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Modelling of Vehicle Induced Turbulence in Air Pollution Studies for Streets

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ABSTRACT: Vehicle-induced turbulence can be an important factor of pollutant dispersion in urban areas, especially under conditions of low wind speeds which are typical for street canyons. An experimental concept (Plate, 1982) for modelling the effects of vehicle induced turbulence was applied in the present study. The movement of vehicles was simulated in a boundary - layer wind tunnel by small metal plates mounted on two belts moving along a modelled street canyon. The scaling factor was based on the ratio of turbulence production by cars to that by wind flow. The traffic was represented by the velocity, density, frontal area and drag coefficients of the vehicles. The vehicle velocity and traffic density were varied, and the influence of the vehicle-induced turbulence on concentration patterns at the canyon walls was studied. It was found that the concentration decreases with an increasing ratio of vehicle to wind velocity and with an increase of traffic density. A dimensionless combination of vehicle to wind velocity ratio and density factor was proved to be a universal parameter describing the dependence of the concentration on vehicle-induced turbulence.

The wind-tunnel measurements were compared with predictions by the numerical Operational Street Pollution Model (OSPM, Hertel and Berkowicz, 1989). Differences between the wind-tunnel and numerical results regarding effects of vehicle-induced turbulence are discussed.

The comparison revealed general agreement between wind-tunnel and numerical data. Turbulence and concentration measurements in a street canyon in Copenhagen have been additionally employed for analysis of the model results.

Keywords: Traffic pollution, street canyon, vehicle induced turbulence, wind-tunnel modelling

1 Introduction

During the last years, results of several wind-tunnel studies concerning the dispersion of vehicle exhaust gases in urban areas were published in the literature (see e.g. Pavageau et al., 1997, Kastner-Klein et al., 1997 and Kastner-Klein and Plate, 1998). One of the open questions is the influence of vehicle induced turbulence. An experimental concept for simulating the effects of vehicle induced turbulence in a wind tunnel was proposed by Plate (1982). This concept was applied in the present study. In a wind tunnel city traffic was simulated by metal plates mounted on belts moving along the street in a street - canyon model. Parameters characterising traffic flow were varied. Results of concentration measurements at the building walls are presented. Principal changes of the concentration patterns under the influence of moving traffic are demonstrated and modelling scaling parameters are tested. The results are compared with a numerical air pollution model which takes into account the effects of vehicle induced turbulence.

2 Wind-tunnel modelling

Experiments were performed in the boundary-layer wind tunnel of the Institute of Hydromechanics (formerly Institute of Hydrology and Water Resources Planning, IHW), University of Karlsruhe. A turbulent boundary layer is formed with aid of vortex generators installed at the entrance of the test section and roughness elements on the test-section floor. The parameters of the velocity profile and the turbulence intensity in the generated boundary layer are set similar to those in the atmospheric boundary layer according to the methodology given in Plate (1982). More details on the experiments performed are given in Rastetter (1997).

Special attention was paid to the modelling of moving traffic. It was simulated by means of two moving belts with small rectangular plates, which generate turbulence on a characteristic scale related to the plate size. Plate (1982) based the modelling criterion for vehicle induced turbulence on the condition that the ratio of energy production P_T caused by moving traffic to the energy production P_W caused by the wind should be the same in the wind-tunnel model and in the prototype:

$$\frac{P_{Tm}}{P_{Wm}} = \frac{P_{Tn}}{P_{Wn}}, \qquad (1)$$

where the index *m* stands for model, and the index *n* for full size conditions. The energy production per unit street length P_T in a city street canyon with the height *H* and width *B* is given by

$$P_T = \frac{\rho \cdot C_{DT} \cdot A_T \cdot n_T \cdot v^3}{B \cdot H}, \qquad (2)$$

where ρ is the density of air. C_{DT} is the drag coefficient, A_T the frontal area, and v the average velocity of the vehicles. n_T is the number of vehicles per unit length.

The value of P_W can be estimated by:

$$P_W = \tau \frac{\Delta u}{\Delta z} \approx \frac{\rho \cdot u_*^2}{H} u(H) \propto \frac{\rho \cdot c_{fh} \cdot u^3}{H}, \qquad (3)$$

where the shear velocity $u_* = \sqrt{c_{fh}} \cdot u$ has been expressed through the friction coefficient c_{fh} and the wind velocity *u* at boundary-layer top. Consequently, Eq. 1 can be formulated as

$$\underbrace{\frac{C_{DTm} \cdot A_{Tm} \cdot n_{Tm}}{c_{fhm} \cdot B_m}}_{a_m} \cdot \frac{v_m^3}{u_m^3} = \underbrace{\frac{C_{DTn} \cdot A_{Tn} \cdot n_{Tn}}{c_{fhn} \cdot B_n}}_{a_n} \cdot \frac{v_n^3}{u_n^3} \tag{4}$$

