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OSPM: Comparison between modelled results obtained for the Erzeijstraat in the Netherlands and measurements

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Abstract

OSPM: Comparison between modelled results obtained for the Erzeijstraat in the Netherlands and measurements

RIVM has compared the results obtained with a Danish model for the calculation of air quality in streets, the OSPM (Operational Street Pollution Model), with measurements of the Dutch National Air Quality Monitoring Network (LML) and the calculations performed using the Dutch CAR-II (Calculation of Air pollution from Road traffic) model. The yearly average concentrations calculated using the OSPM are in reasonably good agreement with both the measurements and the calculations performed using CAR-II. However, there is a large scatter between the calculated and measured hourly concentrations. In the study reported here, the OSPM was used to calculate the NO_x and NO_2 concentrations in the Erzeijstraat in Utrecht, which is a good example of a typical Dutch street canyon. Calculations were performed for 2002, 2003 and 2006.

Dutch municipalities use the CAR-II model to estimate local air quality in streets with traffic. Research by the RIVM in 2007 demonstrated that the annual concentrations calculated by CAR-II are in fairly good agreement with measurements. However, it is not possible to calculate hourly concentrations using the CAR-II model. Hourly concentrations can be calculated using the OSPM model, which is a more sophisticated and detailed model. This model has been tested successfully in Denmark.

The yearly average concentrations of NO_2, as calculated using the OSPM, were found to be one to two micrograms per cubic meter lower than the measured values. This result is comparable to that obtained using CAR-II. There is a good correlation between modelled total hourly concentrations and measured total hourly concentrations (background plus contribution from the traffic), but only a moderate correlation for modelled and measured street increment. The lack of accurate meteorological data is probably the main factor contributing to this latter result. There were also contributions from nearby roads and highways, but these can not be incorporated in the OSPM.

Key words: Air Quality, OSPM, NO_x, NO_2

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Rapport in het kort

OSPM: een vergelijking tussen berekende resultaten en metingen in de Erzeijstraat in Nederland

Het RIVM heeft een Deens model om luchtkwaliteit in straten te berekenen, OSPM (Operational Street Pollution Model), vergeleken met metingen van het Landelijk Meetnet Luchtkwaliteit (LML) en berekeningen met het Nederlandse CAR II-model. De berekende jaargemiddelde concentraties komen redelijk goed overeen met zowel de LML-metingen als de CAR II-berekeningen. De verschillen tussen de voor individuele uren berekende en gemeten concentraties zijn echter groot. In dit onderzoek gaat het om de concentraties stikstofdioxide en stikstofoxiden in de Erzeijstraat in Utrecht in de jaren 2002, 2003 en 2006.

Lokale overheden gebruiken CAR II (Calculation of Air pollution from Roadtraffic) om de luchtkwaliteit in situaties met veel verkeer te berekenen. Uit onderzoek van het RIVM in 2007 is gebleken dat de berekende jaargemiddelden van CAR-II redelijk goed overeenkomen met metingen. Het is echter niet mogelijk om met behulp van CAR-II concentraties per uur te berekenen. Dat kan wel met OSPM, dat complexer en gedetailleerder is. Dit model is met succes uitgebreid getest in Denemarken.

De met OSPM berekende jaargemiddelde concentraties stikstofdioxide liggen één tot twee microgram per kubieke meter lager dan metingen. In dit opzicht is OSPM vergelijkbaar met CAR-II. De correlatie tussen voor individuele uren berekende concentraties en metingen is voor de totale concentraties (omgeving plus bijdrage van de weg) goed, maar voor de verkeersbijdragen hooguit redelijk te noemen. Een gebrek aan lokale meteorologische gegevens is waarschijnlijk de belangrijkste factor voor het verschil. Daarnaast kon de invloed van verkeer op nabij gelegen (snel)wegen niet in het model worden meegenomen.

Trefwoorden: Luchtkwaliteit, OSPM, NO_x, NO_2

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Summary

In this study the model OSPM was used to calculate the hourly NO_x and NO_2 concentrations in the Erzeijstraat in Utrecht, the Netherlands, which is a good example of a typical Dutch canyon. Calculations were performed for 2002, 2003 and 2006 using two sets of traffic data, and the results were compared to measurements of the LML (the Dutch National Air Quality Monitoring Network). The OSPM method used to calculate the NO_2 was compared to the Dutch method and to the results obtained by the OSPM using a larger residence time.

It was found that:

- A good correlation between modelled and measured total NO_x concentrations (R = 0.89) can be obtained with the OSPM, but the correlation between the modelled and measured street increments is only moderate (R = 0.64). The lack of accurate meteorological data and the contributions from the southern intersections and highways are probably the main factors contributing to this result.
- The new set of traffic data, which is based on the traffic counts performed by the city of Utrecht in 2006, produces much better results for working days than the old set of traffic data (bias of ± 2% on total NO_x concentration compared to a bias of up to –10%, respectively). The new set of data assumes that the traffic during the weekends is the same as that on working days; this assumption is clearly not valid. Consequently, when data for the weekends are included in the calculation, the results obtained with the new set of traffic data become worse.
- The OSPM seems to be robust. A small change in the street configuration setting does not result in a significant change in the result
- The correlation between the modelled and measured NO_2 concentrations is mainly determined by the quality of the modelled NO_x.
- The modelled annual NO_2 concentration has a bias of less than 5% of the measured total NO_2 concentration, which is comparable to the performance of the CAR II model. It is possible to reduce the difference between the modelled and measured average concentrations to almost zero by multiplying the τ values produced by the OSPM by 1.5 before they are used for the NO_2 calculations. This manipulation results in a larger NO_x/NO_2 conversion.
- The Dutch method for calculating the NO_x/NO_2 conversion gives slightly worse results than the OSPM method.

Based on these preliminary results, the authors recommend that the OSPM should be explored in more depth. To achieve this aim, however, better input data are necessary.

1 Introduction

The CAR II (Calculation of Air pollution from Road traffic) model is currently used by Dutch municipalities to estimate local air quality in streets with traffic. Although the results from the CAR II model are in good agreement with measured values (Wesseling and Sauter, 2007), this model can only estimate the annual average concentrations of pollutants [nitrogen dioxide (NO_2), particulate matter]. A more sophisticated model has been developed by the National Environmental Research Institute (NERI) of Denmark that enables hourly concentrations to be estimated. This model, called the OSPM (Operational Street Pollution Model), has been tested thoroughly in Denmark by the NERI. In the study reported here, the OSPM model was used to calculate the concentrations of various nitrogen oxides (NO_x) and NO_2 in the Erzeijstraat, which is representative of typical Dutch street canyons, and the results were compared to the measurements of the Dutch National Air Quality Monitoring Network (LML).

The results of this validation are presented herein.

2 The OSPM model

2.1 History of the OSPM

The need for a simple method/model for estimating pollution from traffic in Nordic cities resulted in a decision by the Nordic Council of Ministers to promote the development of the Nordic Computational Method for Car Exhausts (NBB) (Hertel et al., 1997). The NBB method is based on two submodels – an emission model and a dispersion model – and was used to predict NO_2 and carbon monoxide (CO) pollution. However, evident shortcomings in the dispersion part of the NBB method led to the need for a better description of dispersion phenomena in streets. This search for a better dispersion model of traffic pollution was initiated in 1987 at the National Environmental Research Institute (NERI), Denmark, in co-operation with the Norwegian Institute for Air Research (NILU) and The Swedish Meteorological and Hydrological Institute (SMHI). The result of this collaboration was the successful development of a new dispersion model – the Operational Street Pollution Model (OSPM) (Hertel et al., 1997).

2.2 The structure of OSPM

A complete description and a free evaluation version of WinOSPM (OSPM with a Windows user interface) can be downloaded from the website of NERI (http://ospm.dmu.dk). In this chapter only a short description is presented (see also the User's Guide to WinOSPM, 2003).

Dispersion of pollutants

OSPM makes use of a simplified parameterization of flow and dispersion conditions in a street canyon. The concentrations of pollutants in exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street; see Figure 2.1.

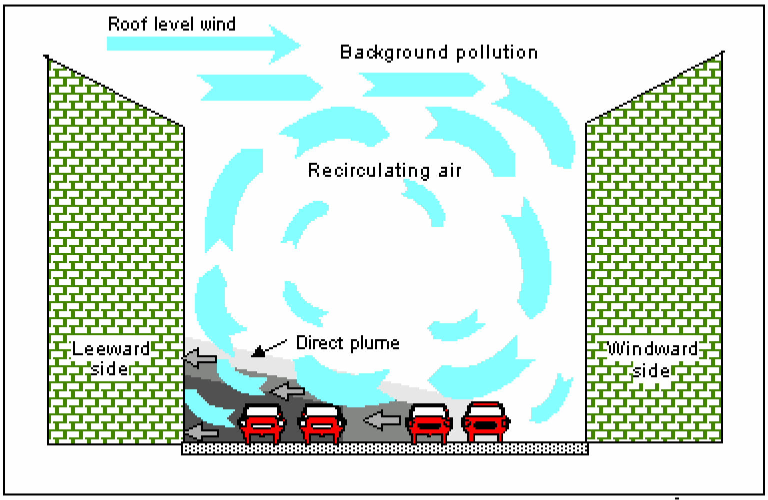


Figure 2.1 Schematic illustration of the basic model principles in OSPM. Concentrations are calculated as a sum of the direct plume contribution and the recirculating pollution. It is assumed in OSPM that the receptors (the monitoring stations) are always positioned against the buildings.

Direct contribution:

Calculation of the direct flow of pollutants in OSPM is based on the assumption that both the traffic and traffic emissions are uniformly distributed across the canyon. The emission field is treated as a number of infinitesimal line sources, with thickness dx, that are aligned perpendicular to the wind direction at street level. Inside the circulation zone, the wind direction at the street level is assumed to be mirror reflected with respect to the roof level wind. Outside the circulation zone, the wind direction is the same as that at roof level (Figure 2.2).

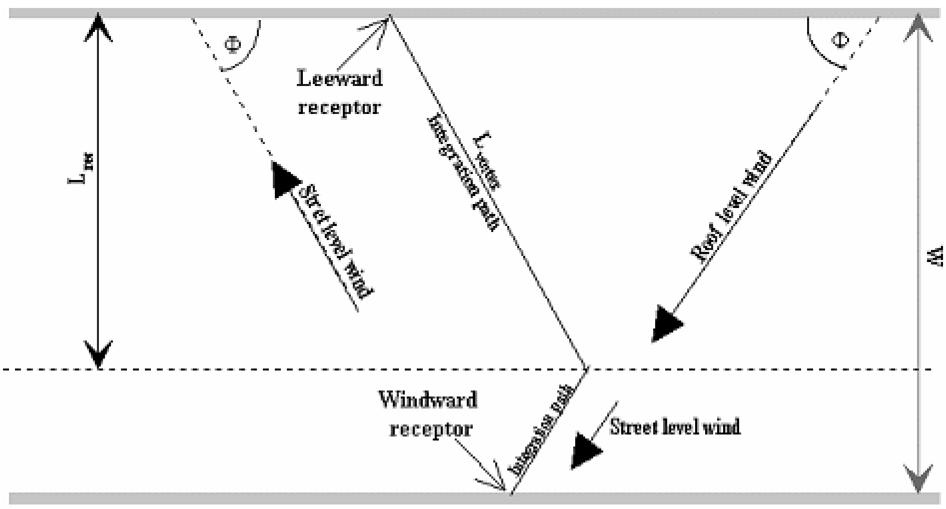


Figure 2.2 Illustration of the wind flow and formation of the recirculation zone in a street canyon (top view).

The emission density is then given as:

$$dQ = \frac{Q}{W} * dx \tag{2.1}$$

where:
Q is the emission in the street (g m^{-1} s^{-1}) ;
W is the width (m) of the street canyon;
dx (m) is the line perpendicular to the street axis.

The contribution to the concentration at a point located at a distance x from the line source is given by:

$$dC_d = \sqrt{\frac{2}{\pi}} * \frac{dQ}{u_b * \sigma_z(x)} \tag{2.2}$$

where:
u_b is the wind speed at the street level;
$\sigma_z(x)$ is the vertical dispersion parameter at a downwind distance x.
Equation (2.2) is integrated along the wind path at the street level.

Calculation of the vertical dispersion parameter σ_z in OSPM is based on the assumption that the dispersion of the plume is solely governed by the mechanical turbulence, which is considered to be generated by two mechanisms: the wind and the traffic in the street.

Recirculation contribution:

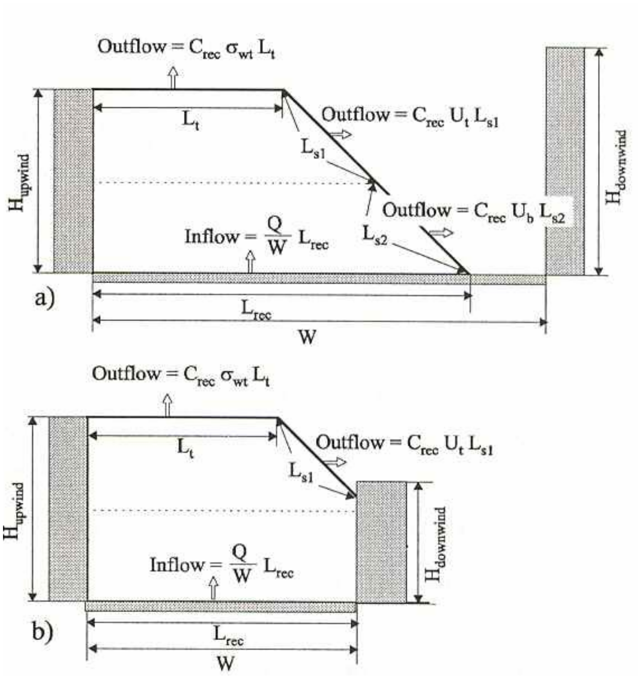


Figure 2.3 Geometry of the recirculation zone. a) The recirculation zone is totally inside the canyon; b) the downwind building intercepts the recirculation zone.

The contribution from the recirculation part of OSPM is calculated assuming a simple box model, which is illustrated in Figure 2.3. The canyon vortex is considered to have a specific shape (see Figure 2.3), with the maximum length of the upper edge being half that of the vortex L_{vortex}. The ventilation of the recirculation zone takes place through the side of the vortex region, but the ventilation can be limited by the presence of a downwind building if the building intercepts one of the edges (Figure 2.3b).

