NILU OR: 34/98

NILU : OR 34/98
REFERENCE : O-96132
DATE : JUNE 1998
ISBN : 82-425-0986-7

Air Quality Indicators

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Summary

This report proposes and describes in detail several air quality indicators that may be used to describe population exposure. The suggested indicators account for temporal and spatial patterns of pollution and movements of individuals' between different micro-environments.

The Air Quality Indicator (AQI) should represent both the spatial and temporal aspects of pollution exposure that may have important effects on health. Two indicators are needed, the Population Air Quality Indicator and the Individual Air Quality Indicator.

Mean concentrations, 98th percentile and maximum values are the traditional indicators for estimating exposure. The temporal variability of PM_{10} and NO_2, however, is here described by means of: 1) the **rate of change** of pollution as the difference between two consecutive hourly values, and of 2) **episodes**, described in terms of number, duration and inter-episode period, maximum concentration in the episode, and **integrated episode exposure** (episode AOT50/100).

The spatial variation of AQIs can be described in several ways, e.g.: 1) concentrations in neighboring grid squares can be compared as an indication of spatial variation, and 2) point estimates can be compared to grid values for a description of variation within a grid. Both methods are presented here.

A test of the representativity of static point estimates for pollution exposure is to compare them to an estimate of air pollution exposure accounting for movements between different locations, obtained using diaries.

The ultimate aim of AQIs is to describe the population exposure to ambient pollution. This is done by estimating the number of people exposed using different characteristics of AQIs.

The data used to describe these indicators originates from dispersion modeling of short-term air pollution concentrations in Oslo. Two series of data are used. One represents hour-for-hour concentrations in the 1-km^2 grid system covering the city of Oslo, winter 1994/95, calculated by the grid (version 1). The other series is individual exposure estimated hour-for-hour for a 4 month period for children.

We suggest that the two most promising air quality indicators are, the number of episodes and the integrated episodic exposure over a threshold.

Air Quality Indicators

1. Introduction

Health effects are increasingly being described in the form of the dose-response (or exposure-effect) relationship. This relationship allows quantifying the altered health status of a population by quantifying both the current and future health status based on measured and projected pollution concentrations.

Public authorities are currently using as air quality indicators (AQI) for health effects, average and peak concentrations of pollutants, together with the number of exceedances of existing air quality guidelines. The average concentrations can be of short duration (hourly) or longer duration (6 months, yearly) to reflect the more long term accumulation of pollution. These AQIs may then be considered together with the size of the population exposed.

However, it is more and more evident that attempts to characterize health effects using a simple relationship have not been quite effective. There is considerable variation in reported relationships between investigations. The reasons for these discrepancies are many. For example, it is not precluded that the temporal variation of exposure to a pollutant may be influencing the health impact. It may be necessary in the future to account for the temporal pattern of exposure in the setting of air quality guidelines.

The temporal pattern of exposure to a specific compound may affect health in several ways. Exposure to pollution can have short-term effects (immediately or in the next few days) or more long-term effects. For some compounds there is a threshold under which there is no presumed measurable effect, whereas for other compounds, there is no presumed threshold (for example PAH). A more detailed description of these situations can be found in other reports (SFT, 1992). For short-term effects, the exposure to a high concentration of a compound one day may possibly either increase or decrease the response if values of the same compound become high again the next day. Adaptation to effects of short-term exposure to ozone, for example, is reported (Hazucha et al., 1989). Similarly, health response to sudden high peaks of concentration, may also possibly differ in effect from those to peaks attained more gradually. For long-term effects of some compounds, the cumulative exposure may be more decisive in influencing health.

If there are differences in physiological response in the varying exposure situations described in the previous paragraph, then the following characteristics of exposure need to be considered, in addition to average and peak exposure:

1. the temporal pattern with which exceedances of threshold or AQG occur,
2. how many of these exceedances are in reality occurring during the same episode,

3. how many episodes have in reality occurred, or
4. how long the episodes have lasted.

Authorities need a better planning tool that more correctly describes the effects of air pollution reduction measures on all aspects of population exposure. Improved data technology, together with the development of dispersion models, allows refining AQIs further.

This note proposes several new types of AQIs. Oslo data generated using models that provide spatial distribution of hourly pollutant concentrations (Episode/ AirQUIS models) are used to demonstrate the possible application of such indicators. The applicability of the AQIs is indicated by comparing them with individual estimates of pollution exposure.

2. What should the indicator represent

The Air Quality Indicator (AQI) should represent both the spatial and temporal aspects of pollution exposure that may have important effects on health. Two indicators are needed, the Population Air Quality Indicator and the Individual Air Quality Indicator.

An air quality indicator should provide information relevant in evaluating possible health effects. It should be applicable for the evaluation of both short-term health effects and long-term to chronic health effects. The indicator should also be usable to measure or predict changes in exposure resulting from pollution abatement measures. The elements necessary for the proper definition of AQI are, therefore, the spatial distribution of the pollution, the time structure of the exposure, and the magnitude of the exposure.

The air pollution episode can be the basic entity underlying the air quality indicators. The definition of an **episode** is the period of time that pollution concentrations are above a predefined level such as effect threshold or air quality guideline. Episodes have a time structure that defines when and how often episodes occur, and a magnitude which reflects both, the duration of the episode and the peak concentration reached during the episode.

Health effects of pollution are continuously under study. It remains unknown whether the absolute concentration of pollution or the rate of change of concentrations has the greatest effect on different health end-points.

An air quality indicator may also reflect how rapidly pollution levels change. The health effect of exposure to 100 $\mu g/m^3$ of a pollutant may differ if the previous level for some days has been 20 as opposed to 90 $\mu g/m^3$.

Exposure may be described on individual basis, whenever individual data are available. Population air quality indicators may be obtained from integrated exposure estimates, such as from estimates based on square kilometer grid, or air quality measurements on a city level.

3. Methods

This section describes the criteria and methods used for the selection of AQIs. Basic concepts such as rate of change of exposure, episode, and inter-episode period are defined. The procedure for selection of the example locations used for further exploration of AQIs is described.

3.1 Definition of specific air quality indicators to describe temporal variability

Both the temporal and spatial aspects of air pollution concentrations need to be described. To obtain relevant data, the AirQUIS/Episode model was run hourly for 6 months. The assumptions of the model, the emissions used and type of model, are described in Slørdal (1997) and Grønskei et al. (1993). The pollution concentrations (hourly and daily) were given for each selected square kilometer grid, and for the components NO_2 and PM_{10}. The statistical parameters of the time series were given as mean (μg/m^3), maximum hourly and daily concentration, and 98th percentile of hourly values. In addition to these descriptors, rate of change of the time series, and description of episodes, may prove useful.

The **rate of change** for hourly and daily data may be described as the difference between the two consecutive values in the time series ("delta concentrations") (see Figure 1).

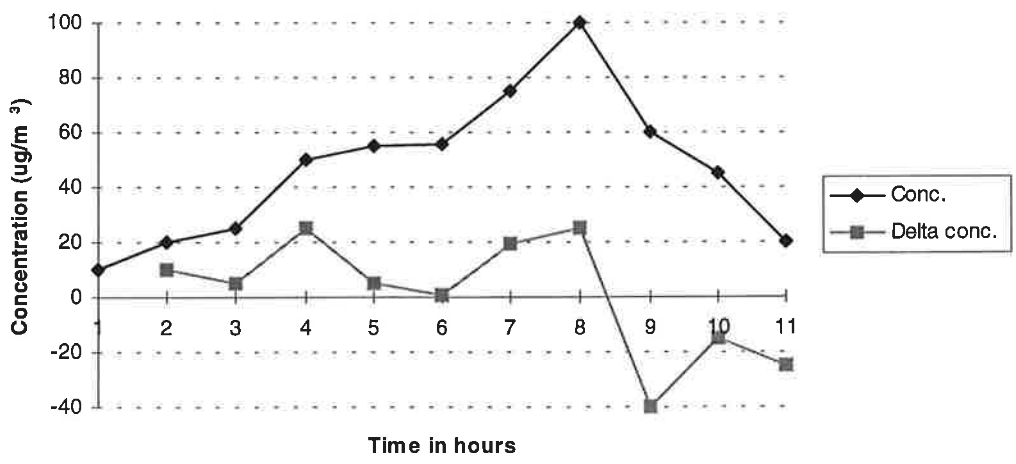


Figure 1: Defining the rate of change (delta conc. in caption) of exposure to pollution.

As pollution concentrations change, episodes occur. An **episode** is in this study defined as the period when hourly concentrations of pollutants exceed a threshold, here set as 50 µg/m³ for PM_{10} and 100 µg/m³ for NO_2 (see Figure 2 and Figure 3). Should the values consistently lie around the threshold for several hours, a series of concentrations which is generally considered one episode, would in this case, because of technical reasons, count as several.

The episodes may then be described by:

- **peak height** (maximum value in episode),
- **duration** of episode,
- **inter-episode period**, and
- **integrated episode exposure**, episode AOTx (sum of the concentration hours during an episode that exceed the threshold value of x). AOT values are usually given in ppb-hours (ozone), but may also be represented by µg/m³-hours as in this report.

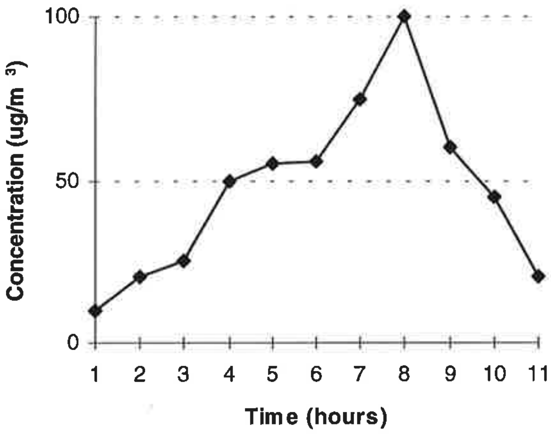


Figure 2: Definition of episode: the time interval when all consecutive concentrations continuously exceed a set value (e.g. guideline – here chosen as 50 µg/m³). In this case, an episode is observed from hour 4 to 9.

Figure 3: Comparison of two episodes with different duration and peak height, but with similar total integrated exposure (120 µg/m³ hours).

3.2 Selection of data to describe spatial variability

Pollution concentrations vary significantly over a city. These variations can be described in several ways. Strategically placed measurement stations provide a description of levels at the location of the station. The strategic placement of stations includes roadside, representative city and background measurements. The advantages of measurements is that the values are more unquestionable since they are directly measured, and the variation from hour to hour or day to day provides a relatively correct view of the variation at other places in the city. The next stage is dispersion modeling that provides concentrations at the square kilometer level. Dispersion modeling is itself done at two levels, the area model that includes all emissions, including traffic, at the kilometer square level. This is the current operating level of the AirQUIS system. The dispersion model can also include a line model, representing pollution from major traffic arteries throughout the city. The latter model provides point pollution estimates that reflect pollution from the specific traffic arteries.

Based on the AirQUIS model, air quality concentrations were calculated for Oslo for the winter 1994-95 (Slørdal, 1997). This study estimated different air quality indicators based on these calculations for NO_2 and PM_{10} for 10 grid squares (km^2) (indicated in Table 1). Of the 10 grid squares, 3 were chosen for a more detailed description (Carl Berners plass, Majorstua and Lysaker).

