Selected Characteristics of Turbulent CO_2 Exchange above an Urban Surface

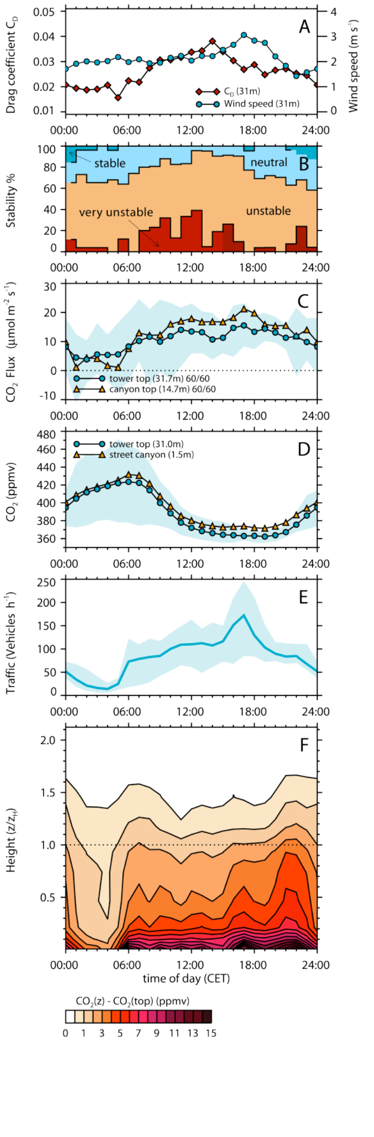
by Andreas Christen(1), Christian Feigenwinter(1), Matthias Roth(2) and Roland Vogt(1)

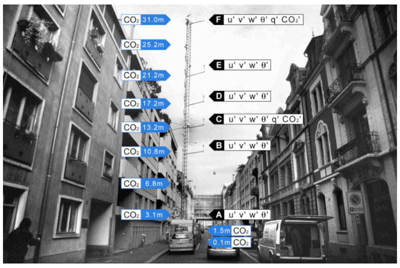
(1) Institute of Meteorology, Climatology and Remote Sensing, University of Basel
(2) Department of Geography, National University of Singapore

Measurements of CO_2-fluxes and concentrations over urban surfaces are rare, even though cities are an important source of CO_2. Results from a short term campaign during the Basel Urban Boundary Layer Experiment (BUBBLE) allow insights in their magnitude, diurnal pattern, and the associated turbulent exchange mechanisms. Unlike over vegetated surfaces where the exchange is dominated by photosynthetic activity and respiration, in this dense city center emissions from fixed industrial, commercial or residential and mobile (traffic) sources are of primary importance.

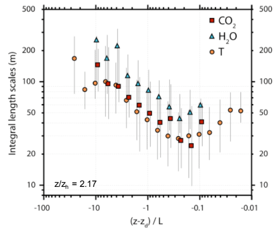
▼ Average diurnal course - **A:** wind speed above the canyon and the drag coefficient derived from measurements at the top level. **B:** stability derived from measurements at tower top. **C:** CO_2-fluxes from eddy covariance. **D:** CO_2 concentrations inside and above the street canyon (1.5 and 31.7 m). **E:** traffic load in the canyon. **F:** CO_2-concentration differences from all 10 levels to the measurement at tower top. Averaging period is June 15 to July 12, 2002, except for C and E: where data were available only during 3 weeks in June/July 2002.

Concentrations are always decreasing with height. This results in positive fluxes of CO_2 away from the urban surface all the time. This is in agreement with other urban CO_2-studies and in contrast to suburban surfaces where daytime CO_2-uptakes are reported (higher vegetation fraction). Smallest gradients are observed during early morning hours with low traffic. Simultaneously, the maximum CO_2-concentration is observed at this time due to the low nocturnal mixed layer height.

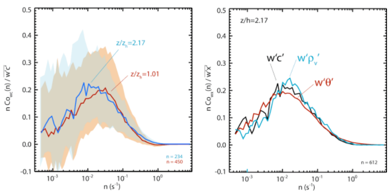




▲ Instrumental setup - The instrumented street canyon "Basel-Sperrstrasse" is located in a densely built-up part of the city of Basel (Switzerland). The surface has a high plane area density of 0.54 and an average building height z_h of 14.6 m. A gas-multiplexer system sampled sequentially air from 10 tower levels during the period January 2002 – July 2002. Air was sucked from each inlet at the tower through a 40 m tube down into a van, where a gas multiplexer and a LICOR 6262 gas-analyzer were operated. During 4 weeks in Summer 2002, two LICOR 7500 open path analyzers were deployed at z/z_h=1.01 (14m) and z/z_h=2.17 (31m).

