DANISH METEOROLOGICAL INSTITUTE

——— TECHNICAL REPORT ———

00-14

Trends of Air Pollution in Denmark
Normalised by a
Simple Weather Index Model

Sissi Kiilsholm
Alix Rasmussen

COPENHAGEN 2000

ISSN: 0906-897X (printed version)
1399-1388 (online version)

Abstract

This report is a part of the Traffic Pool projects on "Traffic and Environments", 1995-99, financed by the Danish Ministry of Transport. The Traffic Pool projects included five different projects on "Surveillance of the Air Quality", "Atmospheric Modelling", "Atmospheric Chemistry Modelling", "Smog and ozone" and "Greenhouse effects and Climate", [Rasmussen, 2000].

This work is a part of the project on "Surveillance of the Air Quality" with the main objectives to make trend analysis of levels of air pollution from traffic in Denmark. Other participants were from the Road Directory mainly focusing on measurement of traffic and trend analysis of the air quality utilising a nordic model for the air pollution in street canyons called BLB (Beregningsmodel for Luftkvalitet i Byluftgader) [Vejdirektoratet 2000], National Environmental Research Institute (NERI) mainly focusing on measurements of air pollution and trend analysis with the Operational Street Pollution Model (OSPM) [DMU 2000], and the Copenhagen Environmental Protection Agency mainly focusing on measurements.

In this study a more simple statistical model has been developed for trend analysis of the air quality. The model is filtering out the influence of the variations from year to year in the meteorological conditions on the air pollution levels.

The weather factors found most important are wind speed, wind direction and mixing height. Measurements of CO, NO and NO_2 from three streets in Copenhagen have been used, these streets are Jagtvej, Bredgade and H. C. Andersen's Boulevard (HCAB). The years 1994-1996 were used for evaluation of the method and annual indexes of air pollution index dependent only on meteorological parameters, called WEATHIX, were calculated for the years 1990-1997 and used for normalisation of the observed air pollution trends.

Meteorological data were taken from either the background stations at the H.C. Ørsted - building situated close to one of the street stations or the synoptic station at Kastrup Airport just outside Copenhagen. The mixing height was calculated using a bulk Richardson method on vertical profiles provided by the Numerical Weather Prediction model DMI-HIRLAM (Danish Meteorological Institute - HIgh Resolution Limited Area Model).

The model in general gives a good explanation of variations from year to year in the air quality.

Contents

1. Introduction

The most important factor contributing to urban air pollution in the cities is the emissions from mobile sources [Stein, 1996]. Streets in cities are often narrow and surrounded by high buildings i.e. so called 'street canyons'. In such a street canyon, the climate differs from the background climate by having its own microscale meteorological processes. The sources of emissions of pollutants in the streets are from motor vehicles near the ground, which makes it of big interest to understand the microscale meteorological processes that control the dispersion of the pollutants in the street canyons. The wind blowing over the roofs has an influence on the wind direction and wind speed in the street canyon, and vortexes are formed depending on the geometry of the canyon [Nakamura, 1988]. The rate between the width of the street and the hight of the buildings, W/H, is often used as a factor that determines the structures of vortexes in the street canyon [Eliasson, 1996], where the most spectacular point is the dramatic change in the vortexes occurring in the range $0<W/H<1$ [Sini, 1996]. Another important factor of the microscale meteorological processes is the differential heating of the buildings and the roadways, which has an influence on the vortexes formed in the street canyon. Modeling studies have shown that overheating of a canyon with 5^oC can change a one-vortex regime to a two-vortex regime, with the consequence that the vertical exchanges of pollutants in the street canyon is largely reduced [Sini, 1996].

Several other factors influencing the flow regime in the street canyon, are probably still unknown, and those known are still rather complicated to model. In order to model the actual values of the air pollution in the street canyons these factors can be very important, while the modeling of long term trends of air pollution concentrations is much less sensitive to building structure than is often assumed [Boeft, 1996].

In this work an statistical model, utilising the most important meteorological factors as wind-direction, wind-speed and mixing height will be developed with the purpose to calculate an annual Air Pollution Index (API), [e.g. Sjødin, 1996], where the influence from the variation in weather is filtered out.

2. Measurements of air pollution

In this work measurements from four stations in the city of Copenhagen have been used for the analysis. Two of them; one in Bredgade and one in H.C. Andersen's Boulevard (HCAB) are operated by Hovedstadsregionens Luftovervågningsenhed (HLU), and the other two; in Jagtvej and on the H.C. Ørsted building, are operated by the National Air Quality Monitoring Programme (LMP III). Several species are measured at these stations, but in this work only CO, NO_x and NO_2 are used because they are good indicators of the state of the air pollution in the streets.

2.1 The monitoring stations

2.1.1 Background station, H.C. Ørsted building

The monitor at this station is placed on the roof of a 20 m high building close to Jagtvej. Measurements performed at this altitude, placed on the top of the highest building in the area, makes the data useful as urban background data.

Additional to the chemical measurements some meteorological observations are performed. The meteorological data consists of wind speed, wind direction, global radiation, temperature and relative humidity.

2.1.2 Street stations

The street stations, Jagtvej (JAGT), Bredgade (BRED) and H. C. Andersens Boulevard (HCAB), all have their monitors placed near the ground next to the traffic.

Jagtvej is a narrow road with two lanes, with blocks of flats on both sides reaching up to 4. floor.

Bredgade is a one-way narrow road with two lanes between blocks of flats up to 5. floor. Both of these streets can be considered as street canyons. Bredgade has a bigger depth to width ratio than Jagtvej.

HCAB is wide with 6 primary lanes, a parking area on both sides of the 6 lanes, and outermost one lane for buses toward the centre of the city. On the south-western side of the street an open park (Tivoli)is situated, and on the north-eastern side some storeyed buildings are situated.

The monitors are placed at the south-eastern side of Jagtvej, where the traffic-load is highest in the afternoon, at the north-western side of Bredgade, and at the north-eastern side of HCAB, where the highest traffic-load also occurs in the afternoon.

All the streets are heavily loaded by traffic, around 20.000 vehicles on Jagtvej and Bredgade per. day and app. 60.000 on HCAB per. day [Miljøkontrollen, 1996].

2.2 Seasonal variations

The concentrations of pollutants in the streets over a year are influenced of the change in the weather and traffic patterns. The traffic changes from workday to weekend and holidays and from sunny warm weather to rainy and cold weather (summer to winter). Especially July differs very much from the other months, because of the summer holidays, so in this work July is excluded from the simulations. The seasonal variations of CO in 1994 for Jagtvej, Bredgade and HCAB is shown in Fig. 1. The seasonal variation is only week at Jagtvej and Bredgade, while the concentrations of CO at HCAB are lowest in the spring and summer period.

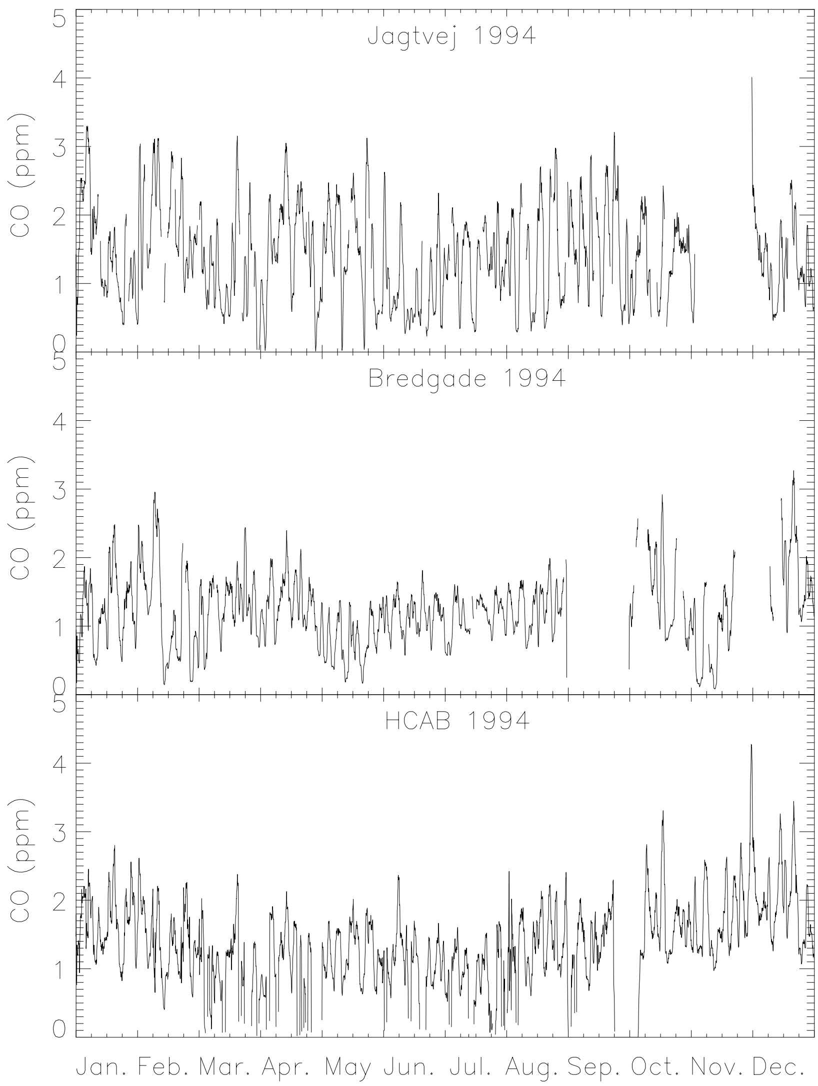

Fig. 1 Seasonal variation of CO in 1994 for Jagtvej, Bredgade and HCAB..

2.3 Diurnal variations

In Fig. 2 the mean diurnal variations of NO_2, NO_x and CO for 1994-96 is shown for Jagtvej, Bredgade and HCAB. For working days there are two peaks, one in the morning and one in the afternoon rush-hours. The peaks are highest in the afternoon for Bredgade and HCAB, whereas Jagtvej has the highest peak in the morning. This pattern is mostly caused by the traffic intensity in the rush-hours, but also factors as wind speed, wind direction, atmospheric stability and insolation has an influence.

In the weekend the changed traffic pattern gives another daily variation with a more even distribution through the day.

CO and NO_x have the largest diurnal variation due to the close connection to the traffical combustion, whereas NO_2 is noticeable influenced by other factors, as it is not a primary resultant of the traffical pollution, but primarily created in an oxidation process of NO and removed by dispersion processes and in a photodissociation of NO_2.

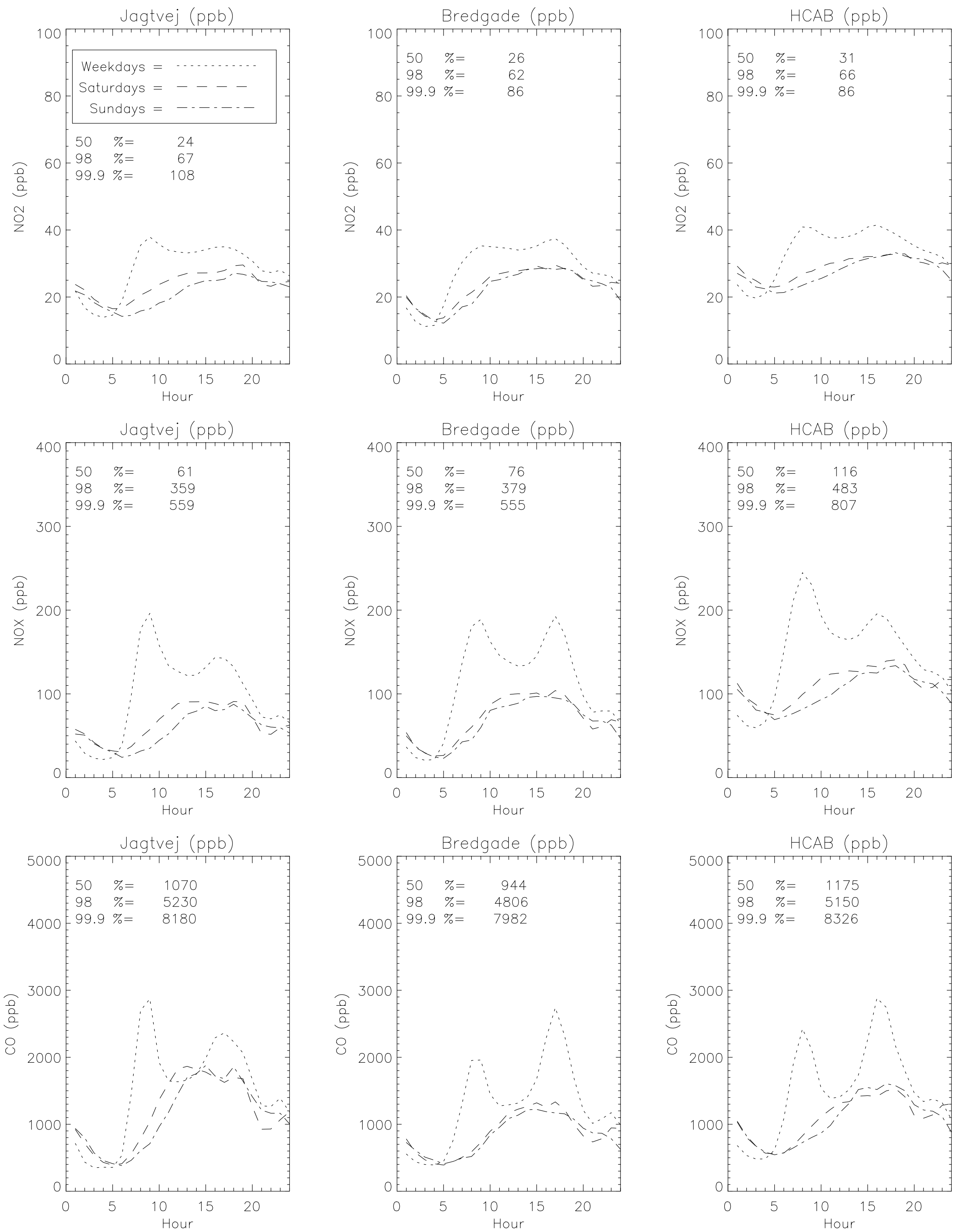

Fig. 2 Mean diurnal variations of NO_2, NO_x and CO for 1994-96 for Jagtvej, Bredgade and HCAB.

2.4 Errors in observations

Missing data and zeropoint displacement occur in the period 1994-96. An effort to correct these data has been done without luck. The missing data can give a systematic failure if it is a longer continuous period, giving a displacement of the annual mean. A small zeropoint displacement has also an influence on the annual mean.

3. Emission

The emission of pollutants from the traffic are depending on the traffic load, the composition of the traffic, the speed of the vehicles and the use of catalysts. Many of these factors are not very well known, so rough assumptions must be used in the modelling.

3.1 Traffic counts

Traffic count on the three used streets has been carried out by Vejdirektoratet (The Road Directory). In the period before 1996, the counting of vehicles was performed irregularly or for short periods, which makes it difficult to determine trends in the emissions for this period.