In order to test the validity of Eq. 4, measurements of flow and concentration fields in an idealised street canyon were conducted. The experimental set-up is shown in Fig. 1. The geometrical parameters of the buildings were as follows: height *H*=12 cm, length *L*=120 cm and width *W*=12 cm. The width *B* of the street was 12 cm. The model scale *M* was approximately $1{:}150$. The approach flow was perpendicular to the canyon axis. Vehicle exhaust gases were simulated by two line sources designed as proposed by Meroney et al. (1996). The metal plates simulating vehicles are also seen in Fig. 1. The velocity and direction of motion could be adjusted independently for each belt. Both one-way and two-way traffic situations have been studied. The metal plates were designed to fit the requirements of Eq. 4. The product $C_{DTm} \cdot A_{Tm}$ was adjusted to be $\left(C_{DTn} \cdot A_{Tn}\right) / M^2$. For rectangular plates the drag coefficient C_{DTm} is 1.15. Taking into account typical values of drag coefficients and frontal areas of cars and heavy vehicles in nature we estimated: $C_{DTn} \cdot A_{Tn} \approx 1$. The frontal area of the metals plates was calculated as $A_{Tm} = \frac{C_{DTn} \cdot A_{Tn}}{M^2 \cdot C_{DTm}} \approx \frac{1}{150^2 \cdot 1.15} \approx 40 \text{ mm}^2$. We assume the friction coefficient c_{fh} to have the same values in the model and in the nature. Summarising above relationships and taking into account $B_m = B_n / M$ Eq. (4) can be rewritten as

$$\frac{\left(v_n / u_n\right)^3}{\left(v_m / u_m\right)^3} = \frac{a_m}{a_n} = \frac{n_{tm}}{n_{tn} \cdot M} = a\,. \tag{5}$$

The effect of variations of the traffic density, the vehicle velocity v and the wind velocity u were studied during the experiments. The variations of the traffic density in the model were described by variations of *a*. If *a* equals one, the traffic density in the model n_{tm} was 10 m^{-1}, which corresponds to 0.067 m^{-1} in the nature. Finally the modelling criterion can be expressed as

$$\left(\frac{v^3}{u^3}\right)_n = a \cdot \left(\frac{v^3}{u^3}\right)_m \quad \Leftrightarrow \quad \left(\frac{v}{u}\right)_n = a^{1/3} \cdot \left(\frac{v}{u}\right)_m . \qquad (6)$$

Within the first part of the measurement program mean concentrations at the building walls were measured. A tracer gas (SF_6) was released by line sources with a constant emission rate E_m per unit length of the line source. The results can be presented as normalised concentrations:

$$c^* = \frac{c_m}{E_m} \cdot u_{m,ref} \cdot L_m , \qquad (7)$$

where c_m is the measured tracer-gas concentration, $u_{m,ref}$ is the reference velocity, and L_m is a characteristic length scale (in our case the building height).

Concentration distributions at the leeward canyon wall (in Fig. 2) demonstrate the difference of pollutant patterns for two-way and one-way traffic situations. The concentration fields are represented by isolines of normalised concentrations (Eq. 7). The approach flow velocity at the height equivalent to 10 m in nature, $u_{10} \approx 4.5$ m/s, was used as reference velocity $u_{m,ref}$. The wind velocity *u* at the height of the boundary layer was 7 m/s.

The results for the reference case (without traffic), are shown in the upper plot of Fig. 2. In this case the flow characteristics are determined by the interaction of a canyon vortex, typical for a street canyon with a perpendicular approach flow, and vorticity zones near the building edges. The pollutants are transported to the leeward canyon wall where a three-dimensional, symmetric concentration pattern was observed. The maximum concentration was found in the canyon centre near the ground. For the two-way traffic situation, in which both belts were moving in opposite directions with a velocity of 30 km/h each, similar results were found. The moving traffic did not essentially affect the concentration pattern, which was still approximately symmetric with respect to the canyon centre. Nevertheless, the maximum concentration was lower than in the reference case. In the case of a one-way traffic situation, with both belts moving in the same direction, the concentration field changes fundamentally. The moving traffic leads to a pronounced transport of pollutants along the canyon axis. The concentration pattern at the leeward canyon wall is no more symmetric and the point of maximum concentration is shifted to the canyon end.

The discussed results reveal the essential influence of moving traffic on concentration distributions in street canyons. The analysis of flow-field measurements with a LDA system confirmed that two-way traffic has no influence on the mean flow characteristics whereas one-way traffic can cause a significant flow along the canyon with mean velocities of up to $0.15 \cdot u$. In the second part of the wind-tunnel study we focused on two-way traffic situations and studied the influence of traffic-parameter variations on the concentrations in the canyon centre.

Several values of the wind velocity *u*, of the vehicle velocity *v* and of the factor *a* were tested (Rastetter, 1997). According to the modelling law expressed by Eq. 6, different combinations of the parameters *u* and *v* with the ratio *v/u* = constant, at a constant traffic density should lead to the same concentration values. This prediction was tested with respect to vertical concentration profiles measured in the canyon centre for four different combinations of *u* and *v* with the constant ratio *v/u*=1.7. Results are shown in Fig. 3.

Finally the generalised scaling combining the velocity ratio *v/u* and the traffic density (Eq. 6) was tested. In Fig. 4 the concentration ratio (concentration related to the concentration in the reference case without traffic) at the reference point in the canyon centre near the ground is shown as a function of the velocity ratio for three different traffic densities, represented by the factor *a*. In the left diagram the concentration ratio is plotted against the velocity ratio *v/u.* The concentration at the reference point decreases with an increasing velocity ratio. The effect is stronger for higher traffic densities. The three series with different traffic densities lead to three separate curves. In the right diagram, the concentration ratio is plotted against the combined ratio $\sqrt[3]{a} \cdot {}^{v}\!/_{u}$. This scaling allows to summarise the results for different traffic densities. All results collapse in one curve. This supports the idea that Eq. 6 provides appropriate scaling for the wind-tunnel data. Furthermore, the results show that the concentration decreases linearly with $\sqrt[3]{a} \cdot {}^{v}\!/_{u}$:

$$c_{vt}^{*}(a,u,v) = c_0^{*}\left(1 - \gamma \cdot a^{1/3}\frac{v}{u}\right), \qquad (8)$$

where c_0^{*} is the normalised concentration for the reference case without moving vehicles (v=0). A linear regression for the experimental data is plotted in Fig. 4. The value of the gradient γ is given in the diagram. Obviously, the linear reduction can be valid only up to a certain upper limit, which should be figured out.

