Do Field Data Represent the Truth?

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1. Introduction

The quality of CFD model results depends largely on the quality of parameterisations employed within the computer codes. Such parameterisations are needed in order to close the equations and to describe the effects of sub-grid-scale processes on the development of the flow. These parameterisations are basically empirical. To justify the assumptions involved and to determine the values of the constants the parameterisations contain, appropriate data sets with which the model results can be compared are needed.

In the subsequent analysis we restrict ourselves to obstacle-resolving, micro-scale meteorological models developed to predict traffic-generated urban air pollution. The emission source in such models is usually assumed to be a line source since it is not yet feasible to simulate individual, moving vehicles. For momentum-free line sources it is to be expected that the concentration C [g/m^3] (in excess above background) at any point in the vicinity of the source is proportional to the source strength Q/L [g/(s ∀ m)] and invers proportional to the wind velocity u [m/s] measured at a reference height well above the buildings. Under these conditions, dimensional reasoning suggests to introduce a normalized concentration c^* [-] which depends on the following non-dimensional variables

$$c^* = \frac{C \cdot u \cdot H}{(Q/L)} = f\left(DD, \frac{l_i}{H}, Re, \frac{H}{L_M}, TIT \right) \qquad (1)$$

with the additional parameters:

H	=	characteristic building height (in m), here H = 25 m,
DD	=	wind direction (in degree),
$\frac{l_i}{H}$	=	multiple length scales (normalized by H) describing all details of the urban geometry,
Re	=	Reynolds number (Re = H ∀ u/ν),
$\frac{H}{L_M}$	=	Monin-Obukhov length (normalized by H) which characterizes the density stratification,
TIT	=	an appropriately defined dimensionless parameter describing the traffic induced turbulence.

If the wind speed is sufficiently high, the Reynolds number takes on an above-critical value and the turbulence within the canopy layer is dominated by shear turbulence. This means that effects of stratification or traffic induced turbulence should be of minor importance. Then, for a given urban landscape (H and all l_i/H-values are fixed), c^* is a function of the wind direction alone

$$c^* = \frac{C \cdot u \cdot H}{(Q/L)} = f\,(DD) \qquad (2)$$

Practitioners seldom care for the limiting conditions mentioned so far. Those who carry out the field measurements either provide the raw data or group the excess concentration mean values from a whole year according to the wind direction, average over all values which fall into a 10 degree interval and present the results according to Equ. (2). Numerical modellers use the processed data, believing that they present the truth, and tune their models accordingly. At the example of field data from an urban monitoring station it will be demonstrated how dangerous this practice can be.

2. Field Experiments

From March 1999 till February 2000 the Lower Saxony State Agency for Ecology (NLÖ, 2000) operated a monitoring station at the pedestrian walkway in a busy street canyon (Podbielski-Strasse in Hanover) with a load of up to 20000 vehicles/day. Pollutant concentrations of NO and NO_2 were measured and 30 min average values were determined. Since NO and NO_2 are reactive gases, these data were transformed into NO_x concentrations (equivalent to the molecular weight of NO_2 and for 20°C). NO_x can be regarded as a passive tracer for the short dispersion time periods of interest here. Although other pollutants were monitored as well, the subsequent analysis focuses on NO_x only since the NO and NO_2-measurements as well as the calculated NO_x-emissions were probably the most accurate.

3. Data Processing

For reasons explained in Schatzmann et al. (1999), single half-hourly values are not suitable for model calibration or validation. It is advisable to average over sufficiently large ensembles of data to achieve representative results. Data ensembles over which averaging makes sense are obtained when individual 30 min-values are grouped according to Equ. (1). As will be subsequently shown, this processing of the raw data involves assumptions and decisions which have strong impact on the final result.

3.1 Determination of C

In Equ. (1), C is the concentration above ambient which means the background concentration C_b needs to be subtracted from the measured value C_t. To determine a meaningful background is not at all easy in a city environment with numerous sources and large local concentration differences. In case of the Podbielski-Strasse, the background measurements were carried out 4.5 km apart from the street monitoring station on top of the NLÖ-building. Occasionally the backgrounds measured here were higher than the total concentrations C_t determined simultaneously inside the street canyon. Four different ways were followed in the determination of C:

Assumption 1: $C = C_t – C_b$. For $C_t < C_b$: $C = 0.74\ C_t$ since, averaged over the whole year, $C_b = 0.26\ C_t$.

Assumption 2: $C = C_t – C_b$. For $C_t < C_b$: $C = 1\ \mu g/m^3$ since this value corresponds to the detection limit of the instrument and is the lowest measurable difference.

Assumption 3: $C = C_t – C_b$. For $C_t < C_b$: $C = 0$ which means negative C-values are ignored.