Two kinds of traffic counts are used: the count of number of vehicles which can be done by using counting wires in the lane and the counting of the distribution of vehicle types which demand use of manpower, a very expensive task. The traffic counts by type of vehicle are best represented in the daytime, nighttime counts are often a mean of few counts. In 1996 longer periods of traffic count by wires were performed at several places, but unfortunately problems showed up at Jagtvej. Therefore a time series of the traffic load had to be created on basis of the relatively few data known for the modelling period. Physical changes on the streets, like road constructions, felled trees and reorganisation of the traffic, will not be reflected in the partly invented time series of traffic count and thereby not show up in the simulation.

The rate of vehicles with catalysts is another not well known factor. A car with catalyst has an emission rate 4 times less than a car without, so this factor has a great effect on the emission.

Traffic velocity in the streets is changing throughout the day depending on traffic intensity. This is also a factor which must be taken into account because the emissions of the vehicles are depending on the speed, unfortunately this is another not well known parameter in the modeling. The diurnal variation of the traffic load accumulated for 6 different vehicle types for the year 1996 at 3 streets in Copenhagen is shown in Fig. 3.

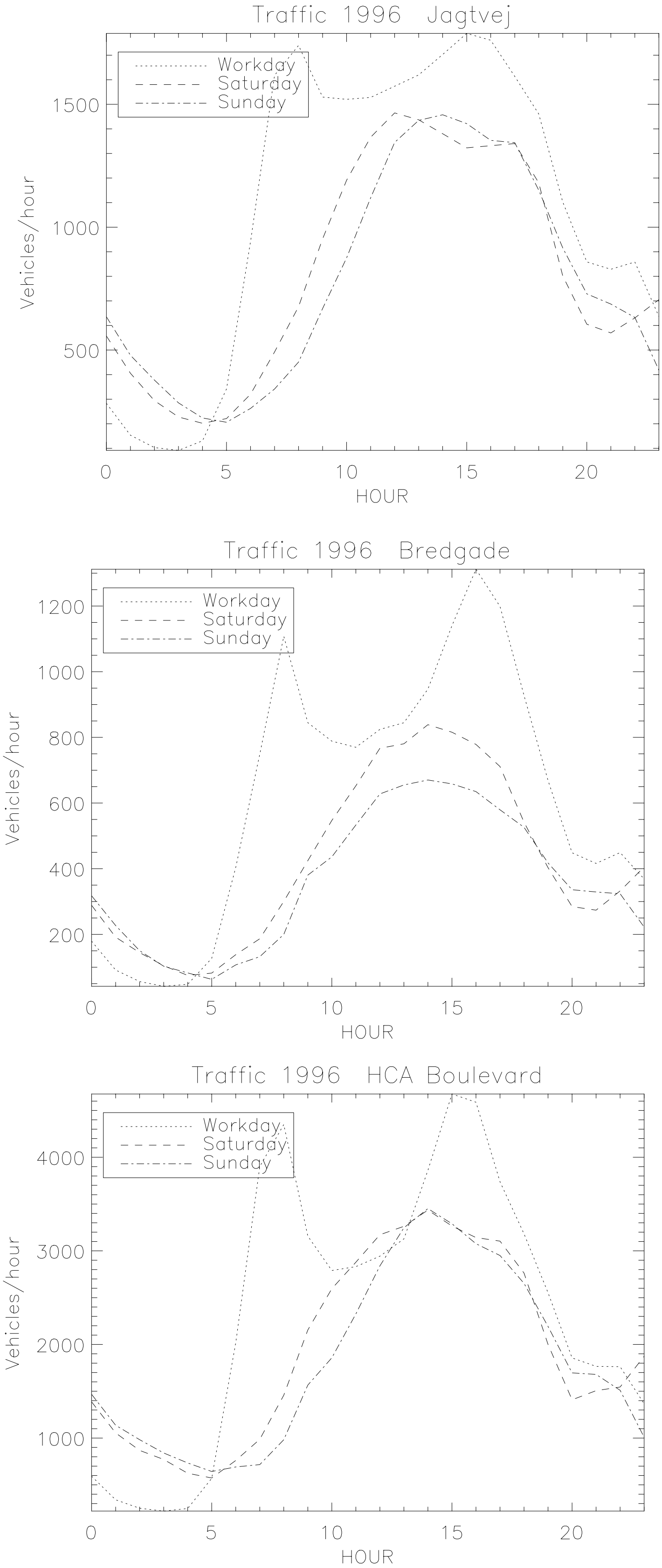

Fig. 3 Diurnal variation of the traffic load (as vehicles/hour) for Jagtvej, Bredgade and HCAB in 1996.

The rate of catalysts in gasoline operated passenger cars is calculated from the numbers of gasoline operated cars in Denmark registered after 1. October 1990, when all new cars according to the law should have catalysts for reduction of emissions. The general trend of the numbers of cars in the Copenhagen area follows in general the trend in all of Denmark [Danmarks Statistik, 1993, 1994, 1995 and 1996]. This makes it acceptable to use these national total numbers for the specific Copenhagen sites.

Cars in Denmark (%)	1991	1992	1993	1994	1995	1996
Age ≤ 1/9-90 (with catalyst)	6.5	11.5	16.1	24.8	31.5	38.3
1/9-90 ≤ Age ≤ 4 years	21.3	13.3	8.5	3.7	0.0	0.0
Age≤ 4 years	27.8	24.8	24.6	28.5	31.5	38.3
5 ≤ Age ≤ 9 years	39.1	41.4	39.2	35.9	29.0	20.6
10 years ≤ Age	33.1	33.8	36.2	35.6	39.5	41.1

Table 1. The rate of catalysts in petrol cars

Before 1994, when a favourable reward campaign for old cars was initiated, an upward trend was detected in the number of very old cars while the number of new cars had a down-ward trend. After 1994, the upward trend for the very old cars are still dominating but from a higher level and the number of new cars have increased percentages. New cars are in general driving more and longer distances than old cars, so the rate of driving cars is influenced of the fact that new cars run about 32.500 km when a 5-year old car runs 17.900 km and a 10-year old car runs 14.600 km [Vejdirektoratet, 1996].

The efficiency of a catalyst is gradually reduced, and after a working period of about 4 years the catalysts do not work optimal anymore, so it is recommended to renew or repair the catalyst every 4. year [Trafikministeriet, 1994] to reduce the emissions. This is however expensive and therefor not implemented by law.

A rate of higher emissions, due to the fact that catalysts are not replaced/repaired every 4. year, is not taken into account in this work.

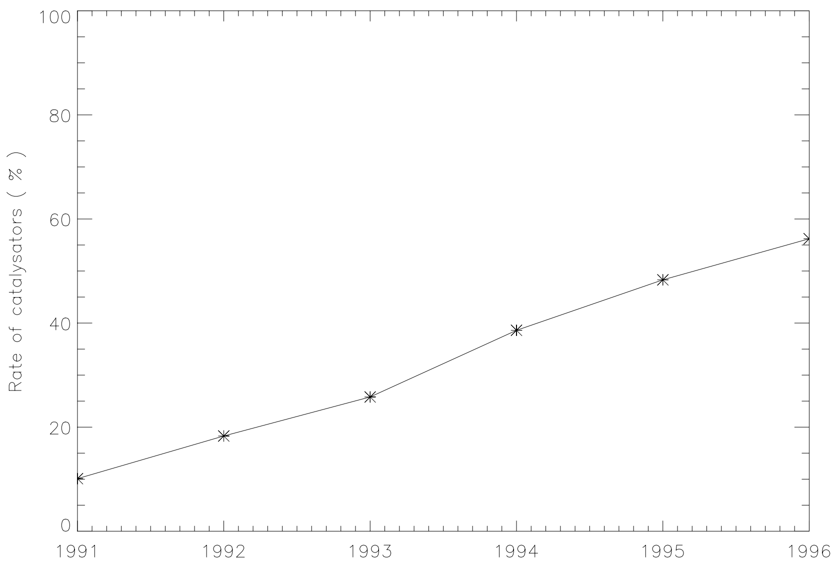

Fig. 4 Rate of catalysts in gasoline driven passenger cars possibly met on the street.

The probability to meet a car with catalyst on the street can be calculated by weightening the number of cars with the general travel length per year for the specific age of the car. Cars on the road with or without catalysts will then be counted as follows (also plotted in Fig. 4):

Cars on the road	1991	1992	1993	1994	1995	1996
With catalysts	10.1	18.3	25.8	38.6	48.3	56.2
Without catalysts	89.9	81.7	74.2	61.4	51.7	43.8

Table 3. The rate of catalysts in "cars on the road"

3.2 Emissions

The emissions of vehicles are depended on the speed and the type of vehicle. The NO_x and CO emissions factors are used as in Vejdirektoratet, 1996. The NO_x emission factors are used for NO_2 as well.

	Travel speed (km/hour)					
CO g/km	20	30	40	50	60	100
PC-no-cat	41	31	26	22	17	16
PC-cat	19	14	11	8.9	7.8	6.1
PC-diesel	1.3	1	0.9	0.7	0.6	0.5
DV	17	13	11	9.3	7.4	6.5
Truck	3.6	2.8	2.3	2	1.7	1.3
Bus	4.1	3.1	2.4	1.9	1.6	1.1
mean		22.1	18.1	15.0		10.3

Table 4.a Emissions factor for CO. PC are personal cars and DV are delivery vans.

	Travel speed (km/hour)					
NO_x g/km	20	30	40	50	60	100
PC-no-cat	2.4	2.1	2	2	2	2.5
PC-cat	0.7	0.6	0.5	0.5	0.4	0.4
PC-diesel	1.3	0.9	0.8	0.6	0.6	0.6
DV	2.3	1.8	1.6	1.5	1.4	1.6
Truck	15	12	11	9.8	9.1	9.4
Bus	41	32	29	25	23	24
mean		2.0	2.1	2.1		2.8

Table 4.b Emissions factor for NO_x. PC are personal cars and DV are delivery vans.

4. Model description

In order to filter out the influence of the variations in the meteorological conditions on the state of the air pollution levels in the streets, a statistical model simulating the actual measured pollution is developed. In this work wind direction (D), wind speed (W), the atmospheric mixing height (H_{mix}) and the emissions from the traffic (E) have been taken into account. The concentration of the hourly values can then be calculated by the following formula;

$$Concentration \equiv f(W) * f(D) * f(H_{mix}) * f(E) \qquad (1)$$

Several other factors could be included such as the turbulence in the street canyon effected by e.g. the insolation that heats up the buildings and thereby construct a different turbulence pattern in the canyon [Sini, 1996], or by the traffical induced turbulence, or the geometric constructions of the street canyon. The buildings do have a very strong and complicated influence on the flow of air in the direct vicinity, but the long-term (annual) average concentrations are much less sensitive to building structure than is often assumed [Boeft, 1996].

4.1 Meteorological parameters

4.1.1 Wind speed, W

Wind speed is a very well-known indicator for the state of the pollution in street canyons. An inverse wind relation is often used in other model works [Sjødin, 1996, Hertel, 1989].

The algorithm used for the wind dependency is given by:

$$f(W) \equiv 3.7/max(3.7,min(7.0,W)) \qquad (2)$$

An analyses of the bias, RMSE and correlation for several runs have been performed with varying limits, see Fig. 15 and Fig. 16 in the appendix, giving the most optimal lower and upper limit at 3.7 m/s and 7 m/s.

An exponential relation with calculated parameters for every hour and species also has been tested. These parameters have been calculated by making a non-linear least squares fit to the mean of the observed concentrations, based on a 3 year period, 1994-1996. The relation looks like this:

$$f(W) \equiv A*wind^{B}+C \qquad (3)$$

The calculated parameters (A,B and C) for two meteorological measurement sites/sources (at the roof of the HCØ building close to the Jagtvej measurement station and meteorological measurements from Kastrup airport) are shown in Fig. 17 in the Appendix. The disadvantage using this method is that the parameters A and C are empirical and specific for the years the calculation are based on.

Three different observed meteorological data sets have been used: HCØ, synop data from Kastrup and one calculated from DMI-HIRLAM. These data sets have different levels of annual wind speed means, cf. table 5 below.

Mean wind speed (m/s)/year	HCØ	Kastrup	DMI-HIRLAM
Sample interval (hours)	1	3	6
1993	5.720	4.036	
1994	4.435	5.687	3.792
1995	4.354	5.624	3.624
1996	4.009	5.199	3.542
1997	4.330	5.312	

Table 5. Meteorological datasets

The year 1996 differs from the other years by having a very low mean wind speed. The DMI-HIRLAM data are only represented every 6. hour, leading to rejection of the use of these data, as they do not catch the daily variations in the wind speed which has a big influence on the air pollution levels.

4.1.2 Wind direction, D

An analyses of the wind direction dependence of observed CO concentrations shows a big influence in the narrow streets when the measuring instrument is situated close to the buildings, where separate vortexes are formed under specific conditions [Berkowicz, 1996, Sini, 1996]. This is a leewind effect on the roof-measured wind, giving a more realistic picture of the wind pattern on ground-level in the street canyon.

The concentrations and wind directions for HCAB have no detectable leewind effect, which can be explained by the fact that the width of the street is so wide that the turbulent cells do not build up where the measurement stations is situated. At Jagtvej and Bredgade a close relation is seen, cf. Fig. 5 showing the concentrations of NO_2, NO_x and CO versus the wind direction for 1994 for these two stations. In this work an exponential algorithm is used in the lee area, for Jagtvej between 200^o to 20^o and for Bredgade between 10^o and 190^o.

The dependency has a greater effect on the concentrations in Jagtvej than in Bredgade, which probably is caused by a lower W/H ratio in Bredgade than Jagtvej.