3 Modelling traffic induced turbulence in the Operational Street Pollution Model (OSPM)

The Operational Street Pollution Model (OSPM) is described in Berkowicz et al. (1997). Concentrations of 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. OSPM makes use of a very simplified parameterisation of flow and dispersion conditions in a street canyon. This parameterisation was deduced from extensive analysis of experimental data and model tests. Results of these tests were used to improve the model performance, especially with regard to different street configurations and a variety of meteorological conditions.

The plume model is based on the assumption that the vertical dispersion depends linearly on the distance from the source. The dispersion parameter σ_z is modelled assuming that the dispersion of the plume is solely governed by mechanical turbulence. The mechanical turbulence σ_w is assumed to be generated by two mechanisms: by the wind (σ_{ww}) and by the traffic (σ_{wt}) in the street.

$$\sigma_w = \left(\sigma_{ww}^2 + \sigma_{wt}^2\right)^{1/2} = \left[(\alpha u_b)^2 + \sigma_{wt}^2\right]^{1/2}, \qquad (9)$$

where u_b is the street level wind speed, α is a constant and σ_{wt} is the traffic-induced turbulence. The proportionality constant α is given a value of 0.1, which corresponds to typical levels of mechanically induced turbulence.

The box model is based on the assumption that the recirculating part of pollution in the street results in a homogeneous distribution. The concentrations are calculated assuming that the ventilation of the "box" is governed by the turbulent exchange with the background air and the exchange velocity is given by an expression similar to Eq. (9), but with u_b replaced by the roof-level wind speed and the traffic turbulence reduced to 40% of the street-level value. At low wind speeds, the plume and the box model merge to one expression describing the non-recirculating regime. In this case the street level concentrations are roughly given by

$$C \propto \frac{Q}{\sigma_w \cdot B}, \qquad (10)$$

where Q is the emission strength (per unit length) and B is the street-canyon width.

A simple approach for modelling the traffic induced turbulence was introduced by Hertel and Berkowicz (1989). Vehicles in the street are considered as moving flow distortion elements creating additional turbulence in the air:

$$\sigma_{wt}^2 = b^2 v^2 D^2, \qquad (11)$$

with *v* to be the average vehicle speed, *D* the density of the moving elements (cars) and *b* an empirical constant related to the aerodynamic drag coefficient. The density of the traffic in the canyon is given by the relative area occupied by the moving vehicles with respect to the canyon area

$$D = \frac{N_{veh} \cdot S^2}{v \cdot B}, \tag{12}$$

with N_{veh} the number of cars passing the street per time unit, S^2 the horizontal area occupied by a single car and *B* the width of the street. N_{veh} can be expressed as $N_{veh} = n_t \cdot v$, where n_t is the number of cars per unit length. Finally,

$$\sigma_{wt} = b\left(\frac{N_{veh} \cdot v \cdot S^2}{B}\right)^{1/2} = b\left(\frac{n_t \cdot v^2 \cdot S^2}{B}\right)^{1/2}. \tag{13}$$

The scaling criterion for the traffic-induced turbulence can be expressed by the ratio of turbulence intensities generated by the traffic and the wind:

$$\frac{\sigma_{wt}^2}{\sigma_{ww}^2} \propto S^2 \cdot n_t \cdot \frac{v^2}{u^2}. \tag{14}$$

The main difference between Eq. (14) and Eq. (4) proposed by Plate (1982), is that a square-root dependence on the traffic density is predicted instead of the 1/3-dependence in Plate (1982). Furthermore, the horizontal area S^2 of a vehicle in relation to the canyon width *B* is taken into account, whereas Plate (1982) based Eq. (4) on the frontal area A_t of the moving vehicles.

Concentration ratios at the reference point calculated with OSPM as a function of the corrected velocity ratio $\sqrt[3]{a} \cdot v / u$ are presented in Fig. 5. The situation modelled is comparable to the situation studied in the wind tunnel. Variations of the traffic density are expressed by the factor *a*, where *a*=1 corresponds to $n_t = 0.067$ m^{-1}. The linear approximation of the wind-tunnel data $c^*_{vt} / c^*_0 = 1 - 0.18\left(\sqrt[3]{a} \cdot v / u\right)$, shown in Fig. 4, is plotted as dashed line. The calculated results generally agree well with the measurement data. Nevertheless the calculated curves for three different traffic densities do not collapse. It corresponds to the different scaling criteria in OSPM with a square-root dependence on traffic density as prescribed by Eq. (14). Furthermore OSPM results show a different curvature. Especially for high velocity ratios and bigger traffic densities the results do not fit a linear curve. It is obvious that in the nature a linear concentration decrease can be valid only up to a certain upper limit. It could not be derived from the wind-tunnel data because the biggest value of $\sqrt[3]{a} \cdot v / u$ studied, was about 3.

4 Field measurements and OSPM results

Field measurements of the traffic-induced turbulence are not easily accessible because there is no straight-forward way to separate this turbulence from other forms of turbulence and the results will always be a matter of interpretation. Two methods can be distinguished: a *direct method* based on turbulence measurements and an *indirect method* based on examination of the effect the turbulence has on the pollution in a street.