As can be seen in Table 1, concentrations varied considerably between the 10 sites. Concentrations estimated at Lambertseter were much lower and not further considered since they did not provide much information useful in the further discussion of indicators. As Table 1 indicates, higher mean concentrations of pollutants lead to higher, but not necessarily proportionally higher, numbers of episodes. Numbers of episodes of the two pollutants, PM_{10} and NO_2 in the grid squares, vary independently of each other and therefore, in some cases, there are a greater number of episodes of NO_2 than PM_{10}, and other times the reverse.

Geographic distribution of pollution can also be examined on a smaller scale by examining the results of dispersion modeling for the immediate area surrounding a grid square. This gives an indication of the variability in geographic area and how representative a square might be for its surrounding area. Lysaker and the neighboring 8 squares were chosen for this analysis.

A yet finer spatial description is to compare concentrations at individual homes, calculated using disposure models consisting of both area and line sub-models, to those as of a grid square average. Proceeding down in level of detail, the individual address reflects sub-grid differences in pollution concentration. In this report this was done by comparing pollution concentrations estimated at children's homes to those of the school they attended.

As a final step, the temporal and spatial aspects of pollution exposure are combined in the refined exposure estimate. Such an estimate reflects that individuals move around from area to area. The air pollution concentration that they are exposed to should reflect differences in individuals in their movements. This is done here, by comparing calculated child's exposure on hourly basis, reflecting the child's movements, to a static estimate at the child's home.

The increased detail in estimating exposure proceeding from the crudest estimate (a few point measurements) to individual air pollution estimates either as a point estimate for example home, or a continuous estimate from a diary, provides information on the known or calculable variation or uncertainty.

*Table 1: Description of the general situation of pollution exposure in 10 grid squares in Oslo during the winter 94/95 (October 1 - March 31). * represent the grid squares chosen for further description of AQI.*

Grid square	Mean (µg/m^3)		Number of episodes[1)]		Episode duration % episodes > 2h	
	PM_{10}	NO_2	PM_{10}	NO_2	PM_{10}	NO_2
Lindeberg	18	53	124	72	42	17
Sinsen	19	57	120	70	42	20
*Carl Berners	17	53	119	60	33	15
Alnabru	30	66	157	202	44	31
Gamlebyen	22	62	135	152	56	25
Akershus F	16	53	102	53	37	13
*Majorstua	12	47	77	20	29	10
Skoyen	13	46	96	34	28	9
*Lysaker	30	63	170	170	55	21
Lambertseter	4	25	6	2	0	0

1)Threshold: PM_{10} : 50 µg/m^3 , hourly
NO_2 : 100 µg/m^3 , hourly

4. Results – Temporal aspects

Mean concentrations, 98th percentile and maximum values are the traditional indicators for estimating exposure. The temporal variability of PM_{10} and NO_2, however, is here described by means of: 1) the rate of change of pollution as the difference between two consecutive hourly values, and of 2) episodes, described in terms of number, duration and inter-episode period, maximum concentration in the episode, and integrated episode exposure (episode AOT50/100).

The general features of pollution exposure can be described by the more traditional measures as seen in Table 2 and Table 3. It is evident in these tables that Lysaker has the highest concentration especially for PM_{10}. However, from the point of view of health, this information may not be sufficient. Measures to protect health may need to account for the pattern in exposure people endure. The severity of pollution in an area is not completely indicated by a simple 98th percentile, since health effects may be worse if high pollution concentrations come sporadically, not allowing the body to adapt to them as may be the case in one or two long episodes. Therefore, it may be necessary in the future to specify, in addition to concentrations, acceptable patterns of exposure. It may be necessary to control the number of episodes, and the severity of the episodes, which are described by the integrated exposure.

Table 2: Mean, maximum and 98th percentile of hourly concentrations of NO_2 and PM_{10} in three selected grid squares in Oslo, winter 94/95.

Grid square	Mean (µg/m^3)	Maximum (µg/m^3)	98th percentile (µg/m^3)
NO_2			
Carl Berners Plass	53	139	101
Majorstua	47	127	94
Lysaker	63	169	117
PM_{10}			
Carl Berners Plass	17	279	100
Majorstua	12	147	68
Lysaker	30	338	160

Table 3: Mean, maximum and 98th percentile of daily concentrations of NO_2 and PM_{10} in three selected grid squares in Oslo, winter 94/95.

Grid square	Mean (µg/m^3)	Maximum (µg/m^3)	98th percentile (µg/m^3)
NO_2			
Carl Berners Plass	53	79	74
Majorstua	47	72	68
Lysaker	63	98	89
PM_{10}			
Carl Berners Plass	17	81	60
Majorstua	12	47	37
Lysaker	30	112	63

4.1 Rate of change of pollution exposure

Urban air pollution concentrations vary periodically with time as shown in the time series plot in Figure 4. In addition, individuals move between areas. Individuals are thus subject to large and sometimes rapid changes in concentrations. Possible health effects related to the change in concentration are connected with the ability of the body to adapt to this rapid change.

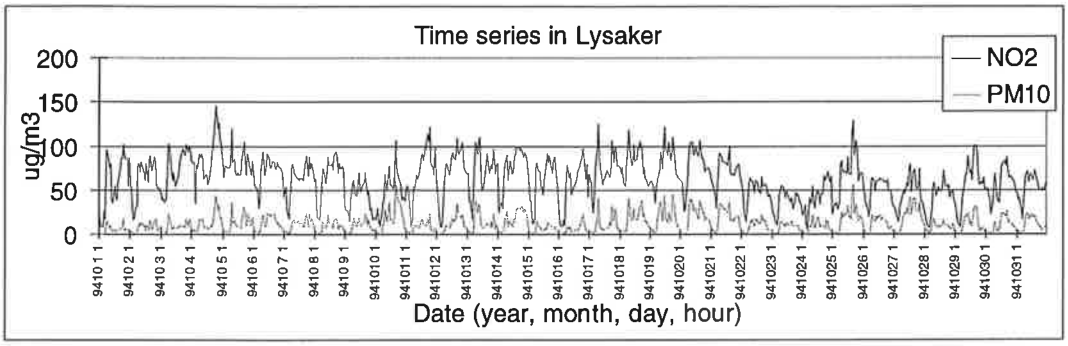


Figure 4: Time series of NO_2 and PM_{10} for October 1994 at Lysaker 1 km^2 grid square.

*Table 4: Calculated rate of change of **hourly** concentrations of NO_2 and PM_{10} in three selected grid squares in Oslo, winter 94/95. Absolute values of both positive and negative changes in concentrations are included.*

Grid square	Maximum rate of change (µg/m³/hr)	98th percentile of rate of change (µg/m³/hr)
NO_2		
Carl Berners Plass	82.2	39.6
Majorstua	80.7	38.8
Lysaker	88.7	40.6
PM_{10}		
Carl Berners Plass	215.4	36.1
Majorstua	93.1	26.1
Lysaker	251.5	53.7

*Table 5: Calculated rate of change of **daily** concentrations of NO_2 and PM_{10} in three selected grid squares in Oslo, winter 94/95. Absolute values of both positive and negative changes in concentrations are included.*

Grid square	Maximum rate of change (µg/m³/hr)	98th percentile of rate of change (µg/m³/hr)
NO_2		
Carl Berners Plass	45.8	32.4
Majorstua	49.45	30.3
Lysaker	50.33	34.4
PM_{10}		
Carl Berners Plass	55.4	36.4
Majorstua	33.7	21.9
Lysaker	77.32	62.8

4.2 Episodes – Time pattern

As indicated by the time-series plots, exposure to air pollution occurs as a series of episodes. We define here an episode as the time period when all consecutive concentrations continuously exceed a given value. The value may be chosen to reflect a threshold for an effect. For NO_2, the hourly air quality guideline of 100 $\mu g/m^3$ is used here as an example. For PM_{10}, WHO AQG levels are not formulated, and information on effects of hourly exposure is non existent. Therefore a more arbitrary value of 50 $\mu g/m^3$ was used.

The time pattern of exposure can then be described in terms of e.g. number of episodes, duration of episodes, and length of periods between episodes (inter-episode periods). The episode statistics for the 3 grid squares in Oslo is given in Table 6.

Only Lysaker had episodes of NO_2 that lasted longer than 8 hours (1 % of total time), whereas 4 % of the total time they lasted only 1 to 2 hours. Lysaker had only 5 periods of 5 days or more without an episode. For PM_{10}, the episodes had a longer duration, so that all three sites experienced episodes lasting longer than 8 hours, and the inter-episode periods were shorter. These statistics would obviously change if the threshold was changed. For daily PM_{10} over the suggested new guidelines of 35 $\mu g/m^3$, all three sites experienced episodes of 1 day duration. Lysaker had 2 over 6 day long episodes. Lysaker had episodes 34% of the total time.

In the future, information of this type may be used to specify control measures that will not allow more than a certain number of episodes, restrict the allowable duration of the episode and will not for example allow more than two episodes with an inter-episode period of 7 days or more, based on the implicated health effects.

Table 6: Duration of episodes and periods between episodes for NO_2 and PM_{10} at three selected sites in Oslo. Percentages are presented both as a function of episode time and of total time.

	Carl Berners plass			Majorstua			Lysaker		
		Duration of episode % of			Duration of episode % of			Duration of episode % of	
	No.	Episode time	Total time	No.	Episode time	Total time	No.	Episode time	Total time
Hourly NO_2 > 100 µg/m³									
Episode length (hours)									
1-2	51	85	1.33	18	90	0.46	135	79.4	3.98
3-7	9	15	0.82	2	10	0.14	30	17.6	2.68
8+	0	0	0.00	0	0	0.00	5	2.9	1.01
Inter-episode period									
1-2 hours	7	11.5	0.25	2	9.5	0.07	35	20.4	1.12
3-8 "	5	8.2	0.73	1	4.8	0.09	34	19.9	4.12
9-24 "	10	16.4	4.42	2	9.5	0.73	60	35.1	23.53
2 day	10	16.4	7.85	2	9.5	1.81	22	12.9	19.55
3 day	8	13.1	12.09	1	4.8	1.19	9	5.3	13.76
4 day	4	6.6	7.49	1	4.8	1.81	6	3.5	12.52
5 day	7	11.5	18.20	3	14.3	7.90	2	1.2	5.43
< 5 days	10	16.4	46.82	9	42.9	85.81	3	1.8	12.29
Hourly PM_{10} > 50 µg/m³									
Episode length (hours)									
1-2	80	67.2	2.38	55	71.4	1.76	77	45.3	2.43
3-7	33	27.7	2.91	20	26.0	1.69	62	36.5	6.59
8+	6	5.0	1.37	2	2.6	0.39	31	18.2	8.13
Inter-episode period									
1-2	33	27.5	1.05	18	23.1	0.57	54	31.6	1.51
3-8	19	15.8	2.24	9	11.5	1.10	29	17.0	4.08
9-24	30	25.0	10.81	19	24.4	7.78	51	29.8	17.74
2 day	19	15.8	15.84	10	12.8	9.23	19	11.1	16.39
3 day	6	5.0	8.47	8	10.3	10.92	8	4.7	11.47
4 day	3	2.5	5.88	3	3.8	6.14	6	3.5	11.58
5 day	4	3.3	10.16	1	1.3	2.59	1	0.6	2.36
< 5 days	6	5.0	38.87	10	12.8	57.83	3	1.8	17.72
Daily PM_{10} > 35 µg/m³									
Episode length (days)									
1	8	40	4.40	5	100	2.75	14	23	7.69
2	3	30	3.30	0	0	0.00	5	16	5.49
3	2	30	3.30	0	0	0.00	3	15	4.95
4-5	0	0	0.00	0	0	0.00	3	23	7.69
6 +	0	0	0.00	0	0	0.00	2	23	7.69
Inter-episode period (days)									
1 - 3	6	7	6.59	1	2	1.65	18	26	17.03
4 - 10	3	17	14.84	1	5	4.40	9	48	31.87
11 - 20	3	26	23.08	1	10	9.34	0	0	0.00
21 - 50	2	50	44.51	1	19	18.13	1	26	17.58
51 +	0	0	0.00	2	66	63.74	0	0	0.00

4.3 Episodes - Peak concentrations

Air pollution situations can be characterized by average concentrations. However, high mean values can be caused by occasional extra high concentrations or by more frequent, not-so-high episodes. The 98th percentile of short-term concentrations does not differentiate between the two situations. In judging the potential health effects of different air pollution situations, it is of interest to know whether the 2% of time that values exceed the 98 percentile all occur during the same episode, as opposed to occasional but not consecutive high values. This differentiating can only be done by examining the number of episodes and the episode peak height.

