ROOF LEVEL URBAN TRACER EXPERIMENT: MEASUREMENTS AND MODELLING

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1. INTRODUCTION

In this study first results from a low-level source urban tracer SF_6 experiment are reported. The experiment was performed in the framework of the Basel UrBan Boundary Layer Experiment – BUBBLE - in an area of the city of Basel (Switzerland) named Kleinbasel. Extensive micrometeorological information on the vertical structure of the atmospheric turbulence within the street canyons and the overlying urban roughness sublayer as well as the flow field over the city was available. In traditional applied dispersion modelling the roughness sublayer is considered sufficiently shallow not to affect the atmospheric dispersion process and fluxes are considered to be constant with height near the surface. This is not the case in the roughness sublayer that exists above an urban area; here fluxes vary considerably with height.

The SF_6 tracer experiments were performed with near roof-level releases. The samplers were distributed close to roof level in a down-wind area stretching out to about 2.4 km. The tracer thus was released and sampled in the roughness sublayer. The part of Basel where the experiments were carried out is fairly homogenous in its city structure. The mean building height in the area is 15.5 m with a mean plan area density of 49%. During the campaign 4 successful tracer experiments were carried out, all in the afternoon

2. TRACER EXPERIMENT

The tracer SF_6 was released from the roof of a parking house about 1.25 times the building height. Only in one occasion the tracer release had to be made from a mobile crane at a different position. Samplers were located in a downwind sector of about 90° opening angle and located at 1.5 m above roof level. For most of the tracer releases

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samplers were located approximately on two arcs at 500 and 1000 m distance from the source. Additionally a profile along the center line of the expected plume extended up to about 2.4 km. Typically 12 sampler sites were operated in that way. The release of tracer typically started 30 min prior to the sampling and was kept constant. Tracer sampling was performed in bags. For most of the experiments, 6 bags were filled in sequence at each sampling location with a filling duration of 30 min for each. Thus a three-hour time series of near-roof concentrations is available at each of the sampling sites. Figure 1 illustrates the tracer measurements on June 26.

Bags were subsequently analyzed in the laboratory and a background concentration, that was measured for each release separately, was finally subtracted from the analyzed concentrations. Reproducibility of the observed concentrations was excellent. More detail about this tracer experiment will be published elsewhere

In order to make an estimate of σ_y, the lateral spread of the plume, as function of distance the concentration field over the area was estimated by interpolation among the measurements. Figure 2 shows the interpolated concentration field for June 26. Crosswind lines were laid out about 0.75 1.0 and 1.25 km from the source and cases that were well covered by the field measurements were selected for further analysis. In the case of June 26 the 0.75 and 1.0 km crosswind profiles were selected and the profile at 1.25 km disregarded. The interpolated concentrations were digitised along the selected crosswind lines and σ_y estimated from a best fit to a Gaussian distribution, Table 1.