As a part of the project on Air Pollution from Traffic in Urban Areas, conducted with support from the Danish National Environmental Research Programme 1992-1996, a meteorological measuring station was established in the street Jagtvej, Copenhagen, close to the permanent pollution sampling station. The purpose of the meteorological station was to create a database that could be used to validate, calibrate or extend models in use to describe the flow and dispersion of pollutants in street canyons (Nielsen et al., 1995). Wind and turbulence parameters were measured on two masts placed on opposite sides of the street. The measurements were conducted continuously from May 1994 to May 1995. Turbulence measurements from a sonic anemometer placed at a height of 6 m are selected for the examination of the effect of traffic on the turbulence in the street.

Observations with the free wind speed u < 1.5m/s (measured on a nearby roof mast) are selected in order to minimise the effect of the wind created turbulence. The diurnal variation of the vertical velocity turbulence is shown in Fig. 6 for working days and Saturdays. Additionally, the traffic created turbulence calculated by OSPM, dependent only on the traffic flow, is shown by continuous lines. It is seen that the turbulence in the street has an evident diurnal variation which follows the traffic pattern quite well. Even the difference in the traffic pattern for working days and weekends is more or less reproduced in the diurnal variation of turbulence. The night time values of σ_w are, however, somewhat higher than one would expect from the traffic induced turbulence only. Some other mechanisms must be of importance here too, as e.g. wind circulation induced by temperature differences across the street (Sini et al., 1996) or other local wind effects.

In order to examine the effect of the traffic created turbulence on street pollution levels, measurements of NO_x from the permanent monitoring station in Jagtvej are used. Again, observations with the free wind speed u < 1.5m/s are used. Additionally, only the easterly wind sector with wind directions within a 30 degree variance normal to the street is selected. For this wind sector the monitoring station is on the leeward side. The background contribution, which is measured on the nearby roof station is subtracted from the measured concentrations. This yields the contribution from the street traffic. The concentrations are normalised using the following expression:

$$\overline{C} = C \frac{u \cdot B}{Q} \qquad (15)$$

The dependence of the normalised concentrations on σ_{wt} / u is shown in Fig. 7. With $\sigma_{wt} / u \propto \sqrt{n_t} \cdot v / u$, see Eq. (13), variations of σ_{wt} / u correspond to variations of the velocity ratio and the traffic density. The decrease of normalised concentrations with increasing σ_{wt} / u is evident and the tendency is similar to that predicted by OSPM. The scatter in the experimental data is, however, very large, mainly due to uncertainties in the estimation of traffic emissions as well as the traffic intensity.

5 Conclusions

Vehicle induced turbulence can be an important factor of pollutant dispersion in streets. Wind-tunnel experiments have demonstrated that significant modification of flow and dispersion conditions can be expected due to the vehicle movement. Field measurements support this finding. A simple scaling parameter derived from the condition of similarity between the turbulent energy production in the wind tunnel and in the nature is proved to be representative for the observed effect of traffic induced turbulence. The wind-tunnel measurements and results from the OSPM model are in good general agreement. Concentration measurements in a real site show the same qualitative tendency as OSPM predictions. Their precise comparison is difficult due to the uncertainty in traffic and emission data.

Acknowledgements

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(TRAPOS, http://www.dmu.dk/AtmosphericEnvironment/trapos/index.htm).

REFERENCES

Berkowicz, R., Hertel, O., Sørensen, N.N. and Michelsen, J.A., (1997), **'**Modelling air pollution from traffic in urban areas'. In *Flow and Dispersion Through Groups of Obstacles*, R.J. Perkins and S.E. Belcher (editors), Clarendon Press, Oxford, pp. 121-141.

Hertel, O. and Berkowicz, R., (1989)**,** 'Modelling pollution from traffic in a street canyon. Evaluation of data and model development', *DMU Luft A-129*, 77pp.

Hertel, O and Berkowicz, R., (1989)**, '**Operational Street Pollution Model (OSPM). Evaluation of model on data from St. Olavs street in Oslo', *DMU Luft A-135*, 34pp.

Kastner-Klein, P., Fedorovich, E. and Plate, E.J., (1997)**,** 'Gaseous pollutant dispersion around urban-canopy elements: wind tunnel case studies', *Int. J. Environment and Pollution*, Vol. 8, pp.727-737.

Kastner-Klein, P. and Plate, E.J., (1998)**, '**Wind-tunnel study of concentration fields in street canyons'. Accepted in *Journal of Atmospheric Environment*.

Meroney, R.N., Pavageau, M., Rafailidis, S. and Schatzmann, M., (1996), **'**Study of line source characteristics for 2-D physical modelling of pollutant dispersion in street canyons', *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 62, pp. 37-65.

Nielsen, M., Lund, S.W. and Larsen, S.E., (1995), 'SMP-Air Pollution from Traffic in Urban Areas. Wind Measurements from Jagtvej. (Mid-term Report)', *Risø-I-825(EN)*, Risø National Laboratory, Roskilde, Denmark.

Pavageau, M., Rafailidis, S. and Schatzmann, M., (1997), 'A comprehensive experimental databank for the verification of urban car emission dispersion models'. *Int. J. Environment and Pollution*, Vol. 8, pp. 738-746.

Plate, E.J., (1982), 'Windkanalmodellierung von Ausbreitungsvorgängen in Stadtgebieten'. Kolloquiumsbericht *Abgasbelastungen durch den Straßenverkehr*, Verlag TÜV Rheinland.

Rastetter, A., (1997), 'Experimentelle Untersuchung in einem atmosphärischen Grenzschicht-windkanal über den Einfluß von Kfz - erzeugter Turbulenz auf die Schadstoffausbreitung in Straßenschluchten'. Diploma thesis, Institute of Hydrology and Water Resources Planning, University of Karlsruhe.

