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Temporal dynamics of CO_2 fluxes and profiles over a Central European city

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With 8 Figures

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Summary

In Summer 2002 eddy covariance flux measurements of CO_2 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 Li7500 open path analysers were installed at $z/z_H = 1.0$ and 2.2 above a street canyon with z_H the average building height of 14.6 m and z the height above street level. Additionally, profiles of CO_2 concentration were sampled at 10 heights from street level up to 2 z_H. The minimum and maximum of the average diurnal course of CO_2 concentration at 2 z_H were 362 and 423 ppmv in late afternoon and early morning, respectively. Daytime CO_2 concentrations were not correlated to local sources, e.g. the minimum occurred together with the maximum in traffic load. During night-time CO_2 is in general accumulated, except when inversion development is suppressed by frontal passages. CO_2 concentrations were always decreasing with height and correspondingly, the fluxes – on average – always directed upward. At $z/z_H = 2.2$ low values of about 3 $\mu mol\,m^{-2}\,s^{-1}$ were measured during the second half of the night. During daytime average values reached up to 14 $\mu mol\,m^{-2}\,s^{-1}$. The CO_2 fluxes are well correlated with the traffic load, with their maxima occurring together in late afternoon. Daytime minimum CO_2 concentrations fell below regional background values. Besides vertical mixing and entrainment, it is suggested that this is also due to advection of rural air with reduced CO_2 concentration. Comparison with other urban observations shows a large range of differences among urban sites in terms of both CO_2 fluxes and concentrations.

1. Introduction

An increasing part of the world's population is living in urban areas. The global increase in atmospheric carbon dioxide (CO_2), however, is monitored exclusively in non-urban areas, even though cities are an important source of this greenhouse gas. It becomes increasingly evident, that monitoring the CO_2 signal at not only remote sites helps to quickly identify changes in strength of regional sources and sinks (e.g. for control of emission reduction measures). Quantification of the emissions of urban areas is mainly based on estimates of fossil fuel consumption rather than on direct measurements of CO_2 concentrations and fluxes (Grimmond et al., 2002). Little is known about CO_2 concentrations in urban areas. Their diurnal pattern is a product of anthropogenic, biogenic and meteorological factors and the few existing studies show, that a prominent feature is a large diurnal amplitude. Grimmond et al. report results from a number of observations with amplitudes ranging from about 20 to more than 100 ppmv. The large variability reflects the high diversity of urban areas, which are diverse especially in terms of anthropogenic and biogenic influences.

Measurements of CO_2 fluxes in and above urban canopies are rare up to now. There is an enormous lack in knowledge on the exchange of CO_2, how it is related to sources and sinks, and whether measured CO_2 fluxes can be used for budget considerations. The complex morphological nature of urban surfaces and the inhomogeneous distribution of CO_2 sources and sinks form methodological difficulties which are a challenge for micrometeorological flux measurement techniques. Eddy covariance instrumentation can be used for flux measurements, even above such a rough surface. However the eddy covariance method derives fluxes from point measurements which are related to source areas in complex ways. Measured CO_2 fluxes are reported by Grimmond et al. (2002), who present values sampled from a 27 m high tower situated in a suburban area of Chicago observed in summer 1995. Nemitz et al. (2002) present direct measurements of urban CO_2 fluxes, which were carried out at about 65 m above street level in the center of Edinburgh, Scotland, in November 2000. More recently, Soegaard and Møller-Jensen (2003) report eddy covariance CO_2 flux measurements as part of a large study to describe the spatial CO_2 budget of the metropolitan region of Copenhagen.

The purpose of this paper is (1) to present profile measurements of CO_2 fluxes and concentrations which were carried out in and above a street canyon in summer 2002 in the Central European city of Basel, and (2) to discuss diurnal variations with respect to influence factors such as traffic load or selected meteorological parameters. The measurements were part of the Basel Urban Boundary Layer Experiment (BUBBLE), a COST 715 action (Fisher et al., 2002). The overall aim of BUBBLE was to increase the knowledge of mass, momentum and energy exchange over urban surfaces (Rotach et al., 2004). Within this context the analysis of the present profile measurements of mean CO_2 concentrations and fluxes will help explaining exchange processes rather than quantifying urban emissions.