The length of the vortex, L_{vortex}, is assumed to be twice the height of the upwind building, H_{upwind}. For wind speeds (roof level) of less than 2 m/s, it is assumed that L_{vortex} decreases linearly with decreasing wind speed. This is consistent with the observations that vortex circulation is not observed at low wind speeds.

The concentration in the recirculation zone is calculated assuming that the inflow rate of the pollutants into the recirculation zone is equal to the outflow rate and that the pollutants are well mixed inside the zone.

If we consider the simple case of the vortex being totally immersed inside the canyon ($W/H \leq 1$), the recirculation contribution is:

$$C_{rec} = \frac{Q}{\sigma_{wt} * W} \qquad (2.3)$$

where:
Q is emission;
W is width;
σ_{wt} is canyon ventilation velocity, which is determined by the turbulence at the top of the canyon.

Roughly, $\sigma_{wt} \approx 0.1 * u_t$
where::
u_t is the wind speed at the top of the canyon.

Chemical processes
Due to the short residence times of air pollutants in street canyons (of the order of seconds or minutes at the most), only the fastest chemical reactions can have any significant influence on the transformation processes in the street canyon air. Therefore, it is assumed in OSPM that only three reactions are of interest:

$$NO + O_3 \xrightarrow{k} NO_2 + O_2$$
$$NO_2 + h\nu \xrightarrow{J} NO + O^{\bullet}$$
$$O^{\bullet} + O_2 \rightarrow O_3$$

The reaction between the oxygen radical (O•) and the molecular oxygen (O_2) is very fast, and for all practical purposes, the above reaction system can be restricted to two reactions only[1]:

[1] Information from Ketzel (2008)

- production of NO_2 due to the reaction of nitric oxide (NO) with ozone (O_3); reaction coefficient: k, $ppb^{-1}\ s^{-1} = 5.38e^{-2}*Exp(-1430/T)$, with T: temperature, Kelvin
- photodissociation of NO_2 leading to reproduction of NO and O_3; reaction coefficient: $J, s^{-1} = 0.8e^{-3}*Exp(-10/Q) + 7.4e^{-6}*Q$, with Q: radiation, W/m^2

Assuming that a steady state is achieved within the residence time (time derivates become zero), the NO_2 concentration in the street canyon can be calculated as follows (Hertel et al., 1997):

$$[NO_2] = 0.5*(B-(B^2-4([NO_x]*[NO_2]_o + [NO_2]_n*D))^{1/2}) \quad (2.4)$$

where:

$[NO_2]_n = [NO_2]_v + [NO_2]_b$, with $[NO_2]_v$: emitted NO_2 and $[NO_2]_v$ = f* NO_x street increment
$[NO_2]_o = [NO_2]_n + [O_3]_b$
$B = [NO_x] + [NO_2]_o + R + D$

where:
R is the photochemical equilibrium coefficient and is given by R=J/k (ppb);
D is the exchange rate coefficient and is equal to $(k\tau)^{-1}$, with τ being the residence time of pollutants in the canyon.

Remark:
In this study, we also performed additional calculations using a method derived from the Dutch model. For convenience, this method is referred to here as “the Dutch method”; it calculates the street increment of NO_2 as follows:

$$dNO_2 = f_{NO_2} * dNO_x + \frac{O_{3,bg} * (1-f) * dNO_x}{(1-f) * dNO_x + 100} \quad (2.5)$$

where:
dNO_2, dNO_x are the street increments of NO_2 and NO_x , respectively (in $\mu g/m^3$);
f is the fraction of emitted NO_2.
The original Dutch method is also used to calculate the annual average concentration of NO_2, and during this operation, it contains a factor 0.6 in the numerator.

2.3 Input and output

Required input

- Street configuration (street geometry): average height of buildings, and width and orientation of the street;
- Traffic data: variation in traffic flow over time, categorized into various types of vehicles. It is possible to use the pre-defined traffic data or to specify user-provided traffic data containing the number of various vehicles per hour. Here, we used traffic data provided for two composite vehicles types: "light" and "heavy". The "light vehicles" category consists of all passenger cars, motor and taxis; the "heavy vehicles" category, all types/sizes of trucks and buses;
- Emission data (car fleet and fuel). By default the emission data are calculated based on the European Emission Model COPERT. However, it is possible to use emission data provided by the user;
- Hourly meteorological data: wind speed, wind direction, radiation, temperature;
- Hourly urban background concentration of calculated pollutants;
- For the purpose of the NO_2 calculation, the urban background concentration of NO_2, NO_x and O_3 and the percentage of emitted NO_2 are also needed.

Output

By default, the results of WinOSPM are summarized in a table where it is possible to compare the model results with air quality limit values. As a supplement to this summary table, it is possible to create a file with an hourly time series and also to create a file with various statistical parameters or daily averages. In this study, we only used the hourly time series.

Comparison between the inputs required by OSPM and those required by the CAR model

OSPM requires both more and more detailed input data than the CAR II model. The major differences between these two models are:

- Street configuration (street geometry): In the OSPM, the street configuration can be given in more detail, with the possibility of defining up to 12 blocks of buildings (and/or open areas) of various heights. However, it is not possible to include the effect of trees in the street in the OSPM. In contrast, in the CAR model, the presence of trees can be compensated for by a factor (the so-called "bomenfactor"). In the OSPM, the monitoring station is assumed to be positioned against the buildings; such positioning is not always the case in the Dutch monitoring network. In the CAR model, such variations in positioning do not represent a problem as the distance between the street axis and the monitoring station is specified in the calculation.
- Traffic and emission data: only average daily data are required by CAR, while average hourly data for working days and for the weekends are required by OSPM.

- Meteorological data: only the yearly average wind speed is required by CAR, while hourly data are required by OSPM. In addition to wind speed data, OSPM also requires data on the wind direction, radiation and temperature.
- Background concentrations: only yearly average concentrations are required by CAR, while hourly data are required by OSPM.

3 Experimental site

3.1 Street configuration

The Erzeijstraat is an urban street with an (almost) continuous line of buildings on both sides (width = 30 m; H = 11 m on the east side and H = 7 m on the west side). The monitoring station is located on the east side of the street, just at the edge of the road surface but off the street itself. Because the distance from the buildings to the monitoring station is approximately 10 m, W = 20 m was used in the standard calculations carried out in this study (the effect of this setting was determined by additional calculations where W was set at 30 m). The street is oriented 16˚ with respect to north. On the south side, 150 m from the monitoring station, is a crossing with more traffic. On the north side, 75 m from the monitoring station, the street becomes more open and is not longer considered to be a street canyon. The developers of OSPM recommend not using length values greater than 75 m, even if the distance is larger; consequently, the model has been run with both L1 and L2 = 75 m (the effect of this setting was determined by additional calculations in which L2 = 150 m was used).

This results in the following street configuration of Erzeijstraat (Figure 3.1) in the standard OSPM calculations:

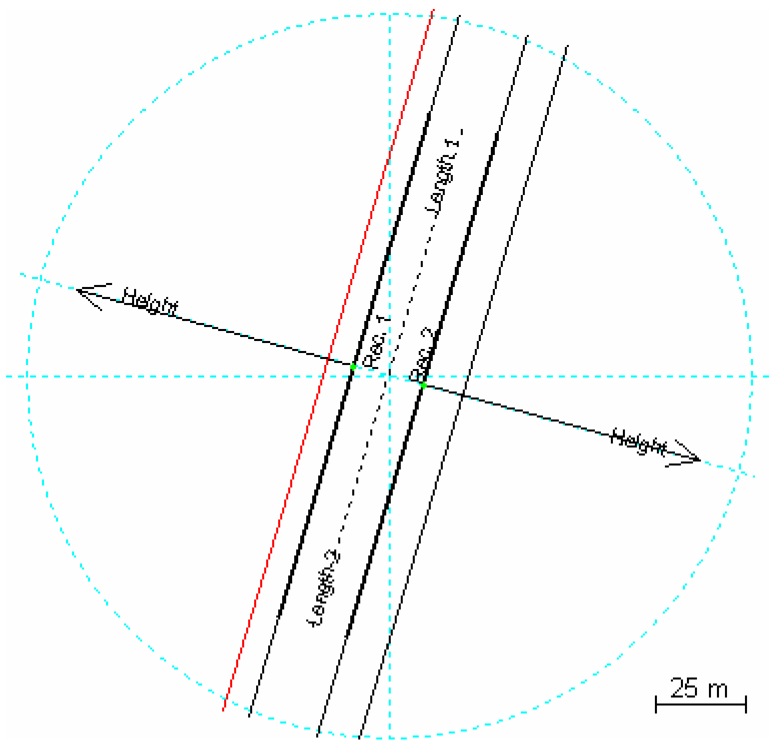


Figure 3.1: Street configuration of Erzeijstraat in the standard calculations performed with OSPM.

See also Figures 3.2A and 3.2B

Figure 3.2A: Erzeijstraat. Upper: west side. Below: east side.

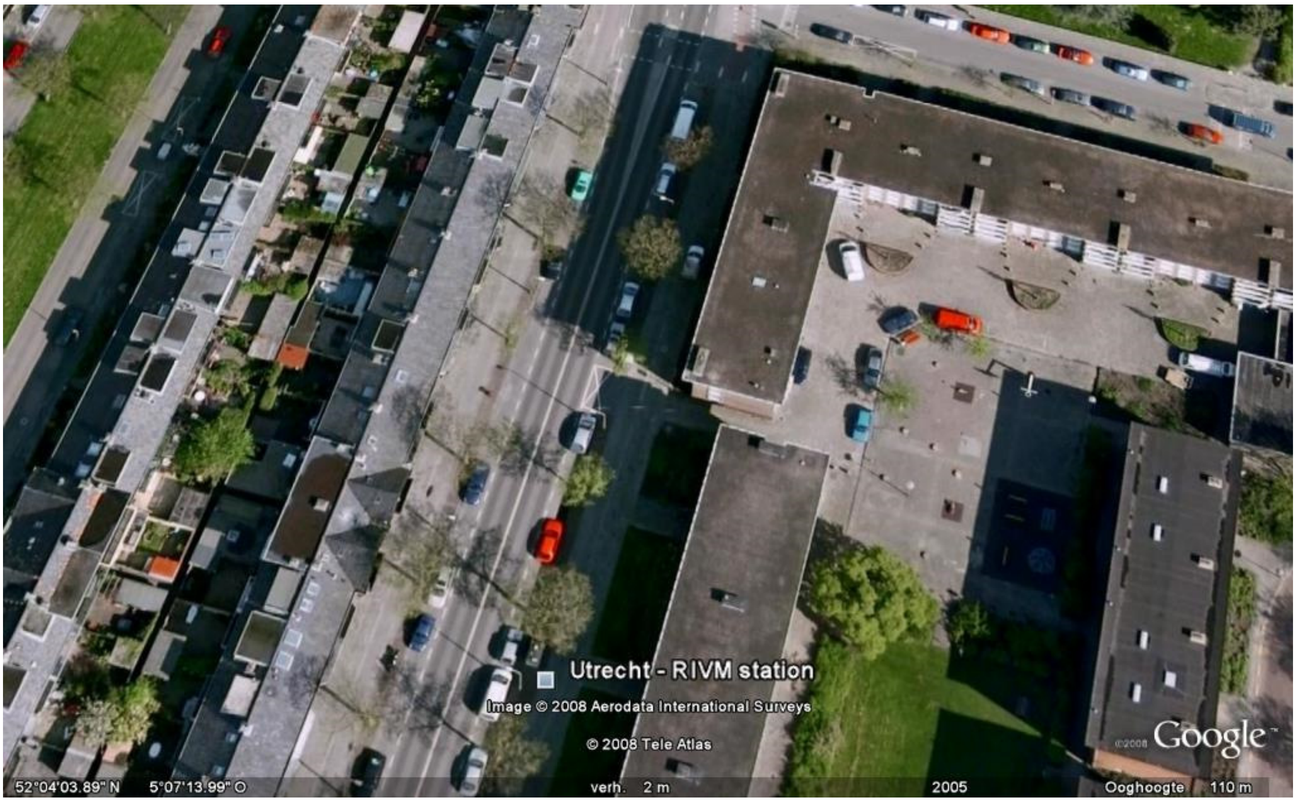


Figure 3.2B: Erzeijstraat, Google Earth view.

3.2 Background concentrations and meteorological data

Background concentrations

Only measured concentrations were used in this study. Measured concentrations of station 640 (Utrecht-Universiteitsbibliotheek, an urban background station) were available and used up to and including 2003. Because this station was rendered non-operational after 2003, data obtained from the Cabauw measurement station were used for subsequent years. However, this station is a rural monitoring station. The differences between the data obtained from these two stations were determined for the period 1997–2003, resulting in the following correction factors (for more details, see Appendix 1):

$NO_x\_bg = NO_x\_Cabauw*1.44$

$NO_2\_bg = NO_2\_Cabauw*1.41$

$O_3\_bg = O_3\_Cabauw*0.887$

Note: another approach using hourly concentrations (Mooibroek and Wesseling, 2008) results in a different relationship: NO_x_Utrecht-Universiteitsbibliotheek = NO_x_Cabauw*1.33+3.52. However, these two approaches give comparable results.

Meteological data:

Because Schiphol was used as the reference station in the CAR II model for the area of Utrecht, we also used the measurements recorded at this station as reference values in the present study. The wind speed was corrected for the difference in roughness between the reference station (Schiphol) and the street using the method applied in the Netherlands to calculate the wind speed in urban areas (“Luchtverontreinigingen en weer”, Staatsdrukkerij, 1979). The roughness of Schiphol and the Erzeijstraat was assumed to be 0.08 and 1.5, respectively, resulting in a correction factor of 0.7, id est:

$$u\_Erzeijstraat = u\_Schiphol*0.7$$

where:

u is the wind speed (m/s).

All other meteorological data obtained from the Schiphol measurement station (temperature, radiation) were used as obtained, without correction.

To check the effect of meteorological data, we also performed additional calculations using the meteorological data recorded by the Cabauw measurement station.

3.3 Traffic and emission data

Traffic data

Two different sets of traffic data were used in this study.
One set consists of the so-called “old traffic data” and is based, as starting point, on a traffic volume of 9,800 vehicles/weekday, determined in 2003. Specific ratios between various vehicle types were assumed for the weekends and working days, respectively (for more details, see Appendix 2), and the Dutch reference diurnal variation of various vehicles types (Appendix 2) was used.