Sini, J.F., Anquetin, S. and Mestayer, P.G., (1996), 'Pollutant dispersion and thermal effects in urban street canyons', *Atmospheric Environment*, Vol. 30, pp. 2659-2677.

FIGURE CAPTIONS

Fig. 1: Experimental set-up: street-canyon model in the wind tunnel.

Fig. 2: Concentration patterns at the leeward canyon wall for different traffic conditions.

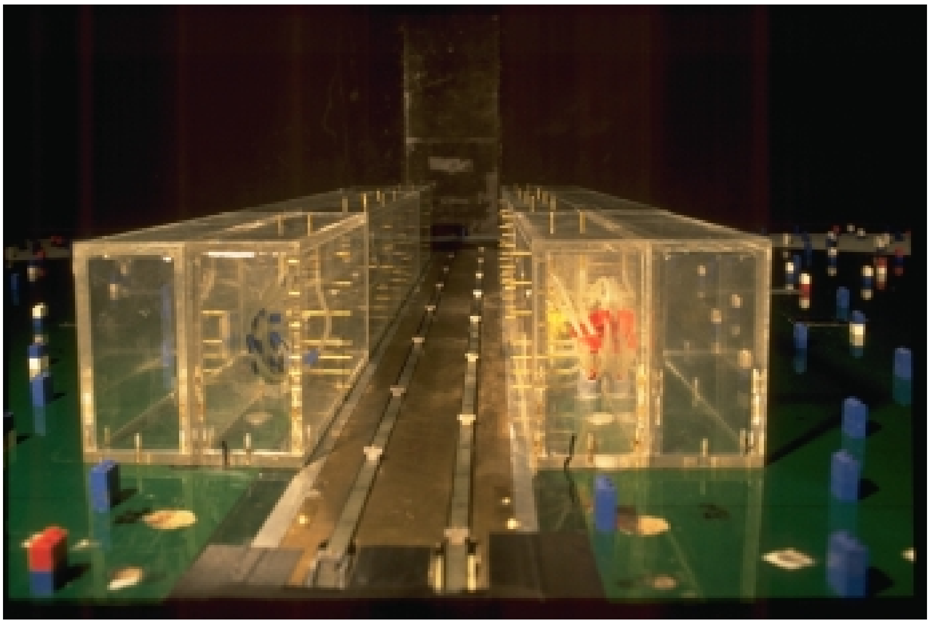
Fig. 3 Vertical concentration profiles at the leeward canyon wall (points with $z/H>1$ are located on the roof) for a constant ratio $v/u = 1.7$.

Fig. 4: Effect of moving traffic: concentration ratios at a reference point (leeward canyon wall, ground level) as function of velocity ratio v/u, with the traffic density expressed through a scaling factor a. Right side: same as left side, but with the velocity ratio v/u corrected by $\sqrt[3]{a}$.

Fig. 5: Concentrations at the reference point calculated with OSPM. An approximation of the wind-tunnel data is shown by a dashed line.

Fig. 6: Diurnal variation of σ_w for $u < 1.5$ m/s on working days and Saturdays. The traffic created turbulence calculated by OSPM is shown by continuous lines.

Fig. 7: Effect of traffic generated turbulence on street concentrations of NO_x.



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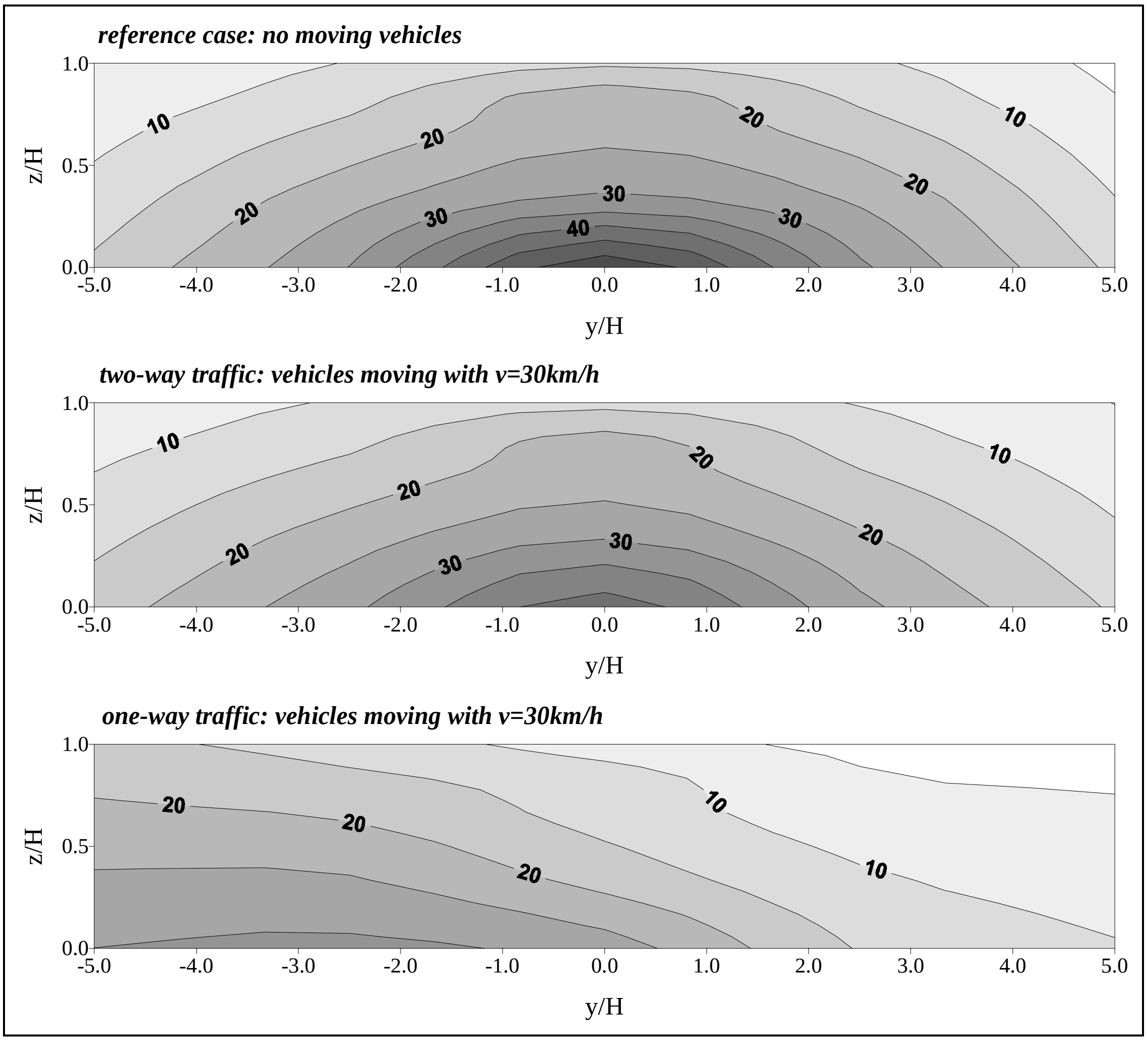

