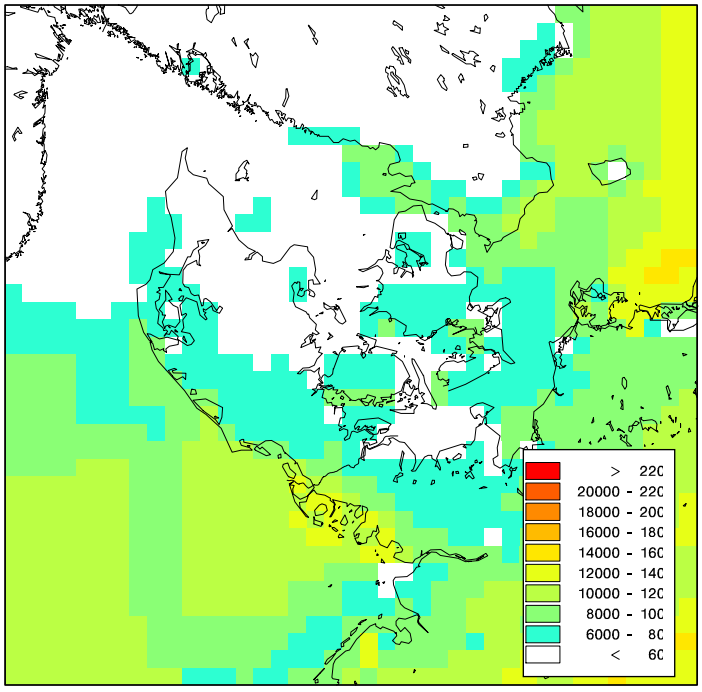


Figure 4.6 AOT40 (µg/m^3·h) calculated for 2006 using DEHM.

AOT40 (in units of µg/m^3·h) is the sum of the hourly difference between values above 80 µg/m^3 (=40 ppbv) and 80 µg/m^3 measured during the time from 8:00 to 20:00 in the period from May to July. The target values and long term objectives for protection of vegetation is 18000 and 6000 µg/m^3·h, respectively. The target values and long term objectives are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations using DEHM (figure 4.5 and 4.6) show that AOT40 was below the target value. However, the long term objective was exceeded for more than half of the country.

5 Carbon monoxide

5.1 Annual statistics

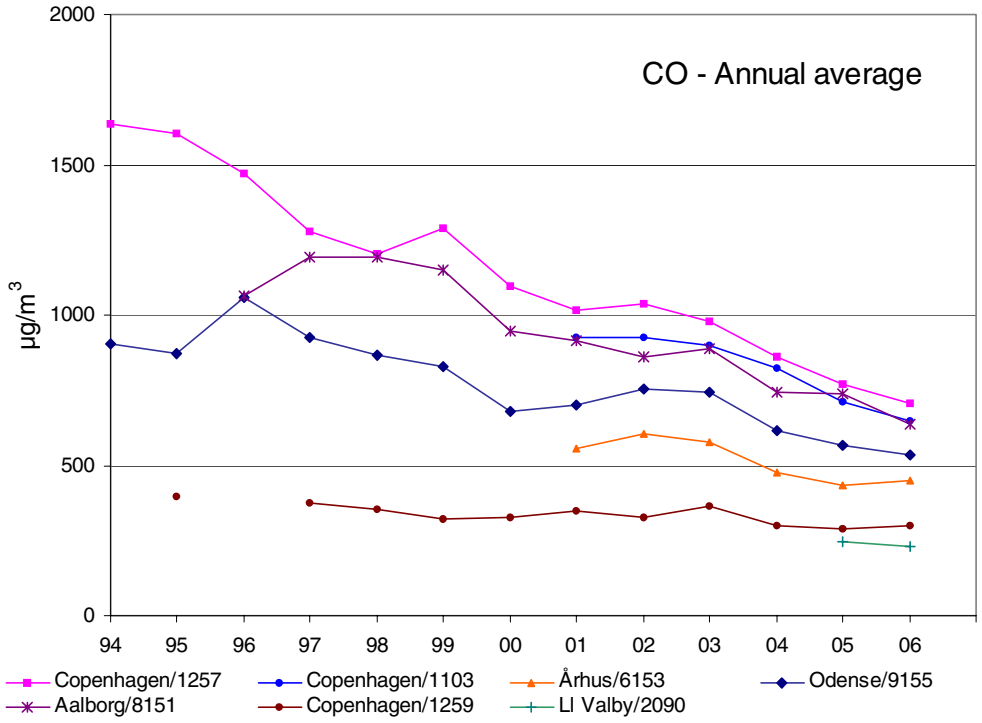
Table 5.1 Annual statistics for carbon monoxide (CO) in 2006. All parameters are calculated with hourly average. The 8-hour values are calculated as a moving average based on hourly results.

Unit: µg/m^3	Number	Average	Median	98-percentile	99.9-percentile	Max. 8-hours	Max hour
Traffic:							
Copenhagen/1257	8011	704	596	1991	3246	2208	3678
Copenhagen/1103	8600	646	578	1571	2448	1860	2819
Århus/6153	7877	452	398	1107	1874	1624	2397
Odense/9155	8194	533	398	1627	2814	2190	3455
Aalborg/8151	8606	636	524	1712	2779	2698	3396
Urban Background:							
Copenhagen/1259	8694	301	268	671	1177	1055	1540
Rural							
Lille Valby/2090	8360	232	209	549	878	808	1021
Limit value	-	-	-	-	-	10 000	-
Guideline values	-	-	-	-	-	10 000	30 000

The limit value is based on EU Council Directive (EC, 2000) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The guideline values are proposed in WHO, 2000. (Air Quality Guidelines for Europe, Second Edition, WHO Regional Publications, European Series, No. 91, Copenhagen 2000).