2. Site and instrumentation

The overall experimental activities of BUBBLE are described in Rotach et al. (2004). This paper deals mainly with measurements carried out in and above the street canyon of Sperrstrasse (47°33′57.2″N, 07°35′48.8″E, 255 m a.s.l.) in Basel. The city has a built-up area of approximately 130 km^2 (30 km^2 dense urban, 80 km^2 suburban and 20 km^2 industrial areas). The instrumented canyon is located in a densely built-up part with a high plane area density λ_p of 0.54, a vegetation fraction λ_v of 0.16 and an average building height z_H of 14.6 m. The values are valid for a circle of 250 m around the tower. The orientation of the canyon is from ENE (67°) to WSW (247°) and its width to height ratio is 1. Additional details are given in Christen et al. (2003) and Christen and Vogt (2004).

A 30 m high triangular lattice tower was installed 3 m off the northern building wall (Fig. 1) and operated during about one year. Six ultrasonic anemometer-thermometers were mounted at 6 levels, components of the net radiation were observed at tower top and inside the canyon, temperature/humidity were measured at 5 levels with psychrometers, wind speed using cup anemometers at 12 levels and CO_2/H_2O-concentration at 10 levels. A CO_2/H_2O gas-multiplexer system sampled sequentially air from the 10 tower inlets. Air was sucked from each inlet through a 40 m tube, routed into a gas multiplexer and was subsequently analyzed by a Li6262 closed path gas-analyzer near the base of the tower. The gas-analyzer was operated in differential mode, i.e. measuring continuously a zero gas in the reference cell. Each channel was sampled for 30 s. The first 10 s after switching were discarded and mean values computed over the remaining 20 s were stored. Mean CO_2/H_2O profiles (10 levels) are therefore available with a resolution of 5 min for the period December 2001 until July 2002. The setup is similar to the one reported by Xu et al. (1999) and a schematic is displayed in Fig. 1.

During an intensive observation period in summer 2002, additional instrumentation was used including two Li7500 open path analyzers installed at $z/z_H = 1.0$ (14 m) and $z/z_H = 2.2$ (31 m). In combination with the sonic anemometers at the same levels (Gill R2 and a Gill HS), they provided CO_2 fluxes. Instantaneous fluctuations were sampled at 20 Hz. Due to the intermittency of the CO_2 sources, 60 min runs were not stationary and CO_2 fluxes were therefore derived from 10 min periods. Block averaging, no rotation, no detrending and the WPL-correction (Webb et al.,