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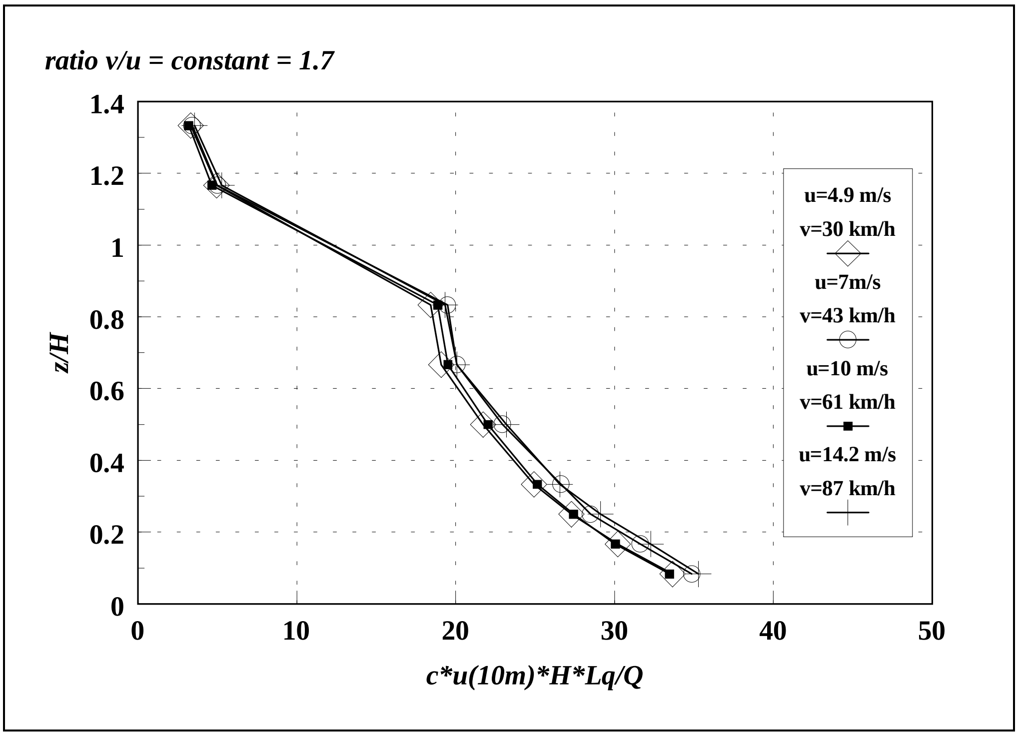