5.2 Trends



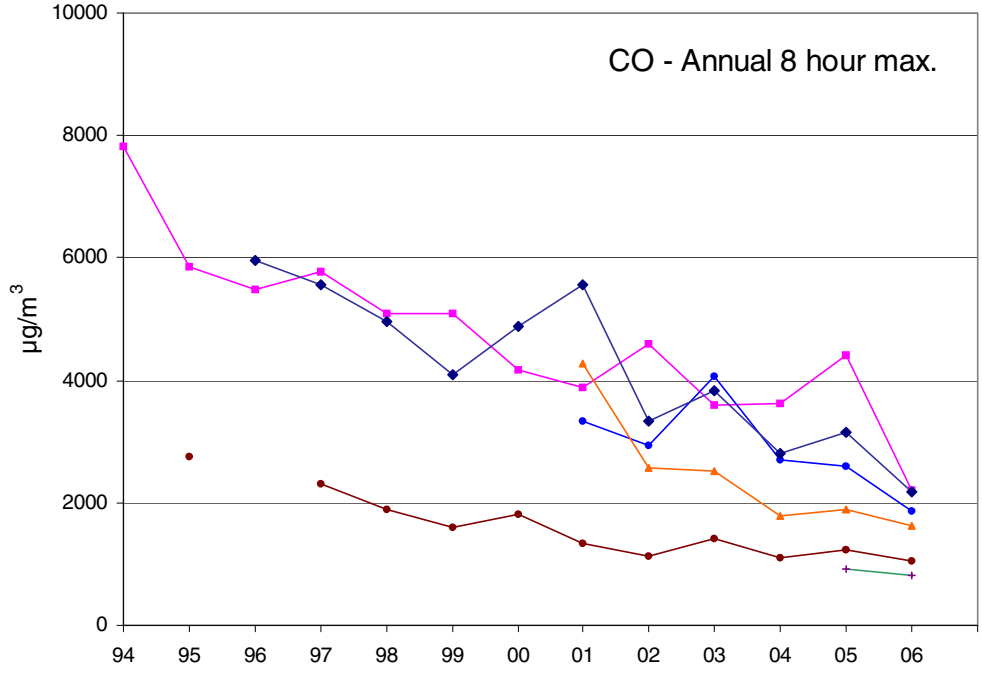


Figure 5.1 Annual average values and highest 8-hour value calculated based on an hourly moving average. Previous results from Copenhagen/1103 can be found at the website of the Copenhagen Environmental Protection Agency (www. Miljoe.kk.dk).

6 Benzene and Toluene

6.1 Annual statistics

Table 6.1 Annual statistics for Benzene in 2006. All values are calculated as 1 hour averages. The 8 hours values are calculated as a moving average of hourly averages. The life time risk level is defined as the concentration that through a lifelong exposure is estimated to give an increase in risk of $1:10^5$ for developing cancer.

Unit: µg/m^3	Number of results	Average	Max. 8 hours	Max. 1 hour
Copenhagen/1257	7813	2.3	9	17
Copenhagen/1103	5195	1.5	5	8
Limit value	>7784	5	-	-
Life time risk level at $1:10^5$		1.7		

The limit value is based on EU Council Directive (EC, 2000) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Table 6.2 Annual statistics for Toluene in 2006. The max. 7 days is calculated as the highest value for a moving 7 days average based on daily averages (WHO, 2000).

Unit: µg/m^3	Number of results	Average	Max. 7 days	Max. 1 hour
Copenhagen/1257	7803	7.9	15	64
Copenhagen/1103	5241	6.3	11	48
Guideline value	-	-	260	-

The guideline and lifetime risk level are established by WHO (WHO, 2000).

6.2 Trends

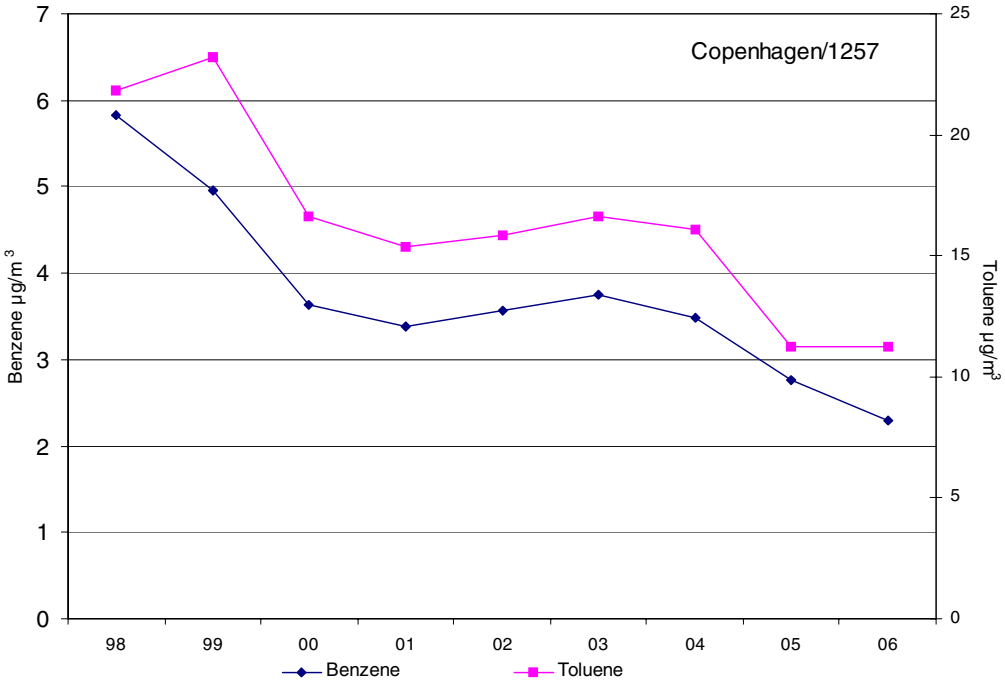


Figure 6.1 Annual average for benzene and toluene measured at Copenhagen/1257.