The algorithms for the wind direction dependency are then:

$$\textit{Jagtvej}: \; if \quad 200^o \le \theta \le 20 \Rightarrow f(D) \equiv max \left\{ \frac{(\theta - 290)^{1.5}}{90^{1.5}} + \; 0.2, \; 1.0 \right\} \; else \; 1.0 \, ;$$

$$\textit{Bredgade}: \; if \quad 10^o \le \theta \le 190 \Rightarrow f(D) \equiv max \left\{ \frac{(\theta - 290)^{1.5}}{90^{1.4}} + \; 0.3, \; 1.0 \right\} \; else \; 1.0 \qquad (4)$$

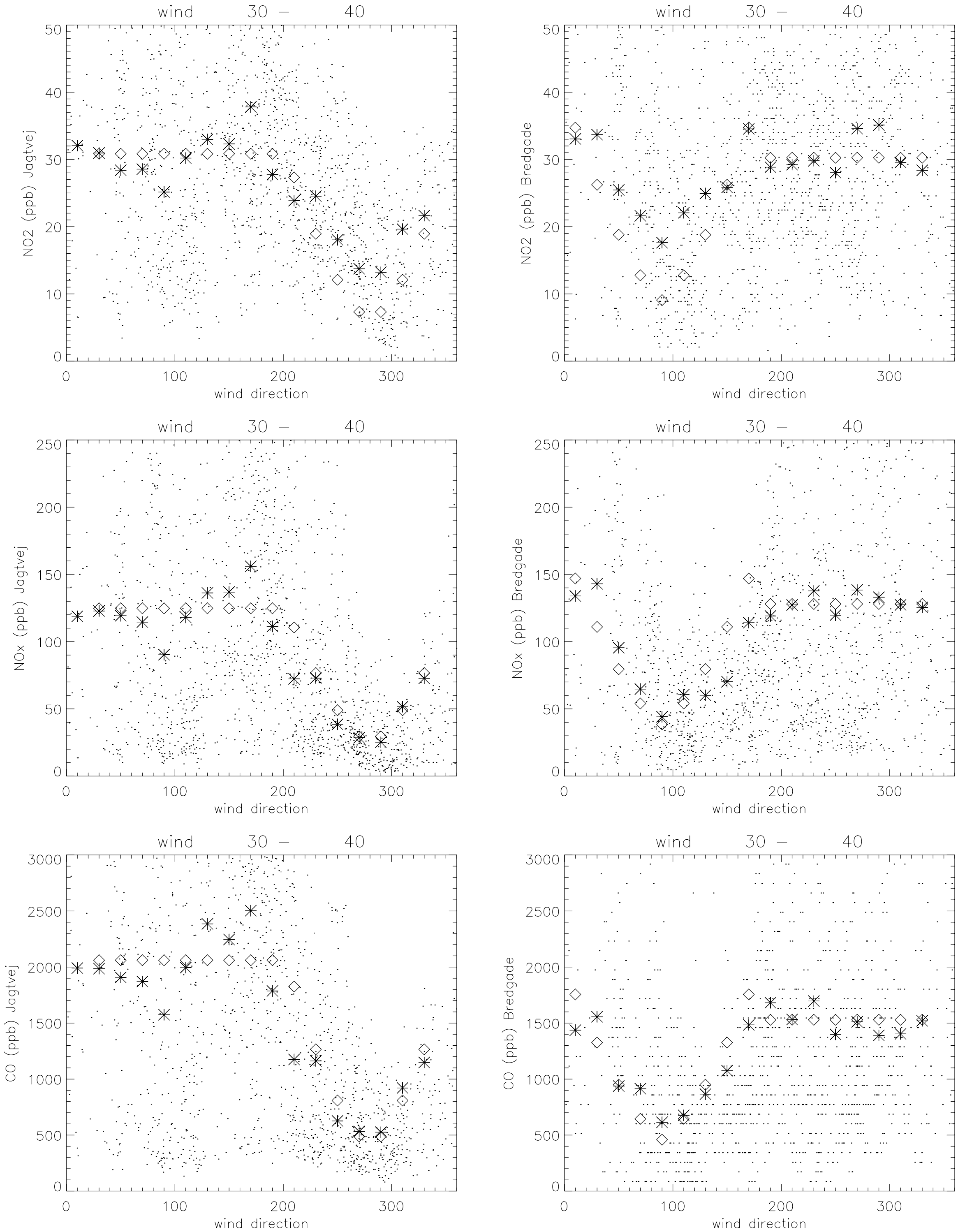

Fig. 5 Wind direction compared to the concentration of NO_2, NO_x and CO at Jagtvej and Bredgade for wind speeds between 3-4 m/s. The stars are the mean concentration in a 20^o wind direction interval and the rhombs are the model values used for the wind direction dependency

4.1.3 Mixing height, H_{mix}

The mixing heights have been calculated using the bulk Richardsons number method on analyzed vertical profiles derived from the numerical weather prediction model DMI-HIRLAM [Sass et. al, 1997]. The bulk Richardsons number is given by

$$Ri_B = \frac{gz(\theta_v - \theta_s)}{\theta_s(u^2 + v^2)} \qquad (5)$$

where g is the gravitational acceleration, z is the height, θ_v and θ_s are the virtual potential temperature at height z and at the surface, and u and v are the horizontal wind components.

As seen in Fig. 6 there is a general trend to lower concentrations of NO_2 and CO with increasing mixing height, especially for low mixing heights (less than 700 m). The strongest dependency is seen for Jagtvej in daytime hours for CO.

The algorithm used for the relation to the mixing height is:

$$f(H_{mix}) \equiv 700/\min[700, \max[100, H_{mix}]] \qquad (6)$$

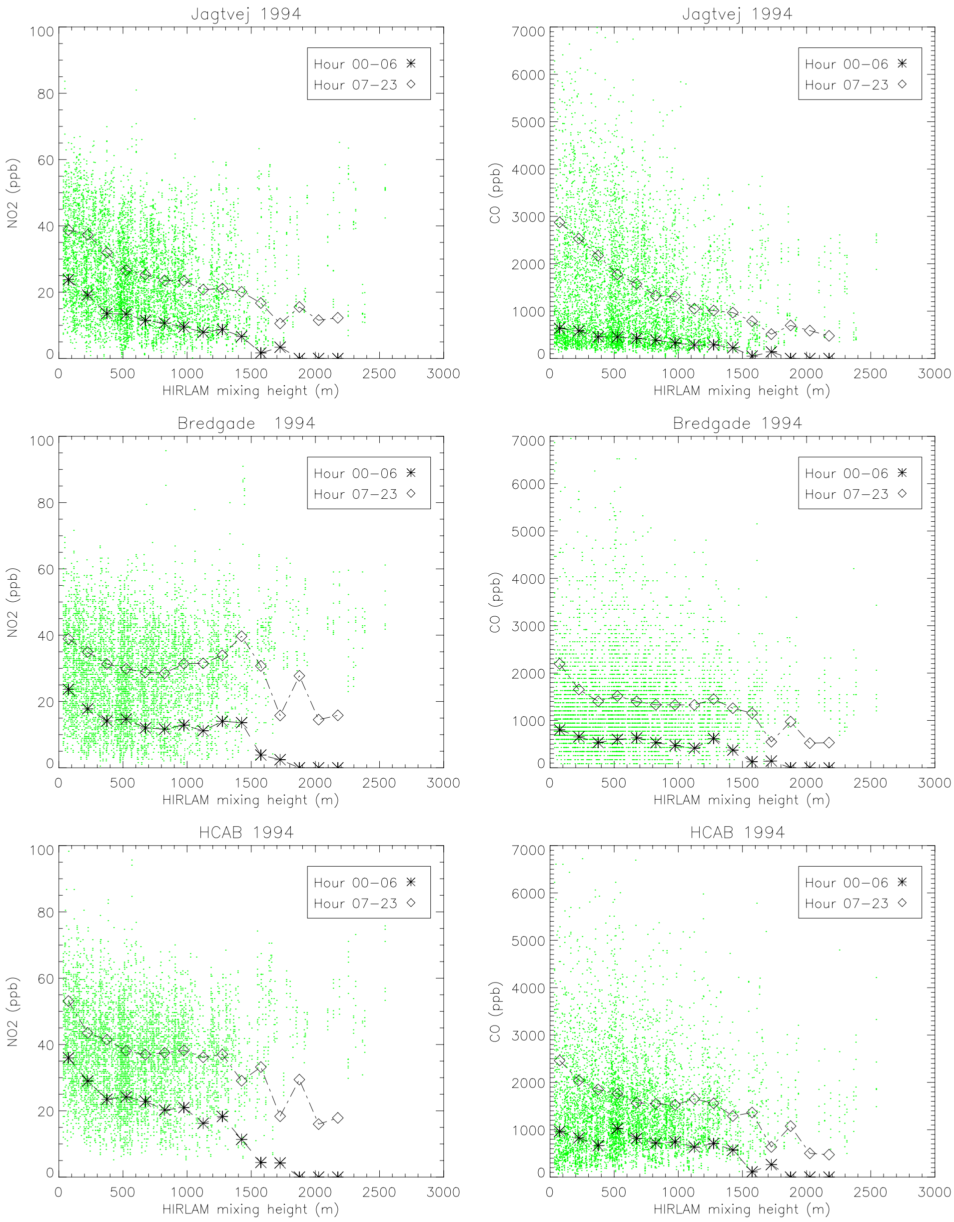

Fig. 6 Mixing height compared to the concentration of NO_2, and CO at Jagtvej, Bredgade and HCAB. The stars and rhombes shows respectively the mean concentrations for the hours 0-6 and 7-23.

5. Results

5.1 Calculations for reference years 1994-96

Two methods for the wind relation have been used, an inverse linear relation, eq. (2), and an exponential relation, eq. (3). The inverse linear method is only useful for a limited range of the wind speed range, whereas the exponential is valid for the whole range. Comparing the performance of these two methods, Fig. 7 and Fig. 8, it is seen that the inverse linear relation method in general have the best fitting percentiles while the exponential relation method in general gives the lowest RMSE and highest correlation.

In Fig. 9 the result of a simulation using meteorological data (wind speed and -direction) from the station on the top of the HCØ building is shown. This simulation gives better results for Jagtvej, which is the station next to the HCØ building, in comparison to the simulations utilising Kastrup meteorology, Fig. 8. The HCØ meteorology represents the local Jagtvej conditions very well, but for the two other stations (Bredgade and HCAB) the meteorology of Kastrup, as used in this connection, seems to represent the local conditions just as well as the HCØ meteorology. The meteorological measurements at Kastrup have a long history and gives good opportunities to make calculations of the weather index for a long period.

Two other simulations (inverse linear and exponential) using meteorological data calculated by the numerical weather prediction model DMI-HIRLAM have also been performed. Results of the statistics of all 6 simulations are shown in the block diagrams, Fig. 10, Fig. 11, Fig. 12.

For the mean daily variation, Fig. 10, all simulations have a high correlation from about 0.92-0.98 with the highest correlation for Jagtvej and the lowest correlation for HCAB especially for NO_x. Also for the RMSE of the mean daily variation the results are best for Jagtvej and worst for HCAB. Concerning the use of wind relation method, the exponential method gives the highest correlation and lowest RMSE for all stations

For the hourly values, Fig. 11, the correlation is much lower, between 0.50-0.65, but again with the highest score for Jagtvej. Generally the correlation is slightly higher using the inverse linear method compared with the exponential method, while the RMSE are lowest for the exponential method.

For the percentiles, Fig. 12, the results for the 50 percentile is fairly good for all simulations, while the simulation generally have too low 98 and 99.9 percentiles.

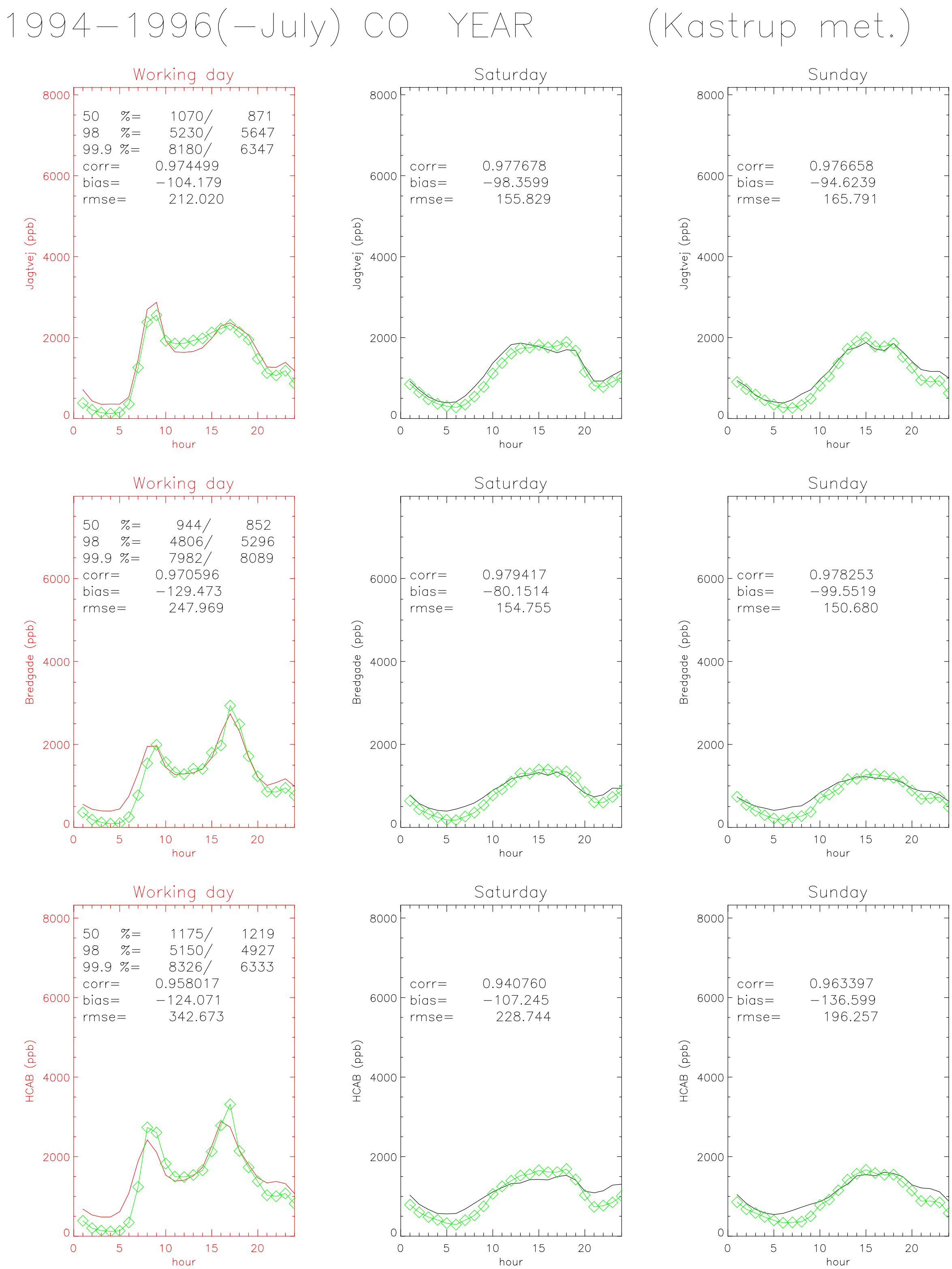

Fig. 7 CO mean daily variation 1994-96. Linear inverse wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from Kastrup airport. The two numbers for percentiles shows observed/modeled