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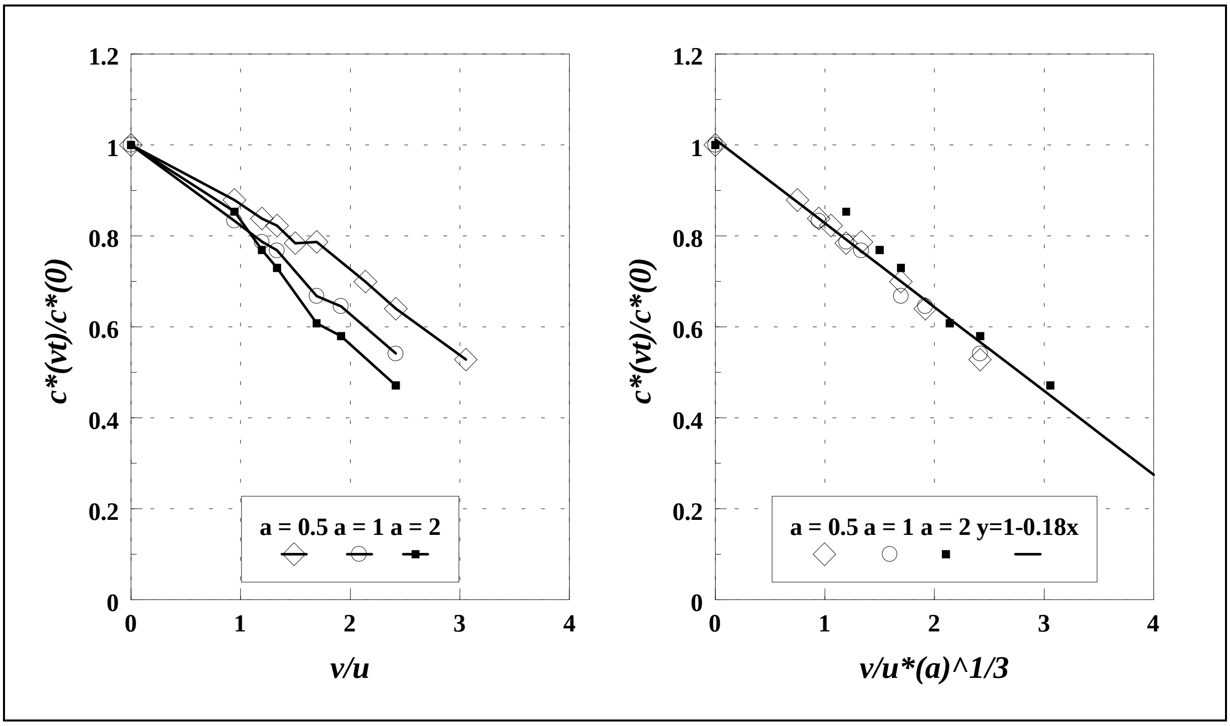

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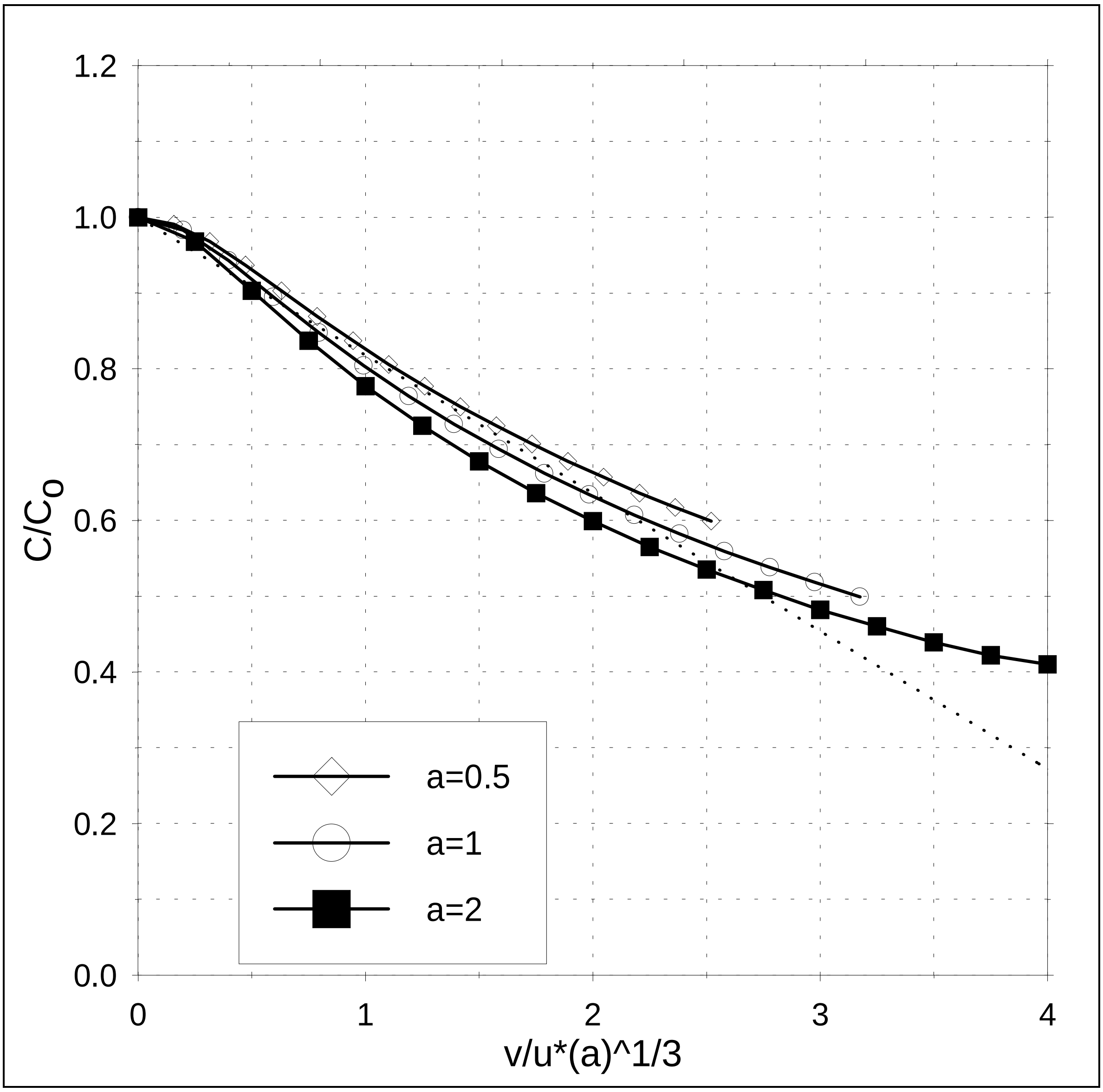