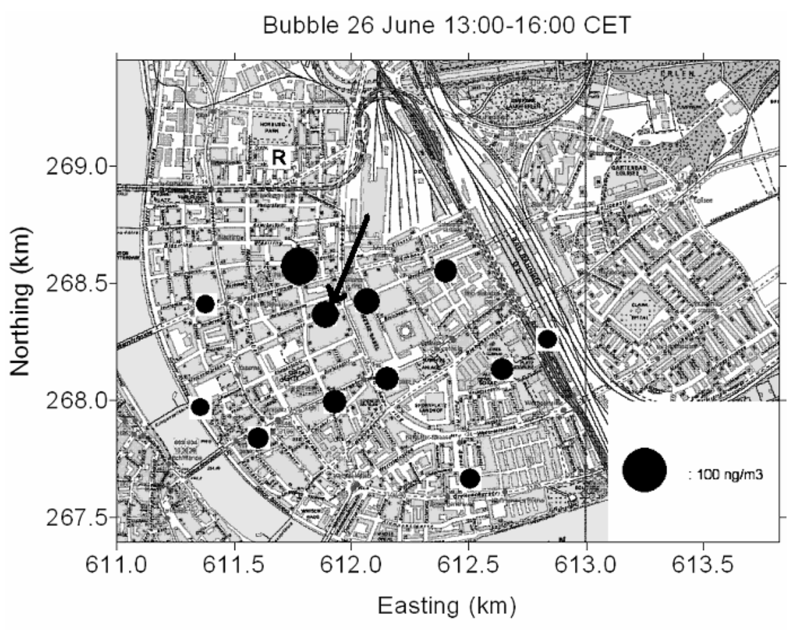

Figure 1. The tracer concentrations on 26 June, 13-16 CET. The release point is marked with R; at the tracer sampling positions the measured concentration is indicated with the area of the filled circle. For comparison a filled circle representing 100 ng m^{-3} is shown in the white box. The arrow shows the position of Sperrstrasse. Base map (c) copyright GVA BS, 25.10.2002.

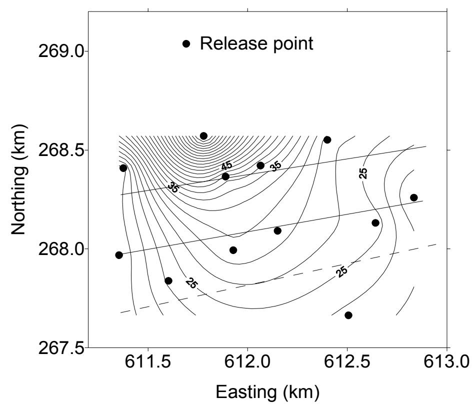

Figure 2. Isolines of interpolated tracer concentrations [ng m^{-3}] averaged over the period for the experiment on 26 June, 13-16 CET. The filled circles designate the tracer release and sampling positions. The full lines represent crosswind profiles that formed the basis for the estimation of σ_y , see Table 1. The profile along the dashed line was not used due to insufficient data coverage. The co-ordinate system as in Figure 1.

Table 1. The lateral spread of the plume σ_y for the 4 experiments.

Experiment:	Downwind distance (m)	σ_y (m)
26 June (13:00-16:00 CET)	750 1000	537 672
4 July (15:00-18:00 CET)	750 1000	296 311
7 July (14:00-17:00 CET)	750 1000	393 424
8 July (15:00-18:00 CET)	1000 1250	425 437

3. METEOROLOGICAL MEASUREMENTS

From the BUBBLE network we use the observations from Sperrstrasse centrally situated in the tracer experimental area, Figure 1. There, Reynolds stress was measured at 6 levels on a tower, namely at 3.6, 11.3, 14.7, 17.9, 22.4 and 31.7 metres above ground. The local building height amounts to 14.6 m. An aerosol Lidar located within Basel 5 km from the experimental area gave information on the height of the mixing layer.

2.1. Meteorological parameters

In traditional applied models of atmospheric dispersion from low-level sources, the input consists of basic meteorological parameters such as the Obukhov length, the height of the mixing layer and a characteristic wind velocity. The Obukhov length is formed from parameters in the surface boundary layer where both the sensible heat flux $\left(\overline{w'T'}\right)$ and friction velocity are constant as function of height. The friction velocity is:

$$u_* = \sqrt{-\left(\overline{u'w'}\right)_o}$$

where the usually small lateral component $\left(\overline{v'w'}\right)_o$ has been neglected. Here o denotes near surface values that are representative for the surface boundary layer. But how do we determine and apply appropriate scaling parameters over a rough surface like in urban environments? There observations (e.g., Rotach 2001) show that $-\overline{u'w'}$ exhibits a distinct profile with a maximum somewhere above roof level, Figure 3. By fitting a curve through the profile of observed measurements both the maximum value and the height z_m where it occurs can be found. In short Rotach (2001) argues that the Reynolds stress component at z_m actually reflects the drag that the flow aloft 'sees' from the bulk of the surface, and hence is a candidate for a scaling velocity with the usual definition in terms of momentum transfer to the surface

$$u_*^r = \sqrt{-\left(\overline{u'w'}\right)_{\max}} \quad .$$

This scaling velocity is called u_*^r in order to avoid confusion with the traditional definition of the friction velocity.

