Selected Characteristics of Turbulent CO$_2$ Exchange above an Urban Surface

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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 and at 14.7 m. E: traffic load in the canyon. F: CO$_2$-concentration differences from all 10 levels to the measurement at tower top.

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.

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$_2$ 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.

Sample period from June 25 to June 30, 2002, at Basel-Sperrstrasse. Hourly values of A: 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-625 gas-multiplexer system at 0.1 m (thin line with spikes) and at 14.7 m (thick line). C: Energy balance at tower top (31.7 m) with net radiation (isol. 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).

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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 PDF’s 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 (“wakes”). 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 (blue) under neutral conditions (0.1 < ($\text{u'}\text{w'}$/H) < 0.5 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.

Cone statistics - The scaled standard deviations of CO$_2$, H$_2$O 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-linear) contribution. Further, the large scale heterogeneity of the urban landscape increases low-frequency contributions.