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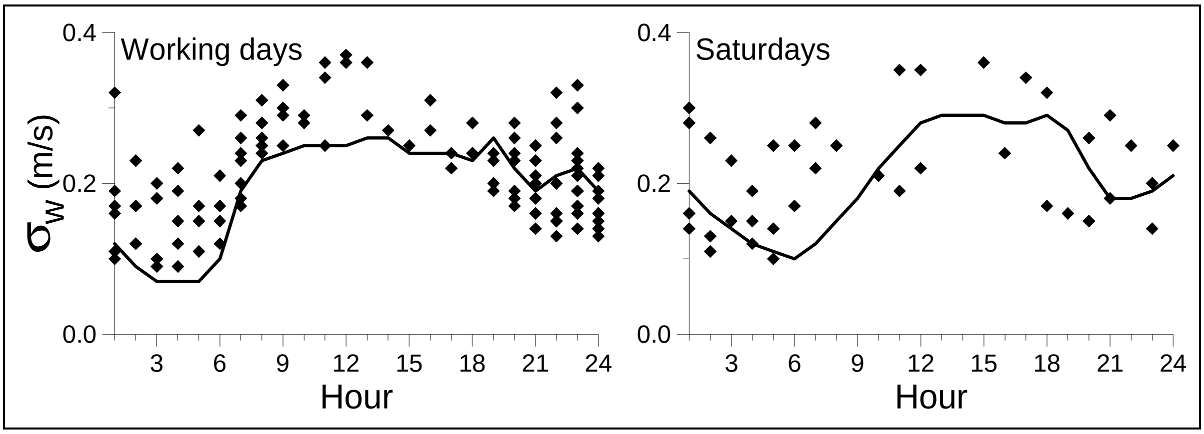

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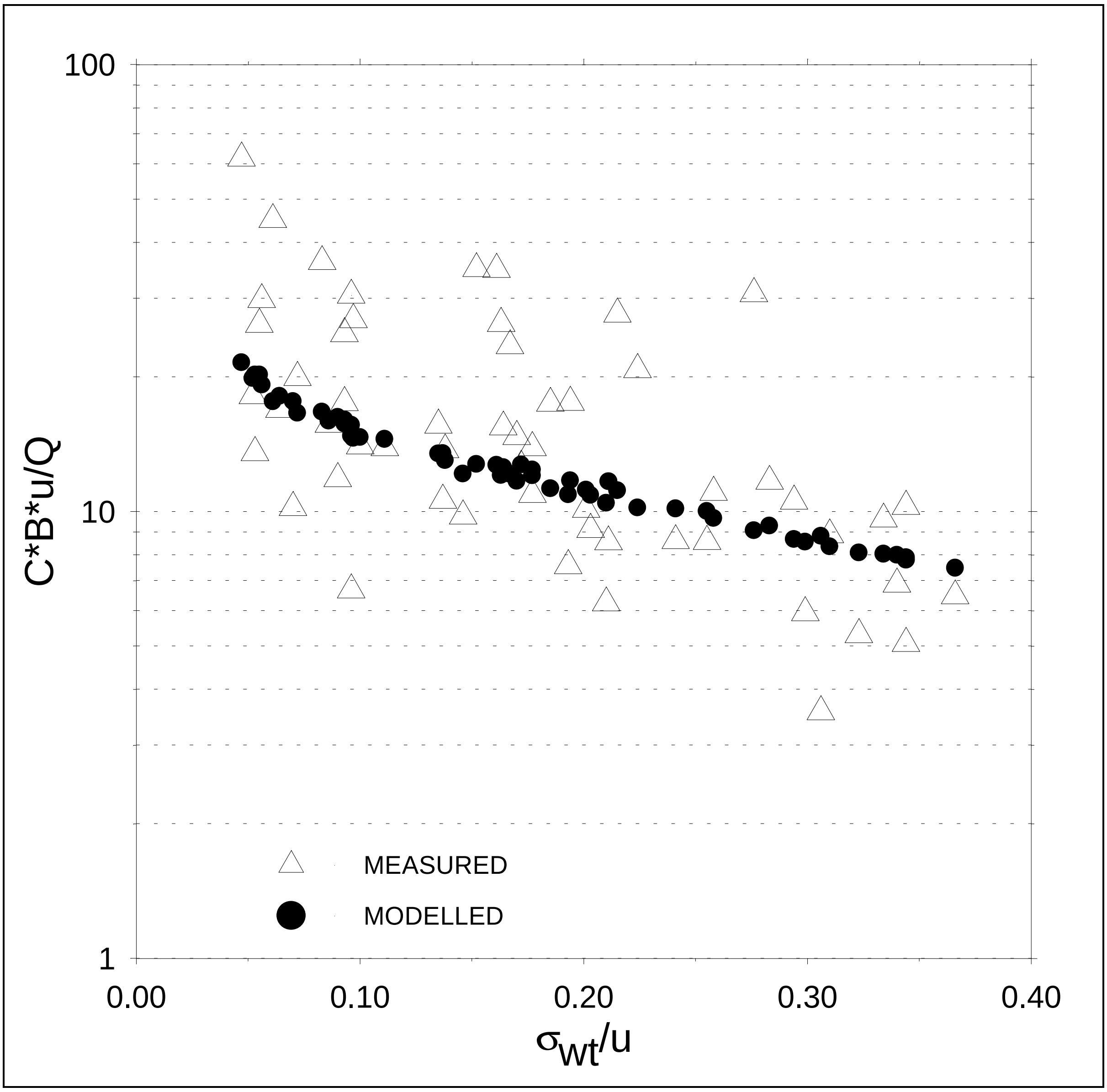

Fig. 7: Effect of traffic generated turbulence on street concentrations of NO_x.