The second set consists of “new traffic data” and is based on a traffic count performed by the city of Utrecht in 2006 (e-mail on 09/04/2008 from Peter Segaar). This traffic count of vehicles (passenger cars, motors, light trucks, heavy trucks and buses) travelling on the Erzeijstraat was carried out between 0700 and 1900 hours on a working day. The daily volume of each category of vehicles was assumed to be 1.2736 times the traffic volume during this daytime period (with the exception of buses, for which the factor is 1). The reference diurnal profile (Appendix 2) was used to determine the distribution of traffic during the night time. The traffic flows were then categorized into three groups:

- motors and passenger cars were placed into the group ”Passenger cars”;
- all buses and light trucks were placed into the group “Light trucks”;
- the group “Heavy trucks”.

This results in the following numbers for 2006:

Passenger cars:	10437	vehicles/day
Light trucks:	318	vehicles/day
Heavy trucks:	129	vehicles/day
Total:	10885	vehicles/day

There is no traffic count available for the weekends. However, because a lot of events take place in this area during the weekends and there are many shopping locations in the area itself or close by, the amount of traffic during weekends was assumed to be the same as that on a working day. To calculate the traffic data in a year other than the base year, we assumed that the traffic has increased each year by 2.5%.

Emission data

The emission data were calculated using the Dutch reference emission factors taken from the CAR II manual. These are shown in Table 3.1.

Table 3.1: Emission factors of NO_x (g/km) used in the present study.

Year	Passenger cars	Light trucks	Heavy trucks
2002	0.832	12.2	17.2
2003	0.778	11.7	16.7
2004	0.730	11.3	16.3
2005	0.595	11.3	14.7
2006	0.570	10.7	13.5

To compensate for the reduced dispersion of pollutants due to the presence of trees in this street, the emissions were multiplied by 1.5 (the so-called “bomenfactor”).
Note: Although it is more logical to apply this bomenfactor to the residence time of the pollutants, this option is not possible with the current version of OSPM. Because a reduced dispersion results in a higher concentration of pollutants, we simulated the effect in this study by changing the emission.

An example of the emission calculation is shown in Appendix 3. The 2006 traffic and emission data are presented in Figures 3.4 and 3.5, respectively.

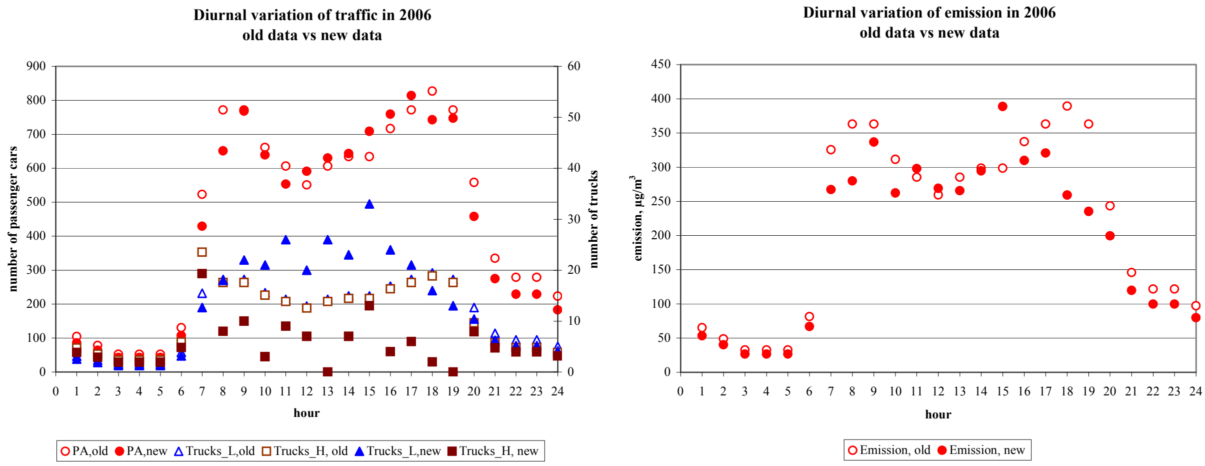


Figure 3.4: Diurnal variation of traffic and emissions on working days in Erzeijstraat according to the “new” and “old” traffic data sets, respectively. The daily average emissions are 219.4 µg/m/s (old) and 193 µg/m/s (new).

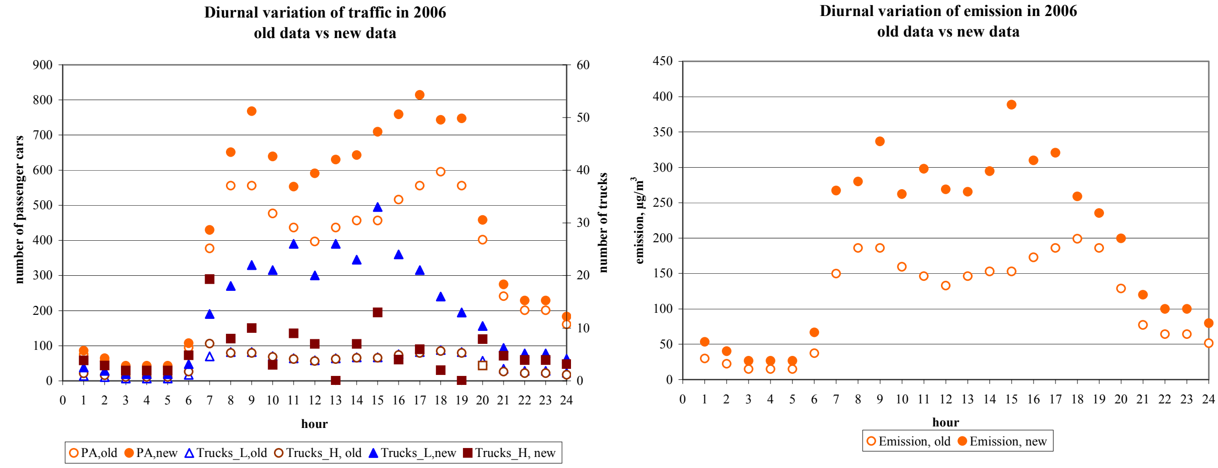


Figure 3.5: Diurnal variation of traffic and emission during weekends in Erzeijstraat according to the "new" and "old" traffic data sets, respectively. The daily average emissions are 111.5 µg/m/s (old) and 193 µg/m/s (new).

It must be noted that the traffic count in 2006 shows that the traffic in the Erzeijstraat is not symmetrical.
The traffic count in Erzeijstraat in 2006 is shown in Figure 3.6.

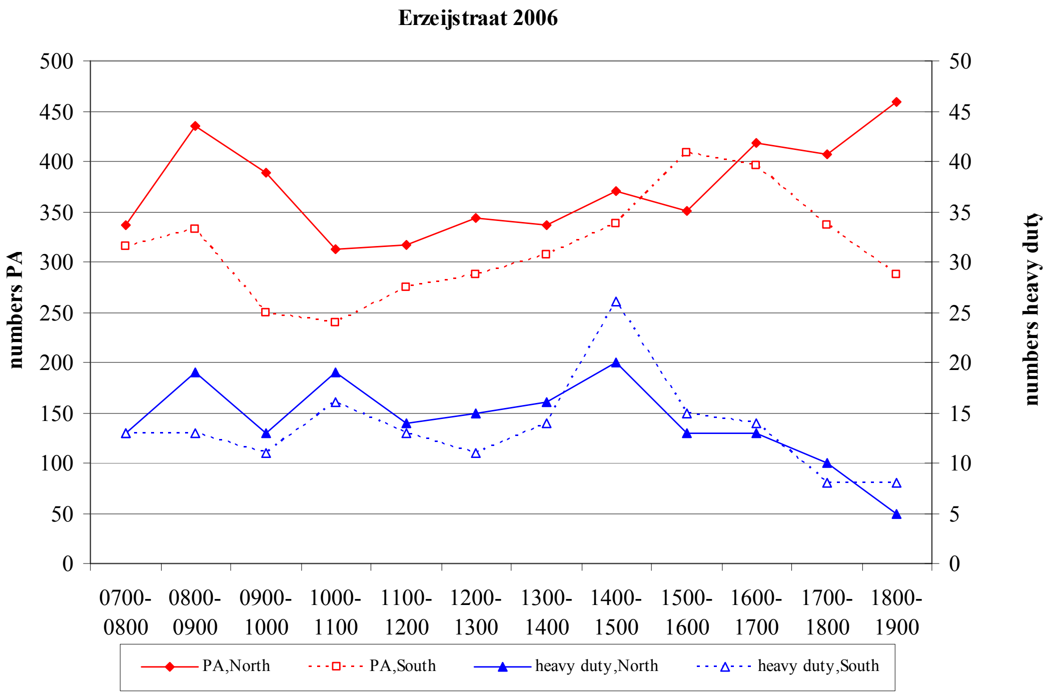


Figure 3.6: Diurnal variation of traffic in Erzeijstraat in the northerly and southerly direction, respectively. PA = motors + passenger cars + taxis; heavy duty = buses + all types/sizes of trucks.

3.4 Performed calculations

The following calculations were performed:

Year	Street configuration	Meteorological station used	Background station	Traffic data	Purpose
2002 & 2003	Standard (*)	Schiphol	Utrecht-Universiteitsbibliotheek (LML640)	Both traffic data (old and new) were used	Standard runs. Also to determine the effect of the traffic data used
2002	Standard (*)	Schiphol	Utrecht-Universiteitsbibliotheek	Alternative profile (**)	Determine the effect of the traffic data used
2002	W=30 m	Schiphol	Utrecht-Universiteitsbibliotheek	new	Determine the effect of setting in OSPM
2002	L2=150 m	Schiphol	Utrecht-Universiteitsbibliotheek	new	Determine the effect of the settings in OSPM
2006	Standard (*)	Schiphol	Cabauw (LML620)	new	Determine the effect of the background data used
2006	Standard (*)	Cabauw	Cabauw	new	Determine the effect of the meteorological data used

(*): Standard street configuration means: L1 = L2 = 75 m; W = 20 m
(**): Based on the assumption that the traffic volume is equal to twofold that of the traffic travelling in the northerly direction

4 Comparison with measurements

4.1 Method

The model results were evaluated both graphically (plotting of model results against observed data) and statistically. The following statistical parameters were used in this study:

- Mean: arithmetic mean
- Bias: observed – modelled
- Sigma: standard deviation
- Cor: correlation between the observed and modelled values (good correlation: R value of 0.9 or higher)
- MSSE (Mean Square of Standard Error), defined as:
  MSSE= $\sqrt{\frac{1}{N} * \sum (Model - Observation)^2}$

Only hourly concentrations for which both measured and modelled values are available, were used. Data with wind direction 0 (defined as variable wind direction) were not used.

4.2 Results of standard calculations for 2002 and 2003

The results obtained for 2002 and 2003 are presented in Table 4.1. The calculations were performed for both sets of traffic data (new and old), and comparisons with measurements were done for all days as well as for working days only. The results of the calculations for 2002 are shown graphically in the Figures 4.1–4.4. To investigate if the correlation improves when the extremes are removed, we also plotted the results for measured NO_x concentrations below 400 and 200 μg/m^3, respectively (Figure 4.2).

Table 4.1: Comparison between modelled and measured NO_x concentrations and street increments (dNO_x) in the Erzeijstraat. Concentrations are given in μg/m³.

Street configuration used: L1 = L2 = 75 m, W = 20 m.

	2002, new traffic data		2002, old traffic data		2003, new traffic data		2003, old traffic data	
	All days	Working days	All days	Working days	All days	Working days	All days	Working days
Data points	6620	4674	6620	4674	6727	4778	6727	4778
Mean_bg	50.0	54.3	50.0	54.3	50.5	56.9	50.5	56.9
Mean_obs	101.0	110.7	101.0	110.7	105.4	118.4	105.4	118.4
Mean_mod	109.1	113.2	108.5	121.5	110.6	116.3	110.0	124.8
Bias	-8.0	-2.4	-7.5	-10.8	-5.2	2.1	-4.6	-6.3
Sigma_obs	96.1	102.2	96.1	102.2	114.9	127.8	114.9	127.8
Sigma_mod	77.5	80.3	80.2	84.5	79.6	86.8	83.4	91.0
Cor_total_NO_x	0.85	0.88	0.87	0.88	0.85	0.88	0.87	0.88
MSSE	50.9	49.7	48.1	50.8	63.8	66.0	60.0	65.1
Cor_dNO_x		0.63		0.64		0.58		0.60

Abbreviations:

Mean_bg: average background concentration;

Mean_obs, mean_mod: average of measured concentrations and modelled concentrations, respectively;

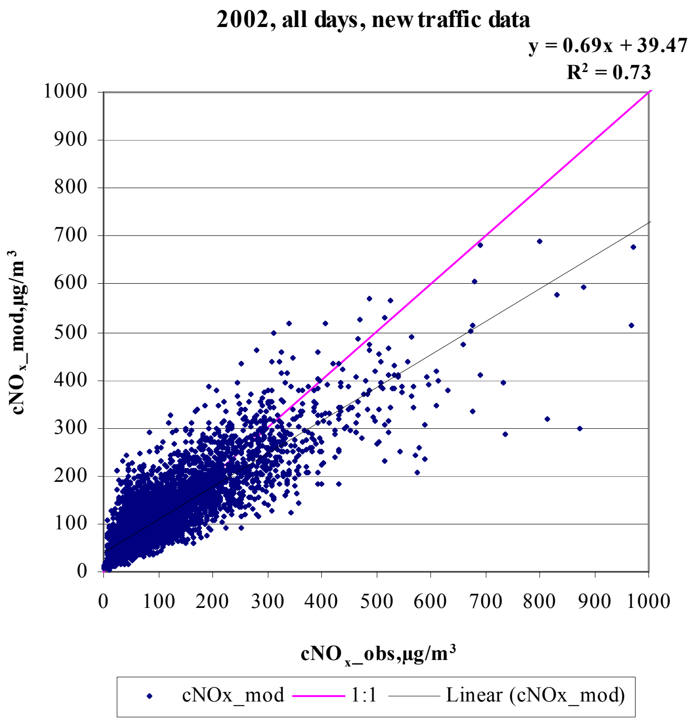
Bias: difference between measured and modelled values;

Sigma_obs, sigma_mod: Standard deviation of measured and modelled concentrations, respectively;

Cor_total_NO_x: Correlation coefficient between measured and modelled total NO_x concentrations;

MSSE: Mean Square of Standard Error, as defined above;

Cor_dNO_x: Correlation coefficient between measured and modelled street increments.