7 Particles (TSP, PM_{10})

7.1 PM_{10} measurements

The limit values are based on the EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The SM200 sampler manufactured by OPSIS, Sweden, has been used in Denmark to demonstrate the compliance with the EU Directive (EC, 1999). The sampler provides the possibility for sampling PM_{10}, which later can be used for weighing and chemical analysis. Further the PM_{10} is determined immediately after exposure by means of absorption of β-rays in the particles. This option provides the possibility of presenting "on-line" results.

Resent results (Harrison, 2006) however indicate that the β-ray results comply better with the reference method given in the Directive. For this reason we have decided from 2006 to report results from the β-method to demonstrate the compliance with limit values

The results from the two methods differ slightly. From 2002 to 2005, where comprehensive data sets are available, it is shown that the β-method in average yields results that are 1.08 times the weighing for the yearly average and 1.09 times the weighing for the 39th highest concentration.

In the trend graphs (fig. 7.1 and 7.2) a slight increase is expected due to the change of method.

7.2 Annual statistics

At all stations PM_{10} is collected continuously on filters in 24 hours intervals for later β-absorption and chemical analysis. Additionally PM_{10} is measured at the stations in Copenhagen using a TEOM (Tapered-element oscillating microbalance) instrument. The TEOM measurements are performed with a time resolution of 30 minutes. During sampling the particles are heated to 50°C. At that temperature some of the volatile compounds may evaporate (mainly secondary aerosols). The loss will depend of the actual composition of the aerosols. The European Commission has accepted that TEOM measurements can be used in relation to EU limit values if the measured values are multiplied with a factor 1.3.

Table 7.1 Annual statistics for PM_{10} in 2006. All parameters are calculated as daily averages. The limit values shall be met at 2005.

Unit µg/m^3	Number of results	Average	36.highest result	90 percen-tile	95 percen-tile	8.highest result	Max. day
Traffic							
Copenhagen/1257	284	32	52*)	55	63	69	79
Copenhagen/1103	285	41*)	58*)	63	69	75	87
Århus/6153	193	32	44	54	60	63	84
Odense/9155	334	40	64*)	66	81	89	120
Aalborg/8151	277	39	60*)	64	74	81	91
Urban background							
Copenhagen/1259	356	27	43	43	53	59	89
Århus/6159	307	26	41	41	52	57	74
Odense/9159	264	26	37	41	51	59	99
Aalborg/8158	303	28	43	45	53	56	69
Rural							
Lille Valby/2090	284	27	44	50	57	61	98
Keldsnor/9055	314	23	38	40	49	54	58
Limit values (2005)	>329	40	50				

*) Limit value exceeded.

Table 7.2 Annual statistics for PM_{10} measured in 2006 using TEOM. The values are calculated based on daily averages.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile	Average × 1.3	36. highest × 1.3
Traffic						
Copenhagen/1103	342	33	50	52	43*)	65*)
Urban background						
Copenhagen/1259	143	17	-	-	22	-
Limit values	>329	-	-	-	40	50

*) Limit value exceeded.

Table 7.3 Annual statistics for $PM_{2.5}$ measured in 2006 using TEOM. The values are calculated based on daily averages.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile
Traffic				
Copenhagen/1257	248	14	20	23
Copenhagen/1103	257	15	21	23
Urban Background				
Copenhagen/1259	298	12	17	19
Rural				
Lille Valby/2090	330	11	19	20

7.3 Trends

Up till 2000 the particulate matter was measured as Total Suspended Particulate matter (TSP) corresponding to particles with a diameter up to around 25 µm. The exact cut-off depended strongly on the wind velocity. From 2001 PM_{10} measurements are started at all stations except Copenhagen/1103 where the TSP measurements were continued to the end of 2005. The TSP is on the average 30-80% higher than PM_{10} at the street stations, while the difference is less at urban background and rural sites.

