

# FLUXES AND PROFILES OF CO<sub>2</sub> IN THE URBAN ROUGHNESS SUBLAYER

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## Abstract

In Summer 2002 flux measurements of CO<sub>2</sub> were performed over a dense urban surface. The month-long measurements were carried out in the framework of the Basel Urban Boundary Layer Experiment (BUBBLE). Two LI-7500 open path analysers were installed at  $z/h = 1.0$  and  $2.2$  above a street canyon with  $h$  the average building height and  $z$  the height above street level. Average diurnal courses of CO<sub>2</sub> concentration profiles and CO<sub>2</sub> fluxes are reported and discussed before the background of traffic data and exchange conditions.

**Key words:** CO<sub>2</sub> profiles, urban CO<sub>2</sub> fluxes, canyon exchange.

## 1. INTRODUCTION

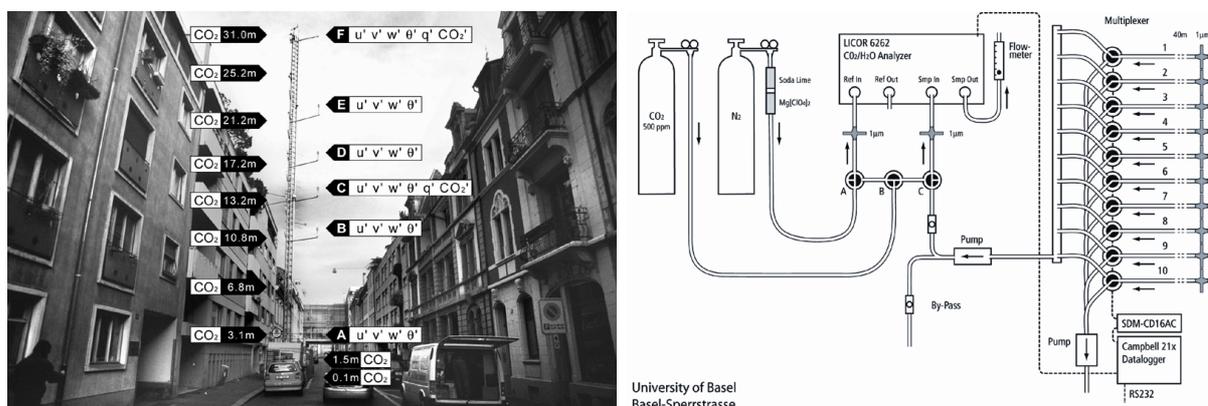
Measurements of CO<sub>2</sub>-fluxes in and above urban canopies are rare, even though cities are an important source of CO<sub>2</sub>. The complex morphometric nature of the surfaces and the inhomogeneous distribution of CO<sub>2</sub>-sources form methodological difficulties. Micrometeorological flux measurement techniques can be applied (e.g. the eddy covariance method), but point measurements can not easily be attributed to source areas. Grimmond et al. (2002) give an overview on studies about urban CO<sub>2</sub> dealing mostly with concentration measurements ("urban CO<sub>2</sub> dome"). They stress the lack of measured CO<sub>2</sub>-fluxes and report measured values from a 27 m high tower in a suburban area of Chicago in 1995. Recently, Nemitz et al. (2002) present direct measurements of urban CO<sub>2</sub> emissions, which were carried out at about 65 m above street level in the center of Edinburgh, Scotland, in 2000.

It is the aim of BUBBLE (Basel Urban Boundary Layer Experiment, a COST 715 action) to increase the knowledge of mass, momentum and energy exchange over urban surfaces (Rotach, 2002). Results from profile measurements of mean CO<sub>2</sub>-concentrations should help explaining the exchange processes rather than quantifying urban emissions. The presented results focus on diurnal mean courses combined with traffic data and selected turbulence parameters.

## 2. SITE AND INSTRUMENTATION

The instrumented canyon ("Basel-Sperrstrasse") is located in a densely built-up part of the city of Basel. The surface has a high plane area density  $\lambda_p$  of 0.54, a vegetation fraction  $\lambda_v$  of 0.16 and an average building height  $h$  of 14.6 m. Additional details are given in Christen et al. (2003).

A triangular lattice tower was installed 3 m off the northern building wall (Fig. 1, left) and operated over nearly one



**Fig. 1:** Left: View at the tower at Sperrstrasse. Height of inlets for measurement of CO<sub>2</sub> concentration and turbulence instrumentation are indicated. Right: Schematic of gas-multiplexer system for CO<sub>2</sub> concentrations.