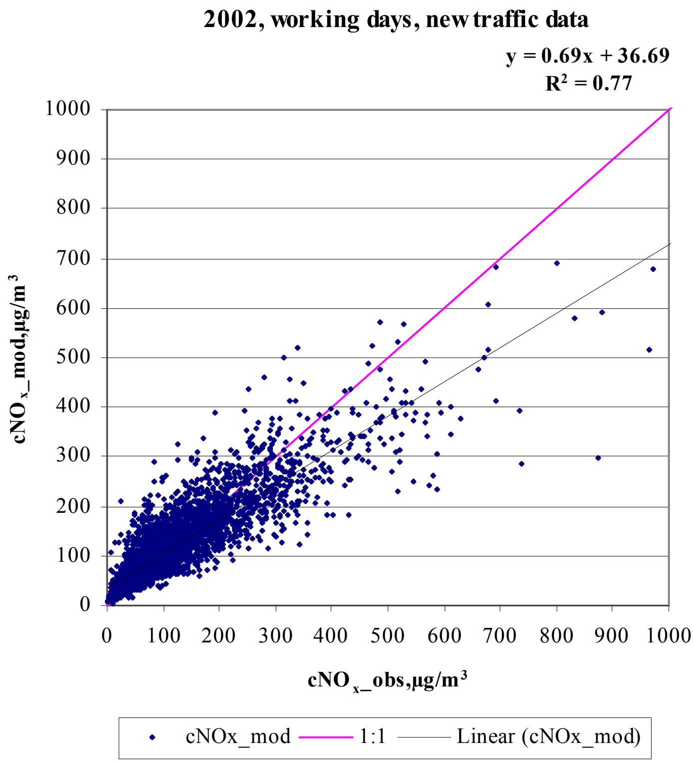


Figure 4.1: Comparison between modelled and measured total NO_x concentrations in 2002 using the new traffic data set. Upper: All days. Below: Working days only. The scatter is smaller when the data for the weekends is excluded.

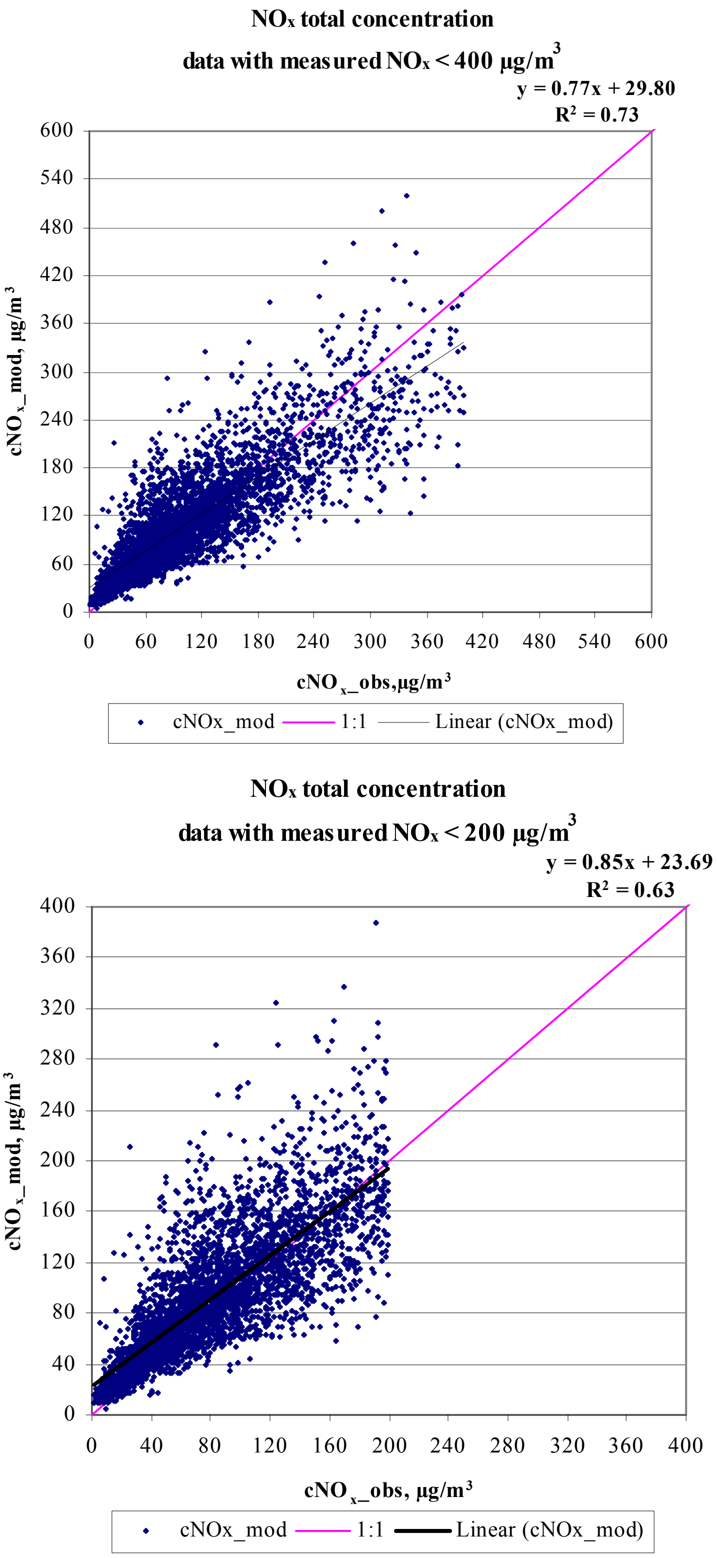


Figure 4.2: Performance of the model for various ranges of measured NO_x concentrations in 2002 using the new traffic data set and working days only. Upper: Model results for measured total NO_x concentration below 400 µg/m³. Below: Model performance for total NO_x concentration below 200 µg/m³.

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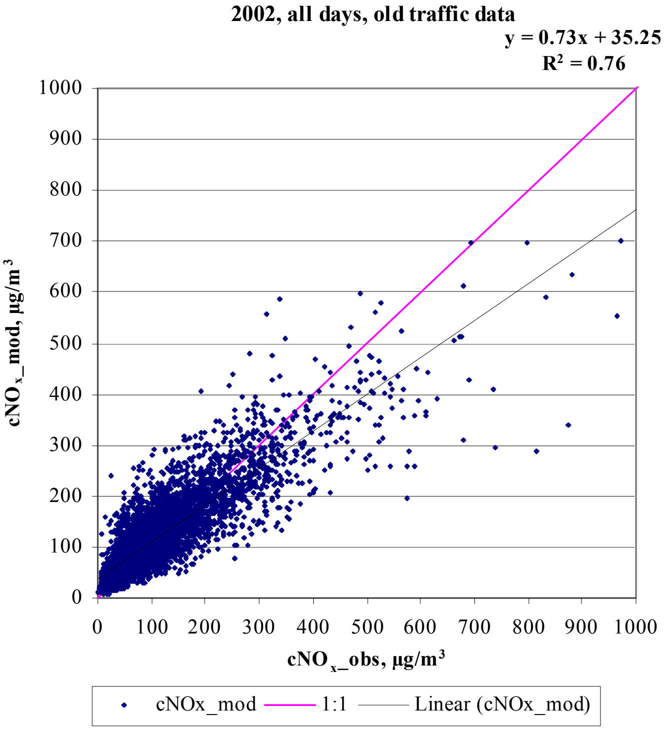


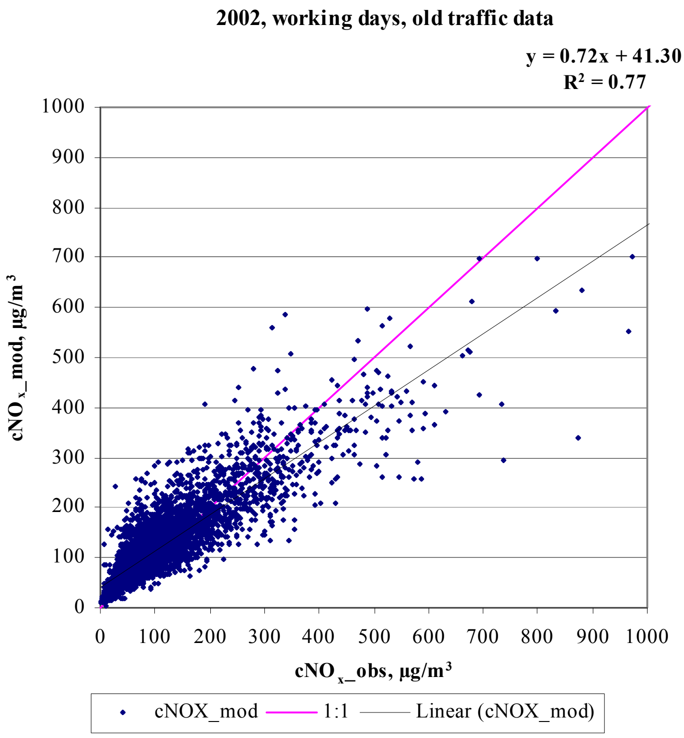


Figure 4.3: Comparison between modelled and measured total NO_x concentrations in 2002 using the old traffic data set. Upper: All days. Below: Working days only. Note that the model results are improved with the old traffic data set also when the weekends are not included.

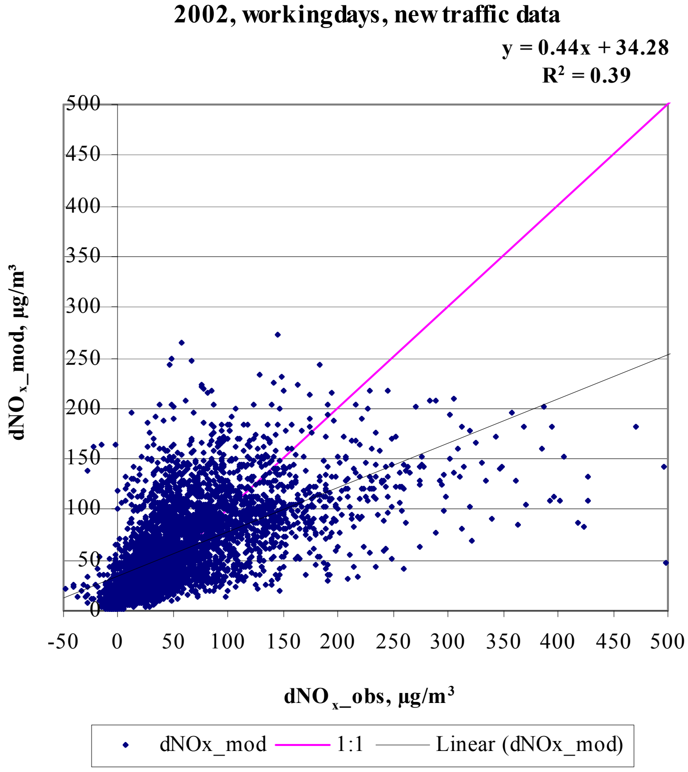


Figure 4.4: Comparison between modelled and measured NO_x street increments in 2002 using the new traffic data set. Only data for working days were used.

Effect of traffic data

The results in Table 4.1 show a good correlation between the measured and the modelled NO_x concentrations (R = 0.88) and a moderate correlation for the street increment (R = 0.63). Measured concentrations have much larger standard deviation (sigma) than modelled values, indicating that the extremes can not be predicted well by the model. The linear (least square) regression lines have intercepts of about 40 $\mu g/m^3$ (Figures 4.1 and 4.3) and slopes of about 0.7. Lower intercepts and higher slopes were obtained when only measured data below 400 $\mu g/m^3$ and 200 $\mu g/m^3$, respectively, were used (Figure 4.2).

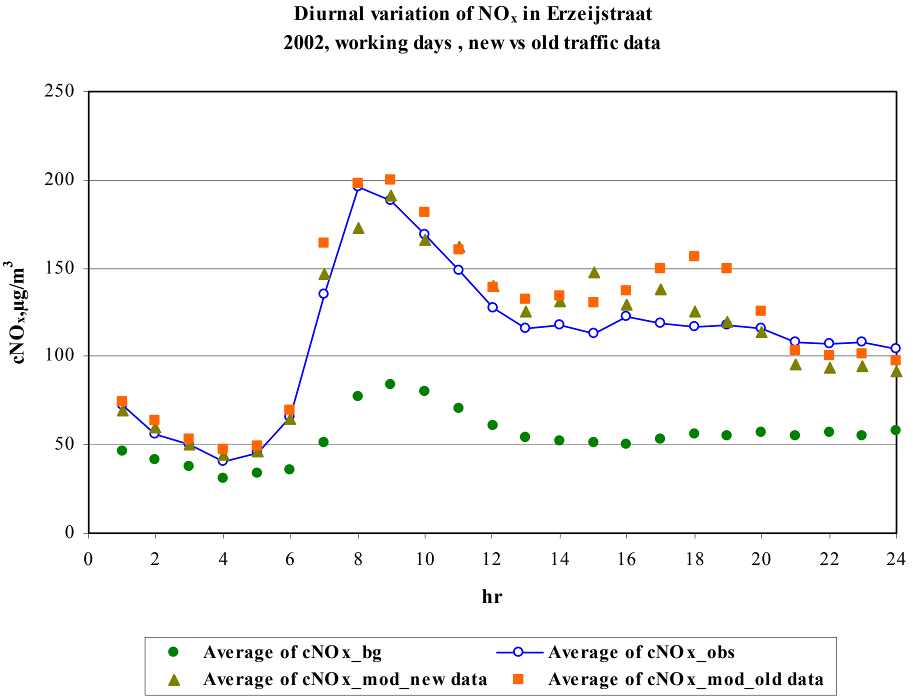
Comparisons between the results obtained with the two sets of traffic data show that:

- Both sets of traffic data lead to an overestimation of the average concentration (negative bias).
- When only data for working days are used, modelling with the new traffic data set results in an average NO_x concentration that is quite close to the measured values (bias ± 2 $\mu g/m^3$). The emissions obtained with the old set of traffic data are about 13% higher than those obtained with the new data set (see Figure 3.4), resulting in the same increase in the street increment and a higher bias.