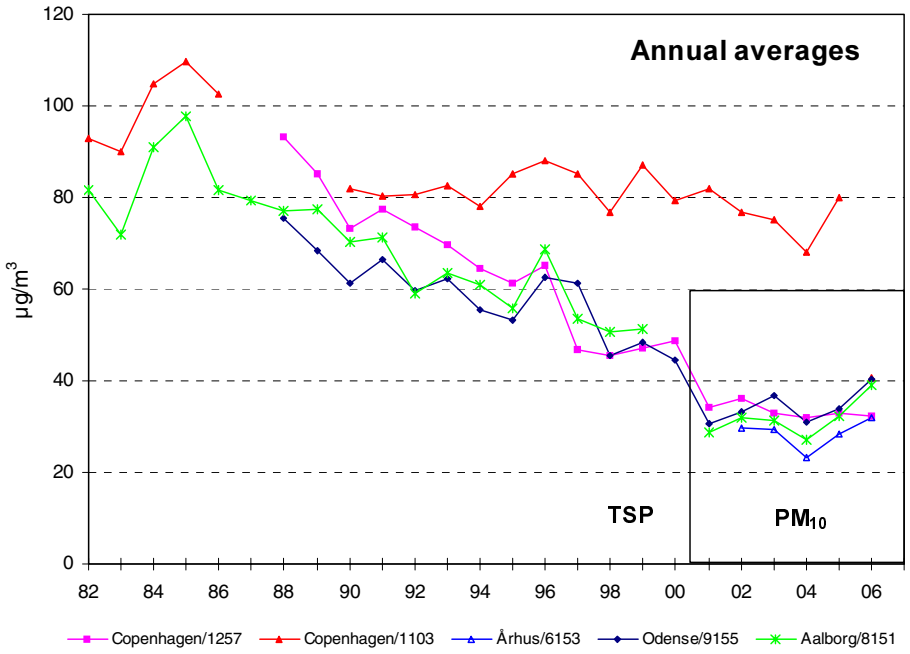


Figure 7.1 Annual averages for TSP and PM10 measured at street stations. Results from 2000 and earlier are for TSP, while later results are for PM10 – except for Copenhagen/1103, where TSP measurements were continued to the end of 2005. The PM10 results are shown in the area in the bottom left of the plot area. The change from gravimetric determination to use of β-measurements from 2006 gives rise to a 5-10% increase from 2005 to 2006.

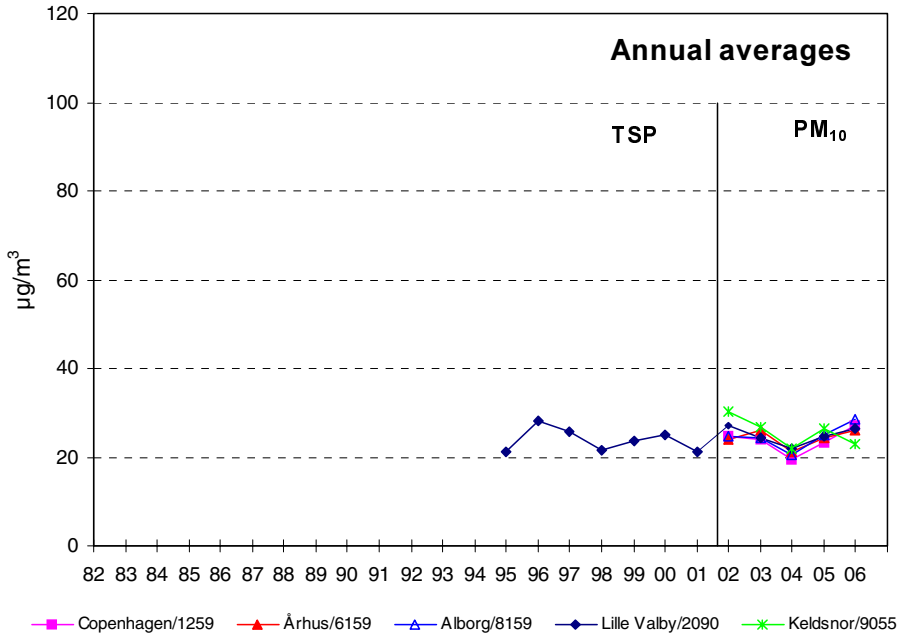


Figure 7.2 Annual averages for TSP and PM_{10} measured at urban background and rural stations. The change from gravimetric determination to use of β-measurements from 2006 gives rise to a 5-10% increase from 2005 to 2006.

8 Heavy Metals

8.1 Annual statistics

Table 8.1 Annual statistics for Vanadium (V), Chromium (Cr), Manganese (Mn), Nickel (Ni), Cupper (Cu), Zink (Zn), Arsenic (As), Selenium (Se), Cadmium (Cd) and Lead (Pb) measured in PM_{10} dust during 2006 The lifetime risk level is defined as the concentration that through a lifelong exposure is estimated to give an excess risk of $1:10^5$ for developing cancer. The filters are occasionally contaminated with Cr, Ni, Cu and Zn. The outliers for these elements are excluded before average calculation. At urban background and rural stations the contamination with Cr still contributes with a significant amount to the average values.

Unit: ng/m^3	V	Cr	Mn	Ni	Cu	Zn	As	Se	Cd	Pb
Traffic										
Copenhagen/1257	4.0	5.4	13.4	3.3	50.5	30.7	0.7	0.4	< 1.6	7.8
Copenhagen/1103	5.4	11.9	45.8	3.5	76.1	61.6	0.7	0.4	< 1.6	9.1
Århus/6153	5.2	4.0	12.8	5.0	33.2	35.2	0.7	0.4	< 2.4	7.6
Odense/9155	3.7	6.2	21.6	2.5	42.4	50.1	0.9	0.5	< 1.6	8.8
Aalborg/8151	3.5	5.9	13.1	2.4	42.7	37.8	0.6	0.4	< 1.1	6.7
Urban background										
Copenhagen/1259	5.3	1.7	6.8	2.9	11.5	21.9	0.8	0.4	< 1.5	7.0
Århus/6159	4.3	2.0	6.2	4.2	7.8	23.2	0.7	0.4	< 1.6	6.2
Odense/9159	3.6	1.7	7.1	1.8	8.5	26.3	0.7	0.4	< 1.7	7.9
Aalborg/8159	3.2	1.4	5.7	1.9	7.1	17.7	0.6	0.4	< 1.3	4.4
Rural										
Lille Valby/2090	3.8	< 0.4	5.5	1.8	5.2	19.7	0.9	0.4	< 1.2	7.2
Keldsnor/9055	5.9	< 0.4	3.4	2.6	3.6	16.3	0.4	0.5	< 1.5	4.9
Target/limit values *)				20			6		5	500
Guideline value (WHO) *)	1000		150						5	
Life time risk level at $1:10^5$ (WHO) *)				25			6.6			

*) Target values for Ni, As and Cd are implemented through EU Council Directive 2004/107/EC (EC, 2005). A limit value for Pb is found in EU Council Directive 1999/30/EC (EC, 1999). The guidelines and life time risk for the carcinogenic metals are established by WHO (WHO, 2000).

