# 5.4 WIND-TUNNEL SIMULATION OF THE JOINT URBAN 2003 TRACER EXPERIMENT

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## 1. INTRODUCTION:

During July 2003, the extensive field campaign JOINT Urban 2003 (JU2003) took place in Oklahoma City, USA (Allwine, 2004). In total, ten intensive observation periods (IOPs) were performed with typically three half-hour tracer releases during each IOP. One of the main objectives of this field campaign is the generation of reliable datasets for the validation of microscale dispersion models, which can be used as fast-response tools for accidental releases of toxic material in an urban environment. Although, the JU2003 campaign was the largest field study ever performed for such purposes, the field data represent only a limited set of atmospheric conditions that varied to a certain extent during each IOP. It was therefore felt, that laboratory datasets from wind-tunnel simulations of the flow and dispersion characteristics in downtown Oklahoma City will significantly enhance the validation capabilities of the JU2003 database. Such laboratory data have the advantage that the flow conditions can be precisely controlled and kept constant over a long period of time. Thus, it is possible to simulate the same steady-state situations as calculated by most of the micro-scale flow and dispersion models.

The first phase of experiments was in Spring 2003 (i.e. before the field campaign started) and the main objective was to provide information for planning of the field studies. Laser light-sheet flow visualizations and measurements of concentration timeseries were performed for wind directions typically observed during July in Oklahoma City and for several possible source locations.

## 2. EXPERIMENTAL SETUP:

A scaled wind-tunnel model (model scale 1:300) of the central business district (CBD) of Oklahoma City was constructed and installed in the atmospheric boundary-layer wind tunnel "Wotan" at the University of Hamburg, Germany. The 25 m long facility "Wotan" provides a 18 m long test section equipped with two turn tables and an adjustable ceiling. The cross section of the tunnel measures 4 m in width and 2.75 to 3.25 m in height, depending on the adjustment of the variable ceiling. For precise probe positioning, the test section of the tunnel is equipped with a computer controlled traverse system with a positioning accuracy better than 0.1 mm on all 3 axes.

Figure 1 shows a map of the model area, which includes the core model to be placed on a turn table (circle) and an outer model fetch to be placed upstream and downstream of the core model. A photo of the wind-tunnel model mounted in the wind tunnel for wind direction south can be seen in Figure 2. The view is from north to south. The building footprints and heights were derived from recent aerial photos and LIDAR data.

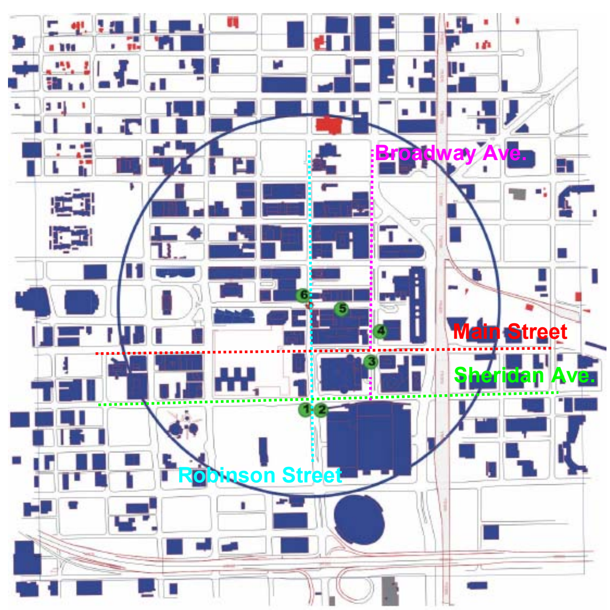


Fig. 1: Map of the Oklahoma City central business district. The circle indicates the area reconstructed in the wind tunnel and the numbers different source locations studied in the wind tunnel.

