HIGH RESOLUTION VALIDATION DATA FOR URBAN TYPE DISPERSION MODELLING

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INTRODUCTION

In 2001, a project for the 'Development and Validation of Tools for the Implementation of European Air Quality Policy in Germany' started in the framework of the 'Atmospheric Research Programme 2000. The main objective of the project is to develop and validate a system of consistent coupled numerical models, which provide the input for local and regional air quality maps. In collaboration with German research institutes, environmental consultants and the environmental agency of the state of Lower Saxony a comprehensive high quality data set for the validation of this model system will be generated, based on a combination of field data and corresponding laboratory experiments.

Several field experiments will be carried out in a city district of Hannover, Germany (Göttinger Street and surroundings). The field data set will be generalized and enhanced through extensive systematic wind tunnel experiments that are suitable to close gaps in meteorological situations, which were not met during the field campaigns. Additionally, selected field situations are replicated and certain parameters are varied systematically in order to improve the understanding of the governing flow and dispersion processes. Furthermore, the inherent scatter within the field data caused by the unsteadiness of meteorological conditions during the time interval of an individual experiment will be quantified.

ACTIVITIES

First high-resolution velocity and concentration measurements were carried out in a large neutral stratified boundary layer wind tunnel recently inaugurated at the University of Hamburg. The tunnel consists of a 18m long flow establishment zone followed by a 4m long test section with a width of 4m and a height of 3.25m (Figure 1).

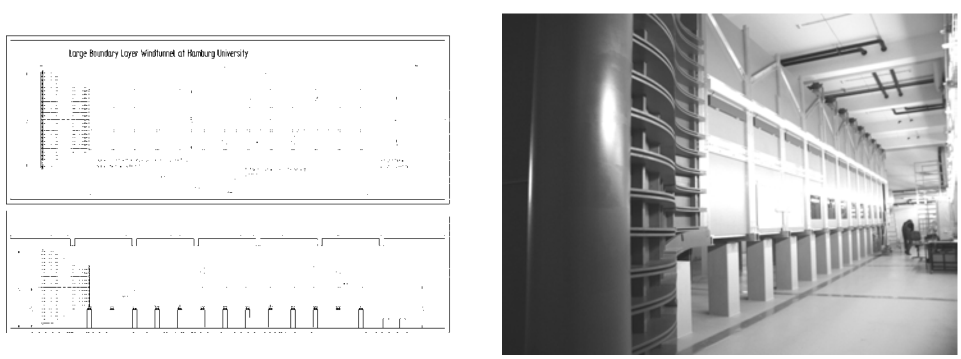

Figure 1. The large wind tunnel at the University of Hamburg.

A detailed aerodynamic model of the urban area was built at a scale of 1:250 including topography. The core of the model covers an area of a 500-meter radius and can be extended to an area of about 1km x 1km for each wind direction. A wind tunnel boundary layer corresponding to the model scale was generated using a combination of vortex generators and roughness elements. The quality of the generated wind tunnel boundary layer was verified and documented by the comparison of all flow and turbulence parameters with default values from nature. Supplementary, all available data from the field site provided by the co-operation partners IMK4 and NLÖ were taken into account.

A preliminary field experiment was carried out in August 2001. An artificial line source of 96m lengths was laid out in the middle of the Göttinger Street, releasing a controlled quantity of SF_6 tracer gas. At a height of 1.50m, air was simultaneously sampled at ten locations in the street canyon (Figure 2). In addition, two additional sampling points were located on the roofs of nearby buildings to measure the background concentration. A total of 120 samples each of 30minute averaging time was sampled and analysed off-line.

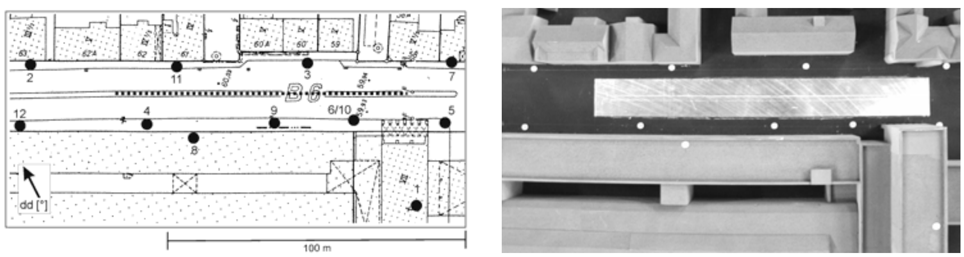

Figure 2. Left side: sampling locations in the street canyon (after Bächlin, 2002), the dotted line represents the line source. Right side: physical model.