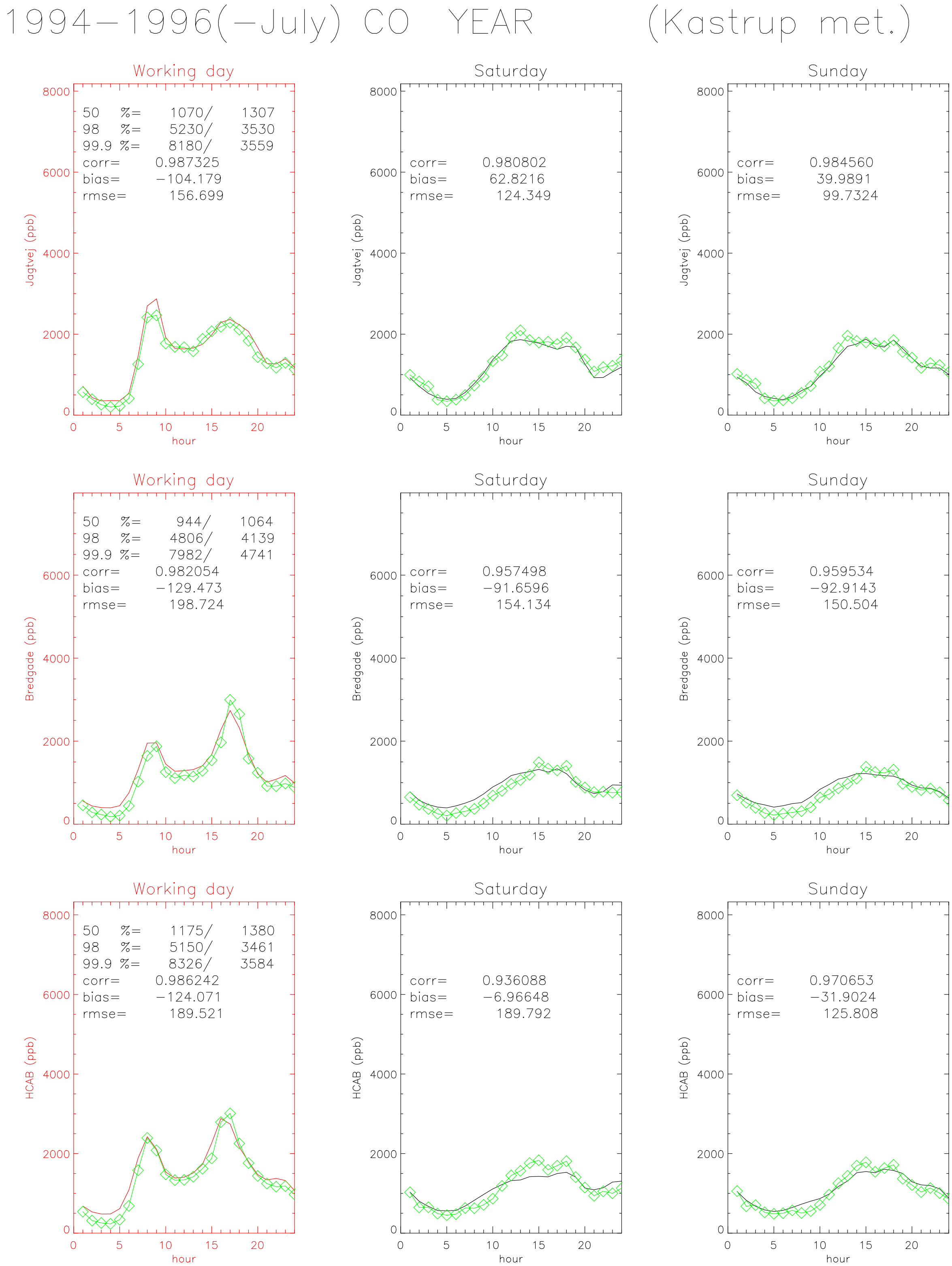

Fig. 8 CO mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from Kastrup airport.The two numbers for percentiles shows observed/modeled.

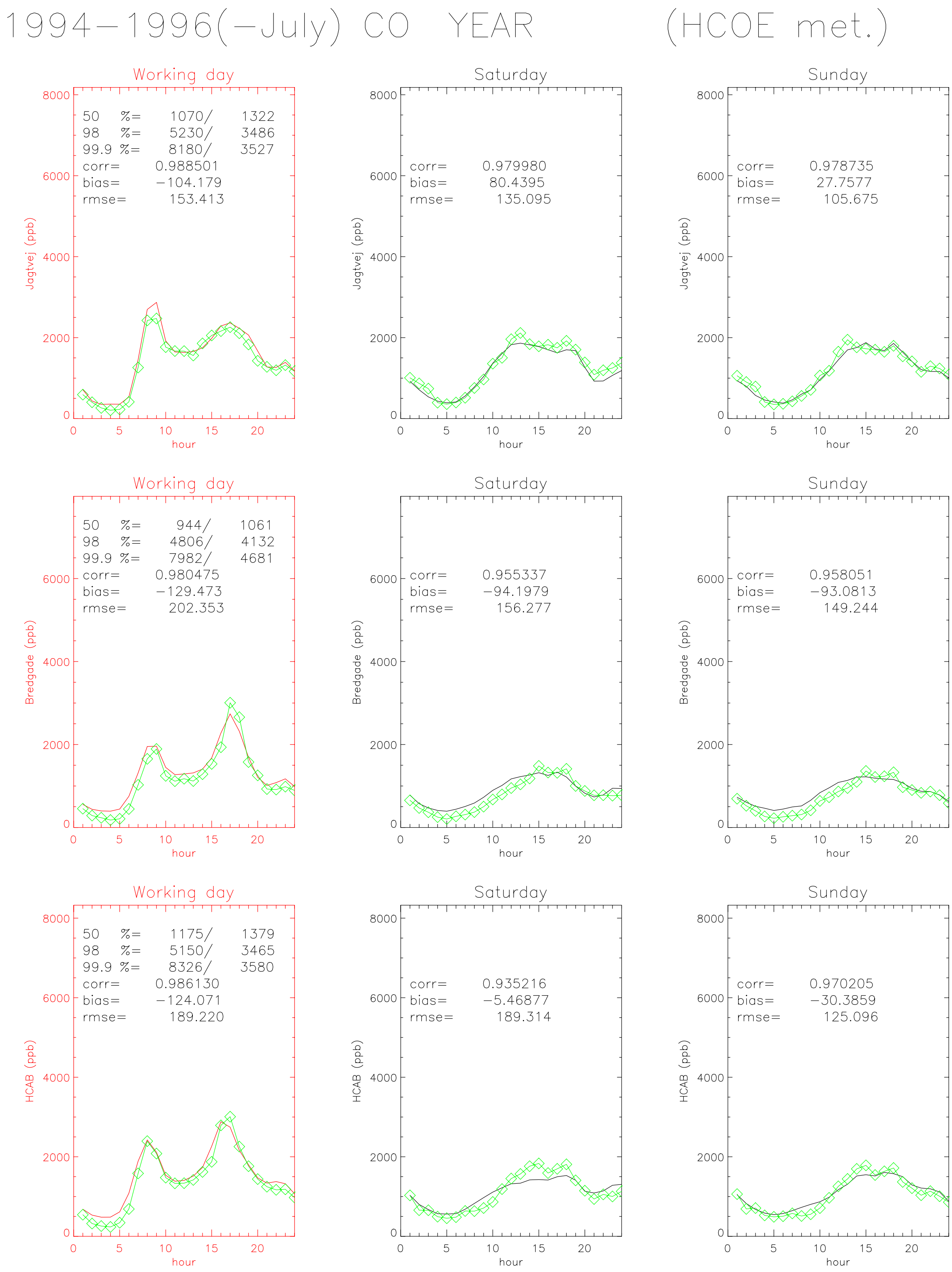

Fig. 9 CO mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from the HCOE building.The two numbers for percentiles shows observed/modeled.

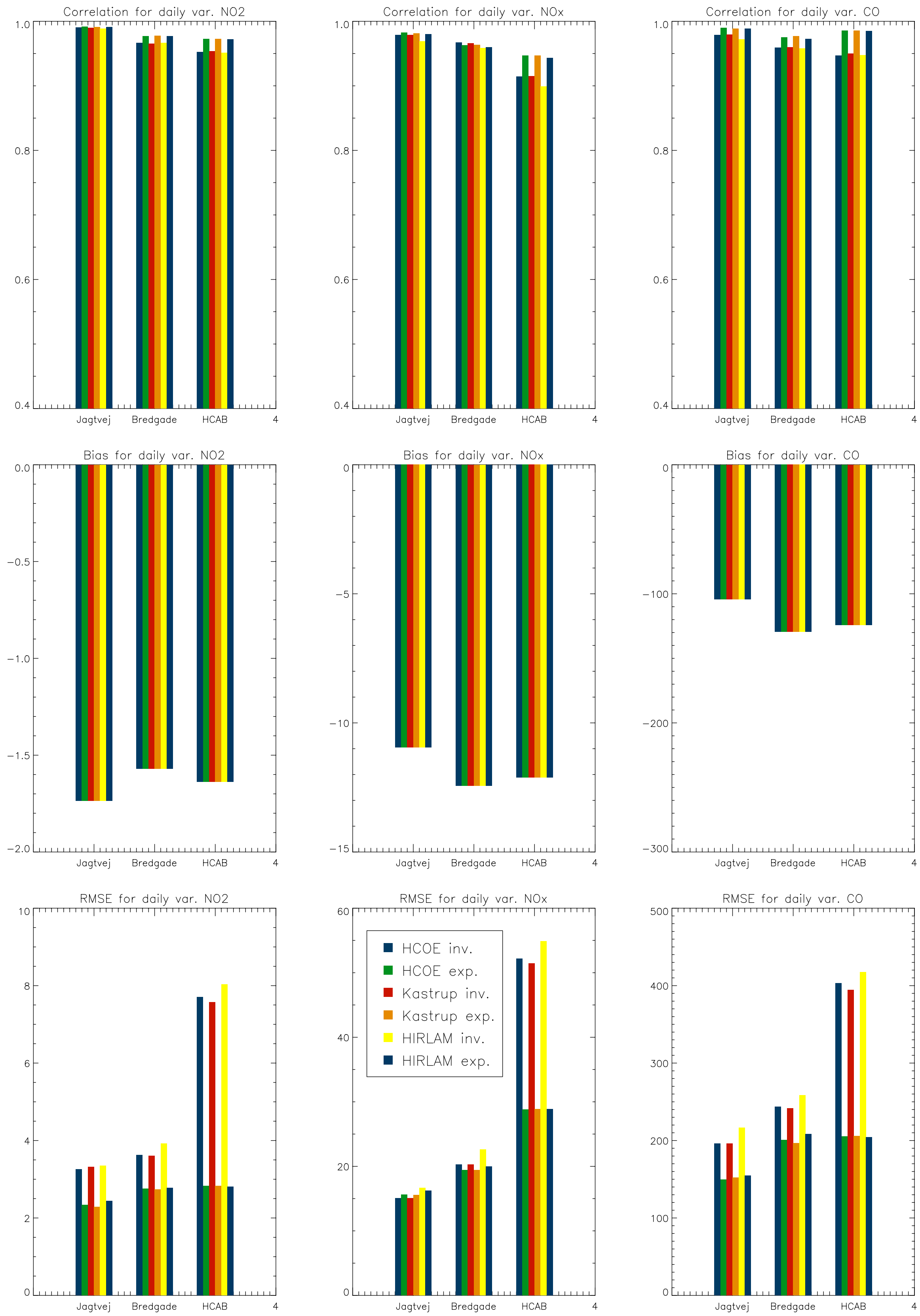

Fig. 10 Correlation, bias and RMSE for the working day simulation of 3 stations for 3 species over the period 1994-1996. 3 different sources of meteorological data and 2 kind of wind relations are used, the combination of these are shown in the bars. The statistics are calculated on a mean of the daily variation.

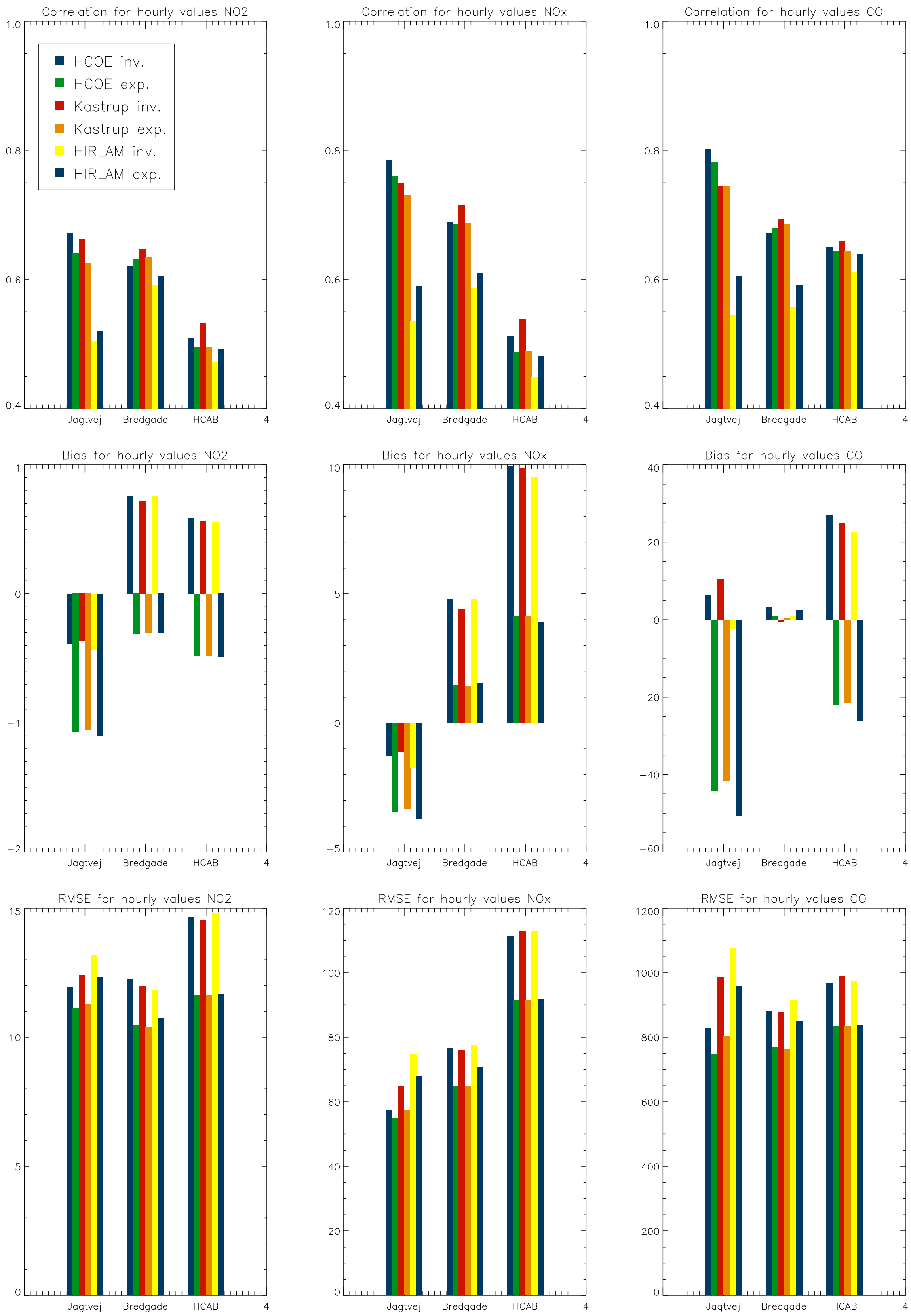

Fig. 11 Correlation, bias and RMSE for the working day simulation of 3 stations for 3 species over the period 1994-1996. 3 different sources of meteorological data and 2 kind of wind relations are used, the combination of these are shown in the bars. The statistics are calculated on hourly values.