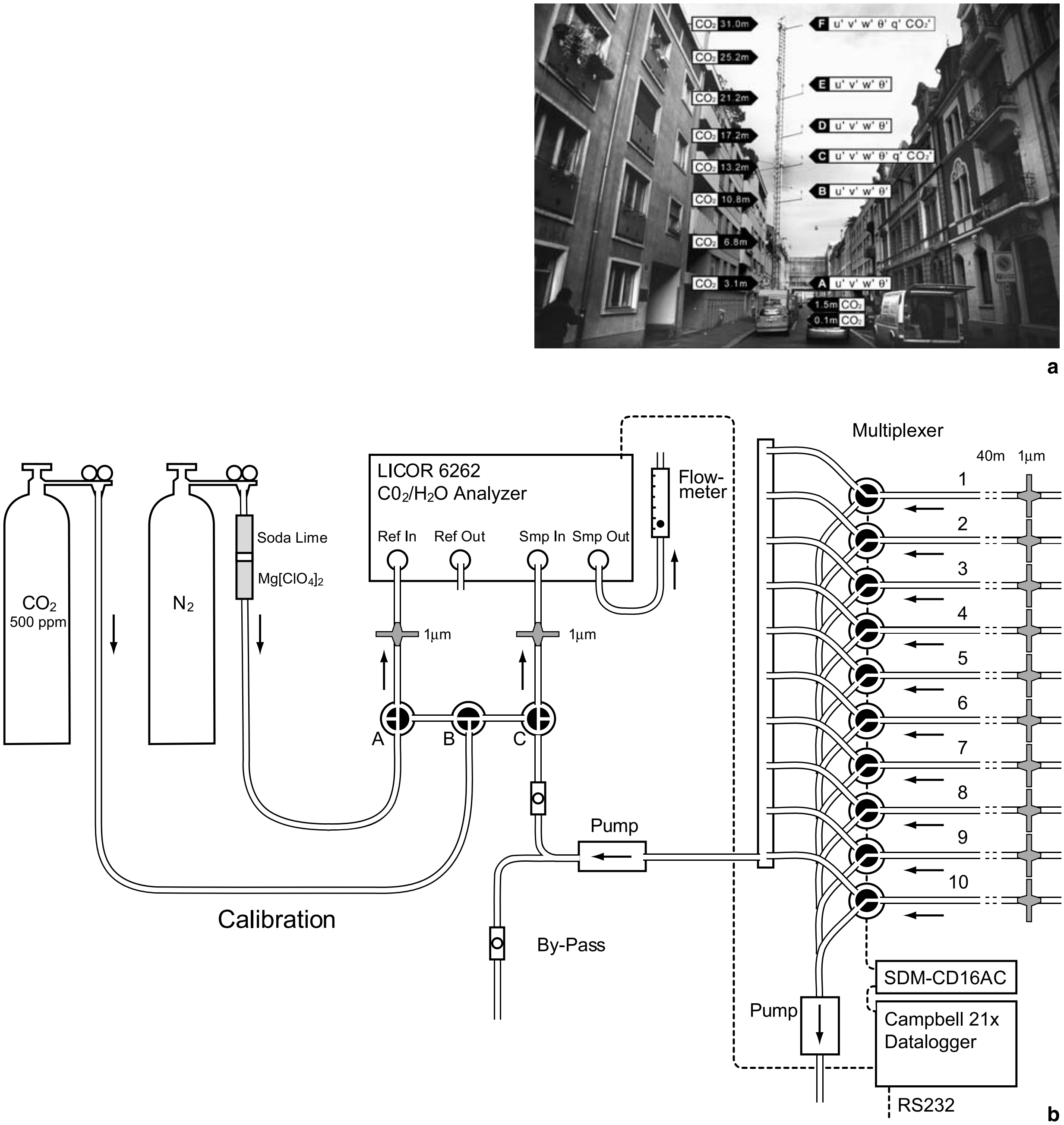

Fig. 1. **a** View on the tower at Sperrstrasse. Heights of inlets for measurement of CO_2 concentration and turbulence instrumentation are indicated. **b** Schematic of the gas-multiplexer system for CO_2 concentration measurements

1980) were applied. The 10 min runs were then aggregated to hourly values.

The traffic in this particular canyon was registered by an automatic traffic counter, which was operated by the city authorities.

3. Results and discussion

An overview of the main variables relevant to the present study during the last days of June 2002 is given in Fig. 2. Wind speed inside the street canyon was generally low and winds at tower top were moderate with peaks around $4\,m\,s^{-1}$ (Fig. 2d). The components of the energy balance (Fig. 2c) indicate, that these days were dominated by clear skies. Sensible heat flux was almost always directed upward with peak values during daytime of around $400\,W\,m^{-2}$. Latent heat flux was smaller, generally below $100\,W\,m^{-2}$.