- The new traffic data set assumes that the traffic during the weekends is the same as that during working days. This assumption leads to a large overestimation of the weekend's emissions; consequently, when the data for the weekends are included, the bias becomes more negative.

Figure 4.4 shows that there is an undesirable effect of using background concentrations measured at a location other than the monitoring site. Although the yearly average concentrations measured at the Utrecht-Universiteitsbibliotheek station were lower than those of the Erzeijstraat, the hourly concentrations at the former location could, on occasion, actually be higher than those at the latter location, as can be seen in Figure 4.4 (negative value for observed street increment). This variation causes a discrepancy between the model results and observations. In Jagtvej (Copenhagen, Denmark), where OSPM has been tested successfully, the background concentration was obtained at a monitoring station located at the experimental site, but at a height of 20 m.

Overall, we can conclude that the new set of traffic data gives slightly better results – provided that the incorrect data for the weekends are not used (id est the seemingly incorrect assumption that traffic during the weekends is the same as that on working days). This is also shown in Figure 4.5, which depicts the diurnal variation of NO_x concentration for both sets of traffic data. Figure 4.5 also shows the effect of traffic on the background station Utrecht–Universiteitsbibliotheek: the background concentration is much higher on working days than during weekends, with a difference of almost 50 $\mu g/m^3$ during peak hours.



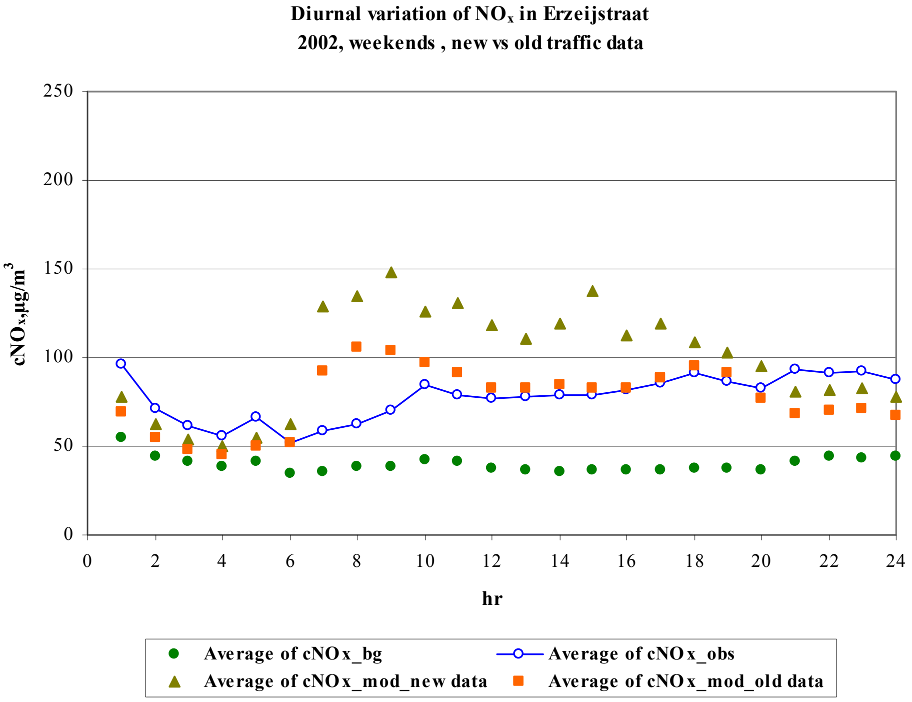


Figure 4.5: Modelled and measured diurnal variations of NO_x. Upper: working days only. Below: weekends only. Both sets of traffic data lead to an overestimation of the concentrations, but the overestimation of the old data set is larger. The new traffic data set strongly overestimates the concentrations during the weekends.

An additional calculation was performed using a modified profile of the new traffic data set. In this calculation the traffic is assumed to be twice that of traffic travelling in the northerly direction. Because the new set of traffic data already overestimates the average concentrations (negative bias), the bias became even more negative when the modified set of traffic data was used. No effect on the correlation was observed.
The result of this calculation is shown in Table 4.2 and Figure 4.6.

Table 4.2.: Comparison between modelled and measured NO_x concentrations: new traffic data versus modified traffic profile. The calculation was performed with data for 2002; only working days were used.

	Standard	Traffic=2* north direction
Data points	4674	4674
Mean_bg	54.3	54.3
Mean_obs	110.7	110.7
Mean_mod	113.2	116.2
Bias	**-2.4**	**-5.5**
Sigma_obs	102.2	102.2
Sigma_mod	80.3	82.0
Cor_total_NO_x	0.88	0.88
MSSE	49.7	50.0
Cor_dNO_x	0.63	0.63

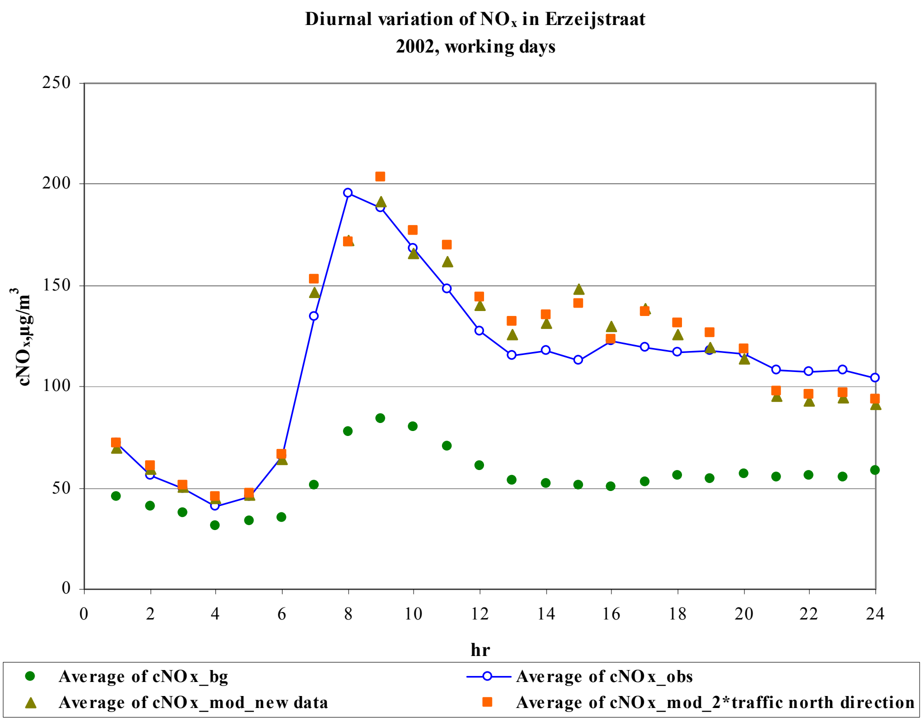


Figure 4.6: Diurnal variation in modelled and measured NO_x concentrations: new traffic data versus modified traffic profile.

Effect of wind directions

Figure 4.7 shows the NO_x concentration as a function of wind directions for 2002. It is evident from this figure that the model makes a large underestimation (up to almost half of the street increment) when the wind is in a southeasterly direction. One possible explanation for this result may be the contribution of the large and crowded intersections located at the southern end of the Erzeijstraat. There are also significant highway emissions roughly 1 km south and roughly 2 km southeast of the Erzeijstraat. However, when the data associated with the southeasterly wind (wind sectors between and including 130–170˚) were left out, the results did not improve because the model then overestimated the average concentration (Figure 4.8 versus Figure 4.5); The correlation between the modelled and measured NO_x concentrations was also not improved (Table 4.3)

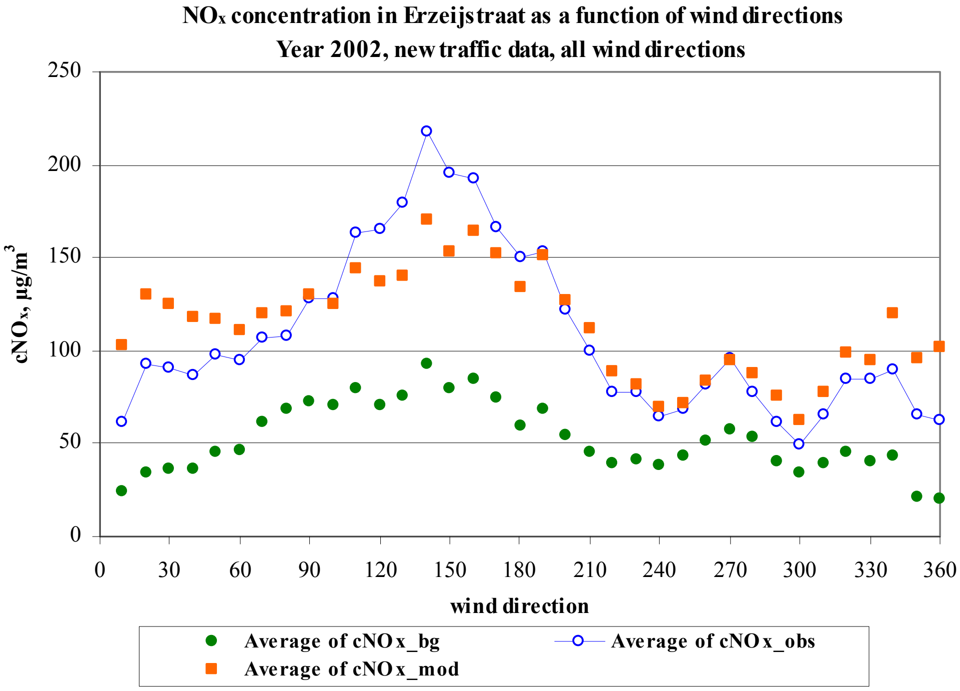


Figure 4.7: Total NO_x concentration as a function of wind direction. Data for working days in 2002.

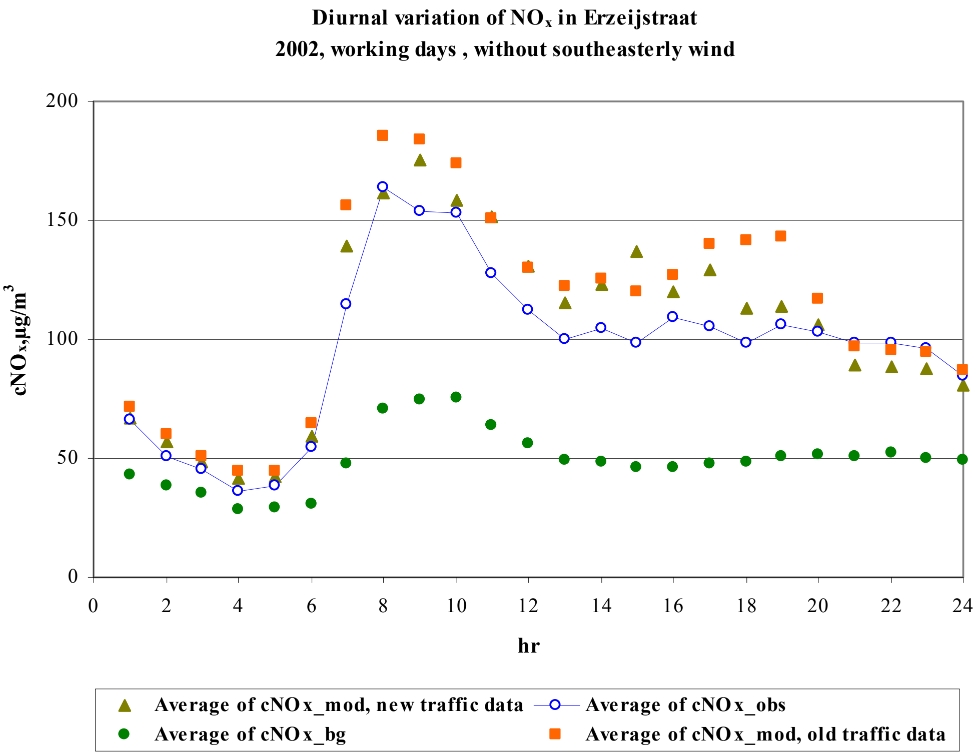


Figure 4.8: Diurnal variations in total NO_x concentrations on working days. The data for southeasterly winds are not included.

Table 4.3. Average total NO_x concentrations and correlations between modelled and measured data. Results of 2002 for new traffic data set and for working days only.

	Without southeasterly wind					All wind directions				
Hour	Mean_bg	Mean_obs	Mean _mod	Bias	Cor_NO_x	Mean_bg	Mean_obs	Mean _moc	Bias	Cor_NO_x
1	43.2	66.4	66.9	-0.5	0.88	45.9	72.3	69.9	2.4	0.89
2	38.6	50.6	56.6	-6.0	0.97	41.2	55.7	59.6	-3.9	0.96
3	35.6	45.3	48.1	-2.8	0.97	37.8	50.0	50.6	-0.6	0.96
4	28.4	35.9	41.6	-5.8	0.90	31.3	40.6	44.6	-4.0	0.93
5	29.5	38.2	42.1	-3.9	0.94	33.5	45.6	46.3	-0.6	0.94
6	31.0	54.3	59.0	-4.8	0.88	35.4	65.8	64.2	1.6	0.88
7	47.6	114.4	139.1	-24.7	0.81	51.4	134.7	146.3	-11.6	0.78
8	71.1	163.6	161.6	2.0	0.81	77.3	195.7	172.7	23.0	0.84
9	74.6	153.7	175.7	-21.9	0.80	84.2	188.4	191.2	-2.8	0.80
10	75.7	153.1	158.8	-5.7	0.90	80.5	168.6	166.0	2.6	0.90
11	64.2	127.6	151.4	-23.9	0.86	70.6	148.2	161.8	-13.6	0.88
12	56.0	112.3	131.1	-18.8	0.80	60.7	127.7	140.1	-12.4	0.84
13	49.1	100.0	115.8	-15.8	0.84	53.6	115.5	125.6	-10.1	0.88
14	48.4	105.0	123.0	-18.0	0.78	52.2	117.5	131.6	-14.0	0.85
15	46.5	98.8	137.0	-38.2	0.75	51.0	113.3	147.9	-34.6	0.81
16	46.0	108.9	119.8	-10.9	0.82	50.6	122.8	129.5	-6.7	0.86
17	47.4	105.2	129.5	-24.3	0.85	52.8	119.1	138.3	-19.2	0.88
18	48.6	98.6	113.1	-14.4	0.87	56.2	117.1	125.7	-8.6	0.90
19	51.0	106.0	113.9	-7.9	0.88	54.8	117.5	119.6	-2.2	0.89
20	51.2	103.4	106.2	-2.8	0.90	56.7	116.0	114.0	1.9	0.92
21	50.8	98.6	89.3	9.3	0.91	55.3	107.9	95.2	12.8	0.91
22	52.3	98.2	88.1	10.1	0.91	56.5	107.6	93.3	14.3	0.92
23	49.7	96.2	87.5	8.8	0.88	55.5	108.4	94.2	14.2	0.90
24	48.9	84.8	80.6	4.2	0.89	58.1	104.1	91.3	12.8	0.91

Effect of wind speed

To determine the effect of wind speed on the model performance, the data for 2002 were divided into two groups: data with wind speeds ≥ 3 m/s and data with lower wind speeds. The results are presented in Table 4.4. As expected, the concentrations are lower at higher wind speeds. The results also suggest that the model performs better at higher wind speeds (better correlation of the street increment). However, a lower wind speed mostly occurs in the Erzeijstraat when the wind is in a southeasterly direction (Figure 4.9). This is precisely the situation in which the contribution from the intersections and highways lying to the south of the Erzeijstraat may be quite pronounced – and the situation which can not be reproduced by the model. Therefore, in this case, it is not possible to draw any conclusion on the effect of wind speed on the performance of the model.