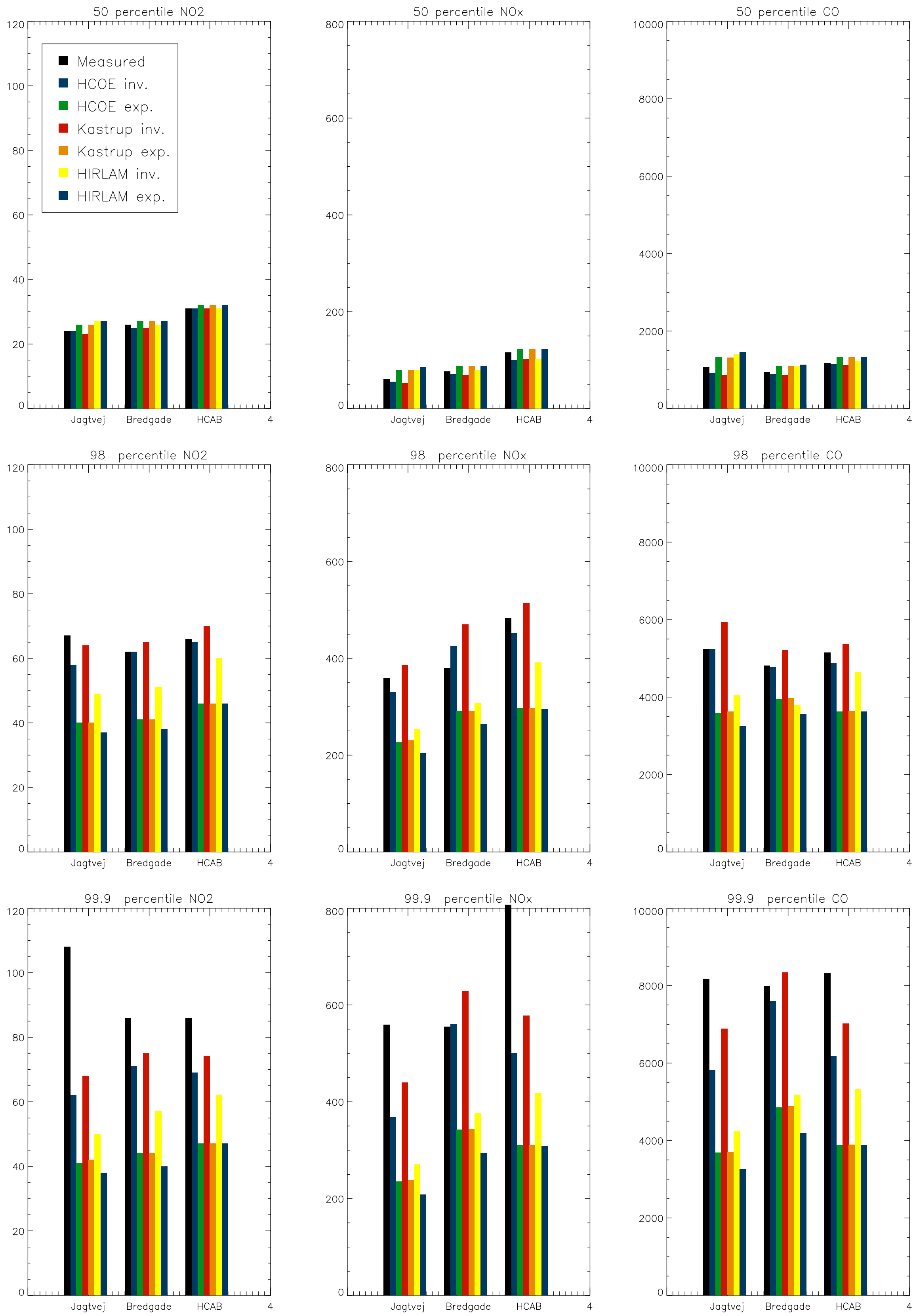

Fig. 12. 50, 98 and 99.9 percentiles for the working day simulation of 3 stations for 3 species over the period 1994-1996. 3 different sources of meteorological data and 2 kind of wind relations are used, the combination of these are shown in the bars. The statistics are calculated on hourly values.

5.2 Weather index

The influence of the weather on the air pollution concentrations in the streets can be calculated, by using the meteorological dependent parameters in eq. (1), i.e. the wind speed relation, W eq. (2) or eq. (3), the wind direction relation, D eq. (4), and the mixing height relation, H_{mix} eq. (6), giving this relation:

$$WEATHIX_{period} = \frac{\sum_{i=1}^{period} f(W) * f(D) * f(H_{mix})}{\left| WEATHIX_{allyears} \right|} \qquad (7)$$

High values of WEATHIX will in general mean elevated concentrations of air pollutants.

5.2.1 WEATHIX for 1990-97

Fig. 13 shows the calculated WEATHIX for 1990-97 for NO_2, NO_x and CO for Jagtvej, Bredgade and HCAB. It can be seen that the index for Jagtvej and Bredgade are generally negatively correlated, which mainly is due to the influence of the wind direction relation. For HCAB there is no dependency on wind direction, so the variation in the index is due to the variations in the wind speed and variations in H_{mix}. Differences between the species are related to the exponential wind speed relation. NO_2 shows up to be less influenced of the weather than the other species.

An illustration of the possible use of WEATHIX is made in Fig. 14, showing the observed annual mean concentrations of NO_2, NO_x and CO normalised with WEATHIX. Normalising the concentration level with WEATHIX would give a concentration level, only caused by the traffic. The normalising gives in most cases the expected result of a more smooth trend in the concentration of the pollutants. The trend are expected to be smooth because no sudden changes in the emissions from the traffic are present, except for the years 1993-1994 where old cars were scraped and catalysts were compulsory.

All observations presented in Fig. 14 are annual means of all hours and days taken from [Miljøkontrollen 1997] for Bredgade and HCAB, and annual means of all hours and days calculated from the observations from Jagtvej. All data have been corrected for background values measured at the HCØ building.

A nice smoothing is seen for CO in general and in most cases for NO_x, while the results are not so clear for NO_2.

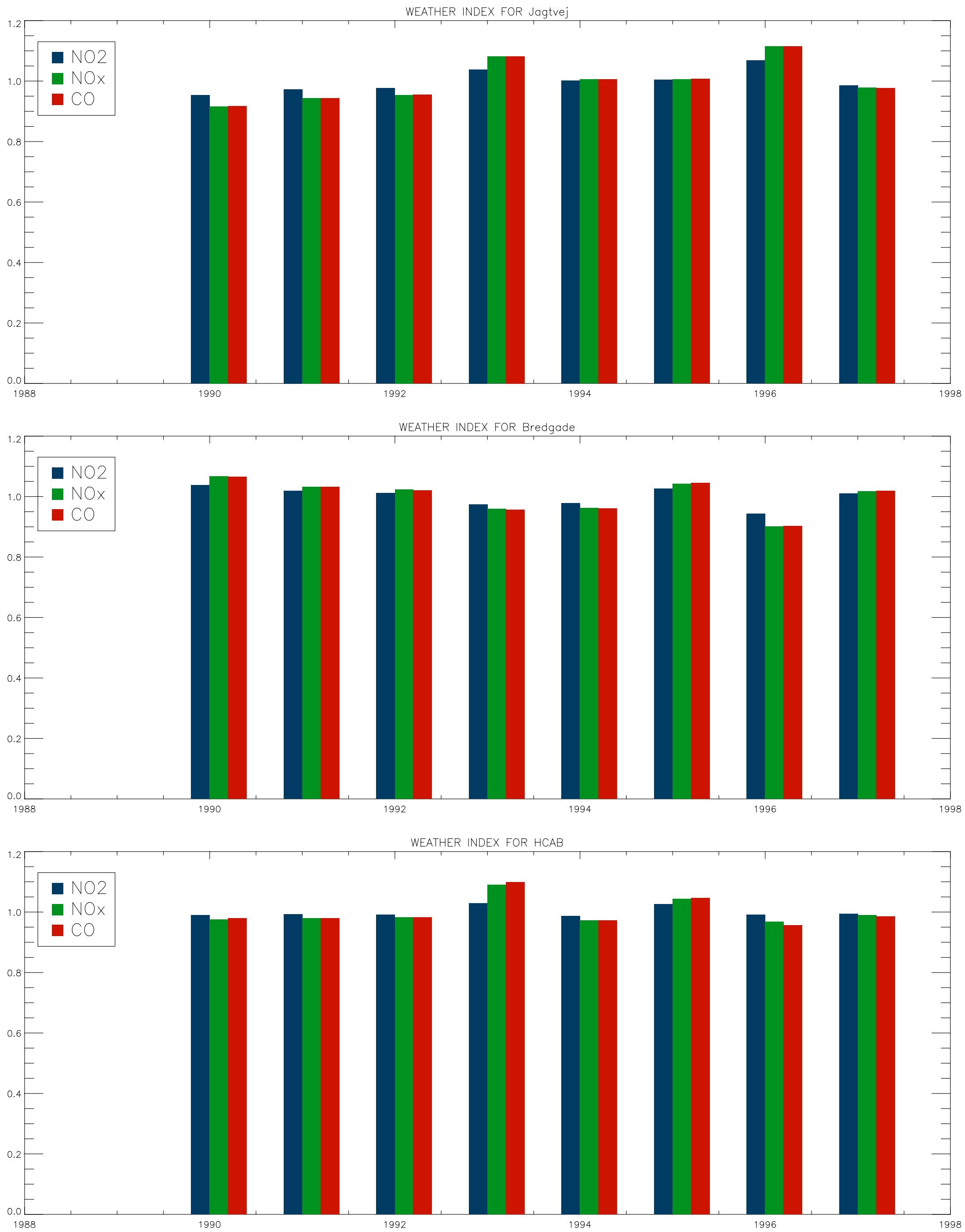

Fig. 13 WEATHIX calculated for 8 years, 1990-1997, for the 3 stations and 3 species.

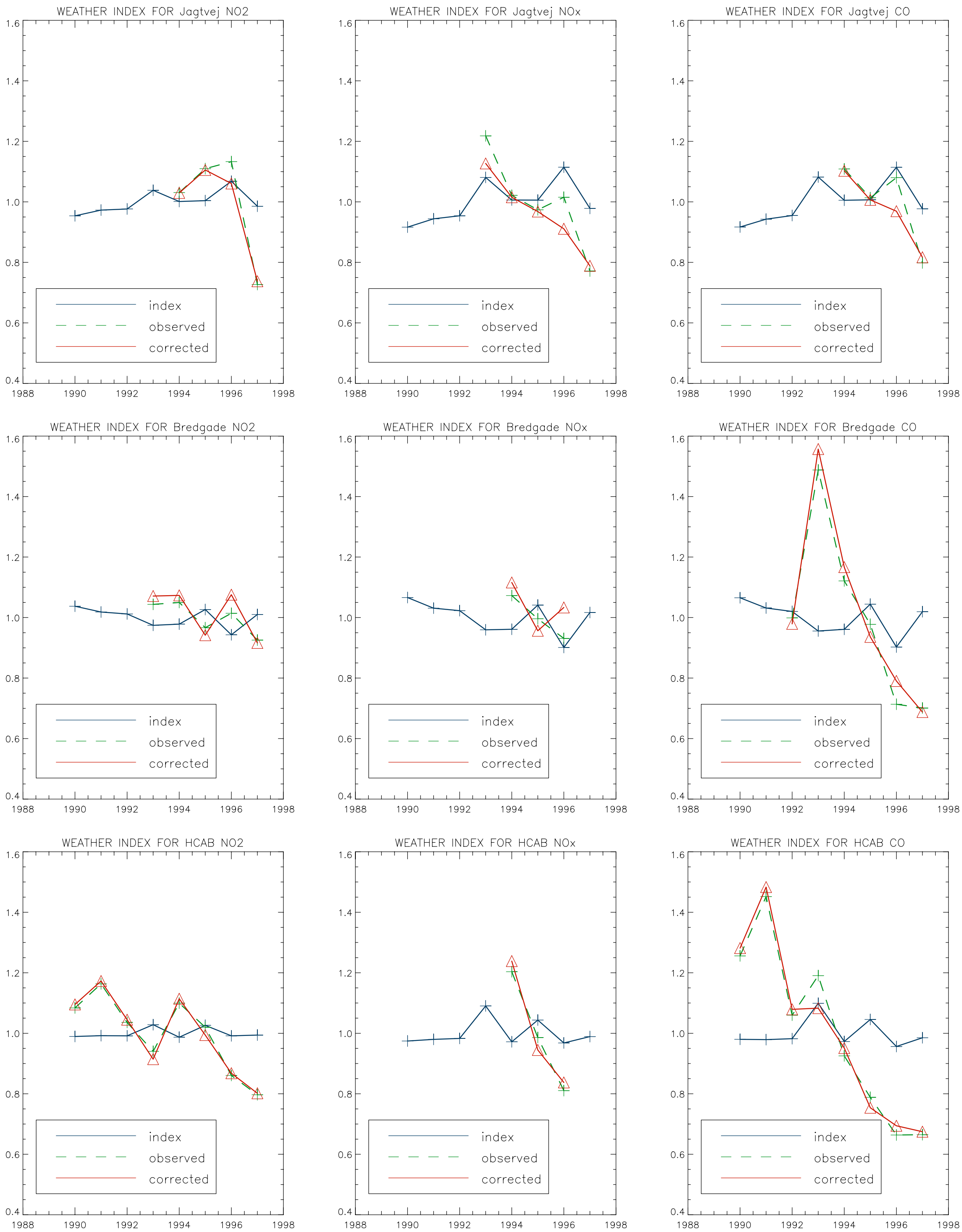

Fig. 14 Observed concentrations, WEATHIX and normalised observed concentrations ("corrected").

6. Conclusion

The developed statistical model, only using the most important meteorological parameters as wind speed, wind direction and mixing heights together with informations of the traffic, seems to perform reasonable results for the annual variability of the mean values.

Different sources of meteorological data and different kind of wind relations have been tested for hourly and mean values over the years 1994-1996. Meteorological data are retrieved from 3 different sites/sources; at the roof of the HCØ building close to the Jagtvej measurement station, at Kastrup airport and calculated data from the NWP model DMI-HIRLAM. Wind measurements from HCØ gave the best results for Jagtvej probably because it pictures the local conditions best, while wind measurements from Kastrup gave better results for Bredgade and HCAB, even though these data only were represented every 3. hour. The DMI-HIRLAM meteorological data were only represented each 6. hour and did not show better results.

The different kinds of wind relations used are the exponential wind relation and the inverse linear wind relation. Using the exponential wind relation the annual mean values show a better correlation, RMSE and bias than using the inverse linear wind relation, but only slightly better results for the hourly values. These results apply to the use of both HCØ and Kastrup measured wind. The best percentiles are performed by the model using the inverse linear wind relation, as this model gives a wider span of results than the other models.