Episodes can be characterized by the peak height, the highest concentration reached during the episode (Table 7). At Lysaker, for NO_2 , as many as 10.6 % of episodes had peak values over 130 µg/m³, whereas Carl Berners plass had only 1.7 % of such episodes. The episode concentrations of PM_{10} were higher. Fifteen percent of episodes in daily concentrations at Lysaker exceeded 91 µg/m³ .

Table 7: Maximum hourly and daily concentrations in episodes for NO_2 and PM_{10} at three selected grid squares in Oslo.

Episode peak	Carl Berners plass		Majorstua		Lysaker	
(µg/m³)	Frequency	%	Frequency	%	Frequency	%
Hourly NO_2 > 100 µg/m³						
100-110	36	60.0	15	75.0	103	60.6
111-130	23	38.3	5	25.0	49	28.8
131-150	1	1.7	0	0	15	8.8
151-170	0	0	0	0	3	1.8
>171	0	0	0	0	0	0
Hourly PM_{10} > 50 > µg/m³						
50-60	35	29.3	20	26	37	21.9
61-80	34	28.5	32	41.6	45	26.7
81-100	14	11.4	11	14.3	20	12.0
101-150	17	13.8	14	18.2	35	21.0
151-200	13	10.8	0	0	16	9.6
>200	6	4.8	0	0	17	10.2
Daily PM_{10} > 35 µg/m³						
35 - 40	3	23.1	4	80.0	6	22.2
41 - 50	5	38.5	1	20.0	4	14.8
51 - 70	3	23.1	0	0.0	6	22.2
71 - 90	2	15.4	0	0.0	7	25.9
91 +	0	0.0	0	0.0	4	14.8

In the future, control measures may be formulated as a restriction in number of episode peak values over a given concentration instead of the 98^{th} percentile.

4.4 Episodes - Integrated exposure

For some short-term health effects it is the concentration that is decisive in initiating a health effect. However, for other short-term and for long-term effects, the cumulative or integrated exposure may be the determinant in causing an effect. It may be of importance whether an episode having a "total exposure" of 120 µg/m³-hours (Figure 3 in section 3.1) occurs as 60 µg/m³ over two hours or as 120 µg/m³ over 1 hour. In the future, it may be necessary to specify in addition to an AQG, a limited total integrated exposure, or a maximum acceptable integrated exposure over one single episode.

In Figure 3, the accumulated exposure is 120 µg/m³-hours for both episode types. Another and more usual way is to define the accumulated exposure over a given threshold (AOT exposure for episodes or episode AOT50/100). Based on Figure 3 this would mean that with a threshold of 50 µg/m³-hours, the two hour episode would have a value of 20 µg/m³-hours, whereas the one hour episode would have a value of 70 µg/m³-hours. The AOT calculated over nonzero threshold would give more weight to the higher peaks. In Table 8, the summed results of the two ways of calculating the cumulative dose are presented, together with the total number of hours of "episode time". The frequency distribution of the individual episode integrals is presented in Table 9.

Table 8: Different expressions for the cumulative dose of hourly NO_2 and PM_{10} for different thresholds in three selected grid squares.

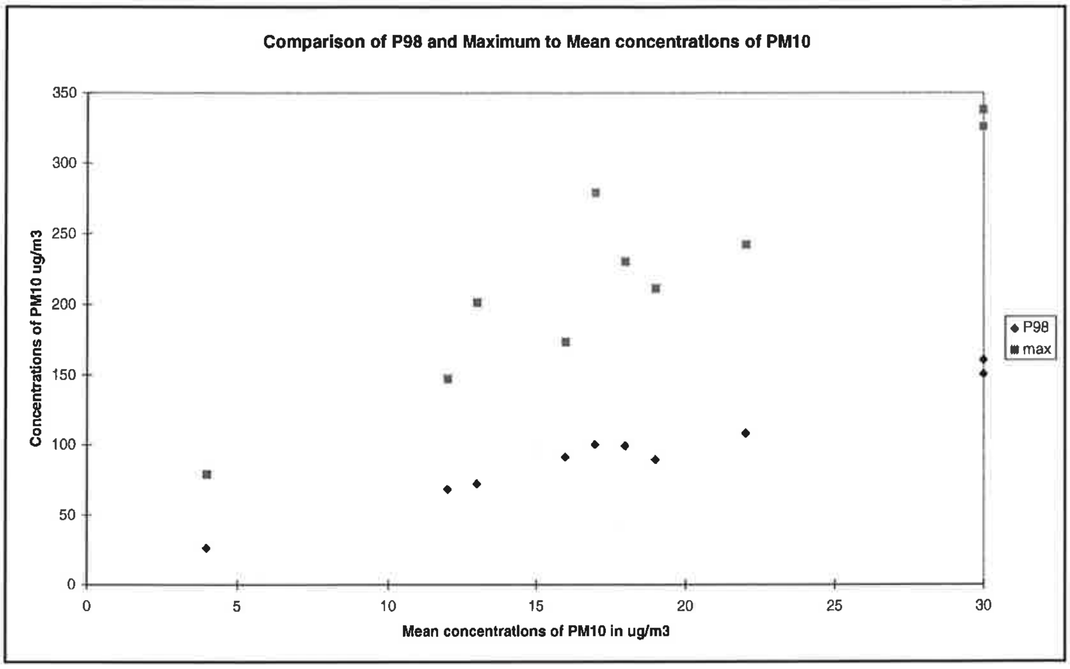
Grid square	No. of hours/days over threshold	Threshold = 100 µg/m³ (NO_2), 50 and 35 µg/m³ (PM_{10}) hourly and daily
Hourly NO_2		AOT100 (µg/m³-hours)
Carl Berners	94	870
Majorstua	26	174
Lysaker	335	4 001
Daily PM_{10}		AOT50 (µg/m³-days)
Carl Berners	291	11 742
Majorstua	168	3 965
Lysaker	749	36 529
Daily PM_{10}		AOT35 (µg/m³-days)
Carl Berners	20	258
Majorstua	5	24
Lysaker	61	1290

Table 9: Distribution of episode AOT for NO_2 and PM_{10} at three selected sites in Oslo. (Threshold = 50 and 35 µg/m³ for PM_{10} (hourly and daily values) and 100 µg/m³ for NO_2.)

Episode AOT	Carl Berners plass		Majorstua		Lysaker	
Σ µg/m³	Frequency	%	Frequency	%	Frequency	%
NO_2 AOT100 (µg/m³-hours)						
0-50	33	55.0	14	70.0	92	54.1
51-80	17	28.3	5	25.0	43	25.3
81-150	8	13.3	1	5.0	15	8.8
151-300	1	1.7	0	0	6	3.5
301-600	1	1.7	0	0	6	3.5
601-1000	0	0	0	0	5	2.9
1001-2000	0	0	0	0	3	1.8
Hourly PM_{10} AOT50 (µg/m³-hours)						
0-50	70	58.8	57	74.0	82	51.9
51-80	13	10.9	6	7.8	6	3.8
81-150	13	10.9	7	9.1	28	17.7
151-300	13	10.9	6	7.8	16	10.1
301-600	6	5.0	1	1.3	19	12.0
601-1000	3	2.5	0	0	7	4.4
1001-2000	1	0.8	0	0	0	0
Daily PM_{10} AOT35 (µg/m³-days)						
0-10	9	45	4	80	7	11
11-30	5	25	1	20	14	23
31-60	6	30	0	0	2	3
61-100	0	0	0	0	19	31
101-150	0	0	0	0	15	25
151+	0	0	0	0	4	7

4.5 Comparison of Air Quality Indicators used to describe spatial variability

A comparison of the traditional AQIs such as maximum and 98th percentile to mean concentrations in the 10 grid squares are shown in Figure 5, whereas a similar comparison of the additional AQI proposed in this report are shown in Figure 6 and Figure 7. The relationship between the AQIs and the mean concentrations differs for NO_2 and $PM_{2,5}$ and for each of the proposed AQIs. A comparison with other cities in Norway and internationally would probably result in different relationships between the two.