Table 4.4: Dependence of model results on wind speed. Results for 2002, the new set of traffic data and only data for working days were used. Reported wind speeds are over the roof level (the so-called "u_mast"in OSPM).

	all wind speeds	ws ≥ 3 m/s	ws < 3 m/s
Data points	4674	2483	2191
Mean_bg	54.3	40.5	69.9
Mean_obs	110.7	81.7	143.7
Mean_mod	113.2	86.7	143.2
Bias	-2.4	-5.0	0.5
Cor_total_NO_x	0.88	0.88	0.86
MSSE	49.7	28.4	66.0
Mean_dNO_x_obs	56.5	41.2	73.8
Mean_dNO_x_mod	58.9	46.2	73.3
Cor_dNO_x	0.63	0.73	0.55

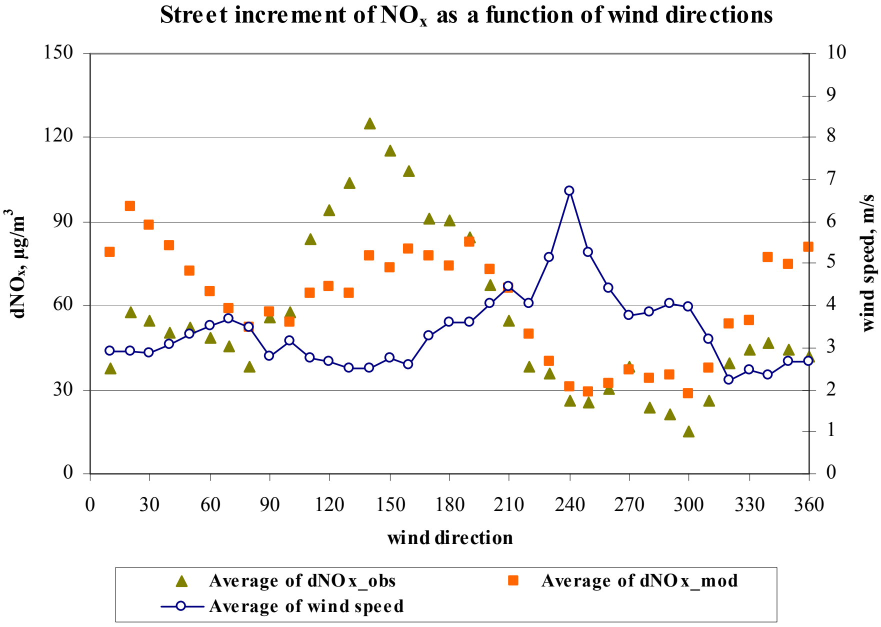


Figure 4.9: Street increment of NO_X. Graph is for the year 2002, new traffic data and working days only.

Effect of the "bomenfactor"

In this study, the emissions were multiplied by 1.5 to simulate the effect of trees in the Erzeijstraat. No distinction was made between the summer and the winter periods. We investigated the effect of the introduction of a constant factor for the whole year. The results are shown in Figures 4.10A, B, C on a per-month basis for 2002, 2003 and 2006, respectively. Theoretically, the effect of trees is more significant during the summer period, and the model should underestimate the results; in contrast, the model should overestimate the effect of trees during the winter periods.

However, Figure 4.10A–C shows that the model overestimates the "bomenfactor" even during June, July and August. One explanation for this unexpected result may be the numerous legal holidays that occur during this period: the reduction in the amount traffic on these days may have a larger effect than the overgrowth of trees.

In 2002 and 2006, the model does make relatively more overestimations during the winter period than in other months (provided that the holiday period is left out of the calculation). This effect is, however, not observed in 2003.

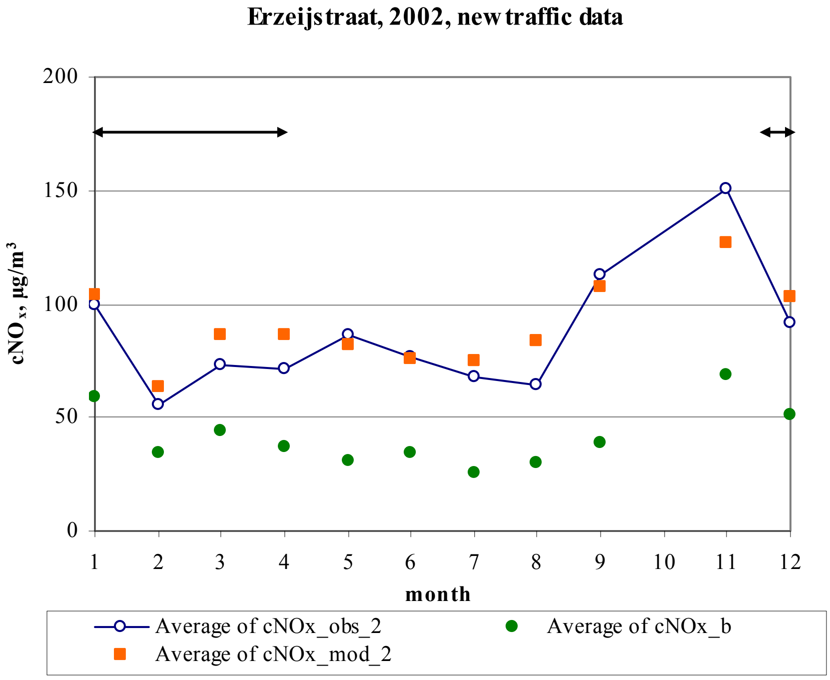


Figure 4.10A: Monthly average of total NO_x concentrations: Model versus observation for working days of 2002. No data are available for October because the background concentration is missing.
The black arrows show the "winter period" (period without any overgrowth of trees).

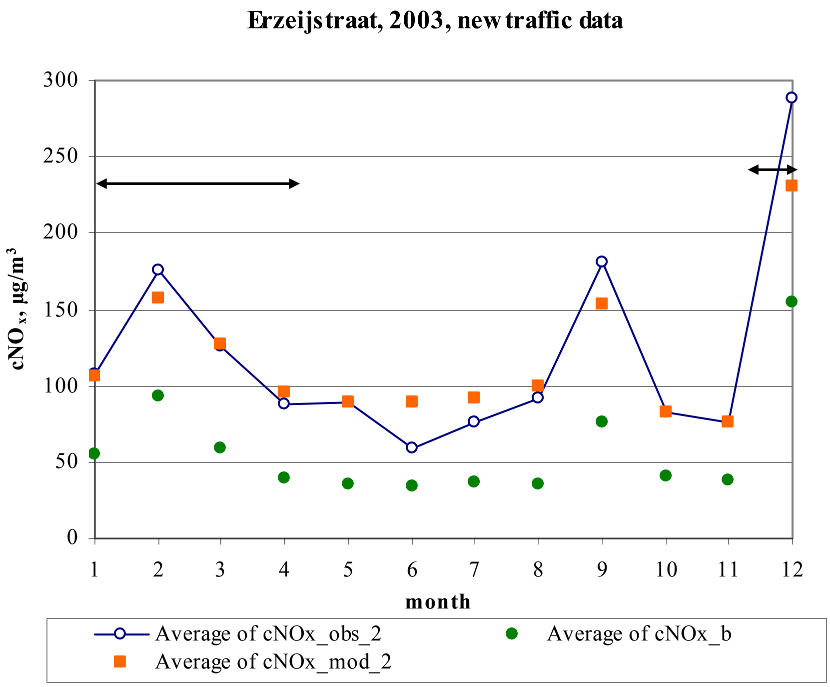


Figure 4.10B: Monthly average of total NO_x concentrations: Model versus observation for working days of 2003. The black arrows show the winter period.

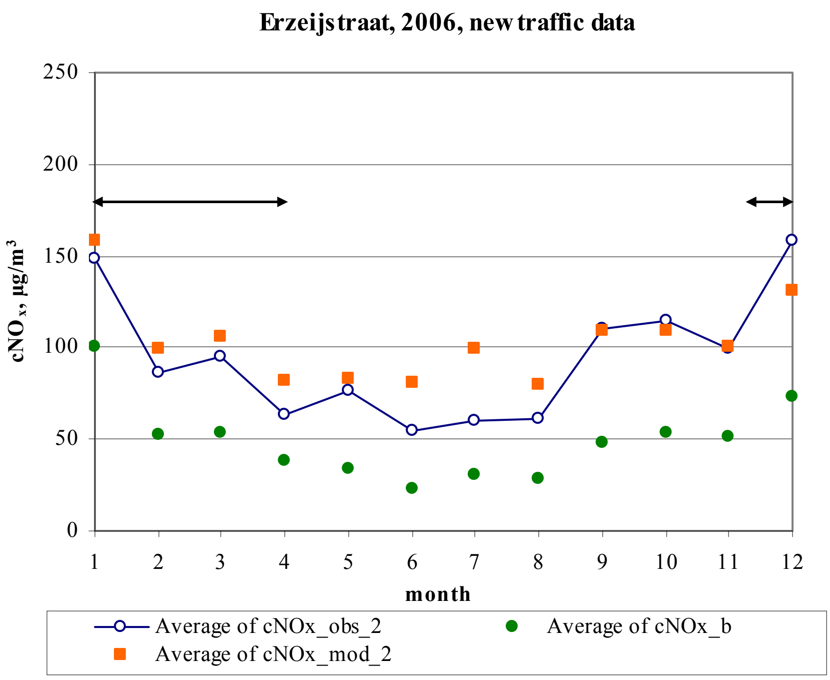


Figure 4.10C: Monthly average of total NO_x concentrations: Model versus observation for working days of 2006, using the meteorological data of Schiphol. The black arrows show the winter period.

4.3 Additional calculations performed for 2002: effect of various settings in OSPM

In previous calculations the street configuration was set at L1 = L2 = 75 m and W = 20 m. We have carried out a number of additional calculations aimed at investigating the effect of the street configuration on the modelled concentrations:

- The actual length of the Erzeijstraat (L2 = 150 m) was used in one calculation. (id est ignoring the recommendation of OSPM not to define a length > 75 m).
- The actual width of Erzeijstraat (W = 30 m) was used in a second calculation (id est without taking into account the fact that the monitoring station is located about 10 m away from the buildings).

Table 4.5: Effect of the street configuration on the average NO_x concentration and on the correlation between model and measurements. Data of 2002, new traffic data set and working days only.

	Standard	L2 = 150 m	W = 30 m
Data points	4674	4674	4674
Mean_bg	54.3	54.3	54.3
Mean_obs	110.7	110.7	110.7
Mean_mod	113.2	114.5	102.4
Bias	-2.4	-3.7	8.3
Sigma_obs	102.2	102.2	102.2
Sigma_mod	80.3	80.9	72.4
Cor_total_NO_x	0.88	0.88	0.88
MSSE	49.7	49.9	52.1
Cor_dNO_x	0.63	0.63	0.59

As expected, the modelled concentration decreases when the width of the street increases from 20 m to 30 m. Using the standard setting, the modelled values are 2.4 µg/m^3 higher than the measurements; with W = 30 m, the modelled values are 8.3 µg/m^3 lower than the measurements. However, despite this noticeable effect on the average concentration, the effect on the correlation (R) is negligible.
When the length of the street is increased from 75 m to 150 m, the average concentration increases slightly (1.3 µg/m^3). There is no observed effect on the correlation.

4.4 Calculations performed for 2006

The results obtained for 2006 are presented in Table 4.6. The calculations were performed using data obtained from the LML station at Cabauw as background values. The NO_x concentration recorded at the Cabauw measurement station was then multiplied by 1.44 to compensate for the (average) difference between this station and the Utrecht-Universiteitsbibliotheek station (see also Appendix 1). To test the effect of the meteorological data, we performed the calculations using meteorological data obtained from both the Cabauw and Schiphol locations.

The roughness of these locations is shown in Appendix 4. At first glance, there is no substantial difference between the roughness of the Cabauw and Schiphol locations. The roughness lengths of Schiphol and the Erzeijstraat are assumed to be 0.08 m and 1.5 m, respectively. If a roughness length of 0.1 m is assumed for Cabauw, the corresponding correction factors for these two locations are 0.705 (Schiphol) and 0.714 (Cabauw), which are more or less the same. We therefore applied a correction factor of 0.7 for both stations in this study.

The results presented in Table 4.6 show that both the bias and the correlation coefficient obtained for 2006 are worse than those for 2002 and 2003. When the Schiphol data were used, the modelled street increment is approximately 5 $\mu g/m^3$ lower than when the Cabauw data were used. This result can be explained by the higher wind speed at Schiphol relative to Cabauw (annual average wind speeds were 5 m/s and 4.3 m/s, respectively). Because the same correction factor was applied, these calculations were therefore performed with different wind speeds. The higher wind speed of the Schiphol data set results in an approximately 10% lower street increment.
For 2006, the results obtained using the meteorological data from Schiphol are slightly better than those obtained using the data from Cabauw.

Table 4.6: Comparison between modelled and measured NO_x concentration and the street increment Calculations were performed with the new traffic data set. The results are for working days only.