Even though use of the exponential wind relation based on the empirical method gave the best results, it can be concluded that the method not based on empirical methods is the most representative, when the purpose is to calculate weather indexes for years ahead of the simulated period 1994-96. Nevertheless, the exponential wind relation method is useful in the state of development, or in situations when new parameters for the exponential relation can be calculated each year.

The influence of the weather on the air pollution concentrations in the streets has been evaluated, by using the meteorological dependent parameters in the statistical model to calculate a weather index, WEATHIX. Normalising the observed concentration level with WEATHIX should give a concentration level, only caused by the traffic. The normalising for the years 1990-97 gives in most cases the expected result of a more smooth trend in the concentration of the pollutants.

7. References

[1] Berkowicz R. et al. *"Using measurements of air pollution in streets for evaluation of urban air quality - meteorological analysis and model calculations."* The Science of the Total Environment", Vols. **189/190**, ISSN 0048-9697, 1996.

[2] Boeft J. et al. CAR International: *"A simple model to determine city street air quality.* The Science of the Total Environment", Vols. **189/190**, ISSN 0048-9697, 1996.

[3] Eliasson, I. *"Urban Nocturnal Temperatures, Street Geometry and Land Use".* Atm. Env. Vol. **30**, No. 3, pp. 379, 1996.

[4] Hertel O., R. Berkowicz. *"Operational Street Pollution Model (OSPM). Evaluation of the Model on Data from St. Olavs Street in Oslo".* DMU LUFT-A135. ISBN. 87-7440-147-5, 1989.

[5] Nakamura, U., T.R. Oke. Wind, *"Temperature and Stability Conditions in an East-West Oriented Urban Canyon".* Atm. Env., Vol. **22**, No. 12, pp. 2691, 1988.

[6] Danmarks Miljøundersøgelser. *"Overvågning af trafikkens bidrag til lokal luftforurening (TOV). Målinger og analyser udført af DMU".* Faglig rapport nr. 316. DMU, 2000.

[7] Danmarks Statistik. *"Statistisk årbog 1994"*, 1994.

[8] Danmarks Statistik. *"Statistisk årbog 1995",* 1995.

[9] Danmarks Statistik. *"Statistisk årbog 1996",* 1996.

[10] Danmarks Statistik. *"Statistisk årbog 1997",* 1997.

[11] Danmarks Statistik. *"Statistisk ti årsoversigt 1997, tema om miljø",* 1997.

[12] Miljøkontrollen. *"Luftkvalitet i Hovedstadsregionen 1996".* ISBN. 87-88920-86-0, 1996.

[13] Rasmussen, A. *"Trafik og Miljø. Overvågning af luftkvaliteten - Atmosfæremodeller - Atmosfærekemimodeller samt smog- og ozon - Drivhuseffekt og klima Sammenfattende rapport over DMI's Trafikpuljeprojekter 1995-99",* ISSN 0906-897X. DMI, TR 00-13, 2000.

[14] Sass, B. H., Nielsen, N. W., Jørgensen, J.U., 2000: *"The operational DMI-HIRLAM system, 2^{nd} rev. ed."* DMI Technical Report, 99-21

[15] Sattler, K., 1999: *"New high resolution physiograpic data and climate generation for the HIRLAM forecast system",* DMI, Technical Report, No. 99-11.

[16] Sini J-F. et al. *"Pollutant Dispersion and Thermal Effects in Urban Street Canyons",* Atm.Env., No.**15**, pp. 2659, 1996.

[17] Sjødin A. et al. *"Verification of expected trends in urban traffic* NO_x *emissions from long-term measurements of ambient* NO_2 *concentrations in urban air."* The Science of the Total Environment, Vols. 189/190, ISSN 0048-9697, 1996.

[18] Sørensen J. H., A. Rasmussen, H. Svensmark. *"Forecast of Atmospheric Boundary-Layer Height Utilised for ETEX Real-Time Dispersion Modelling",* Phys. Chem. Earth. Vol. **21**, No. 5-6, pp. 435, 1996.

[19] Stein A.F., B.M.Toselli. *"Street Level Air Pollution in Cordoba City, Argentina",* Atm. Env. Vol. **30**, No. 20, pp. 3491, 1996.

[20] Trafikministeriet. *"Transportsektorens miljøbelastning",* ISBN 87-88453-51-0, 1994.

[21] Vejdirektoratet. *"Byområders trafikskabte luftforurening",* rapport nr.43, 1996.

[22] Vejdirektoratet. *"Trafik og gadeluft i Danmark. Registrering og beregning for 1995-1998",* rapport nr. 199, 2000.

1. Appendix

1.1 Inverse linear wind speed relation

1.1.1 Analysis of upper limits.

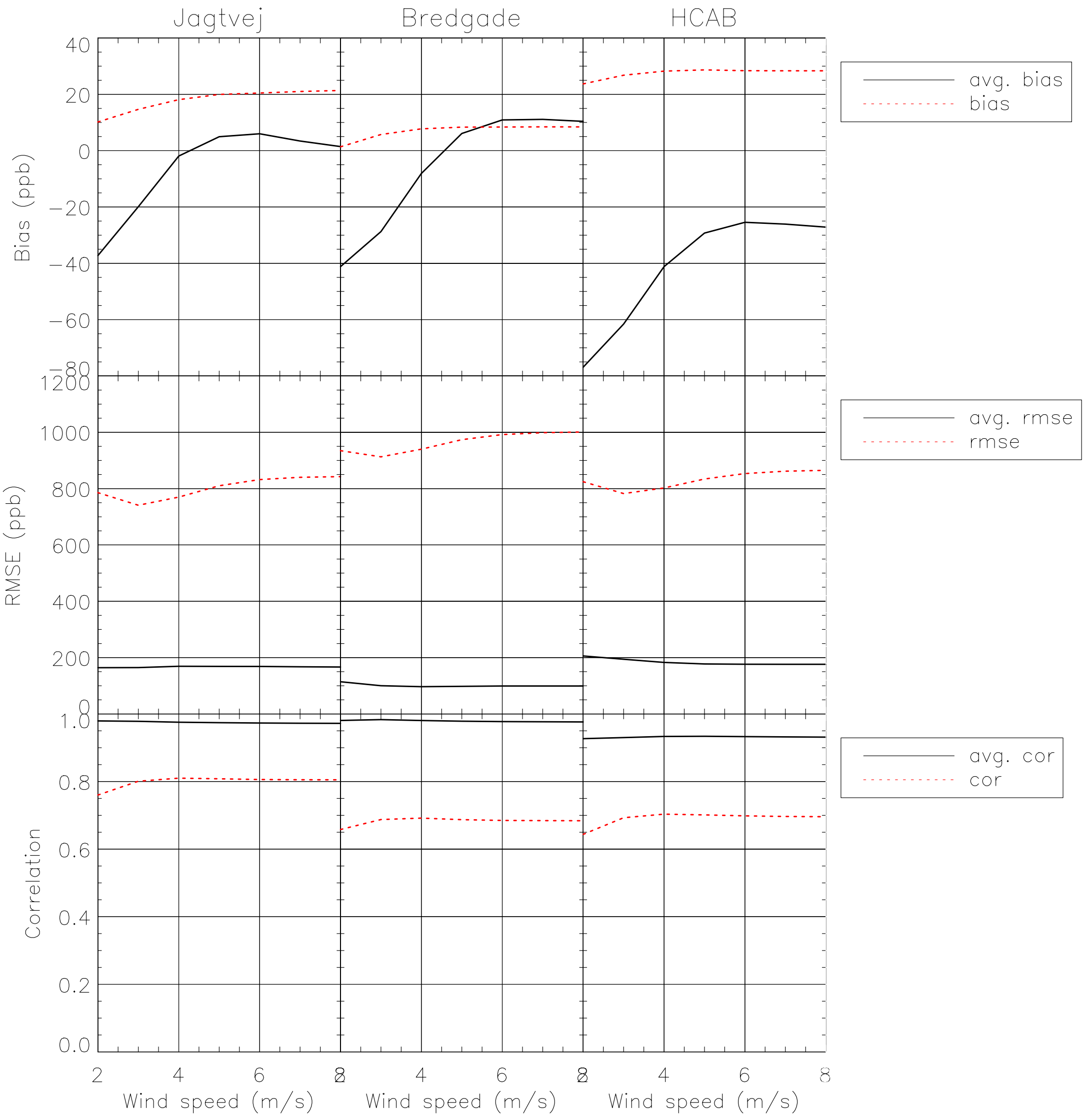

Fig. 15 BIAS, RMSE and correlation of the averaged daily variation hourly values and the hourly values, for several runs changing the upper limit of the inverse linear wind speed relation. The optimal upper limit chosen was 7 m/s.

1.1.2 Analysis of lower limits.

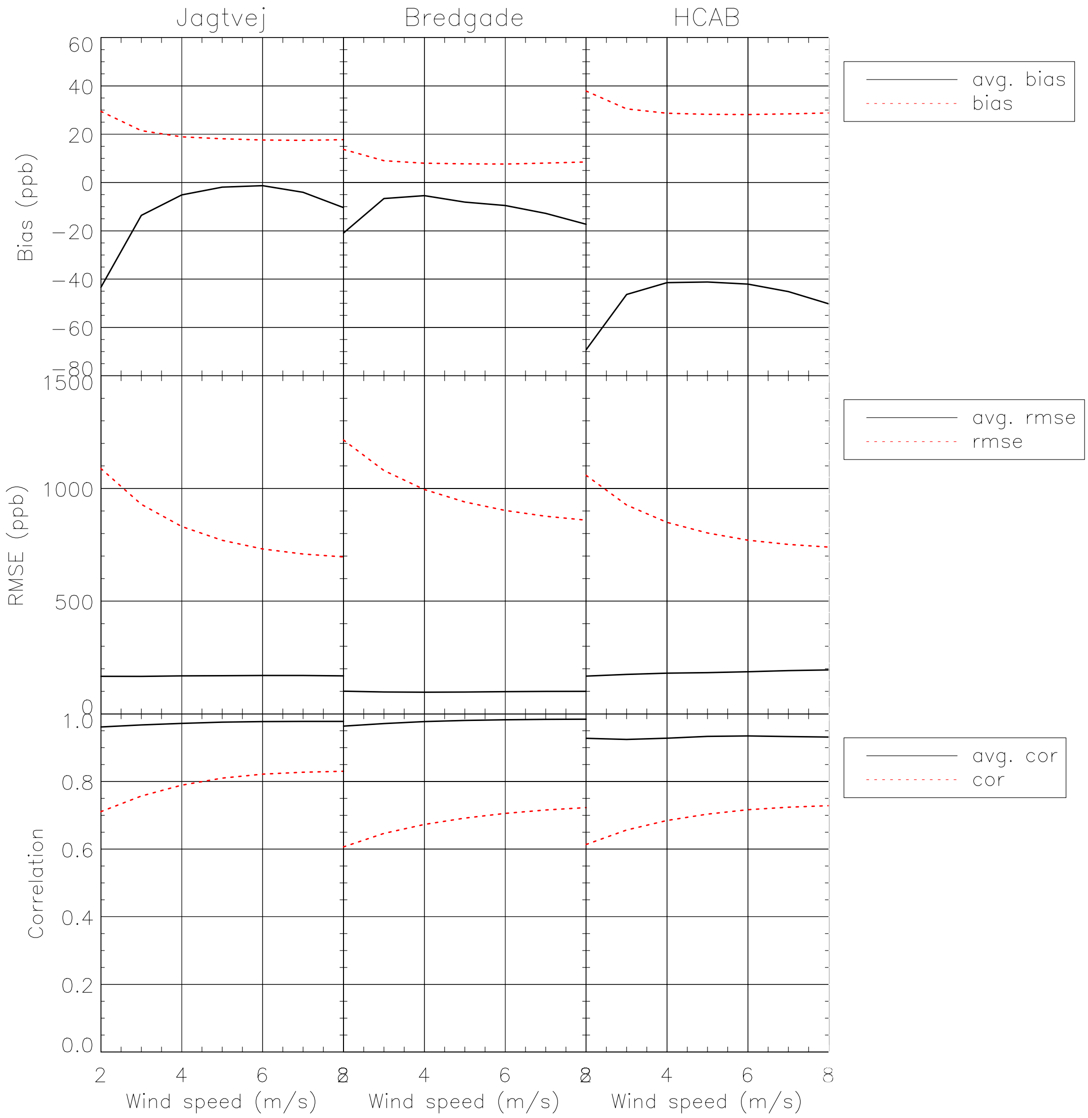

Fig. 16 BIAS, RMSE and correlation on the averaged daily variation hourly values and the hourly values, for several runs changing the lower limit of the inverse linear wind speed relation. The optimal lower limit chosen was 3.7 m/s.