For the near-surface wind speed information from the sonic anemometer profile at Sperrstrasse (levels 17.9 m and 31.7 m) have been selected and interpolated to the height z_m. Concerning the sensible heat fluxes over urban areas often a maximum is observed slightly above roof level. Higher up the heat flux remains approximately constant while there is large variability inside the canyon. In this study the surface heat flux is obtained from averaging the observations of the two uppermost levels at Sperrstrasse (22.4 m and 31.7 m). The mixing layer height z_i was deduced from profiles of Lidar measurements, taken as the height of a major change in the backscatter of the signal.

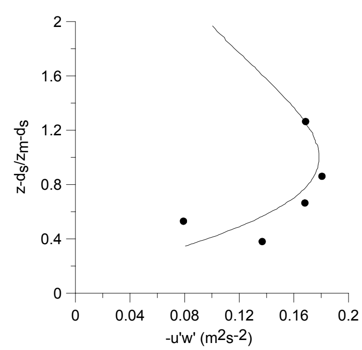

Figure 3. Profile of observed (filled circles) and fitted (full line) Reynolds stress component $-\overline{u'w'}$ at Sperrstrasse during the tracer experiment on 4 July. The displacement height is d_s .

Table 2. Meteorological conditions during the 4 tracer experiments; averaging times as in Table 1. The measurements represent the conditions at the height z_m .

Experiment	z_m (m)	u (m/s)	u_*^r (m/s)	w_* (m/s)	z_i (m)
26 June	21.7	1.28	0.41	2.31	1500
4 July	24.0	2.49	0.60	1.77	1200
7 July	19.2	1.44	0.31	2.22	1800
8 July	20.4	1.78	0.41	2.27	(2000)

2.2. Parameterisation of σ_v and of σ_w

The standard deviation of the crosswind fluctuations of the wind velocity, σ_v , is an important parameter for the lateral dispersion process of plumes. Similarly is σ_w , the standard deviation of the vertical fluctuations of the wind velocity, important in the description of the vertical spread of plumes. Here we compare commonly used parameterisations of σ_w and σ_v to the data from BUBBLE. At our disposition we have 6 half-hourly values of σ_w and σ_v from each of the four experiments. We apply the parameterisations recommended by Gryning et al. (1987). In the report of the COST Action 710 (Cenedese et al, 1998), these parameterisations were validated on a large number of data sets and found to perform well. They read:

$$\sigma_w^2 = u_*^2\left[1.5\left(\frac{z}{z_i}\right)^{2/3}\left(\frac{w_*}{u_*}\right)^2 \exp\left(-2\left(\frac{z}{z_i}\right)\right)+\left(1.7-\left(\frac{z}{z_i}\right)\right)\right]$$

where the convective velocity scale is $w_* = \left((g/T)\overline{w'T'}\, z_i\right)^{1/3}$, with g for the acceleration due to gravity and T for temperature and

$$\sigma_v^2 = 0.35\, w_*^2 + (2 - z\ /z_i)\, u_*^2\ .$$

Here we apply the parameterizations at the level of maximum shear stress, z_m inside the roughness sublayer over the BUBBLE urban area, using u_*^r for the friction velocity. In Figure 4 it can be seen that in general the parameterisations perform well over the urban area. The agreement is better for σ_w than for σ_v in accordance with the general experience from similar investigations over flat terrain. It can also be seen that the parameterised values have both σ_w and σ_v about 30% larger (dashed lines) than measurements. We do not attempt any immediate explanation for these systematic overestimations for σ_w and σ_v in the urban environment, but take them as an empirical fact and cope with them by simply reducing both parameterisations with 30%.