8.2 Trends

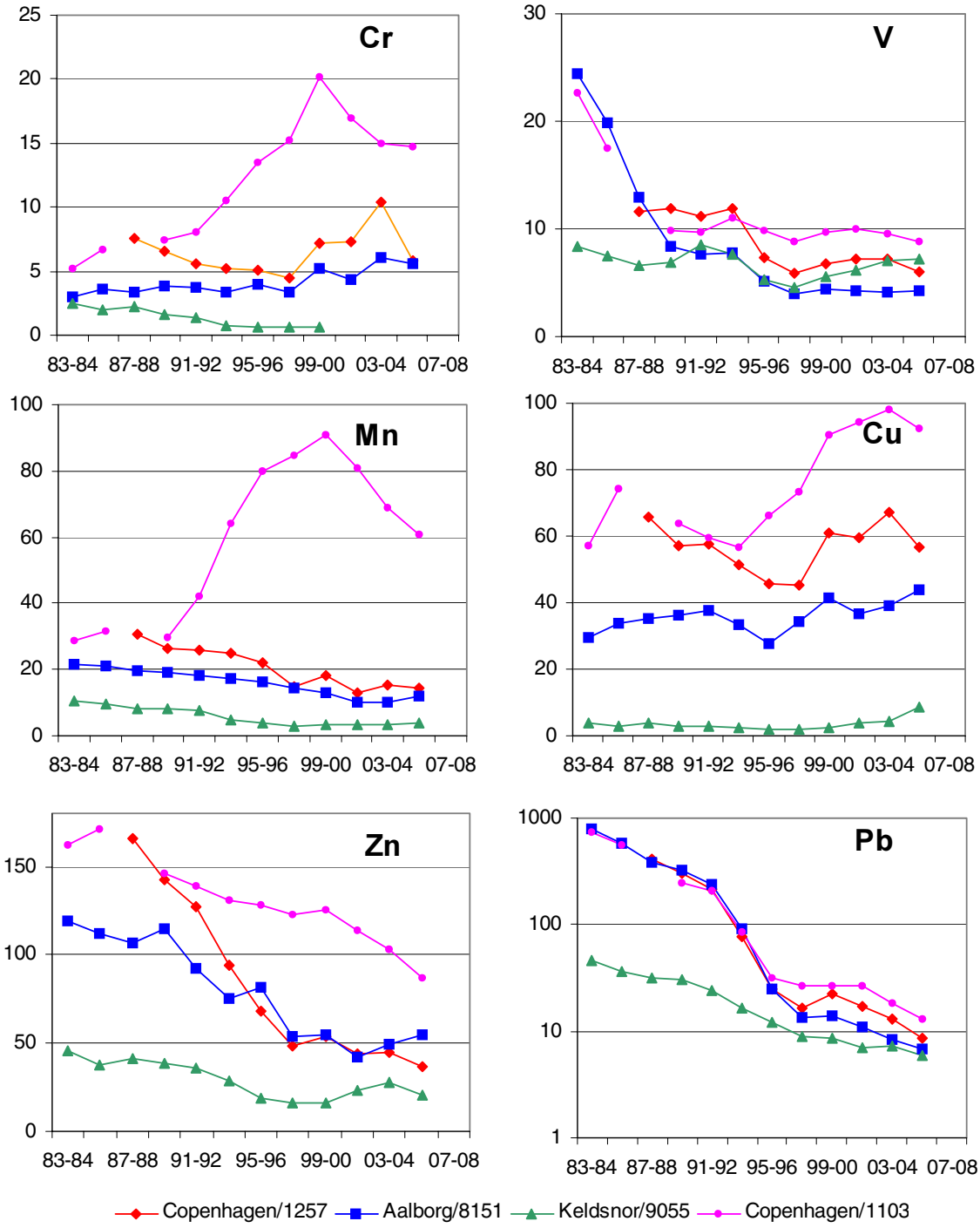


Figure 8.1 Biannual averages from selected stations for some heavy metals in particulate matter. Until 2000 in TSP and later in PM_{10} – except for Copenhagen/1103 where PM_{10} replaced TSP from the beginning of 2006. The heavy metals are usually found in fine particles, which make the TSP and the PM_{10} values comparable. The remarkable increase in the concentrations of especially Mn and to some extent Cr at Copenhagen/1103 may be caused by the use of slag from steel production for filling material in the bitumen at H. C. Andersens Boulevard. The increase in Cu (especially at Copenhagen/1103), which to a large extend comes from brake pads, reflects the increase in traffic volume. y-axis units are ng/m^3. (Note that the scale for Pb is logarithmic.)

9 Sulphur Compounds

9.1 Annual statistics

Table 9.1 Annual statistics for SO_2 in 2006. All parameters are calculated based on hourly averages. The detection limit for the monitors is a few µg/m^3, which makes the average and median values encumbered with high relative uncertainties.