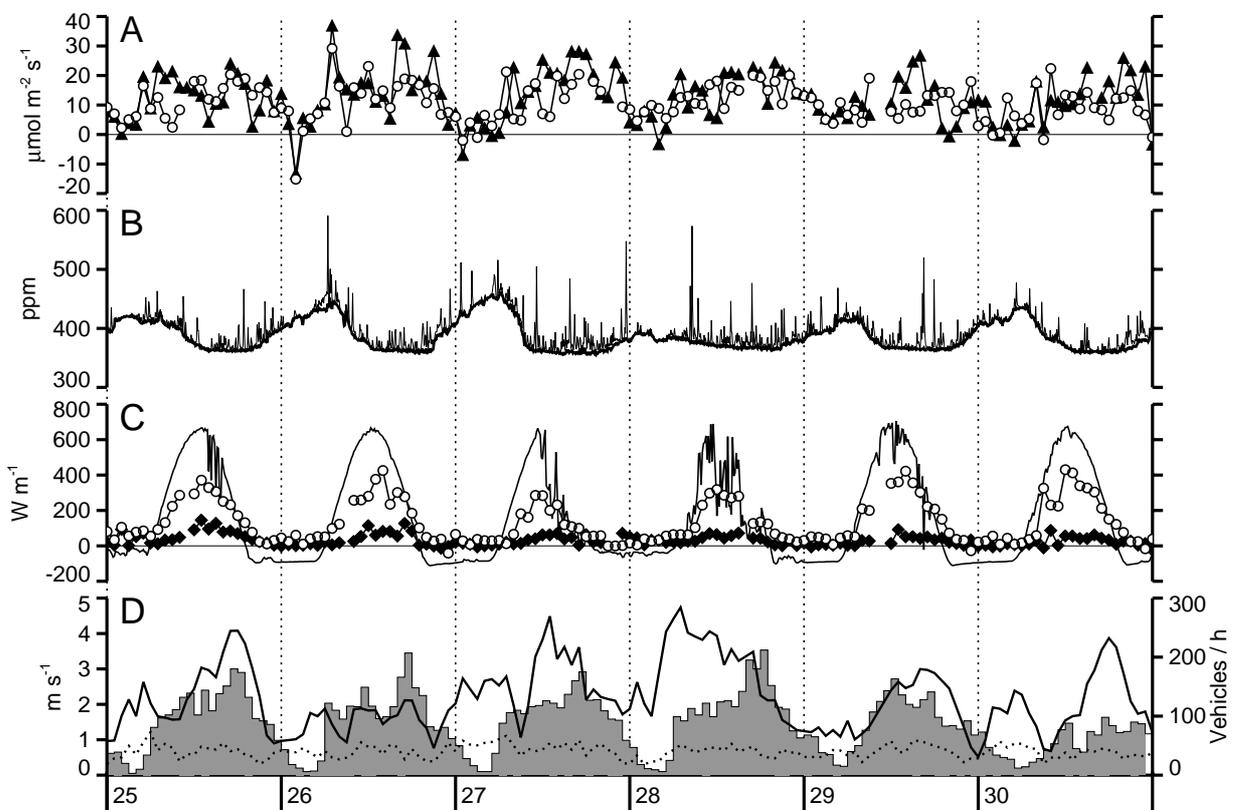
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year. It supported 6 ultrasonic anemometer-thermometers, full radiation components at tower top and inside the canyon, a temperature/humidity profile of 5 levels, 12 levels of cup anemometers and 10 levels with inlets for the CO<sub>2</sub>/H<sub>2</sub>O-analyzer. A CO<sub>2</sub>/H<sub>2</sub>O gas-multiplexer system sampled sequentially air from 10 tower levels. Air was sucked from each inlet at the tower through a 40 m tube down into a van, where the gas multiplexer and a LI-6262 gas-analyzer were operated. Each channel was sampled 30 s, the first 10 s after switching are discarded. Mean values over the remaining 20 s are stored. A schematic of the setup is displayed in Fig. 1 right and it is similar to the one reported by Xu et al. (1999).

This resulted in mean profiles (10 levels) with a resolution of 5 minutes. The gas-analyzer was operated from December 2002 until July 2003 in differential mode, i.e. measuring continuously a zero gas in the reference cell.

During the IOP in summer 2002 additional instrumentation was deployed including two LI-7500 open path analyzers at  $z/h = 1.0$  (14 m) and  $z/h = 2.2$  (31 m), which were combined with the sonics at those levels. The CO<sub>2</sub>-fluxes were derived from 60 min periods (block averaging, no detrending, WPL-correction).