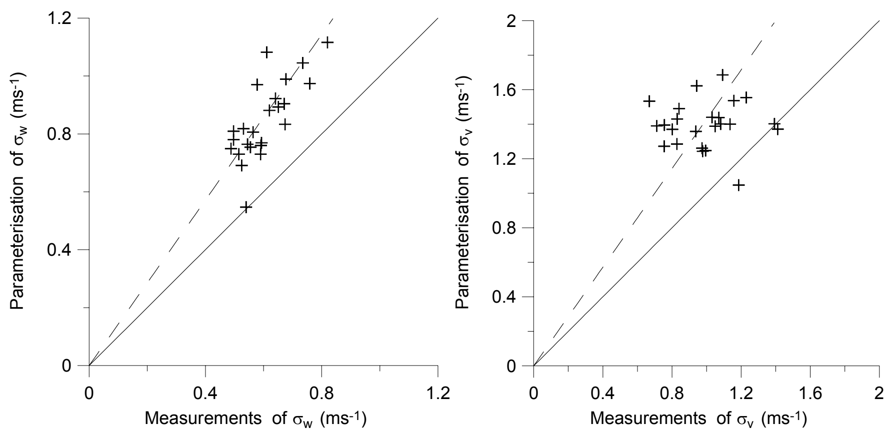

Figure 4. Observed half-hourly averaged versus parameterisations of σ_w (left panel) and σ_v (right panel).

4. EVALUATION OF TRACER CONCENTRATION DATA

4.1. Parameterisations of σ_y

Considering only the effect of atmospheric turbulence a simplified version of Taylor's famous formula for plume dispersion reads:

$$\sigma_y = \sigma_v t \, f_y (t/T_y)$$

where t is travel time of the plume and f_y is a function of the dimensionless travel time t/T_y where T_y is the Lagrangian time scale for the lateral dispersion process. The approximation

$$f_y = \left(1 + \sqrt{t/2T_y}\right)^{-1}$$

is often recommended for applied dispersion modelling (Gryning et al, 1987). For the unstable atmosphere it comes natural to connect the Lagrangian time scale to the time of transport between the surface and the mixing height:

$$T_y = z_i / \sigma_v$$

where σ_v is used as a characteristic velocity for the lateral spread of plumes. For atmospheric neutral conditions the mixing height in the usual sense for the convective atmosphere might not be present, in this case the vertical scaling height can be taken as $z_i = 0.2 \, u_* / f$ where f is the Coriolis parameter. By use of equations above and taking $\sigma_v = 1.7 \, u_*$ we have for neutral conditions $T_y \approx 1000 \, s$. However in the above considerations the height dependence of T_y is neglected. This let Gryning et al (1987) distinguish between ground-level and elevated sources with $T_y = 200$ s recommended for ground-level sources and $T_y = 600$ s for elevated sources.

Cast in terms of pure empirical scaling with $X = (w_*/u_*)t$ Briggs (1985) proposes:

$$\frac{\sigma_y}{z_i} = \frac{0.6X}{\sqrt{1+2X}}$$

The above expressions for the lateral spread of the plume have been developed and validated mainly against data from low level sources over a rural area or from elevated sources over both rural and urban areas at high wind velocities. Such circumstances are very different from the conditions during the four BUBBLE tracer experiments where tracer release and concentration measurements were performed near roof level in an urban area during convective conditions and very low wind speeds.

The simulation of the lateral spread was performed in two steps. In the first one we use the observed σ_v values. Figure 5 shows the measurements and model simulations of σ_y using T_y=200 s, which is the recommended value for ground level sources, and T_y=600 s as suggested for elevated sources. Both assumed values of T_y in combination with the observed σ_v are seen to underestimate the lateral spread. The simulation was also performed with by use of $T_y = z_i/\sigma_v$ which is within a factor of 2 of the value of 600 s recommended for elevated sources. Use of this formulation improves the comparison with the measurements, which suggest that the high values of both the friction velocity and convective velocity typically for urban areas makes the plume behave more like an elevated source than as a ground level source.