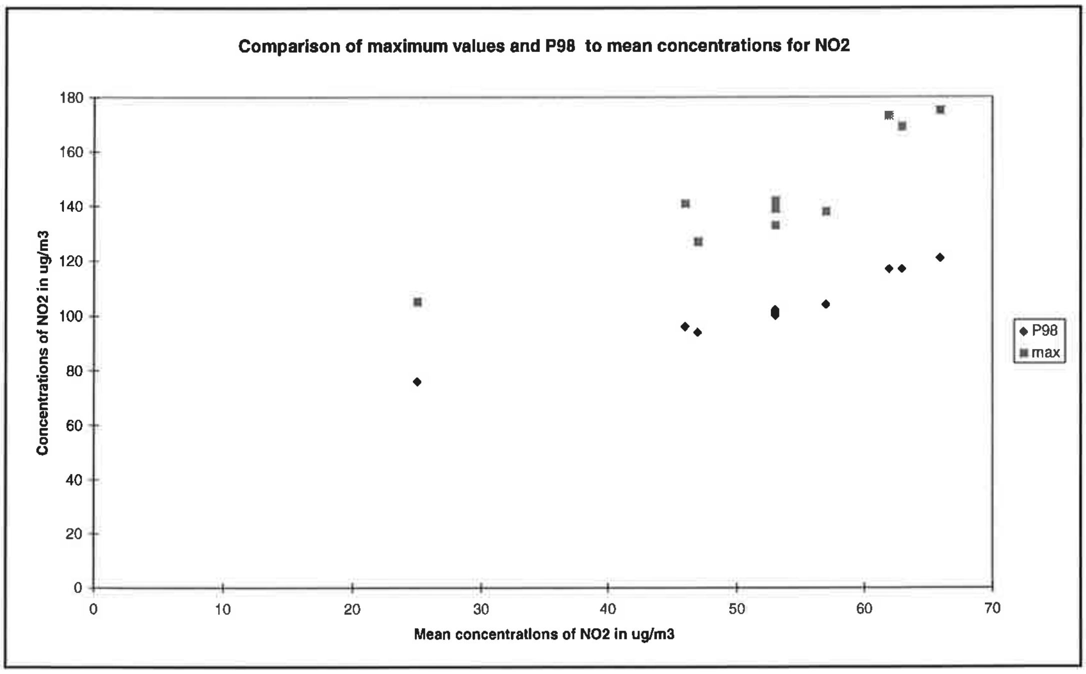
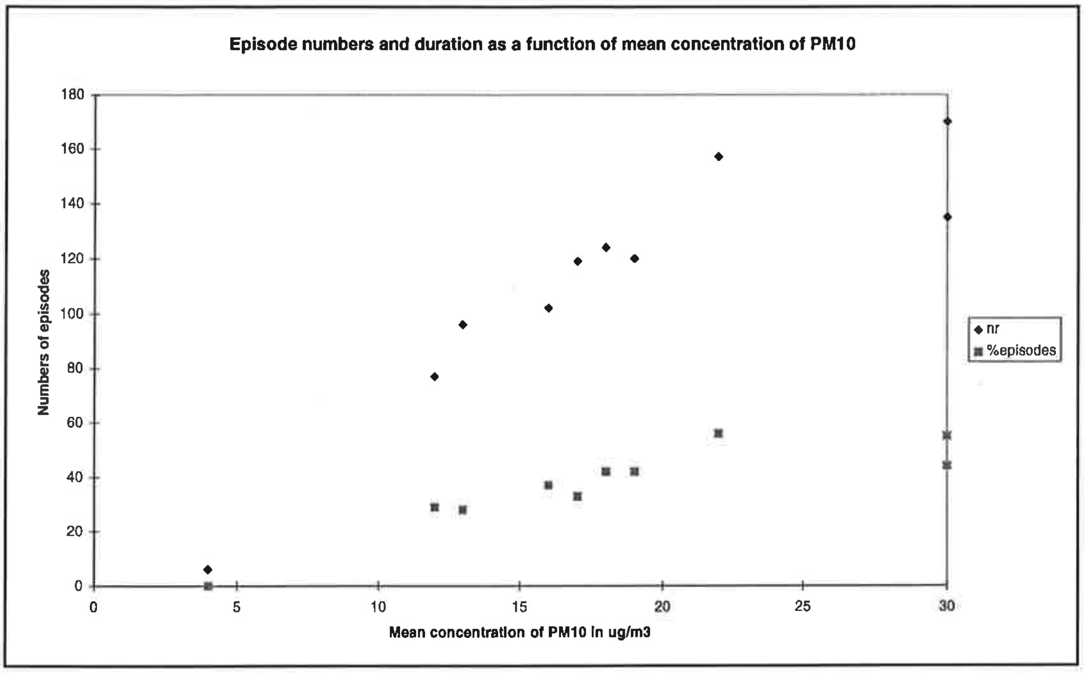


Figure 5: Graphical representation of relationship between maximum values and the 98th percentiles (P98) and mean concentration of PM_{10} and NO_2 for the selected grid squares.



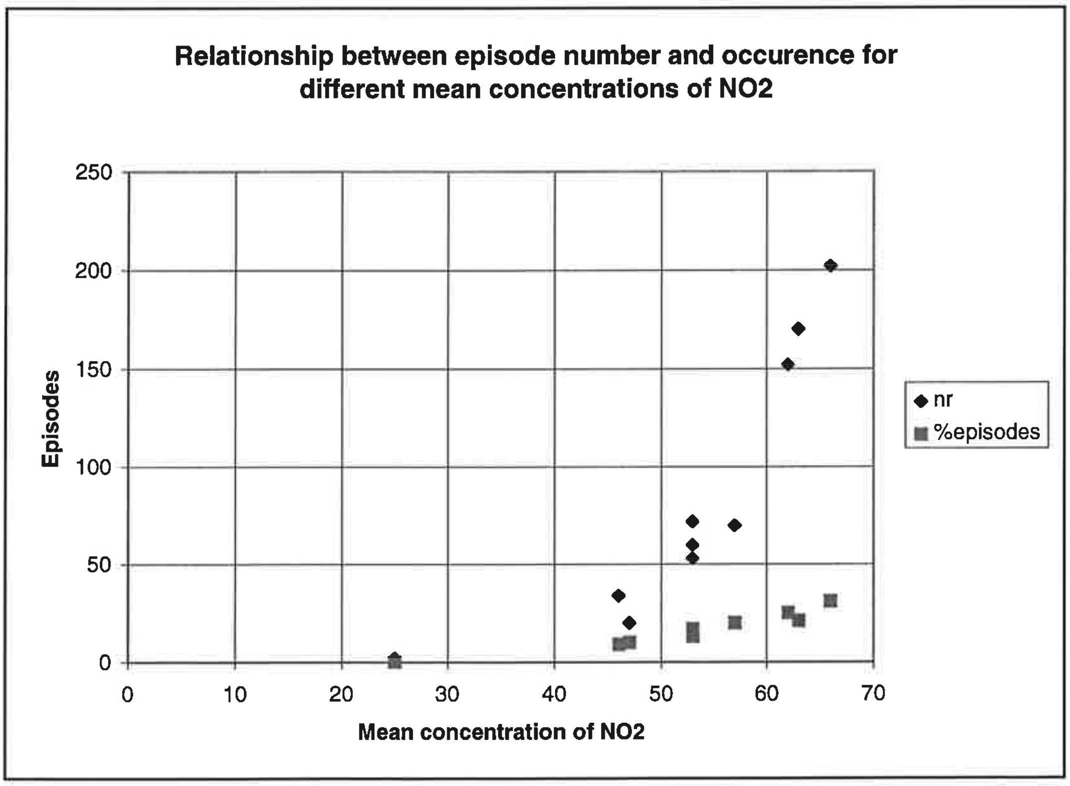
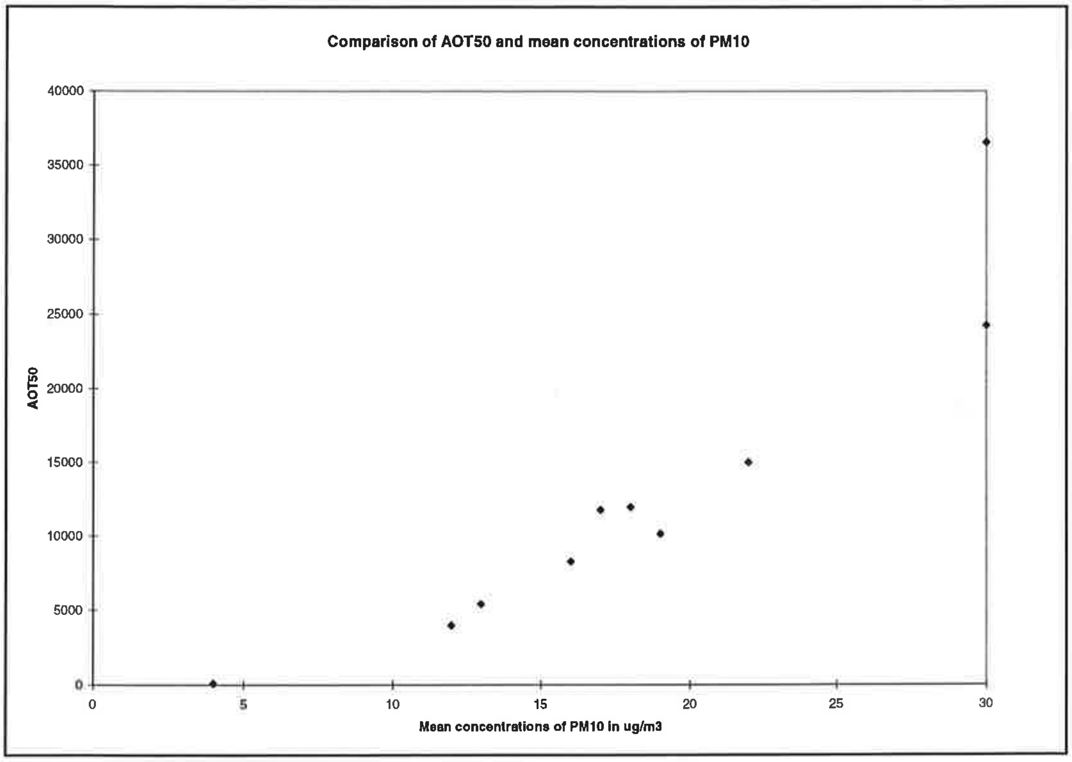


Figure 6: Graphical representation of relationship between number of episodes and duration of episodes (% of time in episodes with duration > 2h) and mean concentration of PM_{10} *and* NO_2 *for the 10 selected grid squares (each dot represents one grid square).*



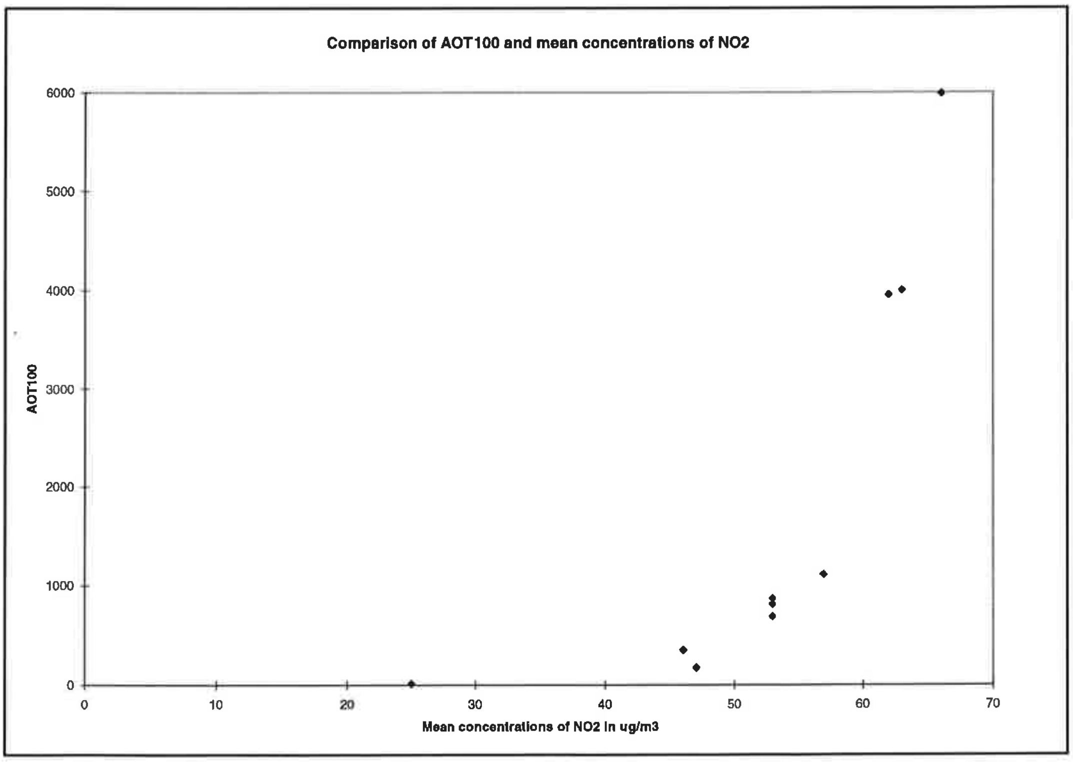


Figure 7: Graphical representation of relationship between AOT (50 and 100 µg/m³ for PM_{10} and NO_2 respectively) and mean concentration of PM_{10} and NO_2 in the selected grid squares. AOT in µg/m³-hours.