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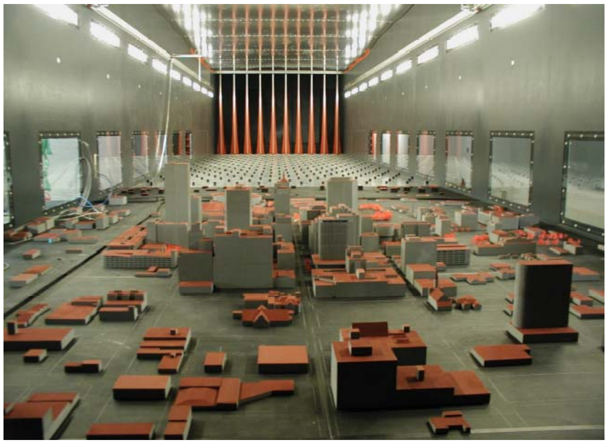


Fig. 2: Model of the Oklahoma City central business district installed in the wind tunnel.

For reference flow velocity measurements a Pitot tube connected to a laboratory grade differential pressure transducer is used. High resolution flow measurements are carried out non-intrusively by means of a 2D fiber-optic Laser-Doppler-Anemometer (LDA). A standard Flame Ionization Detector (FID) was used for monitoring of background concentrations upstream of the model. Concentration time series at several sites inside the CBD were measured with a FastFID-system. The spatial resolution of the FastFID corresponds to 60 mm at full scale and the resolution in time corresponds to at least 4 seconds full scale.

For the laser light-sheet visualization experiments, the light of a low power Argon-Ion-laser is transmitted via an optical fiber into the test section of the wind tunnel. At the end of the fiber, several lenses and mirrors are used to transform the circular laser beam into a triangular plane of laser light, which can be focused to a thickness of approximately 2 mm. The entire optical system is attached to the probe positioning system enabling the light sheet to be moved to any location within the model. A schematic sketch of the light sheet setup is shown in Figure 3.

A 1:300-scaled counterpart of the atmospheric boundary layer was established by means of turbulence generators and floor roughness elements, which are seen in the background in Figure 2. The mean flow profile can be described by a power law with an exponent $\alpha = 0.18$ and by a logarithmic wind profile with a roughness length $z_0 = 0.13\,\text{m}$ (full scale). The turbulence intensities and integral length scales are in good agreement with field data for the categories moderately rough to rough, and the flow spectra match reference spectra of Kaimal et. al. (1972) and Simiu and Scanlan (1986).

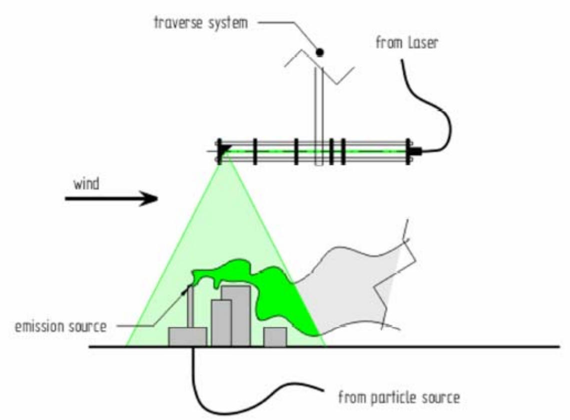



Fig. 3: Schematic view of the laser light-sheet setup.

## 3. RESULTS

### *3.1. Flow visualization experiments*

As a first step, extensive flow visualization experiments were carried out using the described laser light-sheet technique and digital image recording. The main objective of the visualization experiments was to obtain a better understanding of the complexity of the flow and dispersion phenomena to be captured by the field and laboratory experiments.

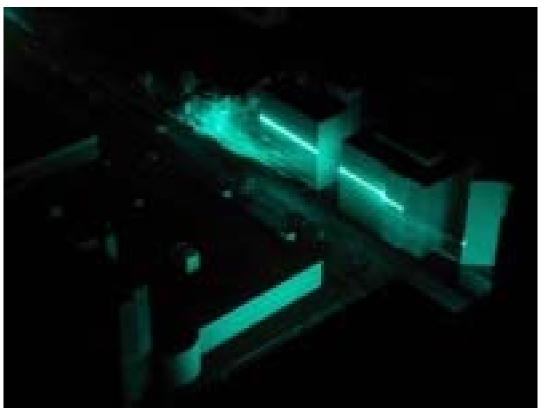
Digital images and/or video sequences are available for sources 1-5 (see Figure 1). A few exemplary images are shown in Figures 4 and 5. These images reveal the instantaneous/non-stationary behavior of the plume. The horizontal and vertical dispersion strongly varies between the individual snapshots shown in Figures 4 and 5.