Assumption 4: $C = 0.74\ C_t$ is always assumed (see explanation to assumption 1).

Since in our particular set-up the background exceeded the total concentration in less than 1% of the time, assumptions 1 to 3 lead to about identical results. Assumption 4 resulted in up to 25% higher c^*-values, depending on the wind direction. Although there is no stringent justification for this decision, only alternative 1 will be followed further on.

3.2 Determination of Wind Direction and Wind Velocity

For want of anything better, the wind direction DD and the wind velocity u are also taken from the NLÖ roof top measurement station 4.5 km apart from the street canyon. Both quantities were measured at a mast 10 m above the highest elevation of the building complex and 42 m above ground.

The wind directions which entered Equ. (1) were those directly measured and grouped into 10° intervals. From the velocity u_{42} a sort of free-stream reference wind speed u_{100} (100 m above ground) was calculated assuming the existence of a power law wind profile above the urban canopy with an exponent of $n = 0.3$. Wind directional changes with height were neglected.

3.3 Determination of the Source Strength

The vehicles passing the Podbielski-Strasse were counted over a period of 3 weeks and classified into passenger cars and trucks. The whole time series was then split into 30 min intervals which were subsequently used to calculate typical traffic loads for each half hourly period of the year. Based on these data corresponding Q/L-values were derived thereby using the emission factors provided by the German Environmental Protection Agency for the year 1999.

3.4 Line Source Approximation

Equ. (1) is valid only for line sources. The question arises which traffic rate must be exceeded before the line source approximation holds. To find an answer, all data were grouped according to the traffic rate and plotted according to Equ. (2). As Fig. 1 shows, a similar behaviour of the different curves is found when the traffic rate exceeds 120 vehicles/30 min. All half hourly values which do not meet this criterion are neglected in the subsequent analysis.

3.5 Minimum Wind Velocity
In the derivation of Equ. (1) it was made clear that the c^*-concept is not applicable to low wind situations. Only if the wind speed exceeds a certain minimum it can be assumed that

(1) the critical Reynolds number is exceeded,
(2) stability effects inside the street canyon are negligible, and
(3) the dispersion is governed rather by wind generated than traffic induced turbulence

which justifies to present the data in the simplified form given in Equ. (2).

In order to determine the minimum wind speed, the data were split into 9 velocity classes. As Fig. 2 shows, at low wind speeds c^* appears to be rather independent on the wind direction which suggests that traffic induced turbulence is the major mixing mechanism. With increasing velocity the wind seems to form a secondary flow inside the canyon which leads to higher concentrations for westerly than for easterly winds. It appears that the curves take on a similar form for wind velocities $u_{100} > 3.9$ m/s which corresponds to wind speeds at standard anemometer height $u_{10} > 2$ m/s.

The canyon has a general southwest-northwest orientation. Winds from 60° or 240° would be street-parallel. The monitoring station was located at the walkway northwest from the traffic lanes which means the c^*-curve should reach its maximum for DD around 330° when the wind blows perpendicular to the canyon. Obviously, the data do not show that. There can be many reasons for this unexpected behaviour. The magnitude and dependency of background concentrations on wind direction at Podbielski-Strasse are most likely quite different from those on top of the NLÖ building. Additionally, there might be geometrical effects. The "roughness" of an urban canopy layer is constantly changing. The wind vector 100 m above the Podbielski-Strasse is probably not the same as that 100 m above the NLÖ building. Finally, and most disturbing for simple street canyon box models, the about 150 m long strip of the Podbielski-Strasse without major bends or side openings might not be long enough to produce an approximately 2-d flow field for perpendicular winds.

4. Conclusions
Fig. 3 presents the Podbielski-Strasse field data according to Equ. (2) but processed in two different ways. Curve 1 (which gave guidance in the BWPLUS/TRAPOS model comparison exercise) is based on all measurements whereas curve 2 comprises only those data which survived the filtering process explained in chapter 3. The difference between the curves is in the range of 50 %. Curve 2 seems to be the more convincing representation of the field data set although it still contains many uncertainties. The question remains whether for complex in-canopy layer dispersion problems field data can ever reach a degree of reliability which puts them into the category of reference data for model validation purposes.

5. References
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6. Acknowledgements
The authors are grateful for financial support from the European TMR network TRAPOS and from the Niedersächsisches Landesamt für Ökologie, Hannover.