	2002_Schiphol	2003_Schiphol	2006_Schiphol	2006_Cabauw
Data points	4674	4778	5694	5651
Mean_bg	54.3	56.9	48.5	49.0
Mean_obs	110.7	118.4	92.8	93.9
Mean_mod	113.2	116.3	97.3	103.3
Bias	-2.4	2.1	-4.5	-9.4
Sigma_obs	102.2	127.8	107.1	109.4
Sigma_mod	80.3	86.8	77.2	79.1
Cor_total_NOx	0.88	0.88	0.77	0.76
MSSE	49.7	66.0	69.0	72.1
Cor_dNOx	0.63	0.58	0.44	0.42

Note: there is small difference between the observed values when meteorological data obtained from Cabauw and Schiphol, respectively, are used. This is due to the fact that data with wind direction 0 are eliminated in this study; therefore, the data sets used in the comparison are not completely the same for Cabauw and Schiphol.

4.5 Performance of the NO_2 calculation by OSPM

The performance of the OSPM model on the NO_2 calculation was determined for 2002 and 2003. Additional calculations performed were:

- NO_2 calculations according to the Dutch method;
- NO_2 calculations according to the OSPM method (see chapter 2.2), although with modified values of τ (residence time of pollutant in the street canyon). In these calculations, the τ values of OSPM were multiplied by a factor, and these modified τ values were used for calculating

NO_2. It is not possible to output the residence time τ in the current version of WinOSPM. We therefore calculated τ outside OSPM using the OSPM method (information from Ketzel, M.; e-mail on 29/05/2008), using H = 11 m. The calculation of τ is described in Appendix 5.

The default factors used by OSPM were used to convert micrograms per cubic metre to parts per billion, and vice versa. These are: 1 $\mu gNO_2/m^3$ = 0.5217 ppb NO_2, 1 $\mu gNO_x/m^3$ = 0.5217 ppb NO_x and 1 $\mu g\ O_3/m^3$ = 0.5 ppb O_3

The fraction of emitted NO_2 in the Netherlands has increased from about 6% in 2000 to 13% in 2006 (Mooibroek and Wesseling, 2008). The following fractions of emitted NO_2 were used in this study:

f_NO_2 Erzeijstraat	
2002	**8.7**
2003	**9.7**
2004	10.6
2005	11.5
2006	**12.5**

(Bold values: years used in the present study)

The results are presented in Tables 4.7 and 4.8.

Table 4.7: Comparison between modelled and measured NO_2 concentrations and NO_2 street increments in the Erzeijstraat using the new traffic data set. Reported values are based on the data for working days in 2002.

First column: Dutch method, using measured NO_x concentrations. The next three columns represent the results obtained using the Dutch method, the OSPM and the OSPM method using modified residence times, which were set at 1.5 times the τ values produced by OSPM. All concentrations are in $\mu g/m^3$.

	Dutch (measured NO_x)	Dutch	OSPM	OSPM_1.5Tau
Mean_bg	35.7	35.7	35.7	35.7
Mean_obs	47.7	47.7	47.7	47.7
Mean_mod	48.0	50.3	46.5	47.7
Bias	-0.3	-2.6	1.2	0.0
Sigma_obs	21.6	21.6	21.6	21.6
Sigma_mod	20.8	18.7	18.6	18.7
Cor_total_NO_2	0.97	0.85	0.87	0.87
Mean_dNO_2_obs	12.1	12.1	12.1	12.1
Mean_dNO_2_mod	12.4	14.7	10.8	12.1
Cor_dNO_2	0.91	0.62	0.63	0.64

Table 4.8: Comparison between modelled and measured NO_2 concentrations: data of 2003

	Dutch (measured NO_x)	Dutch	OSPM	OSPM_1.5Tau
Mean_bg	38.4	38.4	38.4	38.4
Mean_obs	52.9	52.9	52.9	52.9
Mean_mod	53.1	55.5	51.0	52.4
Bias	-0.2	-2.6	1.9	0.5
Sigma_obs	26.7	26.7	26.7	26.7
Sigma_mod	26.1	22.2	22.4	22.3
Cor_total_NO_2	0.97	0.86	0.89	0.89
Mean_dNO_2_obs	14.5	14.5	14.5	14.5
Mean_dNO_2_mod	14.8	17.1	12.7	14.1
Cor_dNO_2	0.90	0.58	0.59	0.59

Tables 4.7 and 4.8 show that the default OSPM results have a positive bias (measured values are higher than those of the model), which is about 12% of the street increment. The correlation between the modelled and measured concentration is good (R = 0.87 and 0.89, respectively), but that for the street increment is only moderate (R = 0.59 and 0.63, respectively). When the residence time produced by OSPM was multiplied by 1.5, the average concentrations became quite close to the measured values (bias close to 0). However, no effect on the correlation was observed.
The Dutch method results in negative bias (overestimation of the average concentration by about 5%) and a slightly worse correlation compared to that obtained using the OSPM method.

A good correlation was obtained between the calculated and the measured NO_2 concentration when the measured NO_x concentrations were used in the calculation of NO_2. This result indicates that the deviation in the modelled NO_2 concentration is mainly caused by the deviation in the modelled NO_x concentration.

The results for 2002 are presented in the Figures 4.11– 4.14.

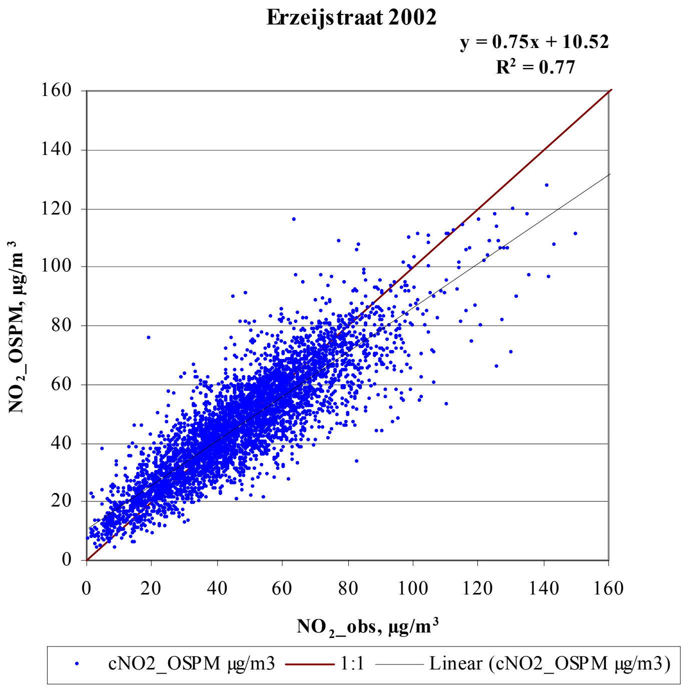


Figure 4.11: Comparison between modelled and measured NO_2 concentrations in 2002 using the new traffic data set. Only data of working days were used.

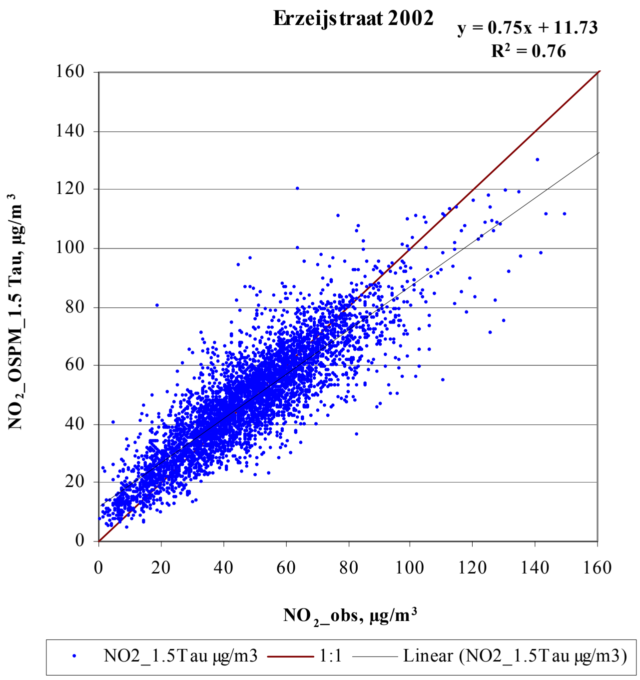


Figure 4.12: Performance of the OSPM method when the residence time used in the NO_2 calculation was set at 1.5*Tau.

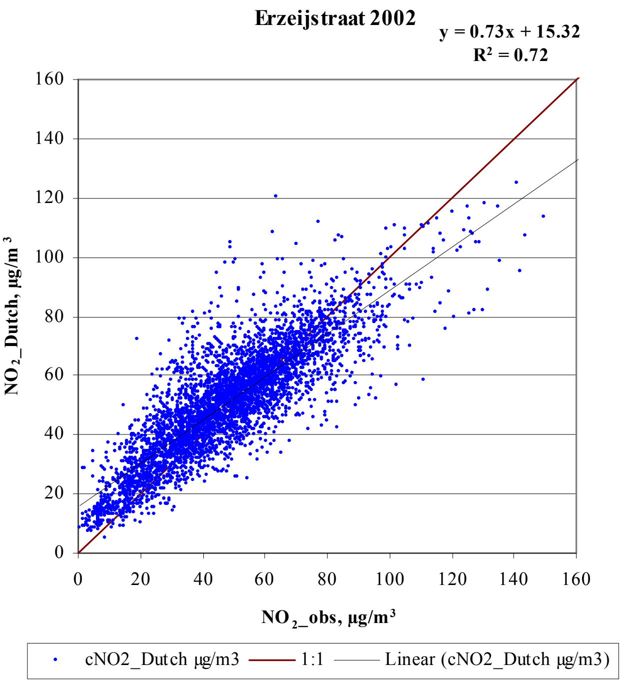


Figure 4.13: Comparison between the Dutch method and measurements.

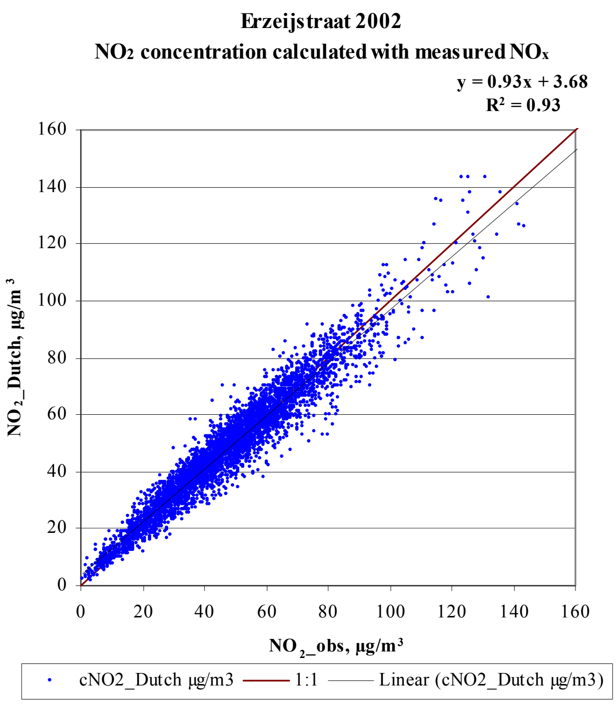


Figure 4.14: Results obtained with the Dutch method when measured NO_x concentration was used. Using the measured NO_x concentration for the calculation of NO_2 produced a very good correlation between the calculated and measured NO_2 concentrations.

5 Discussion

5.1 Quality of used input data

For the OSPM model to perform well, it is essential that the input data (traffic flow, emission data and meteorological data) are accurate. Consequently, the lack of a meteorological station at the experimental site is likely to be an important factor contributing to the observed differences between the modelled results obtained in this study and the measured data. OSPM has been tested extensively in Denmark, where it has proven to be a highly accurate and reliable model for estimating pollution emissions from traffic. Most of the Danish tests were performed using data obtained in Jagtvej, where the meteorological data were recorded on two meteorological masts located at the location itself. It is not yet possible to estimate how much the model results will be improved when detailed local meteorological data are available. The most relevant factor in this context is the wind speed as the street increment is roughly inversely proportional to the wind speed.

Another factor that affects the performance of OSPM is the use of background concentrations measured at a location other than the monitoring site (Dutch situation). Although the yearly average concentrations measured at the Utrecht-Universiteitsbibliotheek station were lower than those obtained for the Erzeijstraat, the hourly concentrations at the Utrecht-Universiteitsbibliotheek can occasionally be higher than those recorded in the Erzeijstraat. As such, this variation also accounts for the discrepancy between the model results and the measurements.

5.2 Erzeijstraat versus Jagtvej

In addition to the better quality of the input data of Jagtvej, as mentioned above, there are a number of other differences between the Jagtvej and Erzeijstraat locations:
The traffic density is much higher in Jagtvej. In 1994, when the model was being tested using the Jagtvej data, the traffic flow in Jagtvej was 22000 vehicles/day; in contrast, in 2006, the traffic flow in Erzeijstraat was only about 11000 vehicles/day. If yearly increases in traffic flow are taken into account, the traffic intensity in Jagtvej is about threefold greater than that of Erzeijstraat (the width of these two streets is comparable).
Furthermore, Jagtvej is flanked on both sides with high buildings (18 m compared to approximately 7–11 m along the Erzeijstraat), which results in a relatively large street increment in Jagtvej compared to that in the Erzeijstraat. In Jagtvej, a large fraction of the total NO_x concentration is street increment (information from M. Ketzel), whereas this fraction is substantially smaller in the Erzeijstraat. Small street increments may lead to a poorer correlation between the modelled and observed values (because the observed street increment is the difference between two relatively large values).

5.3 NO_2 calculation

The NO_2 calculations with modified τ show that the modelled values are improved when a larger τ is used for the NO_2 calculation. The use of this modification does not necessarily mean that the residence time of the pollutants in Erzeijstraat is longer than that modelled by the OSPM; rather, it may imply that the NO_2 reaction kinetic as used in the model OSPM does not represent the Dutch situation very well. This result is not surprising as the reaction constants used by OSPM were determined experimentally in Denmark where the circumstances may different from those found in the Netherlands.