5. Results – Spatial Aspects

The spatial variation of AQIs can be described in several ways, e.g.: 1) concentrations in neighboring grid squares can be compared as an indication of spatial variation, and 2) point estimates can be compared to grid values for a description of variation within a grid. Both methods are presented here.

5.1 Neighboring kilometer grid squares

To examine the spatial variation in concentrations between km^2 grid squares, variation between the 8 grid squares neighboring the Lysaker grid were described based upon dispersion modeling calculations. As indicated in Figure 8 to Figure 14, there are substantial variations on the km scale in exposure indicator values. Thus, it is important to estimate the AQIs for the entire area of interest. Measurements at a few sites do not provide a sufficient base for conclusions. However, measurements do provide confirmation of model results and the basis to validate or modify the models.

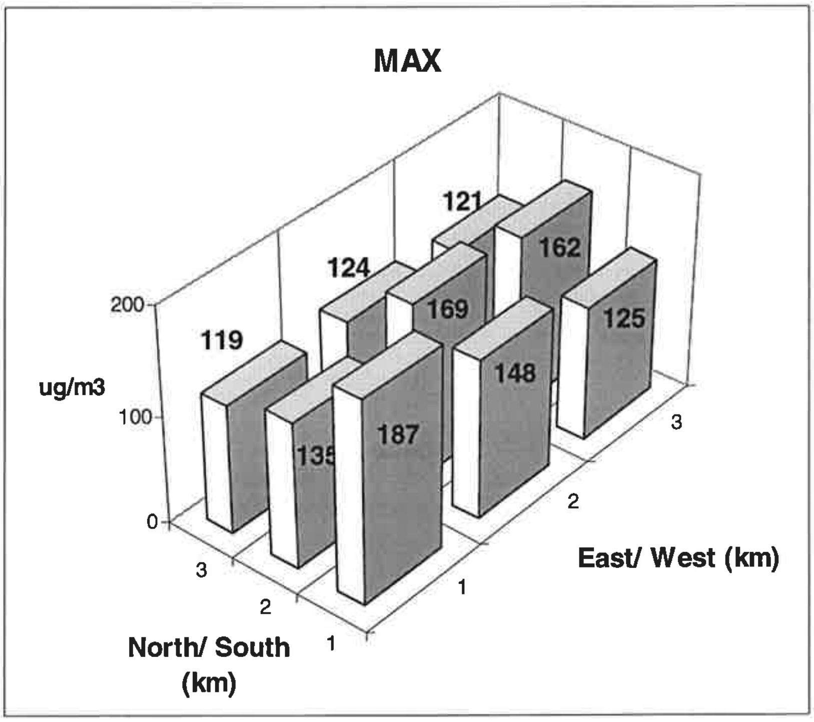
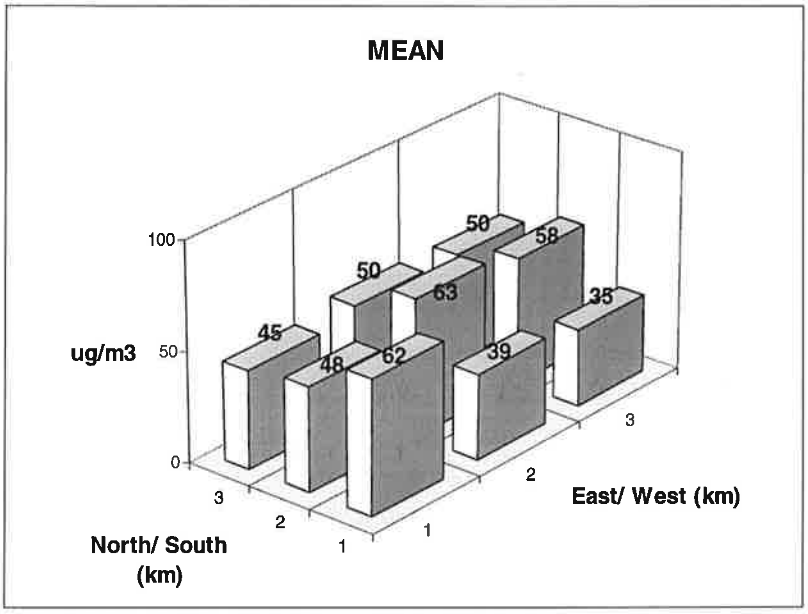


Figure 8: Standard pollution parameters (maximum, 98th percentile and average concentration) for NO_2 winter 94/95 in nine neighboring squares.



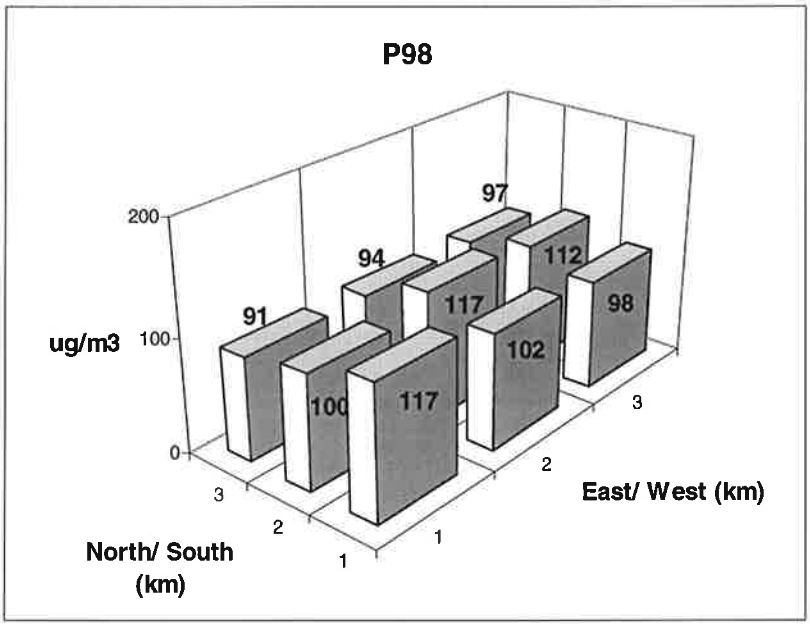


Figure 8, contd.

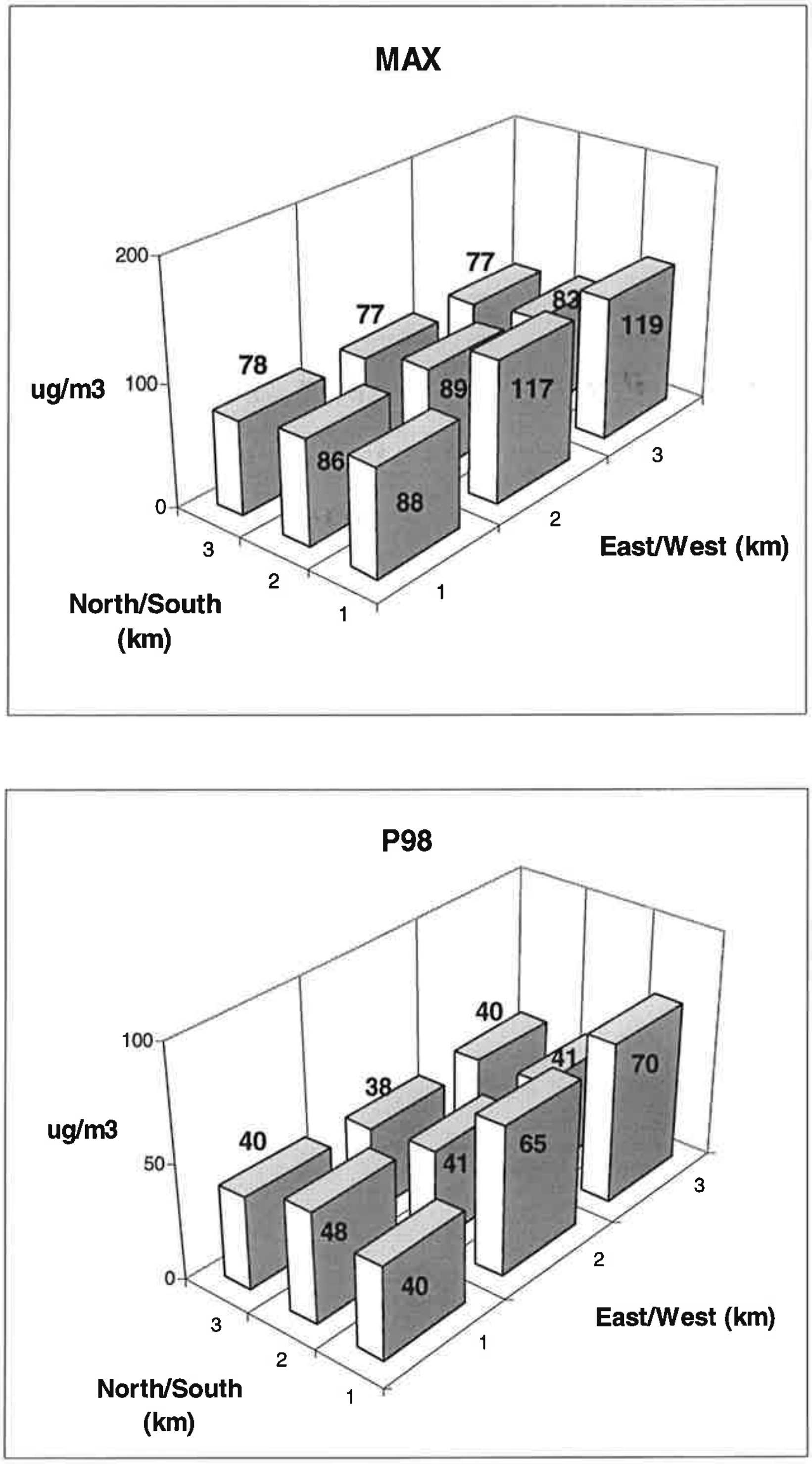


Figure 9: Maximum and 98th percentile P98 for the absolute value of rate of change of NO_2 winter 94/95 in nine neighboring squares.