The traffic in this particular canyon was registered by an automatic traffic counter, which was operated by the city authorities (Hochbauamt Basel-Stadt).



**Fig. 2:** Sample period from June 25 to June 30, 2002, at Basel-Sperrstrasse. Hourly values (except B: 5 min averages) of **A:** WPL-corrected CO<sub>2</sub>-flux from the LI-7500 at 31.7 m (open circles) and at 14.7 m (black triangles). **B:** CO<sub>2</sub>-concentration from the LI-6262 gas-multiplexer-system at 0.1 m (street floor) (thin line with spikes) and at 31.7 m (thick line). **C:** Energy balance at tower top (31.7 m) with net radiation (solid line, 10 min averages), sensible heat flux (open circles) and latent heat flux (black diamonds). **D:** Wind speed inside the canyon and at tower top 31.7 m (solid line) and 3.6 m (dotted line) and local traffic load in the canyon (grey bars).

### 3. RESULTS AND DISCUSSION

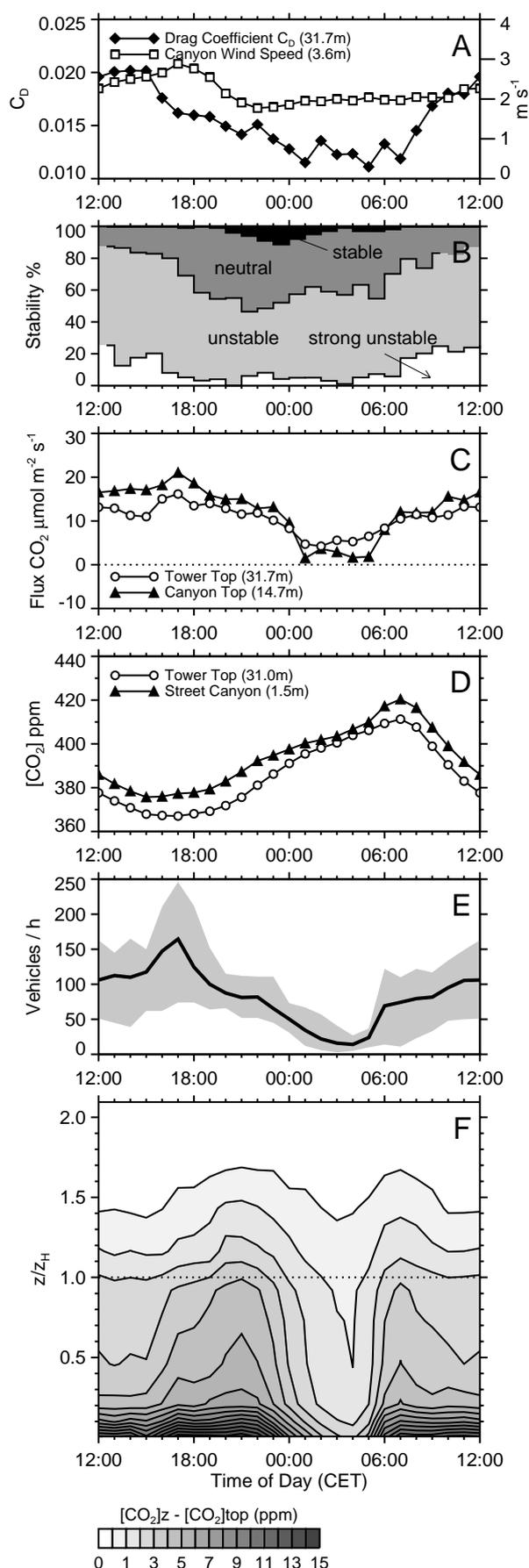
An overview for the six last days of June 2002 is given in Fig. 2A-D. Wind speed inside the street canyon is generally low, and winds at 2h were moderate with peaks around 4 m s<sup>-1</sup>. The traffic load showed a not unexpected diurnal course with a minimum in the second half of the night, and a maximum in late afternoon. June 29 was a Saturday with no afternoon peak and on Sunday, June 30, the drop after 13:00 was likely due to brasilian fans watching the soccer world championship final. The Sperrstrasse is a one-way-street directed out of the city, which explains, that there is only a peak in the afternoon, which is nicely reflected in Fig. 3E.

The energy balance values indicate, that these days were dominated by clear weather (Fig. 2C). Sensible heat flux was almost always directed upward with peak values during daytime around 400 W m<sup>-2</sup>, while latent heat flux was small, generally below 100 W m<sup>-2</sup>.