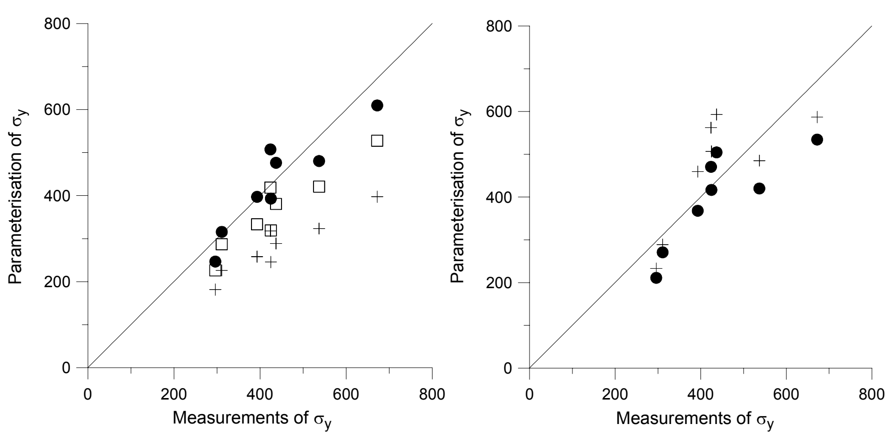

Figure 5. Measured and modelled values of σ_y . . In the left panel the simulations are performed using observed values of σ_v and for T_y =200 s (+); T_y =600 s (□) and $T_y = z_i/\sigma_v$ (●). In the right panel the simulations performed by use of parameterised values of σ_v and $T_y = z_i/\sigma_v$ (●). Also the fully empirical parameterisation based on X is shown (+).

For practical applications the comparison was also carried out with parameterised values of σ_v, Figure 5. The agreement is fair but not as good as the use of measured values of σ_v. The X -based parameterisation is also shown and performs rather well.

4.2. Numerical simulations

The numerical simulations will only be touched upon here as the work is ongoing. A Lagrangian particle dispersion model (LPDM) is used that can be run with parameterised turbulence profiles, Rotach (2001). Close to the surface the turbulence characteristics are parameterized specifically to match urban roughness sublayer observations. The simulation for the 26 June is shown in Figure 6. It can be seen that the present model does a reasonable job in reproducing the dispersion process. It also shows that the plume was caught by the samplers reasonably well and was neither drained into a street canyon nor lifted away from the surface by a large eddy due to highly convective conditions. It can be noted that the simulations reproduce the high concentrations well, while the low concentrations are somewhat underpredicted. Some splashing around in the wind field was observed during the experiment which might prevent the tracer plume from being completely advected out of the area; an effect that is not included in the simulation.

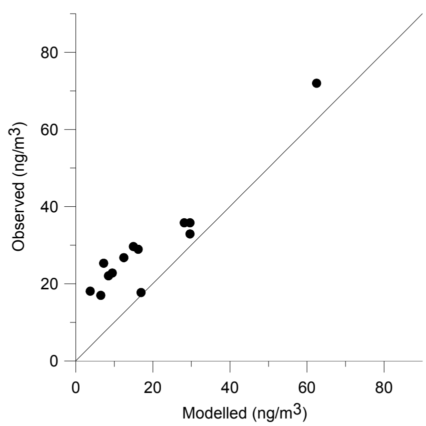

Figure 6. Observed and modeled near-roof concentrations at the 13 tracer sampling sites for the experiment of June 26 2002. Meteorological input data to the model are three-hourly averages and so are the observed concentrations. Parameterizations for the turbulence profiles are employed.

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