Unit: µg/m^3	Number of results	Average year	Average winter	Median	98-percentile	Max. Hour	4. highest day
Traffic							
Copenhagen/1103	8662	2.4	2.9	1.7	10.1	51	1
Aalborg/8151	8671	2.9	3.6	2.1	10.4	57	5
Limit values	>7884	20	20			350	125

The limit values are based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Table 9.2 Annual averages for particulate sulphur (S) measured in PM_{10} 2006 The sulphur containing particles are mainly present in sub-micron particles, which make the TSP and PM_{10} results comparable. Measurements are daily averages.

Unit: µg(S)/m^3	Number of results	Average
Traffic		
Copenhagen/1257	272	0.96
Copenhagen/1103	299	1.01
Århus/6153	264	1.00
Odense/9155	345	1.04
Aalborg/8151	282	0.93
Urban background		
Copenhagen/1259	345	0.94
Århus/6159	314	0.93
Odense/9159	266	0.94
Aalborg/8158	315	0.86
Rural		
Lille Valby/2090	285	0.94
Keldsnor/9055	303	0.98

9.2 Trends

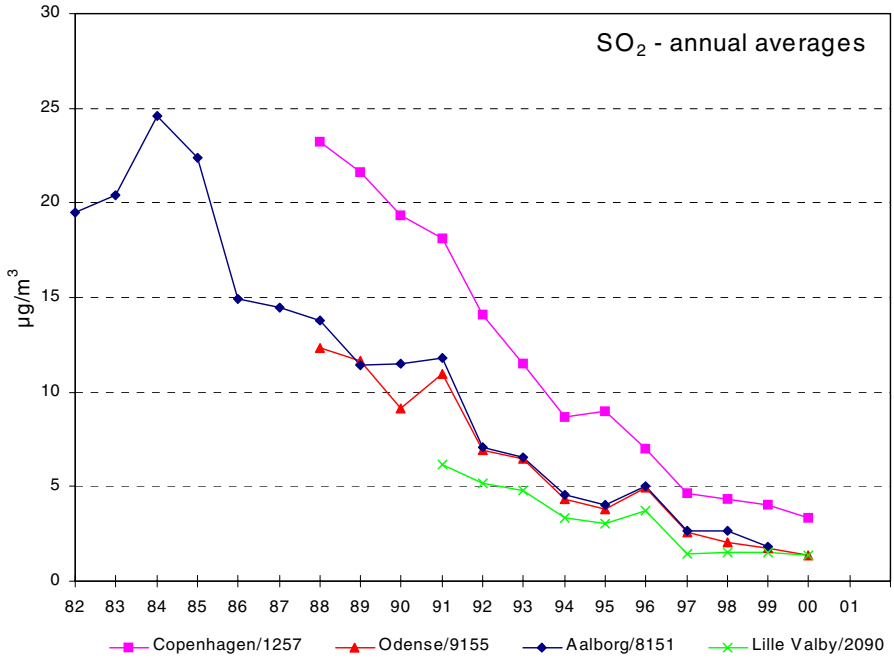


Figure 9.1 Annual averages for SO_2. The results are obtained using KOH impregnated filters for collection of SO_2. These measurements ceased in 2000 because the concentrations had become far below the limit and guideline values.

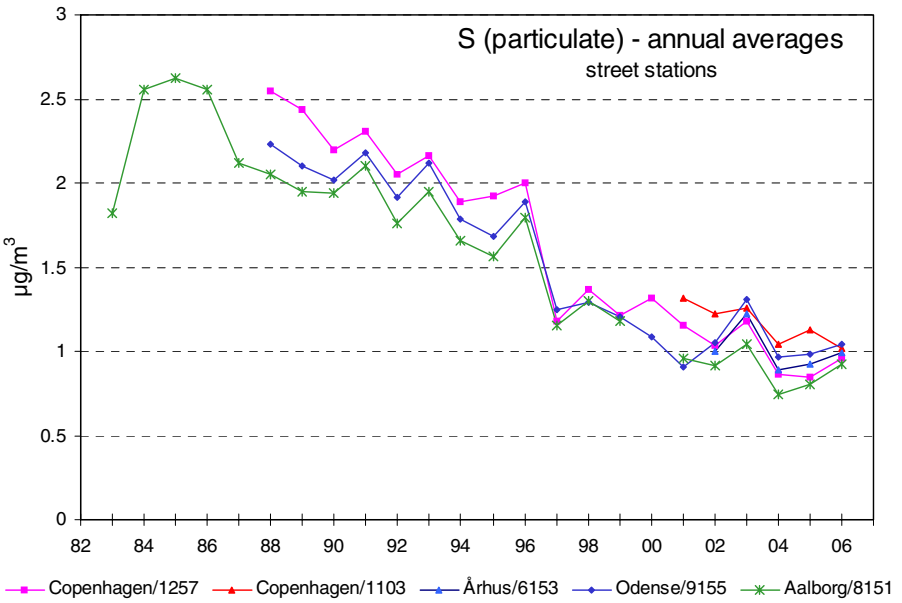


Figure 9.2 Annual averages for particulate sulphur at street stations. The particulate sulphur from 2000 and earlier is determined in TSP, and the 2001 results and later are for PM_{10} – except for Copenhagen/1103, where TSP measurements are continued. The sulphur containing particles are mainly present in sub-micron particles, which makes the TSP and PM_{10} results comparable.