1.1.3 Exponential relation

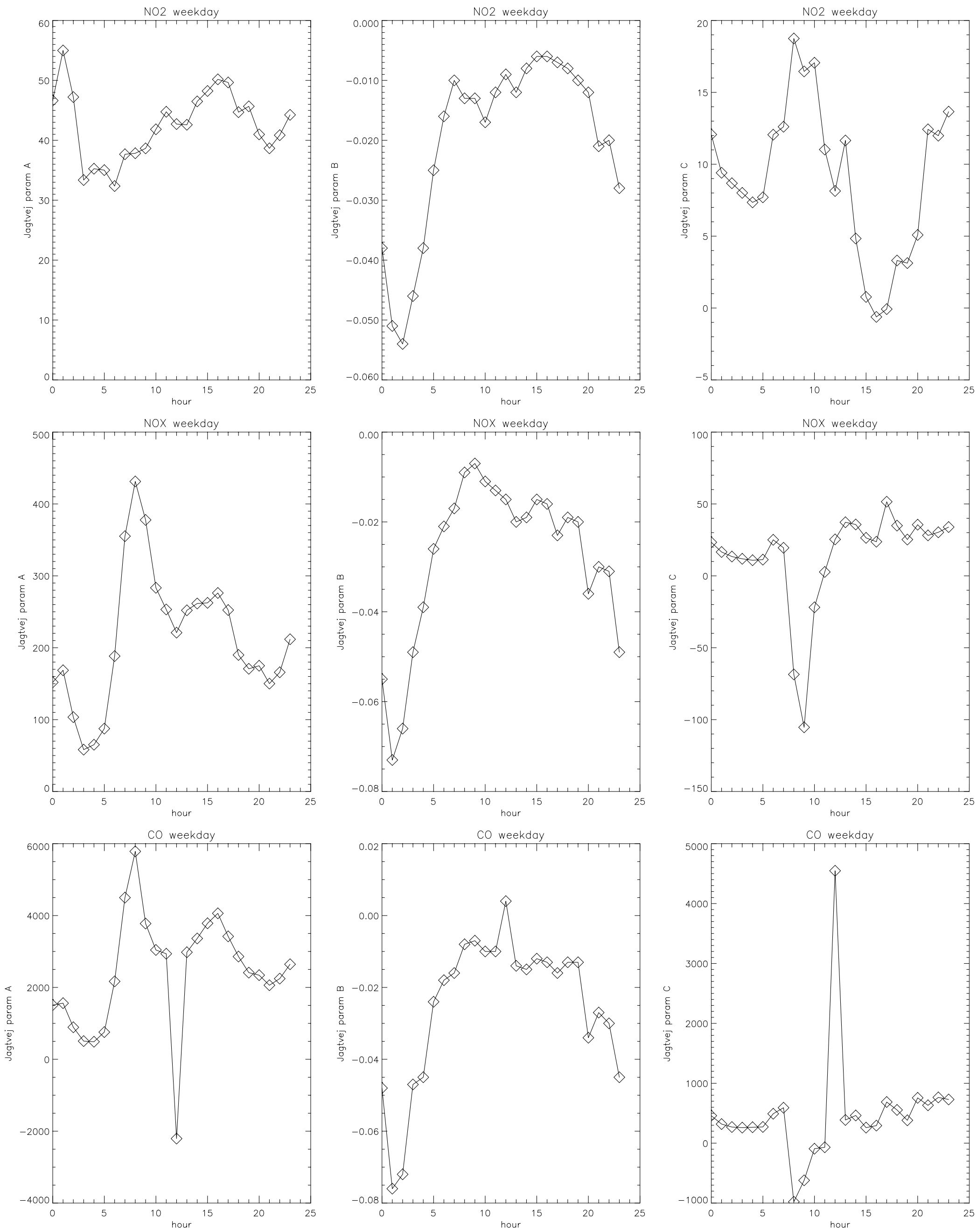

Fig. 17 The parameters A, B and C from the non-linear least squares fit to the mean of the observed concentrations, based on a 3 year period, 1994-1996. These results are for Jagtvej NO_2, NO_x and CO observations using wind observations from Kastrup

1.2 CO, mean daily variation for 1994, 1995 and 1996

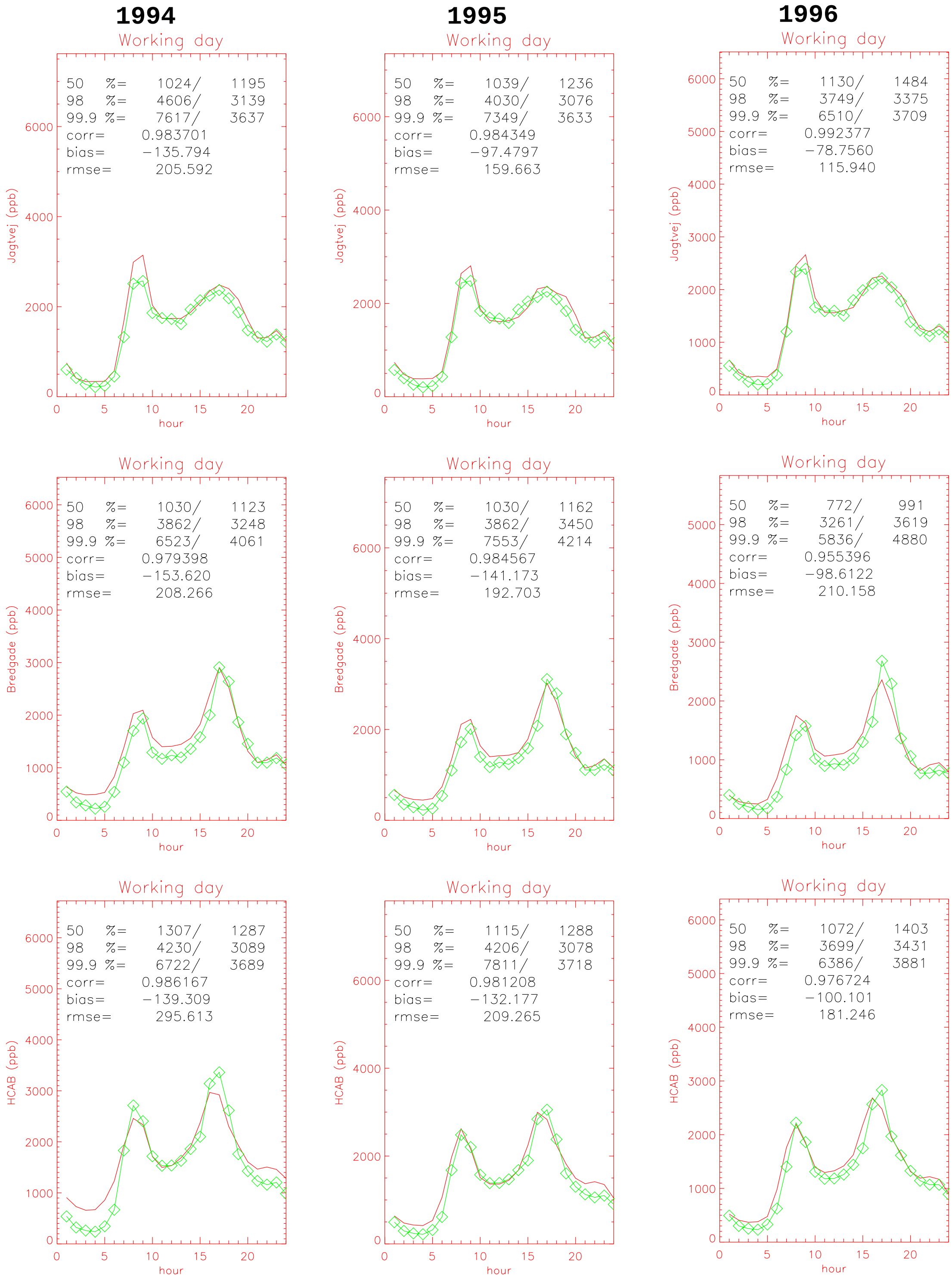

Fig. 18 CO mean daily variation 1994,1995,1996. Observations are full line and marked line are simulation calculated with meteorological data from Kastrup airport.The two numbers for percentiles shows observed/modeled.

1.3 CO, scatter plot of hourly values for 1994, 1995 and 1996

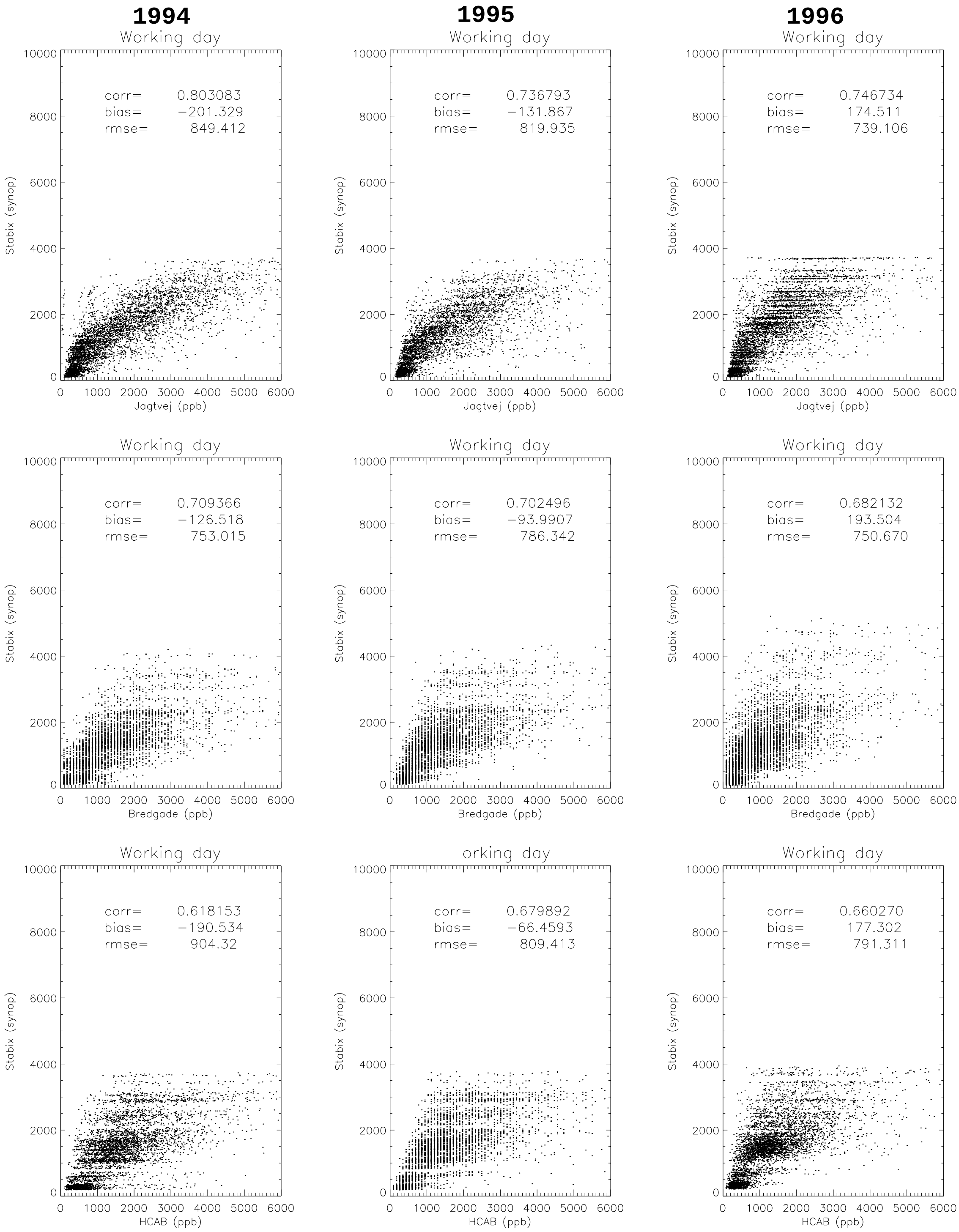

Fig. 19 CO hourly scatterplot 1994, 1995, 1996. Simulation calculated with meteorological data from Kastrup airport.

1.4 NO_2 mean daily variation 1994-96, HCØ-met.

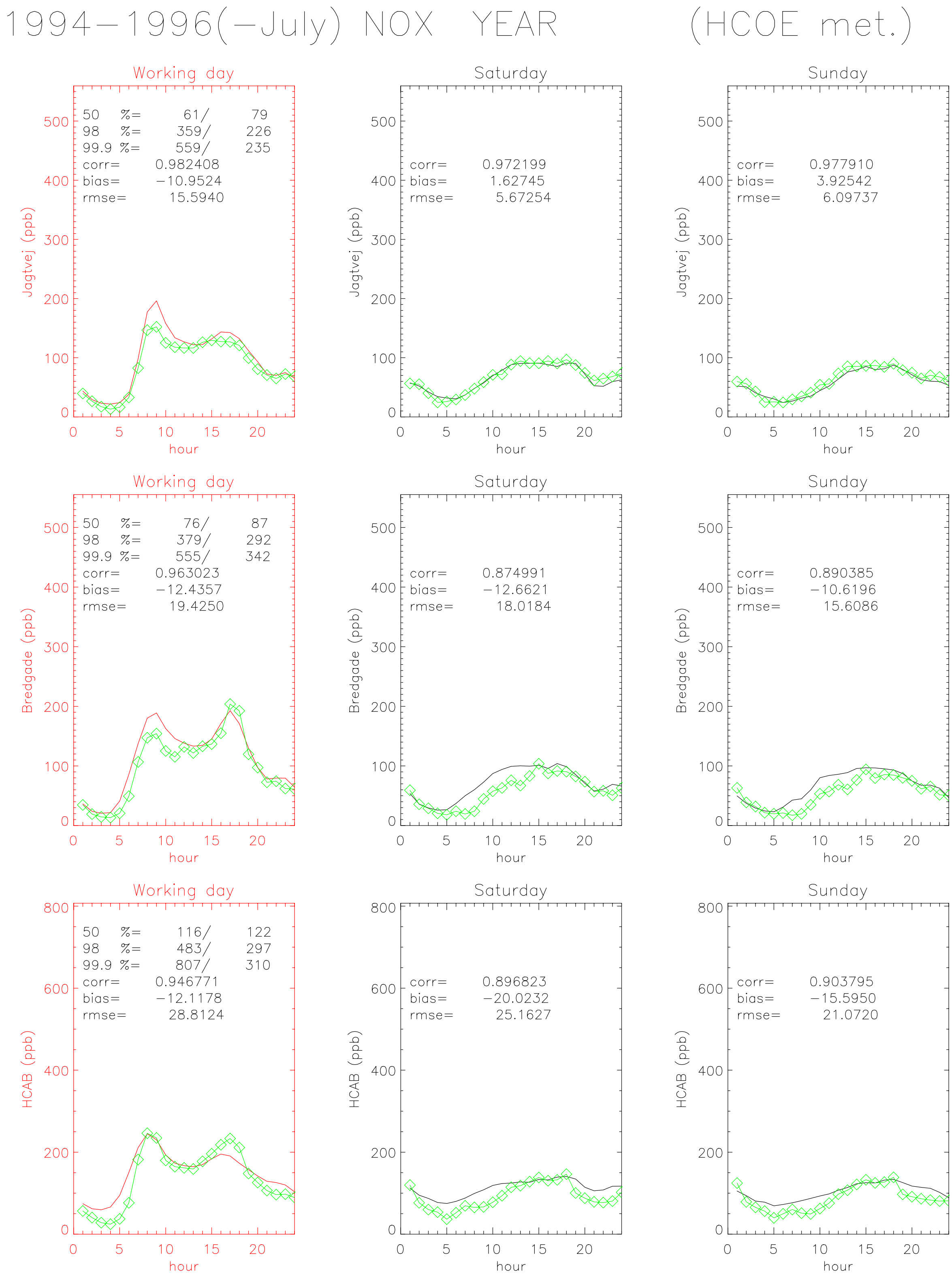

Fig. 20 NO_2 mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from the HCOE building.The two numbers for percentiles shows observed/modeled