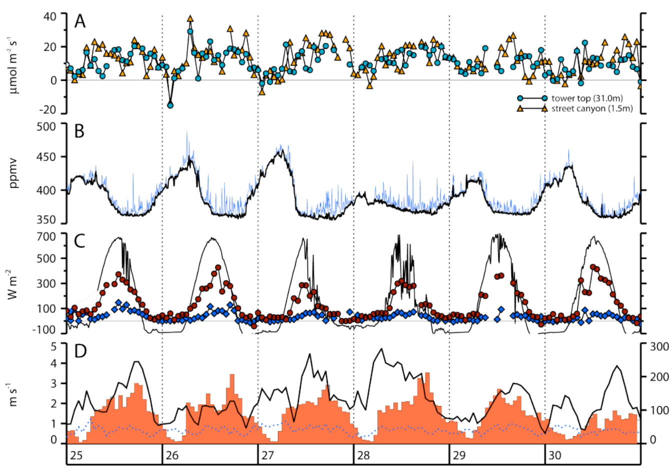


▲ One point integral length scales for neutral and unstable conditions determined from autocorrelation functions indicate that fluctuations of CO_2 have more similarity to temperature fluctuations than water vapour. This may reflect the fact that the urban surface is more homogeneous for heat and CO_2 and than for water vapour. Further, CO_2-fluctuations and temperature are driven by the surface emissions and heating, while the observed water vapour fluctuations (but not the flux density of water vapour) are dominated by processes in the whole PBL, due to low evapotranspiration of the urban surface.

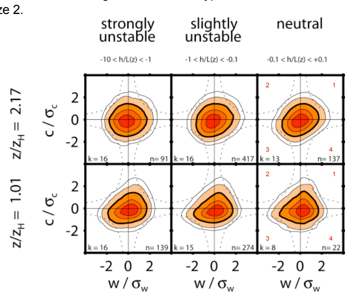


▲ Cospectra – The overall shape of the cospectra Co_{wc} agree well with those from measurements in the homogeneous surface layer. At tower top, the cospectra of $w'\theta'$, $w'\rho_v'$ and $w'c'$ show high agreement, and suggest that same processes dominate the turbulent exchange.

► Sample period from June 25 to June 30, 2002, at Basel-Sperrstrasse. Hourly values of **A:** WPL-corrected CO_2-flux from the LI-7500 at 31.7 m (circles) and at 14.7 m (triangles). **B:** CO_2-concentration from the LI-6262 gas-multiplexer system at 0.1 m (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 (red circles) and latent heat flux (blue diamonds). **D:** Wind speed inside the canyon and at tower top 31.7 m (solid line) and 3.6 m (dotted blue line) and local traffic load in the canyon (orange bars).

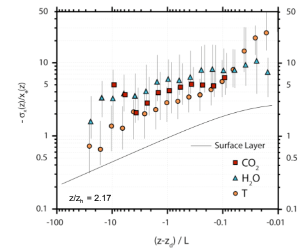


▼ Probability density functions of turbulent CO_2-fluxes illustrate the fundamental differences of the exchange at canyon top and in the urban inertial sublayer at tower top. At street canyon top (lower line), the triangle shape of the PDFs indicates that an increased CO_2-level is higher correlated with upward motions than a lower CO_2-level with downward motions. The exchange is strongly skewed towards the 3rd quadrant ("sweeps"). At tower top, the higher symmetry implies a less skewed exchange. The dashed hyperbolic lines draw a hole of size 2.



▼ Correlation coefficients and quadrant analysis measures for CO_2-flux (black) under neutral conditions (0.1 < $(z-z_d)/L$ < +0.1 at tower top). Values for turbulent flux of water vapour (blue) are given for comparison. The CO_2 exchange is much more effective than water vapour exchange, and it takes place in shorter events. The CO_2 exchange under neutral conditions is dominated by strong downward sweep-like events of air with low CO_2 concentration which mix down into the canyon.

		z/z_h = 1.01 canyon top		z/z_h = 2.17 inertial sublayer	
R_{wc}	Correlation coefficient e.g. $w'c' / (\sigma_w \sigma_c)$	0.13	0.02	0.17	0.08
Sk_c	Skewness	+1.38	+0.04	+0.34	-0.34
Δ_{S0}	Difference between flux fraction of correlated downward motions to upward motions (Q3-Q1)	+0.52	+0.27	+0.13	+0.23
Ex	Counter gradient flux fractions to correlated flux fractions ((Q2+Q4)/(Q1+Q3))	-0.61	-1.06	-0.55	-0.72
H'	Holesize above which half of the flux occurs.	2.15	2.15	1.91	2.00
T'	Time fraction of Events with Holesizes > H' during which half of the flux occurs.	0.07	0.12	0.06	0.07



▲ Integral statistics – The scaled standard deviations of CO_2, H_2O and temperature at tower top are distinctly higher than predicted by surface layer scaling. The irregular three dimensional roughness elements, pressure perturbations and wake-effects behind buildings all enhance mechanical (non-shear) contribution. Further, the large scale heterogeneity of the urban landscape increases low-frequency contributions.