6 Conclusions

The study reported here shows that:

- A good correlation between modelled and measured total NO_x concentrations (R = 0.89) can be obtained with the OSPM. The correlation between the modelled and measured street increments is moderate (R = 0.64). The lack of accurate meteorological data and the contribution from the highways and intersections located south of the Erzeijstraat are probably the main factors contributing to the latter.
- The new set of traffic data, which is based on traffic counts performed by the city of Utrecht in 2006, produces much better results for working days than the old set of traffic data (bias of ± 2% for total NO_x concentrations compared to a bias of up to –10%, respectively). The new data set assumes that traffic intensity during the weekends is the same as that on working days; this assumption is clearly not valid. Therefore, when data on the weekends are included in the model, the results obtained with the new set of traffic data become worse.
- The OSPM seems to be robust. A small change in the street configuration setting does not result in significant changes in the result
- The correlation between the modelled and measured NO_2 concentrations is mainly determined by the quality of the modelled NO_x.
- The modelled annual NO_2 concentration has a bias of less than 5% of the measured total NO_2 concentration, which is comparable to the performance of the CAR II model (Wesseling et al., 2007). The difference between modelled and measured average concentrations can be reduced to almost zero when the τ values produced by OSPM are multiplied by 1.5 before they are used for the NO_2 calculations. This results in a larger NO_x/NO_2 conversion.
- The Dutch method for calculating the NO_x/NO_2 conversion gives slightly worse results than the OSPM method.

Based on these preliminary results, we recommend that the OSPM be explored in more detail. To achieve this aim, however, better input data are necessary.

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User's guide to OSPM, version 2003

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Appendix 1 Comparison between Cabauw and Utrecht-Universiteitsbibliotheek

	NO_2			NO_x			O_3		
	Cabauw	UBIB	UBIB/Cabauw	Cabauw	UBIB	UBIB/Cabauw	Cabauw	UBIB	UBIB/Cabauw
1997	30.8	41.2	1.34	50.6	70.5	1.39	33.1	29.7	0.90
1998	26.5	38.1	1.44	38.9	58.6	1.51	35.0	28.2	0.80
1999	25.9	38.5	1.49	36.1	56.3	1.56	39.6	35.2	0.89
2000	23.1	31.9	1.38	35.8	52.0	1.45	34.5	29.5	0.85
2001	23.7	34.2	1.44	38.3	56.7	1.48	38.5	30.9	0.80
2002	24.5	34.3	1.40	39.6	52.6	1.33	37.4	34.2	0.91
2003	27.1	36.9	1.36	41.0	56.2	1.37	37.9	39.4	1.04
average			**1.41**			**1.44**			**0.89**

UBIB: Utrecht-Universiteitsbibliotheek

Appendix 2 Starting points of old traffic data

The old traffic data are based on the data of 2003 and have the following starting points :
1) The average traffic volume per week day is 9800 vehicles/ weekday, of which 9408 are passenger cars (PA), 196 light trucks and 196 heavy trucks (96%, 2%, 2%, respectively).

2) On working days, traffic is more intense than the average traffic flow.
The relationship between the number of trucks per working day ($Trucks_{workingday}$) and the average number of trucks per weekday ($Trucks_{weekday}$) is:
$Trucks_{weekday} = 0.8 * Trucks_{workingday}$ (1)
because $Trucks_{weekday} = 2/7*Trucks_{weekend} + 5/7*Trucks_{working\ day}$ (2)

The combination of (1) and (2) gives:
$2/7*Trucks_{weekend} + 5/7*Trucks_{working\ day} = 0.8* Trucks_{working\ day}$
id est: $Trucks_{weekend} = Trucks_{working\ day} (0.8-5/7)*7/2 = 0.3* Trucks_{working\ day}$ (3)

Because the average number of trucks per weekday ($Trucks_{weekday}$) is 196, we have:
$196 = Trucks_{weekday} =2/7*Trucks_{weekend} + 5/7*Trucks_{working\ day}$
$=2/7*0.3* Trucks_{working\ day} + 5/7*Trucks_{working\ day}$
$=0.8* Trucks_{working\ day}$,
giving the number of trucks per working day: $Trucks_{working\ day} = 196/0.8 = 245$ vehicles/day

The number of trucks per day during weekend can be calculated using (3):
$Trucks_{weekend} = 0.3*Trucks_{working\ day} = 0.3*245 = 74$ vehicles/day

For passenger cars, the relationship between the number of vehicles per working day ($PA_{workingday}$) and the average number of passenger cars per weekday ($PA_{weekday}$) is:
$PA_{weekday} = 0.92*PA_{workingday}$ (4)
The distribution of passenger cars over the week can be calculated in the same way, giving:
$PA_{workingday} = 10226$ vehicles/day and
$PA_{weekend} = 7363$ vehicles/day

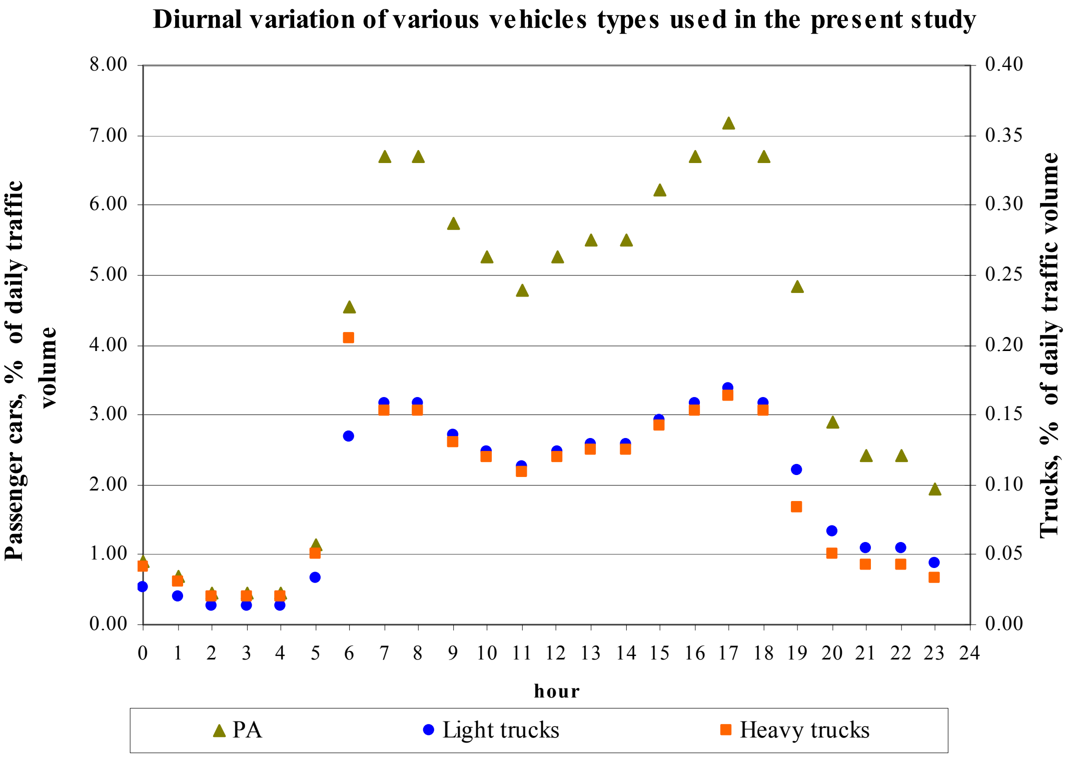

Figure A.2.1: Diurnal variation of various vehicles types used in the present study.

Appendix 3 Calculation of emission

The example below demonstrates how the emission input of OSPM was calculated in this study.
Diurnal variation of traffic in Erzeijstraat in 2006 (new data set):

	Passenger cars vehicles/days	Light trucks vehicles/days	Heavy trucks vehicles/days
1	86	2.5	3.9
2	64	1.9	2.9
3	43	1.3	1.9
4	43	1.3	1.9
5	43	1.3	1.9
6	107	3.2	4.8
7	430	12.7	19.3
8	651	18.0	8.0
9	768	22.0	10.0
10	639	21.0	3.0
11	553	26.0	9.0
12	591	20.0	7.0
13	630	26.0	0.0
14	643	23.0	7.0
15	709	33.0	13.0
16	759	24.0	4.0
17	814	21.0	6.0
18	743	16.0	2.0
19	747	13.0	0.0
20	458	10.4	7.9
21	275	6.2	4.7
22	229	5.2	4.0
23	229	5.2	4.0
24	183	4.2	3.2

The emission factors for 2006 of these vehicles types are assumed as follows:

Passenger cars: 0.57 g/km
Light trucks: 10.7 g/km
Heavy trucks: 13.5 g/km

Taking the “bomenfactor” of 1.5 into account, the emission in the first hour is:
1.5*(86*0.57+2.5*10.7+3.9*13.5) = 192.6 g/km/h, id est 192.6*1000/3600 = 53.4 µg/m/s
Calculation in the same way results in the following diurnal variation of emission, which is the input for OSPM.

hour	Emission µg/m/s
1	53.4
2	40.1
3	26.7
4	26.7
5	26.7
6	66.8
7	267.2
8	279.9
9	336.7
10	262.3
11	297.9
12	268.9
13	265.5
14	294.6
15	388.6
16	309.8
17	320.7
18	259.0
19	235.4
20	199.7
21	119.8
22	99.8
23	99.8
24	79.9
average	193

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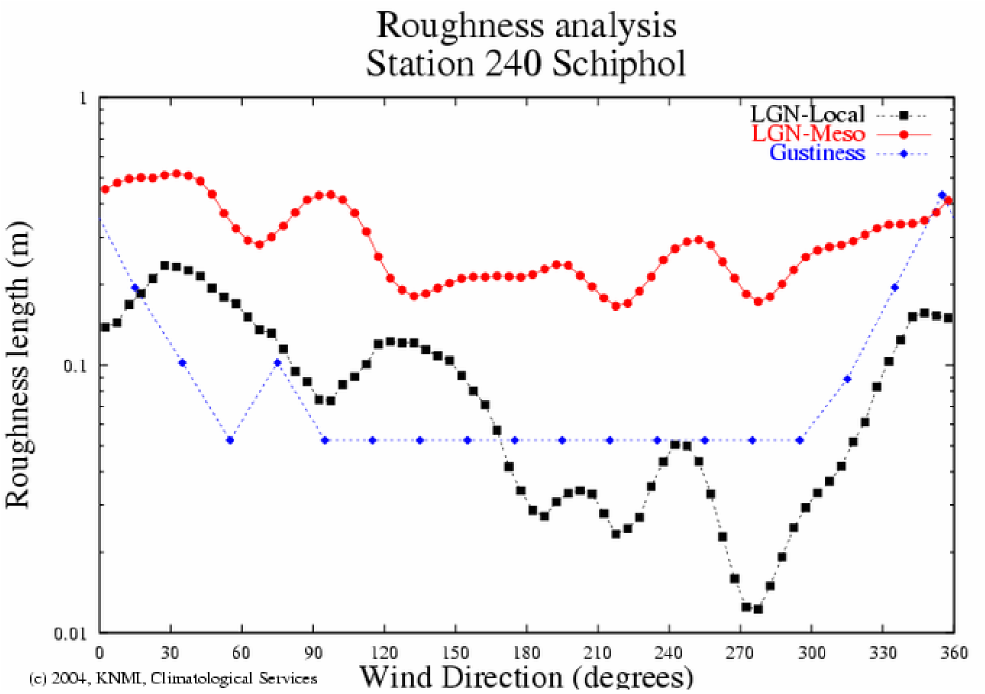
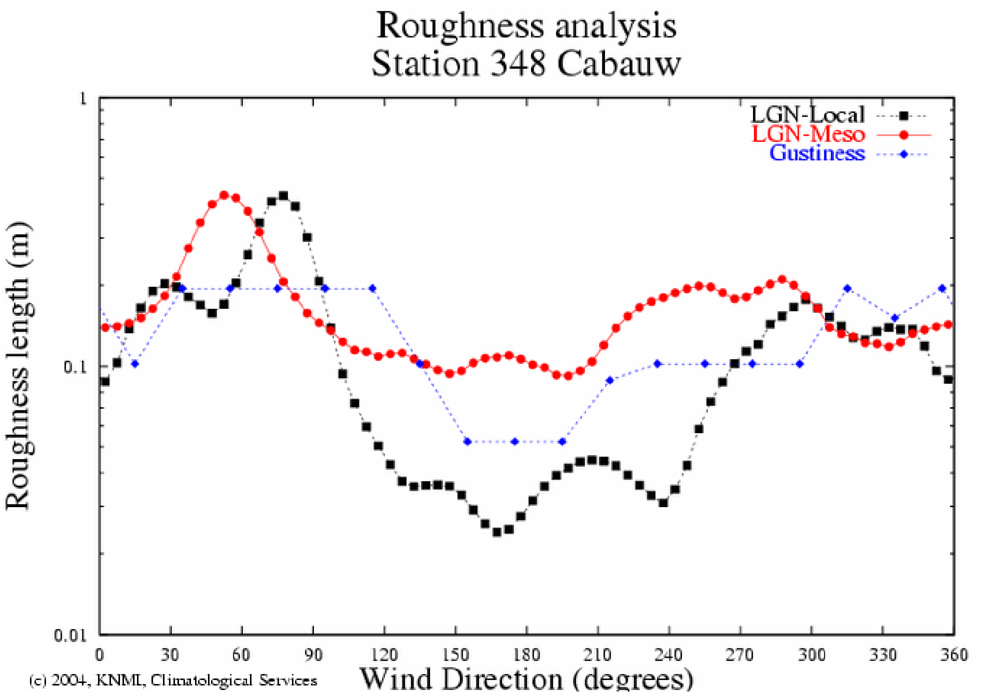
Appendix 4 Roughness of Schiphol and Cabauw





Source: KNMI, Hydra project

Appendix 5 Calculation of Tau according to OSPM

The residence time τ is calculated in OSPM as follows:

$$\tau = max(H,Ho)/s\_wt$$

where H is the height of the building in the street canyon and Ho is a minimum height

$$Ho = 3 - u\_mast/(5 + u\_mast)$$

With:
u_mast : the wind speed over the top of the canyon, given in the output of OSPM;
s_wt: the "exchange velocity" at the top of the street canyon, given by:

$$s\_wt = Sqrt((0.1*u)**2 + 0.4*s\_wo**2),$$

with s_wo being the traffic produced turbulence.

s_wt and s_wo can be given by OSPM in hourly output files, which are called s_w_Roof and s_w_TPT, respectively.

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