In a corresponding wind tunnel experiment (Figure 2), time series of ethane concentrations were recorded at the specified sampling points and at several equidistant locations along the road line (wind direction of 225°, which was the mean given wind direction during the field experiment). Subsequently, mean concentrations and standard deviations were calculated for averaging times equivalent to 10, 30 and 60minutes full scale to quantify the minimum variability of concentration values due to the inhomogeneous turbulent flow field inside the street canyon. In addition, the variation of line source height was studied. Furthermore, the operative parts of the line source related to some of the specified sampling locations were calculated. Thus, the comparability of measured concentrations induced by the artificial line source with real traffic induced exhaust gases measured at fixed monitoring stations can be verified. Finally, the time required to fill the street canyon with tracer gas was examined to define the minimum line source operating time before the measurement start. Time series were therefore taken while the line source was switched on and off at clearly defined times. Subsequently, cumulative averages were calculated.

RESULTS

As expected, the averaging time was significantly affecting the reliability of mean concentration values in the street canyon. Figure 3 displays the percentage standard deviations for averaging times equivalent to 10, 30 and 60minutes full scale. Due to the intermittent signal character and the inhomogeneous flow field, the standard deviations varied along the two road lines. Overall, standard deviations were smaller at the leeward (west) side of the street canyon. Due to a recirculating flow pattern inside the street canyon, a more or less continuous transport of tracer gas contrary to the mean wind direction occurred close to the ground. Although the standard deviations of the 30minutes averages were mainly below 20%, for all locations variations of more than 100% among consecutive mean concentrations were found. During field conditions, these ratios are likely to degrade due to permanent weather changes. At the other street side, the transport of concentration close to the ground occurred less frequently, corresponding to bigger standard deviations.

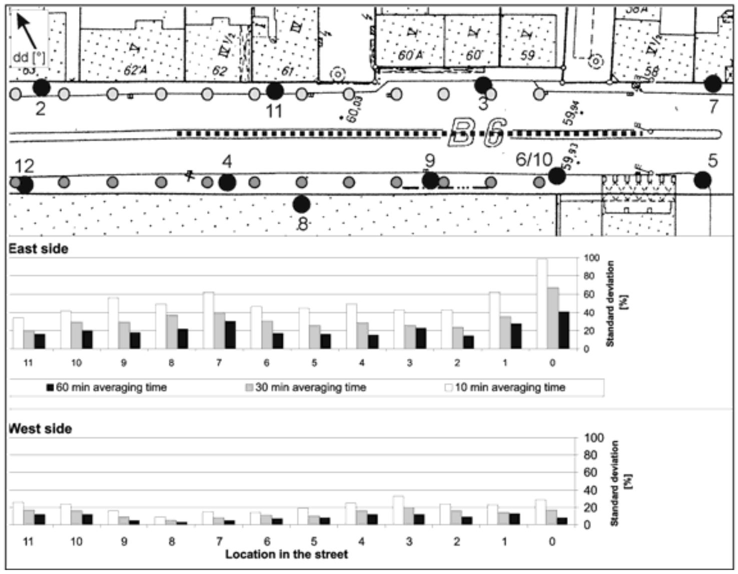

Figure 3. Distribution of concentration standard deviations in the street canyon for different averaging times. Measurement points east side: light grey dots, west side: dark grey dots. The numbered black dots represent the sampling points in the field experiment.

Figure 4 show a comparison between field and wind tunnel results of relative concentrations (referred to SP9). Wind tunnel values as well as field values correspond to 30minutes averages. The error bars were derived from the wind tunnel data representing the minimum variability of the intermittent signal. Even though the field values were taken from a single measurement series sampled at a mean wind direction of 226°, there was a constant wind direction drift during the sampling period. The accuracy of the field line source was not verified, so that changes of the release conditions cannot be completely excluded. Besides, local obstacles like parked vehicles and measurement devices were completely ignored in the physical model, although present during the field measurements. All that taken into account, all measurement locations except SP4 show good agreement. According to the given wind direction in both experiments no concentrations were found at SP5 and SP7, which are south of the line source. As supposed, the two background measurement points (SP1 and SP8) were not affected by the line source. Changes of relative concentrations due to a variation of the releasing height were small.