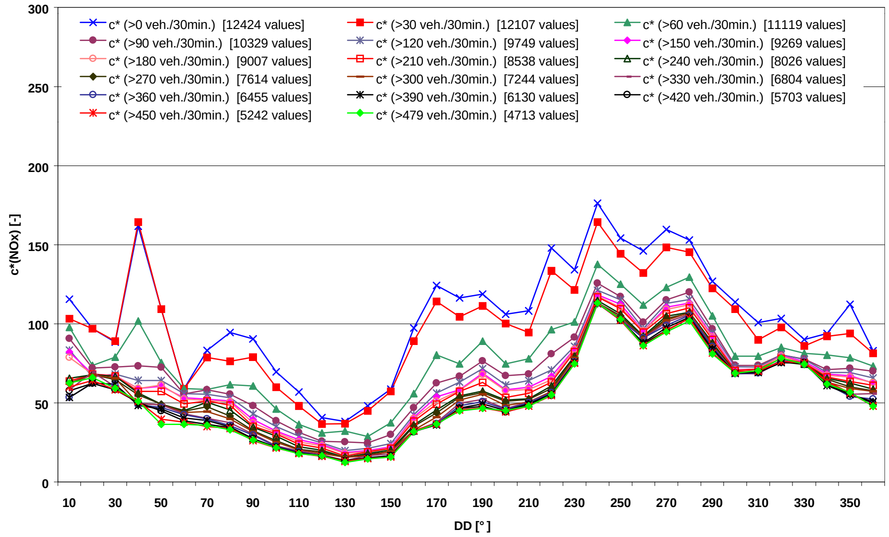

Fig 1: Concentration c* as a function of wind direction and vehicle rate

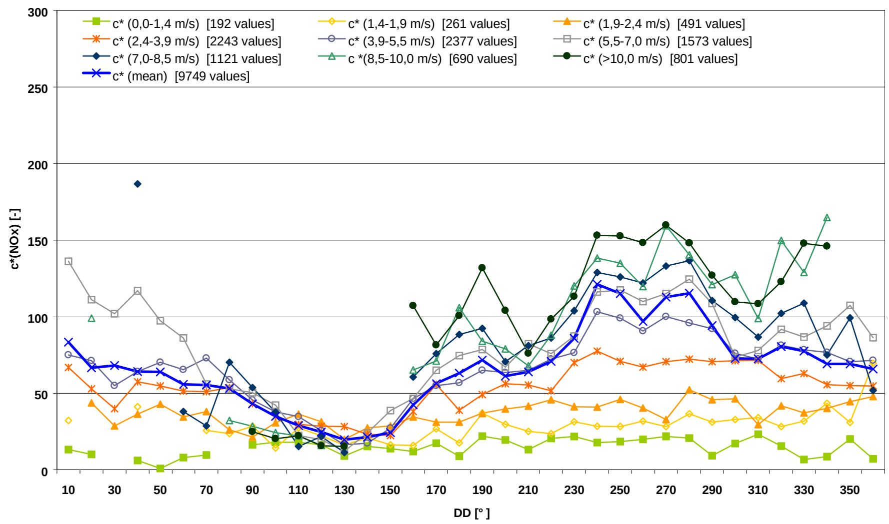

Fig 2: Concentration c* as a function of wind direction and wind velocity interval

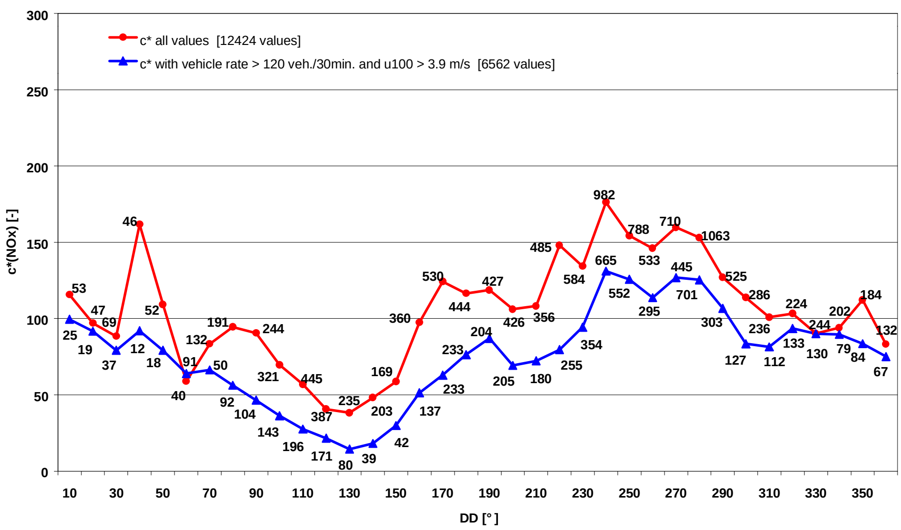

Fig 3: Concentration c* after application of different data processing strategies (figures=number of cases)