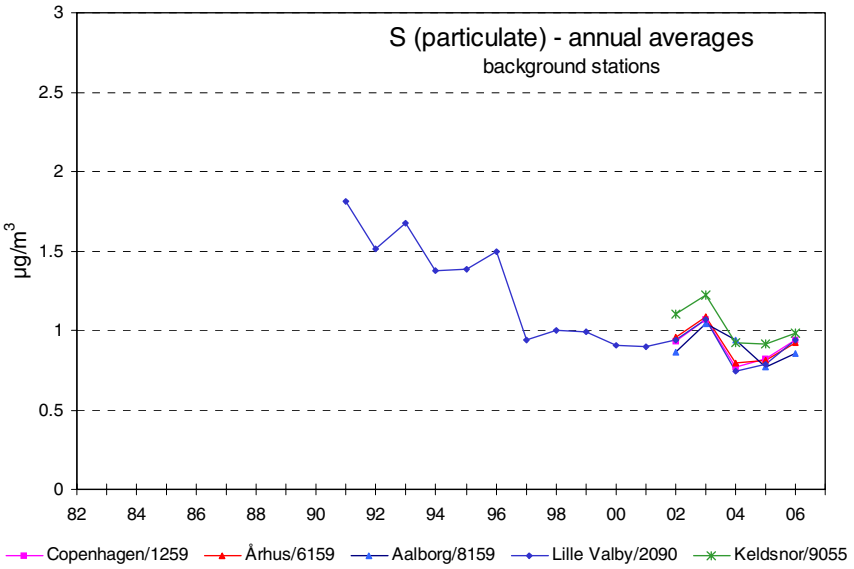


Figure 9.3 Annual averages for particulate sulphur at urban background and rural stations. The particulate sulphur from 2000 and earlier is determined in TSP and the 2001 results and later are in PM_{10}. The sulphur containing particles are mainly present in submicron particles, which makes the TSP and PM_{10} results comparable.

9.3 Results from model calculations

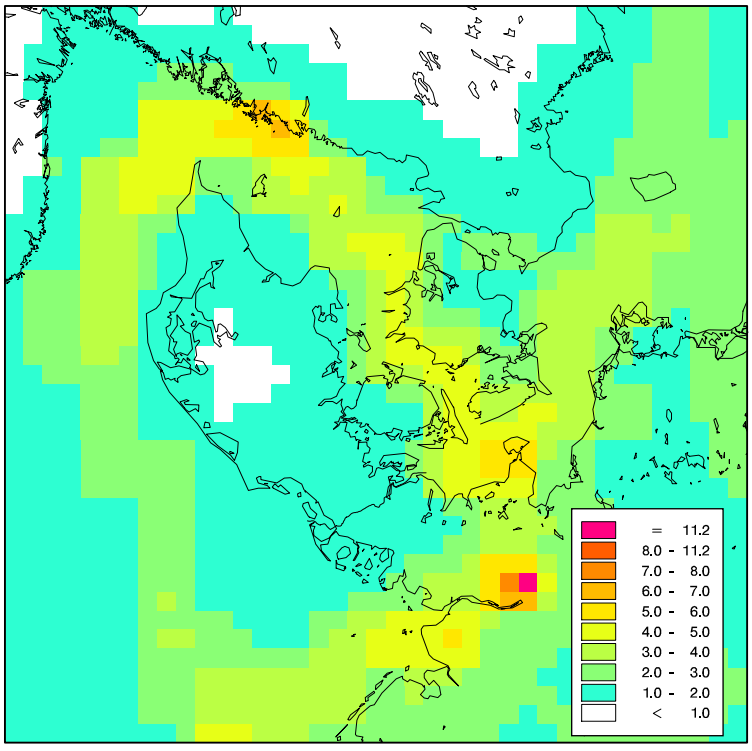


Figure 9.4 Annual mean concentrations of SO_2 (µg/m^3) for 2006 calculated with DEHM. The figure shows the average concentrations for the 16,67 x 16,67 km grit cells used in the model. The high concentrations calculated for the inner Danish waters are due to emissions from ships.

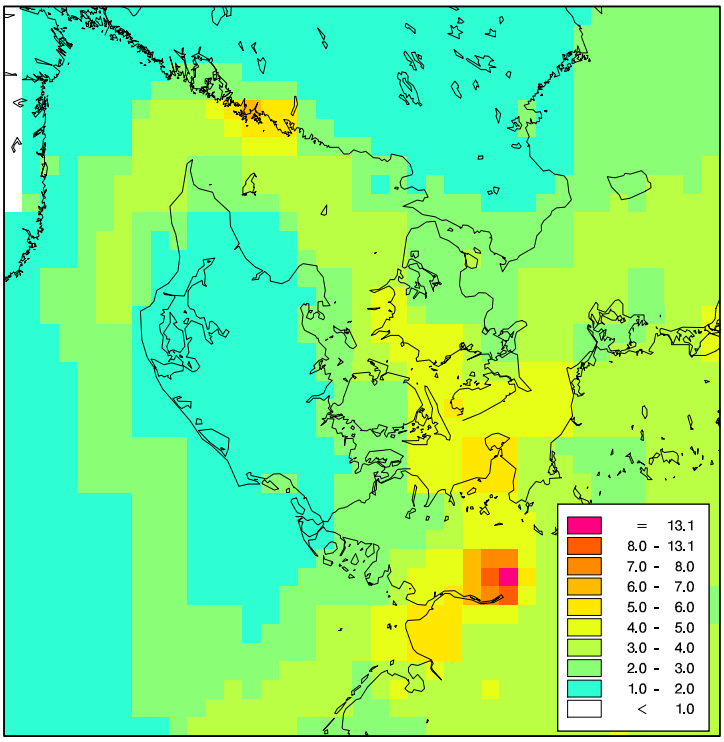


Figure 9.5 Winter mean concentrations of SO_2 (µg/m^3) for 2006 calculated with DEHM. The figure shows the average concentrations for the 16,67 x 16,67 km grit cells used in the model. The high concentrations calculated for the inner Danish waters are due to emissions from ships.