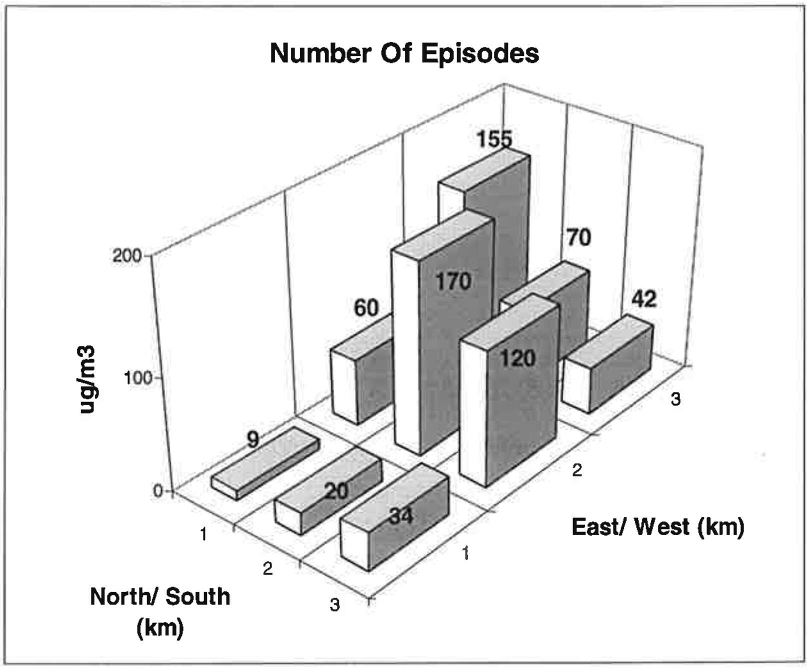


Figure 10: Number of NO_2 episodes winter 94/95, in nine neighboring squares.

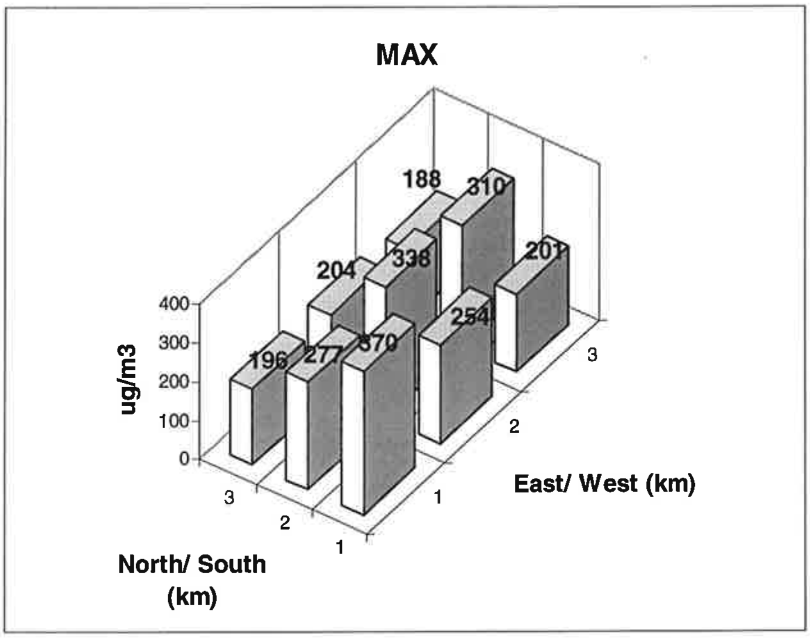
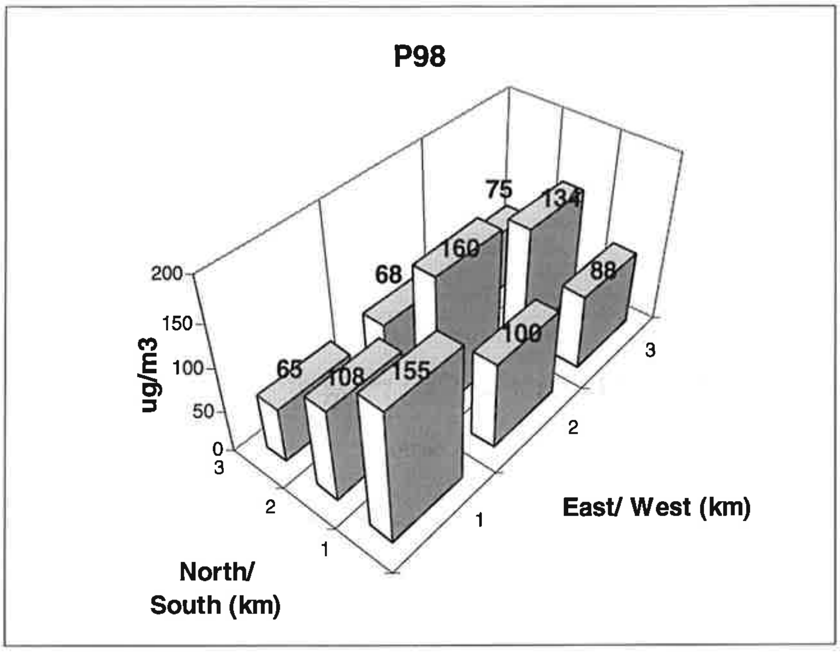


Figure 11: Standard pollution parameters for PM_{10} (maximum, 98^{th} percentile and average concentration) winter 94/95 for nine neighboring squares.



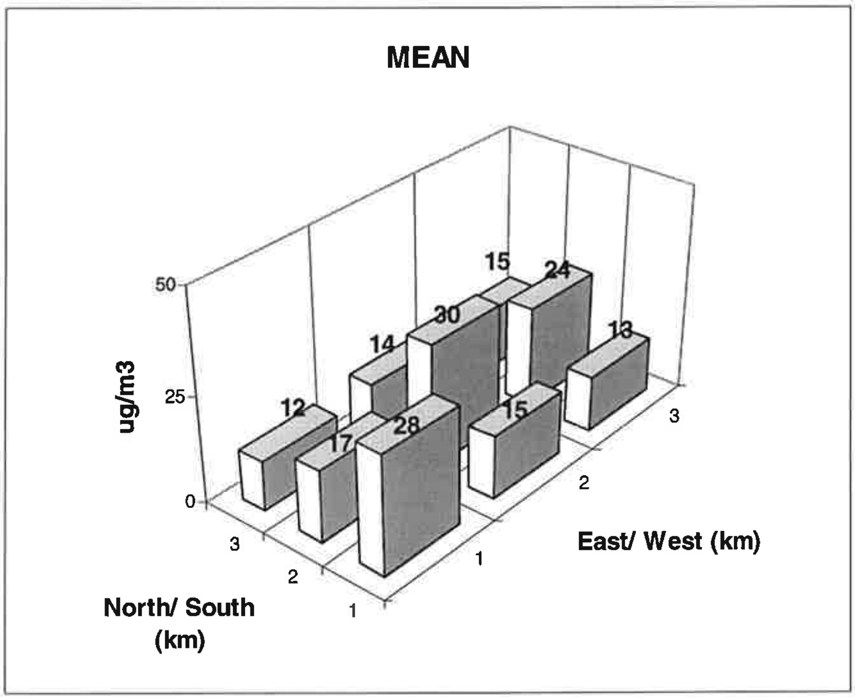


Figure 11, contd.

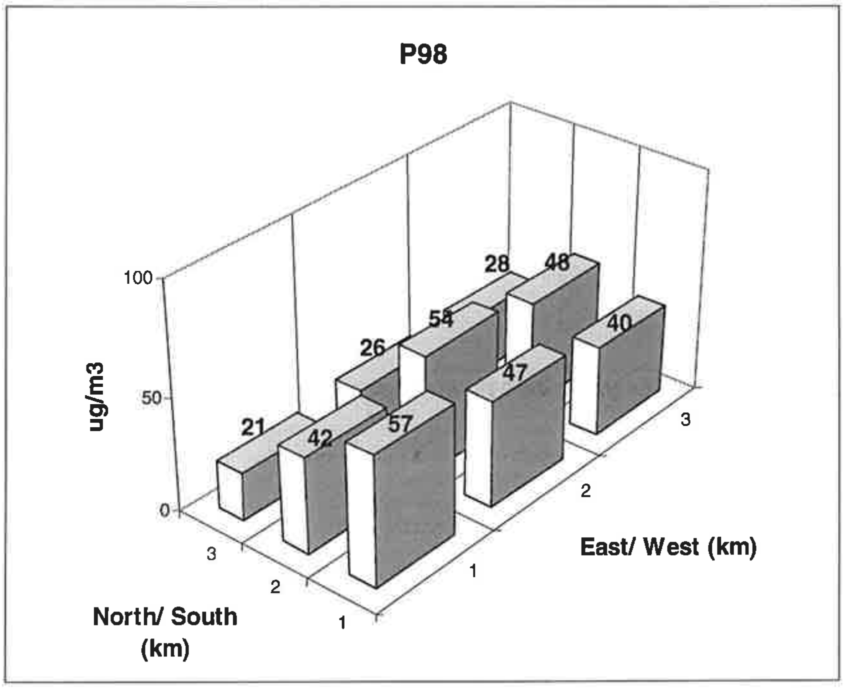


Figure 12: Parameters of absolute value of rate of change of PM_{10} (maximum and 98th percentile) winter 94/95 for nine neighboring squares.

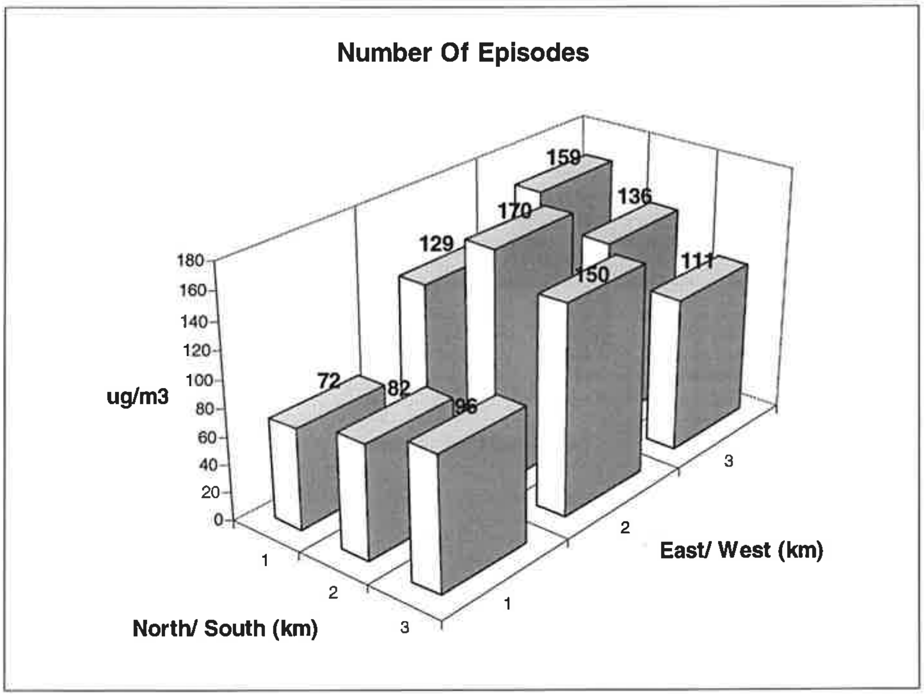


Figure 13: Number of episodes of PM_{10} winter 94/95 for nine neighboring squares.