1.5 NO_x mean daily variation 1994-96, HCØ-met.

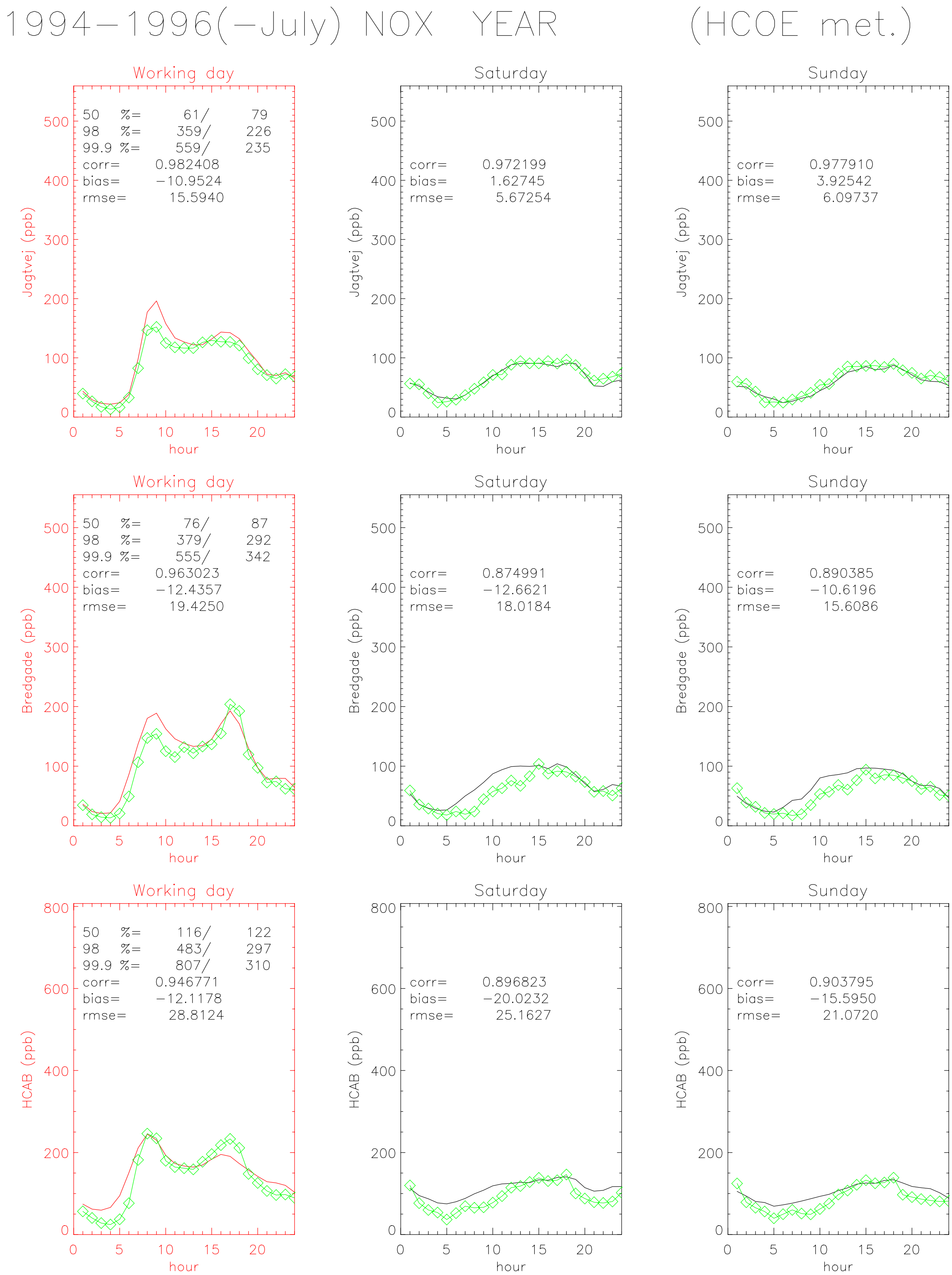

Fig. 21 NO_x mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from the HCOE building.The two numbers for percentiles shows observed/modeled.

1.6 NO_2 mean daily variation 1994-96, Kastrup-met.

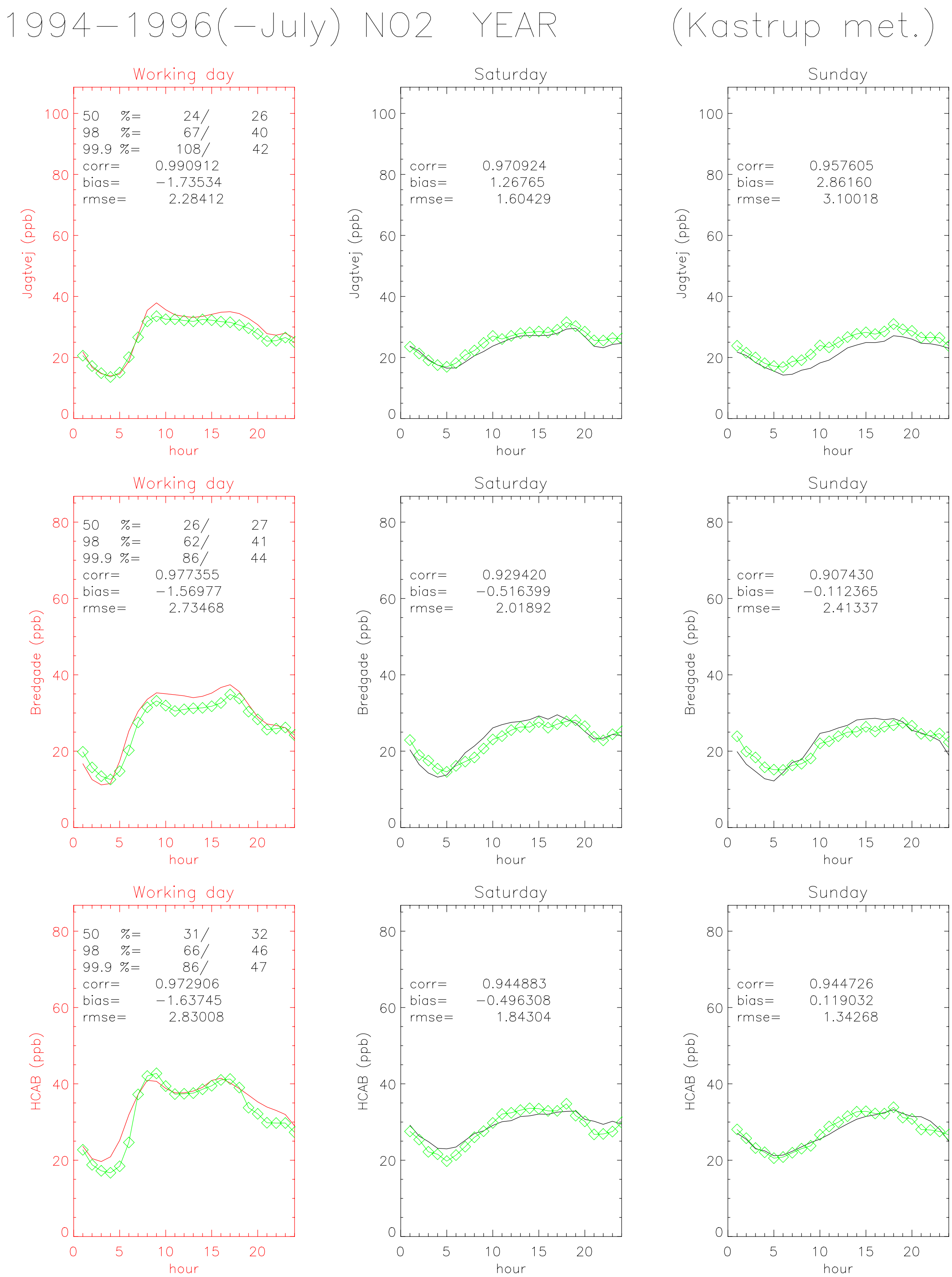

Fig. 22 NO_2 mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from Kastrup airport.The two numbers for percentiles shows observed/modeled.

1.7 NO_x mean daily variation 1994-96, Kastrup-met.

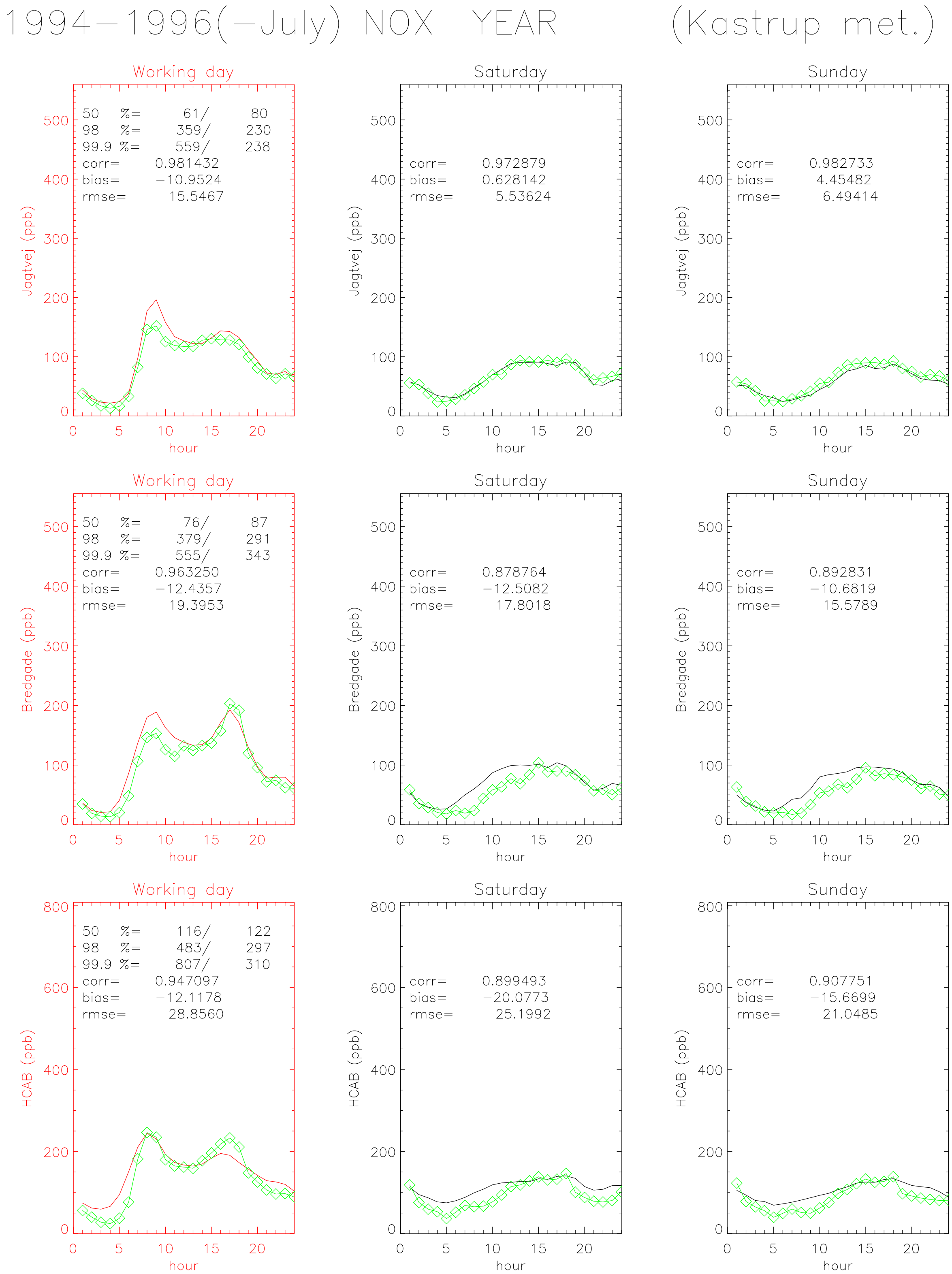

Fig. 23 NO_x mean daily variation 1994-96. Exponential wind relation are used. Observations are full line and marked line are simulation calculated with meteorological data from Kastrup airport.The two numbers for percentiles shows observed/modeled.

1.8 Indexes of WEATHIX for each month all years

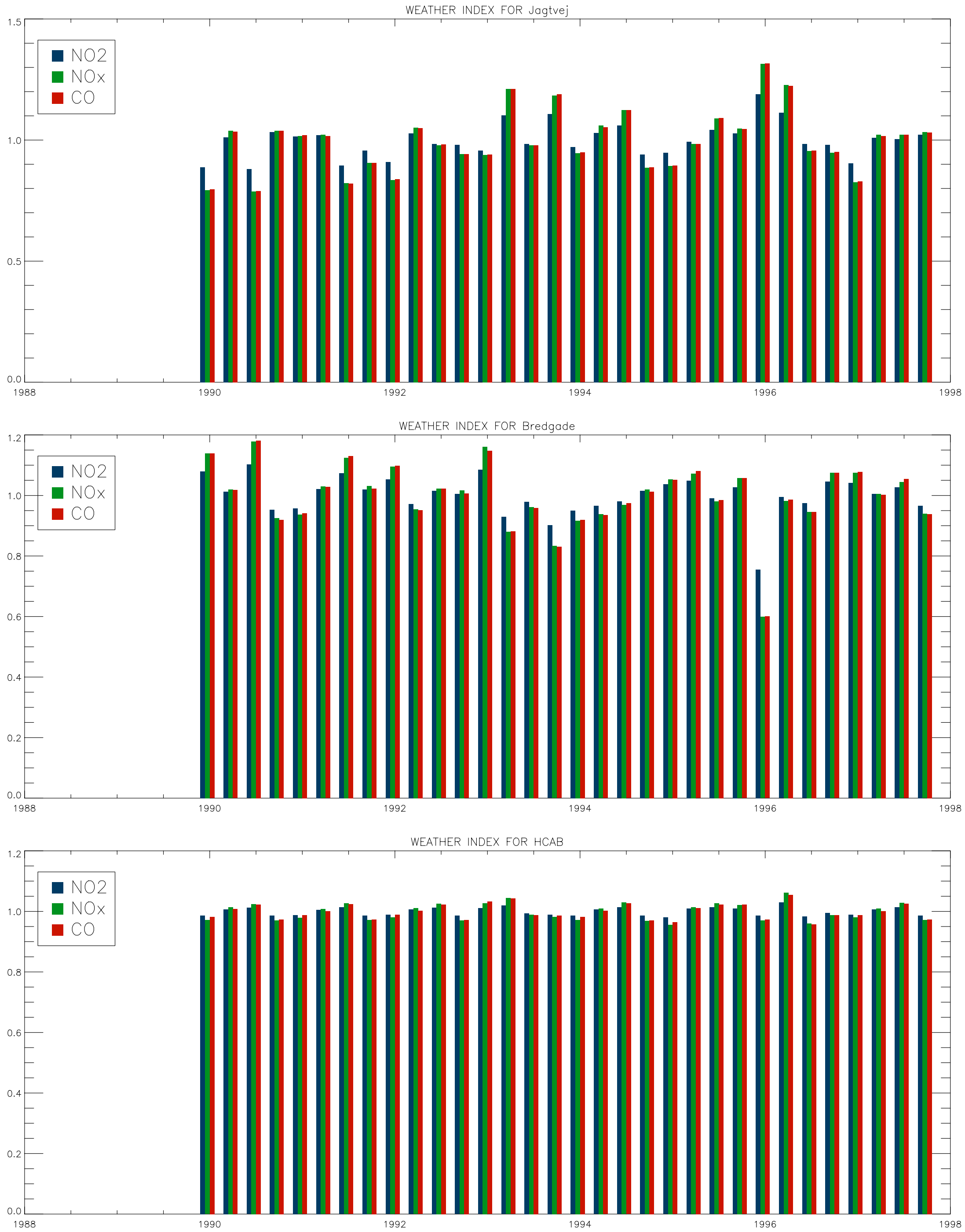

Fig. 24 WEATHIX calculated for 8 years (1990-1997) in quarters, for the 3 stations and 3 species.