The limit value for protection of ecosystems is 20 µg/m^3 SO_2 calculated both for the calendar year and winter period (1 October to 31 March). The limit value is based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations using DEHM show that the annual and winter mean concentrations of SO_2 in 2006 (figure 9.4 and 9.5) are below the limit value.

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Appendix

Pollutants measured in the LMP Network

NO and partly NO_2 are formed by combustion at high temperatures. The main sources are power plants and traffic. At the street stations the traffic is the main source. The application of catalytic converter in the exhaust reduces the emission considerably. NO is relatively harmless, but NO_2 can cause respiratory problems.

Most of the NO_2 in the urban atmosphere is produced by oxidation of nitrogen monoxide (NO) by ozone (O_3). The reaction will take place immediately, if sufficient O_3 is present. O_3 is often the limiting component for a complete oxidation in the street canyons, but practically all NO is oxidised at the urban background and rural stations. Within a few hours the NO_2 is further oxidised to nitrate and/or nitric acid, which may cause acid precipitation and eutrofication. NO_2 is a toxic gas, which may cause respiratory problems. There are limit values for the allowed concentration of NO_2 in the atmosphere.

O_3 is formed by photochemical reactions (i.e. by the influence of sunlight) between nitrogen oxides and volatile organic compounds (VOC's). The VOC's can be of natural and anthropogenic origin. The major part of the O_3 measured in Denmark originates from sources outside the country. Usually the highest concentrations are found at rural and urban background sites. O_3 is removed by NO at street level. O_3 is a toxic gas, which may cause respiratory problems and damage on crops and forests. There are so-called target values for the concentration of O_3 in the atmosphere.

The main source of CO in urban air is petrol-fuelled cars. The CO is formed due to incomplete combustion. The application of catalytic converter in the exhaust reduces the emission considerably. CO is only slowly removed from the atmosphere. CO is a toxic gas that may prevent the uptake of oxygen in the blood. There are limit values for the allowed concentration of CO in the atmosphere.

Benzene is present in petrol. It may also be formed in engines due to incomplete combustion. Since 1994 the benzene content in petrol has been reduced by up to a factor of 5. The concentration in the atmosphere has been reduced correspondingly. Benzene is a carcinogenic gas. There is a limit value for the average content in the atmosphere.

Many different VOC's are present in the air. Several of these are emitted by incomplete combustion in e.g. engines and wood burning stoves. Several of the VOC's are carcinogenic. A "target value" is implemented through an EU Council Directive in 2004 for Benzo(a)-pyrene as indicator for PAH (Polycyclic Aromatic Hydrocarbones). Of the VOC's only benzene, toluene and xylenes are measured routinely in LMP IV at present.

The main sources for PM_{10} are resuspended dust and combustion. PM_{10} particles are also created in the atmosphere by oxidation of nitrogen dioxide and sulphur dioxide. The submicron particles, which are formed by combustion and chemical reactions in the atmosphere, are suspected to be the most harmful for the health. There are still a lack of knowledge about the connection between health effects and particle size. Limit values for the PM_{10} concentration in the atmosphere are implemented at present. The limit values will be revised within a few years, when better knowledge about the adverse health effects of fine particles influence on health has been obtained.

PM_{10} is measured using two different methods in the LMP program:

- The particles are collected on filters in 24^{h} intervals. The mass on the filters is determined by measurements of β-absorption in the dust. This method is considered to be equivalent to the reference method (EN 12341).
- The particles are collected on a "tapered oscillating microbalance" (TEOM) and heated to 50°C. During heating volatile compounds may evaporate. The loss will be most pronounced for "secondary aerosols" containing ammonia, nitrate and sulphate.

There are a number of different HM's in the atmosphere. They are emitted from e.g. coal and oil fired power plants, waste incinerators and industries. HM's may also be emitted from traffic due to wear on engines, tires and brake pads. Several HM's are toxic even in low concentrations and a few also carcinogenic. A limit value is implemented for lead. Target values are values are implemented for arsenic, cadmium, nickel and mercury. WHO has proposed guideline values for the toxic non-carcinogenic and estimated life time risks for the carcinogenic HM's.

Sulphur dioxide (SO_2) is formed by burning of fossil fuel and biomass. The SO_2 is oxidised in the atmosphere to particulate sulphuric acid and sulphate. The conversion time depends strongly of the temperature and humidity in the air. It is typically of the order of one day. Sulphuric acid contributes to "acid rain" and the deposition of sulphate causes damage to sensitive ecosystems. During the last 20 years the reduction of sulphur in fossil fuel and improved flue gas cleaning has reduced the concentration of SO_2 with one order of magnitude. SO_2 may cause respiratory problems. There are limit values for the allowed concentration of SO_2 in the atmosphere.

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The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring (LMP) network. The aim has been to monitor the levels of toxic pollutants in the urban atmosphere and to provide the necessary knowledge to assess the concentration trends, to perform source apportionment, and to evaluate the chemical reactions and the dispersion of the pollutants in the atmosphere. In 2006 the air quality was measured in four Danish cities and at two background sites. Besides this model calculations were carried out to supplement the measurements. NO_2 and PM_{10} were at several stations found in concentrations above EU limit values, which the Member States have to comply 2005 and in 2010. While the concentrations for most other pollutants have been strongly decreasing since 1982, only a minor decrease has been observed for NO_2 and O_3.

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