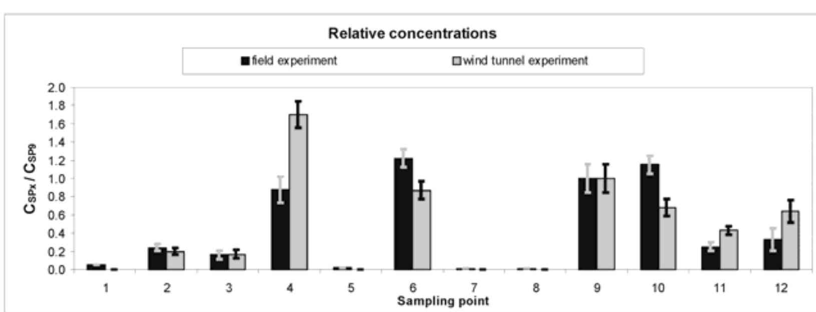

Figure 4. Relative concentrations (referred to SP9), comparison of field and wind tunnel experiment. The error bars are derived from 30 minutes averages (full scale).

Additionally, a check was made to establish whether the artificial line source length was sufficient to represent the real exhaust gases of the street traffic at the specified measurement locations. Figure 5 displays an example of the operative parts of the line source to the concentration at SP6. For the given wind direction, an in-situ monitoring system located at SP6 receives about 50% of the concentration signals from the traffic 90-100m southwards.

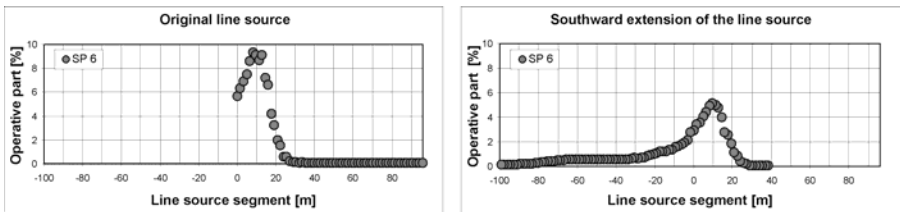

Figure 5. Operative parts of the line source to the mean concentration at SP6. Left figure: original length, right figure: extension to the southward direction.

A rough estimation of the time required to fill the street canyon can be derived from Figure 6. Depending on the measurement location stationary tracer gas release conditions emerge after minimum idle times between 30 minutes (SP4) and 90minutes (SP12).

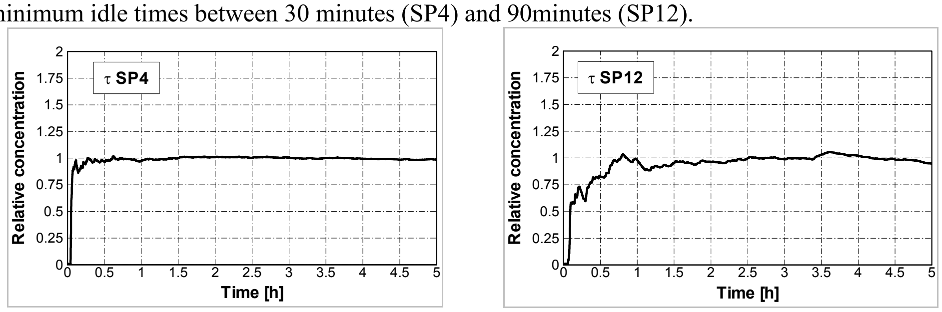

Figure 6. Cumulative averages calculated from time series taken at SP4 and SP12. The time corresponds to full scale.

CONCLUSIONS

Providing a proper wind tunnel boundary layer set-up, high-resolution concentration measurements add to the understanding of micro scale flow and dispersion processes in urban environments. Considerable advantages to field measurements result from the controlled boundary conditions and the comparatively low costs referred to the amount of data. Results from systematic parameter variations and specific experiments like representativity of measurement locations and variations of experimental set-up conditions give useful information in preparations for field campaigns and help to interpret unexpected field results. Gaps remaining in field data can be closed by results from extensive systematic wind tunnel measurements.

ACKNOWLEDGEMENTS

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