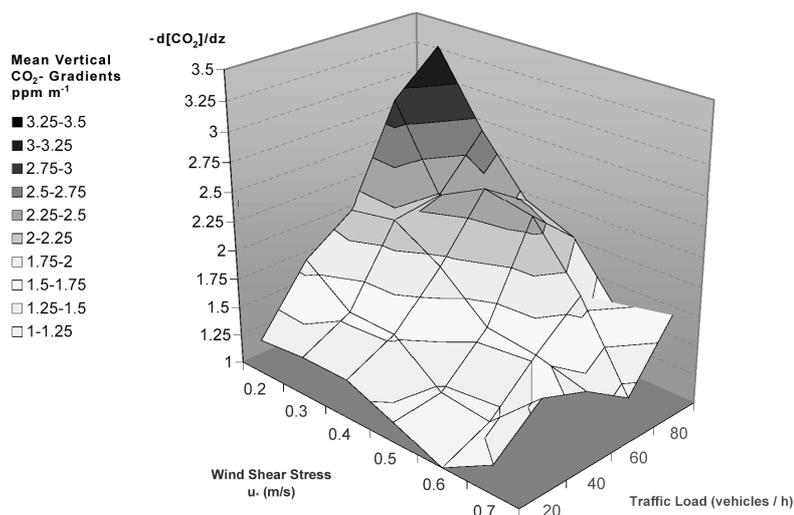
CO<sub>2</sub>-concentrations are always decreasing with height (Fig. 3F). Smallest gradients are observed during early morning hours with low traffic. This results in positive fluxes of CO<sub>2</sub> away from the urban surface all the time with a minimum in the second half of the night and a broad maximum during daytime. This is in agreement with other urban CO<sub>2</sub>-studies. Daytime values are in the range of 10 to 20 μmol m<sup>-2</sup> s<sup>-1</sup> with peak values around 30 μmol m<sup>-2</sup> s<sup>-1</sup>. These values are almost double than the ones reported by Grimmond et al. (2002) half the ones from Nemitz et al. (2002) and in contrast to suburban surfaces, where a daytime CO<sub>2</sub>-uptake was measured (Offerle et al., 2001).

While from Fig. 2A it is not obvious, that there is a difference in CO<sub>2</sub> flux between the two levels, the average diurnal courses reveal, that there is a diurnal pattern in the difference: only during the second half of the night (parallel to the traffic minimum in the street canyon) the fluxes at tower top are larger than the ones at canyon top. During this time also the concentrations at tower top and in the street canyon are coming closest. For the rest of the time, it is – in average- reversed. The reason for that are different source areas. While the fluxes at canyon top are dominated by the local traffic in the Sperrstrasse, the measurements at the tower top see larger areas, which include also assimilation and respiration effects of the (sparse) vegetated backyards. Additionally during night, the top level measures emissions from other streets, where there is still traffic.

The CO<sub>2</sub> concentrations at 0.1 and 31.7 m show a distinct diurnal course: maximum in the morning with the onset of traffic. Although there is less traffic than in the afternoon, the average concentration maximum of around 420 ppm is here, as the mixing is lowest (Fig. 3D,A). The spiky concentration course in Fig. 2B with values of almost 600 ppm comes from the intermittent traffic load. The concentrations at tower top are similar to the one reported by Grimmond et al. (2002) both in terms of amount and time of maximum and minimum. The minimum occurs in the late afternoon due to the efficient high convective mixing. At the same time we observe the maximum in average fluxes, which goes together with the maximum in traffic (Fig. 3E), i.e. the maximum in emissions.



**Fig. 3:** Average diurnal courses of **A:** wind speed in the canyon and the drag coefficient derived from measurements at the top level. **B:** stability derived from measurements at tower top. **C:** CO<sub>2</sub>-fluxes from eddy covariance. **D:** CO<sub>2</sub> concentrations inside and above the street canyon (1.5 and 31.7 m). **E:** traffic load in the canyon. **F:** CO<sub>2</sub>-concentration differences from all 10 levels to the measurement at tower top. Averaging period is March 1 to July 15, 2002, except for C: where data were available only during 3 weeks in June/July 2002.



**Fig. 3:** Mean vertical CO<sub>2</sub>-gradients versus friction velocity  $u_*$  and traffic load.

Another way to look at the CO<sub>2</sub> exchange regime is presented in Fig. 4. Here the interplay between traffic load, mechanical mixing (which depends mainly on wind speed) and CO<sub>2</sub>-gradients (fluxes of CO<sub>2</sub>) becomes obvious: higher emissions (higher traffic) and lower mechanical mixing – here represented by the friction velocity - both increase the absolute value of gradients (spring and summer data, no firing).

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