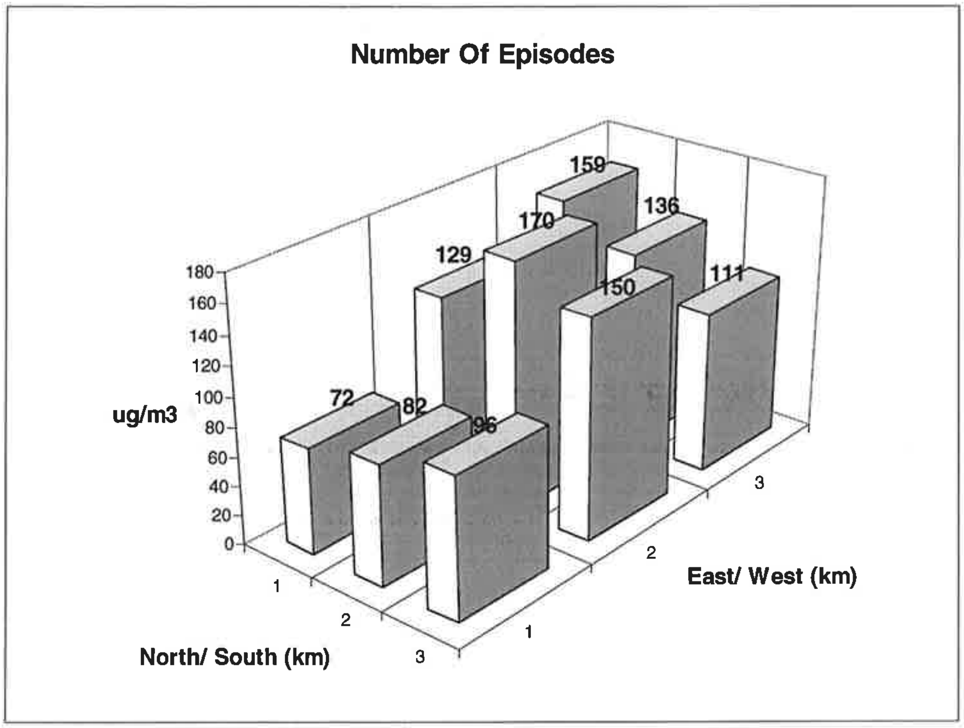


Figure 14: Number of episodes of PM_{10} winter 94/95 for nine neighboring squares.

5.2 Individual point estimates as compared to area estimates

Variations can also be significant on a sub-kilometer grid scale. When the line model representing extra pollution coming from major traffic arteries in included, the variation in point estimates within the grid is substantial. This variation will be illustrated on an example from an individual exposure study performed in Oslo in winter 1991/1992. For each child in the study (3800 children), exposure was calculated for each hour in a 3-month period at the child's home, and for each school the children attended. The concentrations outside homes of children attending schools in Oslo are compared with the values estimated for the location of the school, (see Table 10). The average of the mean concentration estimated at the homes of all children attending a given school is relatively close to the values estimated at the schools, but the individual values have a substantial range. Due to such sub-grid variations, it is preferable to assess individual exposure to pollution rather than to use an area-averaged estimate based on models or measurements.

Table 10: Comparison of the 98th percentile of hourly exposure for each school to the mean of NO_2 and $PM_{2.5}$ concentrations at the children's homes (range given in parenthesis), winter 1991/1992.

Schools	NO_2 (µg/m^3)		$PM_{2.5}$ (µg/m^3)	
	School	Homes	School	Homes
More exposed schools				
A	90.5	85 (44-200)	74.2	73 (7-168)
B	105.4	91 (84-149)	119.7	109 (88-124)
C	90.8	99 (64-143)	112.3	98 (40-128)
D	109.5	103 (61-201)	120.3	94 (17-168)
E	111.7	111 (44-343)	110.1	100 (7-142)
F	97.6	109 (44-379)	60.8	69 (7-142)
G	87.3	91 (84-135)	102.3	106 (54-134)
H	86.0	95 (44-157)	103.0	99 (7-125)
I	78.4	97 (59-198)	48.4	49 (38- 83)
J	100.9	94 (44-202)	112.2	84 (7-153)
K	92.1	98 (44-168)	99.5	110 (7-142)
Less exposed schools				
L	44.1	51 (37- 84)	13.4	17 (5- 34)
M	34.1	37 (30- 62)	4.8	8 (2- 30)
N	62.9	66 (44-119)	49.8	48 (7- 67)
O	68.7	76 (45-206)	21.7	33 (12-111)
P	49.3	56 (32-238)	23.2	22 (5-107)
Q	58.5	56 (32- 95)	30.7	23 (2- 41)

6. Results – Spatial and temporal combined

A test of the representativity of static point estimates for pollution exposure is to compare them to an estimate of air pollution exposure accounting for movements between different locations, obtained using diaries.

Since people change location frequently, the real exposure may not be completely represented by a point estimate at the home. To test the validity of point estimates at the home, means of continuous exposure estimated using a diary for children was compared to the point estimates for $PM_{2.5}$ and for NO_2 at the home of the child. The results are presented in Figure 15 and Figure 16. In this example, point estimates for NO_2 regularly overestimate exposure when compared to diary data. For $PM_{2.5}$ the situation was a little more complex, with the point estimate under-estimating for low exposures and over-estimating at higher exposures.

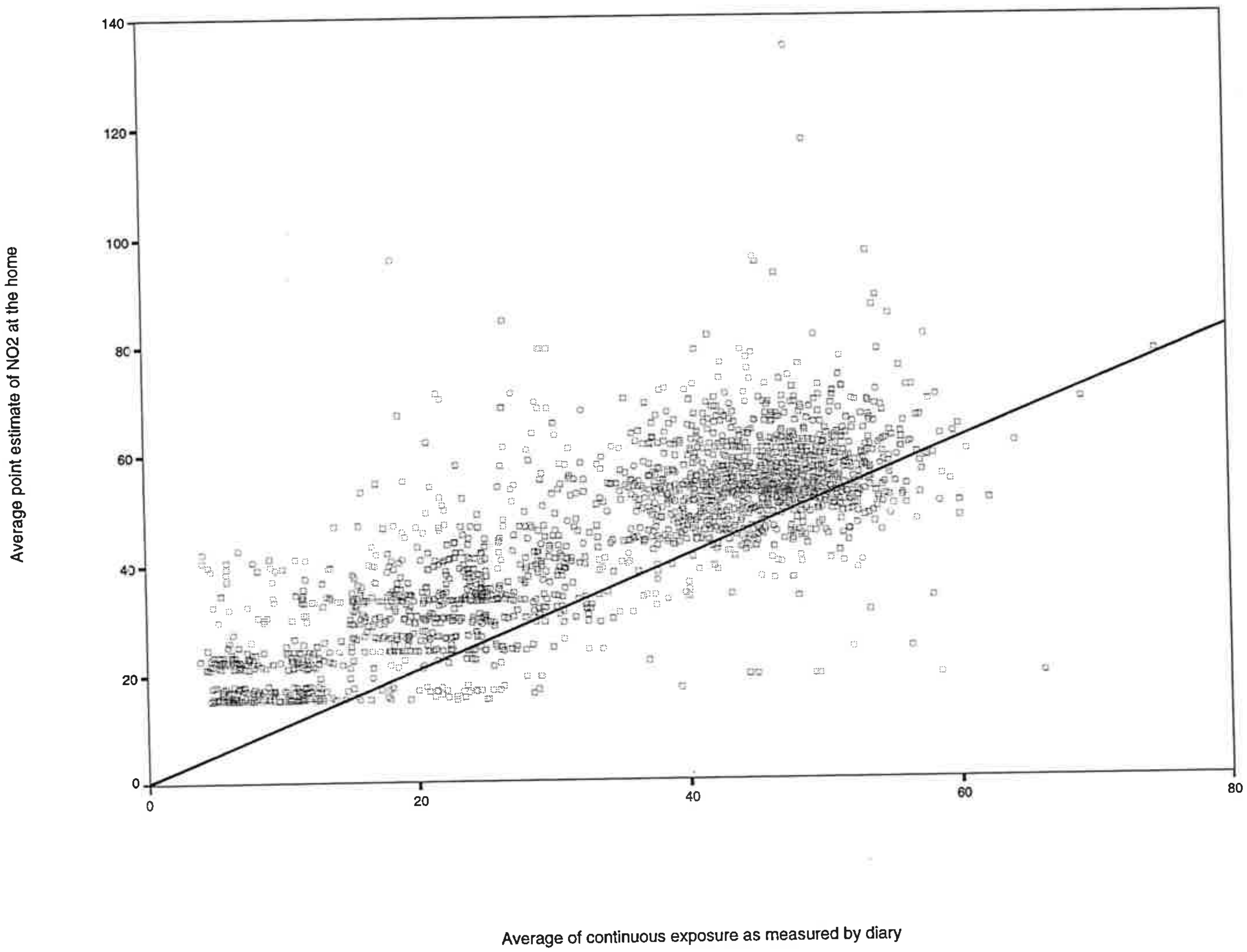


Figure 15: Comparison of average nitrogen dioxide (NO_2) estimated by the point estimate at the child's home and the continuous exposure estimated using the diary method.

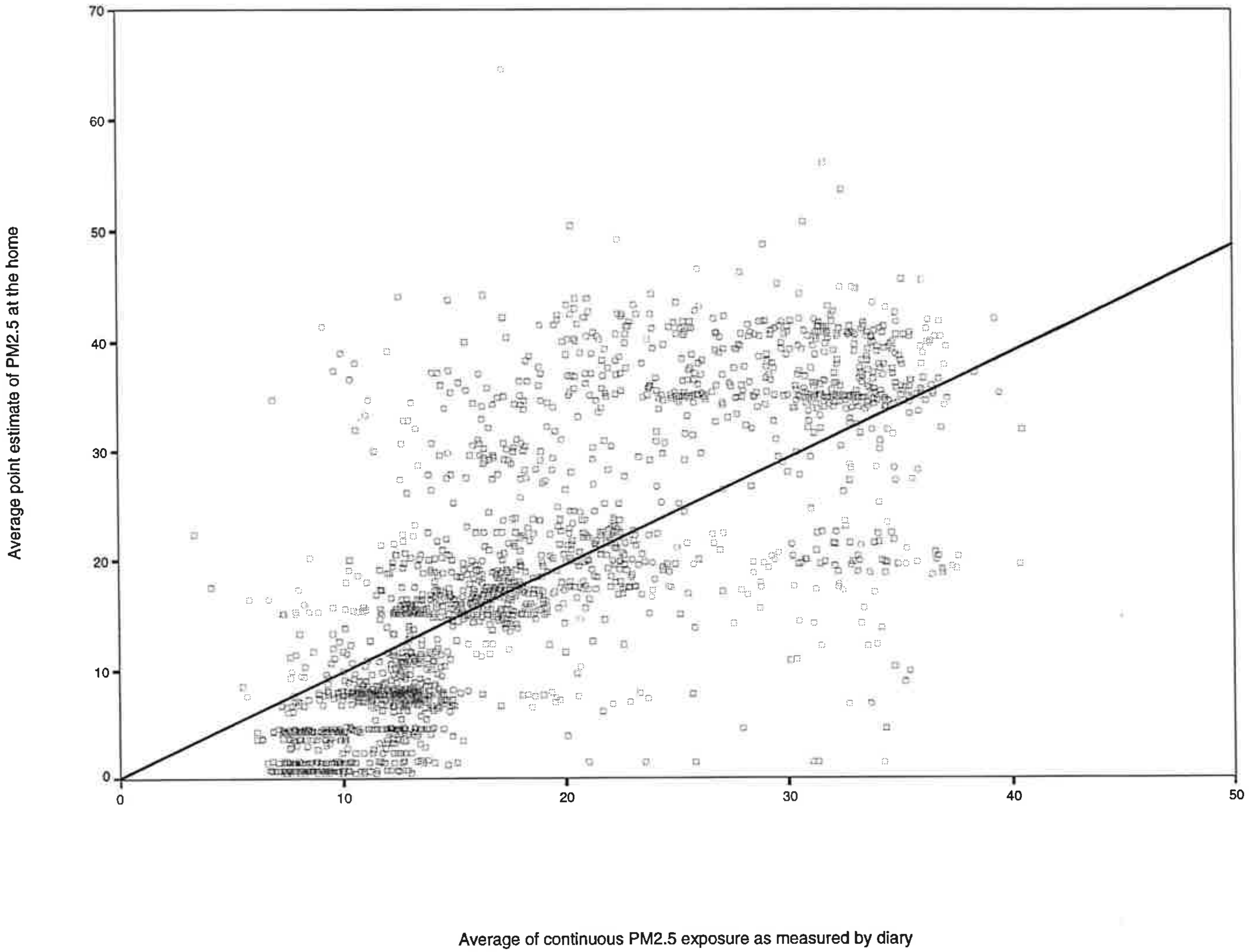


Figure 16: Comparison of average particulate matter ($PM_{2.5}$) and nitrogen dioxide(NO_2) exposure estimated by the static point estimate at the child's home and the continuous exposure estimated using the diary method.