In particular for release locations 1 and 2, the plume is erratically shifted by more than ± 45° horizontally around the mean wind direction. Consequently, long periods with or without measurable tracer gas concentrations must be expected for downwind sampling positions across the entire central business district. The time scale of the erratic 'switching' of the plume is expected to vary over a wide range from just about a minute up to a few hours, depending on the actual wind speed. As a result, a large scatter of the field data is expected to be observed.

For all release locations short periods with a significant upwind transport of the tracer could be observed. Furthermore, an almost instant vertical mixing of the tracer up to the height of the tallest buildings was observed for all release locations. The almost immediate vertical transport of tracer was expected for sources within the CBD, but was also visible for release locations upwind of the CBD. Due to the latter results the number of rooftop tracer samplers was increased during the field campaign and first field data confirm the somewhat unexpected strong vertical mixing.

a)

b)



c)

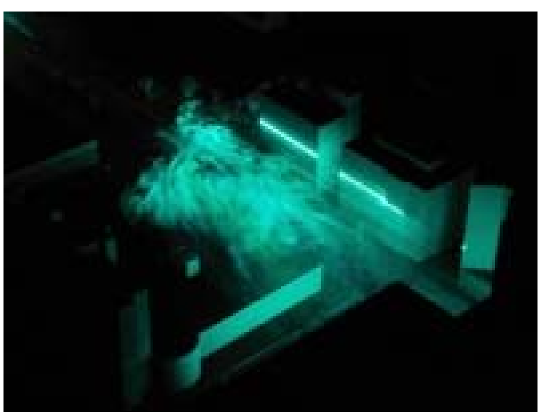
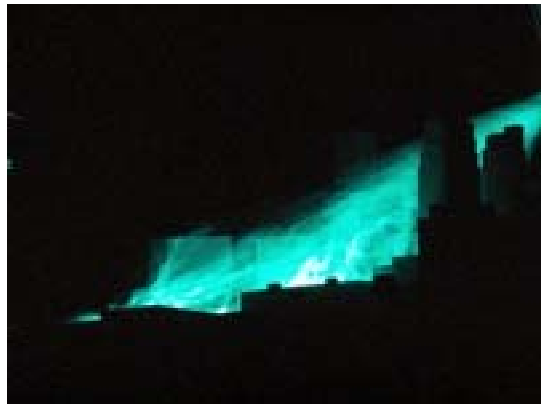


Fig. 4: Laser light-sheet visualization for source 1 and wind direction south. The light sheet is oriented horizontally at about 20m above ground (plot a). The two snapshots (plots b and c) illustrate the instantaneous behavior of the plume.

a)



b)

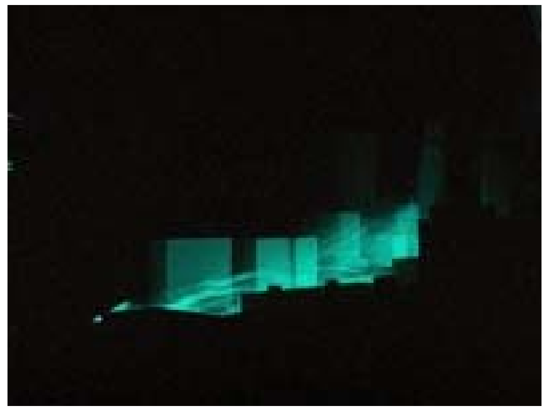


Fig. 5: Same as Figure 4, but the light sheet is oriented vertically along the centre of Robinson Street.

### *3.2. Concentration measurements*

A first set of concentration measurements was carried out in order to further investigate the ground concentration levels, the horizontal and vertical spread of the plume and the instantaneous characteristics of the plume resulting from different source locations and for different wind directions. A HFR400 fast FID system was used and for the sampling setup applied in the present study, a frequency response of about 80Hz was determined, corresponding to about 3 seconds at full scale for wind speeds of approximately 6 m/s at 30 m height above ground.

In order to facilitate the transfer of wind tunnel results to full scale conditions it is useful to transform the wind tunnel time series to a dimensionless time scale, which then can be transformed to any trans-critical wind speed at full scale conditions. Considering the relationship between the time scales, wind speed and the geometrical scale, a dimensionless time scale can be defined as

$$t^* = t \cdot \frac{\overline{u}}{L},$$

with $\overline{u}$ (m/s) equal to the mean wind speed 30 m above ground. $L$ (m) corresponds to a reference length.