At a later date, when hour-to-hour exposure data from the Vålerenga area adult diary study will be available based on the EPISODE model, it will be possible to compare in this way exposure estimates for adults. It is anticipated that differences will be larger. Children go to school in the neighborhood, whereas adults often travel longer distances to work, and exposure while traveling usually is very high.

Any improvements to the static point estimate that can be done in the form of accounting for time spent at work or school should be evaluated. This may be done by calculating the total external dose attributable to each of these micro environments.

7. Population exposure described by indicators

The ultimate aim of AQIs is to describe the population exposure to ambient pollution. This is done by estimating the number of people exposed using different characteristics of AQIs.

The aim of calculating indicators, is to describe the population exposure to pollutants in a way which is indicative of the resulting health effects. As was seen in Slørdal (1997), the number of individuals exposed to values over guidelines when all hours were considered, were substantially higher than when examining the single hour exhibiting the maximum concentration calculated in any grid.

To give an example of how the proposed indicators can be used to describe population exposure, we calculated the percent of the population in the region surrounding Lysaker exposed to the different parameters of air quality described by the indicators. The results are given in the following tables:

Table 11: The size of and percentage of the population in the 9 km2 region surrounding and including Lysaker grid square, exposed to episodes of different lengths.

Episode length (hour)	All 9 grid squares No. of individuals exposed	% of 9 km2 exposed grid population
NO_2		
1-8 hrs.	10 374	100 %
8-16 hrs	2 407	23 %
16 hrs	0	0
Inter-episode period		
≤ 10 days	10 374	100 %
10-70 days	7 967	77 %
> 70 days	0	0 %
PM_{10}		
≤ 16 hrs	10 374	100 %
16-24 hrs	2 407	23 %
> 24 hrs.	0	0 %
Inter-episode period		
≤ 10 days	10 374	100 %
10-34 days	8 525	82 %
> 34 days	0	0 %

Table 12: The size of and percentage of the population in the 9 km2 region surrounding and including Lysaker, exposed to different episode peaks.

Episode peak µg/m3	All 9 grid squares No. of individuals exposed	% of 9 km2 exposed grid population
NO_2		
≤ 120	10 374	100 %
120-130	8 331	80 %
130-200	3 323	32 %
> 200	0	0 %
PM_{10}		
≤ 200	10 374	100 %
200-250	6 255	60 %
250-300	3 227	31 %
300-380	2 407	23 %
> 380	0	0 %

Table 13: The number and percentage of the population in the 9 km^2 grid squares surrounding and including Lysaker, exposed to different cumulative integrated AOT concentration-times by categories (episode AOT50/100).

Episode AOT 50/100 µg/m^3 ·hours	All 9 grid squares	
	No. individuals exposed	% of 9 km^2 exposed grid population
NO_2		
≤ 50	10 374	100 %
50-100	3 444	33 %
100-300	3 227	31 %
> 300	0	0 %
PM_{10}		
≤ 500	10 374	100 %
500-750	5 520	53 %
750-1 000	2 528	24 %
1 000-2 000	3 323	32 %
> 2000	0	0 %

8. Future recommendations

Suggestions for future use of the air quality indicators suggested in this preliminary overview is given. These AQIs may be of use for public authorities in the future.

8.1 General discussion

Guidelines should set the limits of population exposure to air pollution to protect health and the environment.

Currently, guidelines exist that use standard statistical concepts such as mean and maximum concentrations, or percentiles. However, maximum values are very difficult to use, since errors in measurement or estimation can produce false maxima. Means may not reflect sufficiently the short-term peaks in exposure. The 98^{th} percentile (or other high percentile) is a more stable measure.

The European Commission (Commission of European Communities, 1997), has recently proposed guidelines with percentiles different from 98^{th} percentile. For example for sulfur dioxide, hourly maximum cannot be exceeded more than 24 times per year and daily maxima, 3 times per year (equivalent to 99.97 percentile) whereas for NO_2, hourly maximum concentrations cannot be exceeded more than 8 times per year (equivalent to 99.9 percentile). For PM_{10} the daily maximum values cannot be exceeded more than 25 times per year in 2005 (equivalent to 93^{rd} percentile) and 7 times per year in 2010 (equivalent to 98^{th} percentile). For ozone, it has been suggested to use AOT60=0 (ppb-hours) as approximation for health guidelines (UN-ECE/WHO, 1996).

As this report illustrates, however, these air quality indicators do not account for the time variability of the exposure, and do not account properly for the cumulative exposure to pollution. As knowledge of the health effects of pollution increases, there is a basis for specifying limits based on both temporal patterns and cumulative exposure.

The following set of indicators seems useful in evaluating the health effects of air pollution based on the time structure of the exposure.

1. Annual mean, daily/hourly mean, 98^{th} percentile, 99.9 percentile (or other high percentiles).
2. Total semi-annual AOT35/AOT100, etc. (threshold chosen separately for each component).
3. Total semi-annual number of episodes.
4. Episode AOT35/50/100 etc.

These indicators will allow a more complete description of the air pollution situation, so that regulations may be developed in the future that will more completely protect the population.

This report attempts to show how current modeling tools may be used to develop and present different air quality indicators. It will be the role of health authorities to specify, if necessary, what regulations need to be imposed. They will set maximum allowable integrated episode exposures, maximum number of allowable episodes, and maximum allowable peak episode concentrations.

To provide an example of how this system could be used, we use particulate matter (PM_{10}). For PM_{10}, guidelines could be as follows:

- Daily average: 35 µg/m^3
- Total number of episodes over daily value of 35 µg/m^3 not to exceed 5 (similar although not equal to EU directives, where for a daily concentration of 50 µg/m^3, the value should not be exceeded more than 25 or 7 times a year by year 2005 and 2010 respectively).
- The episodic days AOT35 should not exceed 25 µg/m^3-days.

The last two points were arrived at using Majorstua as a criteria in Table 8.

8.2 Future research needs

The indicators presented in this report could also be estimated for Trondheim, Bergen and Drammen, the other three cities included in the first indicator report (Slørdal, 1997). Increasing the scope to four cities will give a broader base for examining the suggested indicators and will allow comparing how effective they are in differentiating the pollution situation for cities with different pollution profiles and concentrations. However, should this be done, it would be more valuable if the latest version of AirQUIS system was used, where traffic is better accounted for with the introduction of the line model.

It is also recommended that the same AQIs be calculated for actual measurements so that AQIs derived from model estimates and measurements can be compared.

It would be valuable to use continuous exposure for individuals calculated using diary data, both for comparison to point estimates for adults and to examine the actual, personnel exposure to episodes.

The health effects of air pollution exposure expressed as episode exposure should be examined. Much data already exist both in the form of cross-sectional data and diary data for both adults and children that could be used to calculate the relationships between health endpoints and the exposure to episodic pollution concentrations.

Finally, the differences between individuals' actual exposure (measured) and exposure characterized by indices calculated from stationary receptor points are sufficiently large that information on individual population exposure should be assembled, and compared to existing guideline values when setting or revising guideline values.

9. References

Commission of the European Communities (1997) Proposal for a Council directive relating to limit values for sulphur dioxide, oxides of nitrogen, particulate matter and lead in ambient air. Brussels 8.10.97 (COM(97) 500 final, 97/0266(SYN)).

Grønskei, K.E., Walker, S.E. and Gram, F. (1993) Evaluation of a model for hourly spatial concentration distributions. *Atmos. Environ., 27B*, 105-120.

Hazucha, M.J., Bates, D.V. and Bromberg, P.A. (1989) Mechanism of ozone on the human lung. *J. Appl. Physiol,* 67, 1535-1541.

Samet, J., Zeger, S. L. and Berhane, K. (1995) Particulate air pollution and daily mortality: replication and validation of selected studies. The phase I report of the particle epidemiology evaluation project. Cambridge, MA., Health Effects Institute.

Slørdal, L. H. (1997) Beregning av NO_2 og PM_{10} -eksponering for Oslo, Drammen, Bergen og Trondheim vinteren 1994-1995. Kjeller (NILU OR 23/97).

Statens forurensningstilsyn (1992) Virkninger av luftforurensning på helse og miljø. Anbefalte luftkvalitetskriterier. Oslo (SFT-rapport 92:16).

United Nations Economic Commission for Europe/World Health Organization (1997) Health effects of ozone and nitrogen oxides in an integrated assessment of air pollution. Convention on Long-Range Transboundary Air Pollution. The proceedings of an International Workshop, Eastbourne, UK, 10-12 June 1996. Institute for Environment and Health University of Leicester.

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REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 34/98	ISBN 82-425-0986-7 ISSN 0807-7207	
DATE 29/7-98	SIGN.	NO. OF PAGES 36	PRICE NOK 60.-
TITLE Air Quality Indicators		PROJECT LEADER Jocelyne Clench-Aas	
		NILU PROJECT NO. O-96132	
AUTHOR(S) Jocelyne Clench-Aas, Cristina Guerreiro and Alena Bartonova		CLASSIFICATION * A	
		CONTRACT REF.	

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ABSTRACT
This report proposes and describes in detail several new methods for describing population exposure. These suggested methods of describing population exposure are a function of temporal, spatial and individual micro-environment movements. The episode is the basic entity, and the AQIs include the duration, the inter-episode period, the peak and the integrated concentration of the episodes.

The data used to describe these methods originates from dispersion modeling of Oslo.

NORWEGIAN TITLE
Indikatorer av luftkvalitet

KEYWORDS		
Indicators	Pollution	Population exposure

ABSTRAKT (in Norwegian)
Denne rapporten gir en detaljert beskrivelse av flere nye indikatorer foreslått for å kvantifisere befolknings-eksponering for luftforurensning. Disse indikatorene (AQI) er basert på variasjon i tid og rom i luftforurensnings-konsentrasjon. AQI er knyttet til episoder med høye konsentrasjoner. AQI beskriver lengden av episoden, tiden mellom episodene, den høyeste konsentrasjonen og konsentrasjon integrert over hver episode.

** Classification*   *A* *Unclassified (can be ordered from NILU)*
B *Restricted distribution*
C *Classified (not to be distributed)*