Assuming a fully developed turbulent flow for both the wind tunnel and the full scale conditions, and provided that the results of tracer experiments are mass-consistent, the results of point-source concentration measurements must be proportional to the source strength and inversely proportional to the mean wind speed. Consequently, a normalized concentration can be defined as

$$C^* = C \cdot \frac{\overline{u}\, L_{ref}^2}{Q_s}$$

with $C$ (ppm) equal to the measured concentration, $Q_s$ (m$^3$/s) to the source strength and $L_{ref}$ (m) to a reference length which was chosen to be 1m in the model (300 m at full scale).

In a first step of data analysis, all acquired time series were transformed into non-dimensional time scales and normalized concentrations. The scaled time series were then analyzed with respect to mean values, maximum and minimum concentrations and the frequency of occurrence of certain concentrations (C*-Histogram). A cumulative average was calculated for each of the time series in order to estimate the averaging time required to get a 'stable' representative mean value. In Figure 6 the mean ground level concentrations measured at 3m height above ground are plotted for source 1 and wind direction south-south west. The initial plume drift along Sheridan Avenue becomes obvious and the concentration levels are higher along Broadway Avenue than along Robinson Street. The vertical concentration profiles plotted in Figure 7 for the same source location and wind direction illustrate the pronounced vertical mixing. Already the first profile measured in Main Street shows higher concentrations at elevated locations than close to the ground.

## 4. CONCLUSIONS

The concentration measurements confirmed the instant vertical transport observed during the flow visualization experiments. Basically, two distinct dispersion regimes could be identified for the release configurations tested so far. For winds from southwest, south and southeast, the plumes were lifted over long distances leading to maximum mean concentrations measured at significant elevations for a number of sampling locations. A more 'diffuse' plume spread over a wide lateral and vertical range was observed for winds from the southeast and source location 4. This information has been valuable for planning of the field experiments. Additional measurements are planned to generate high resolution data sets for model evaluation studies.

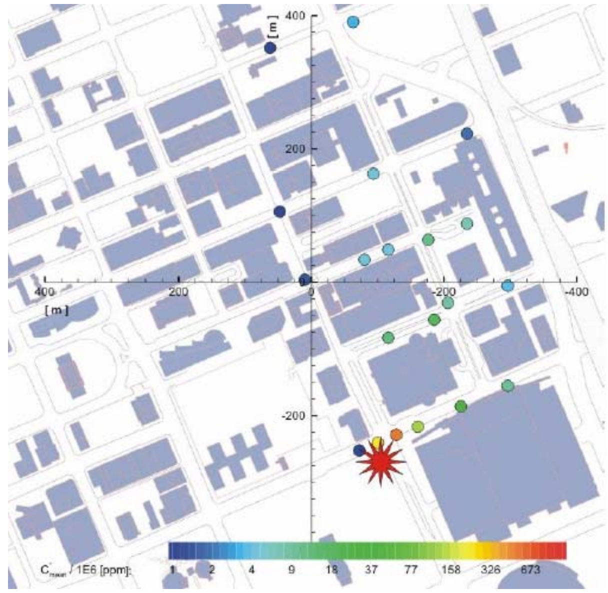



Fig. 6: Mean concentration 3m above ground for source 1 and wind direction SSW

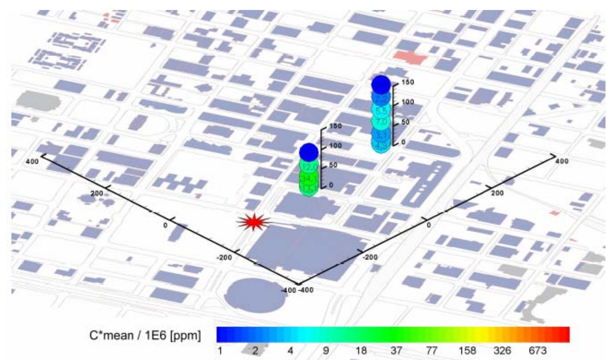



Fig. 7: Vertical profiles of mean concentration for source 1 and wind direction SSW

## 5. REFERENCES

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