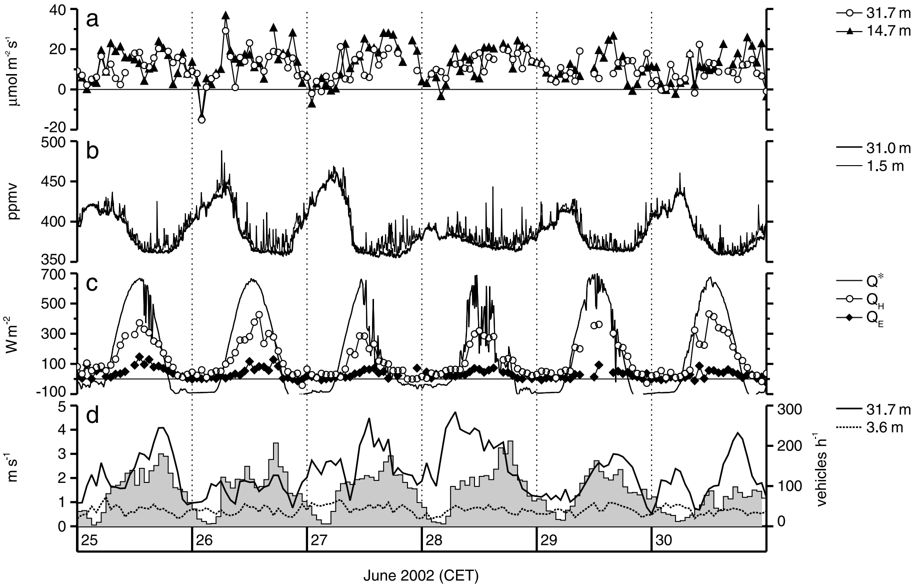

Fig. 2. Overview of main variables used in the present study during June 25 to June 30, 2002, at Basel-Sperrstrasse. Hourly values (except (b): 5 min averages) of **a** WPL-corrected CO_2 fluxes from the LI-7500 at 31.7 m (open circles) and at 14.7 m (black triangles). **b** CO_2 concentration from the LI-6262 gas-multiplexer-system at 1.5 m above street floor (spiky thin line) and at 31.0 m (thick line). **c** energy balance at top of the tower (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)

Traffic load showed the expected diurnal course with a minimum in the second half of the night, and a maximum in late afternoon (Fig. 2d). Sperrstrasse is a one-way-street directing traffic out of the city. This explains the lack of a morning rush hour peak and the singular peak in the afternoon, which is also shown in Fig. 3e, where the average diurnal course of the traffic load is displayed. June 29 was a Saturday and hence did not show a significant afternoon peak. The drop seen after 13 h on Sunday, June 30, was likely caused by reduced traffic due to people watching the soccer world championship final.

3.1 CO_2 concentrations and gradients

The CO_2 concentrations at 1.5 and 31.0 m are plotted in Fig. 2b. The diurnal variability can be clearly seen. The spiky curve of the observations at 1.5 m with values close to 500 ppmv (600 ppm at 0.1 m, not shown) is related to the intermittent traffic load in the street canyon. The atmosphere and hence the concentrations are well mixed at the top of the tower which explains the lower variability seen in the corresponding measurements. The average diurnal courses (27 days) at these two levels are shown in Fig. 3d. Similar to Reid and Steyn (1997) four stages can be identified: (i) low concentrations in the afternoon with minimum values of about 362 ppmv around 19:00, (ii) rising concentrations during late evening and through the night, (iii) maximum value of 423 ppmv between 5:00 to 7:00, followed by (iv), which is characterised by a rapid decrease until noon. The inter-diurnal variation of the values at tower top is documented by the grey area, which contains 90% of the data.

The average diurnal courses of CO_2 concentration reported by Reid and Steyn (1997) and Grimmond et al. (2002) are similar, but have different amplitudes. In Vancouver the range was 27 ppmv (averaged over 11 days), in Chicago site 35 ppmv (13 days), compared to 61 ppmv in Basel (28 days). Day et al. (2002) measured CO_2 concentrations at four locations in Phoenix and their average amplitudes for 19 days range between about 30 to slightly below 60 ppmv, with the latter valid for the two more urbanized stations. Day et al. were interested in the effects of vegetation type on urban CO_2 concentrations and therefore placed their measurements above vegetated areas. The diurnal patterns they found are different from the ones mentioned before. Daytime low concentrations are reached earlier

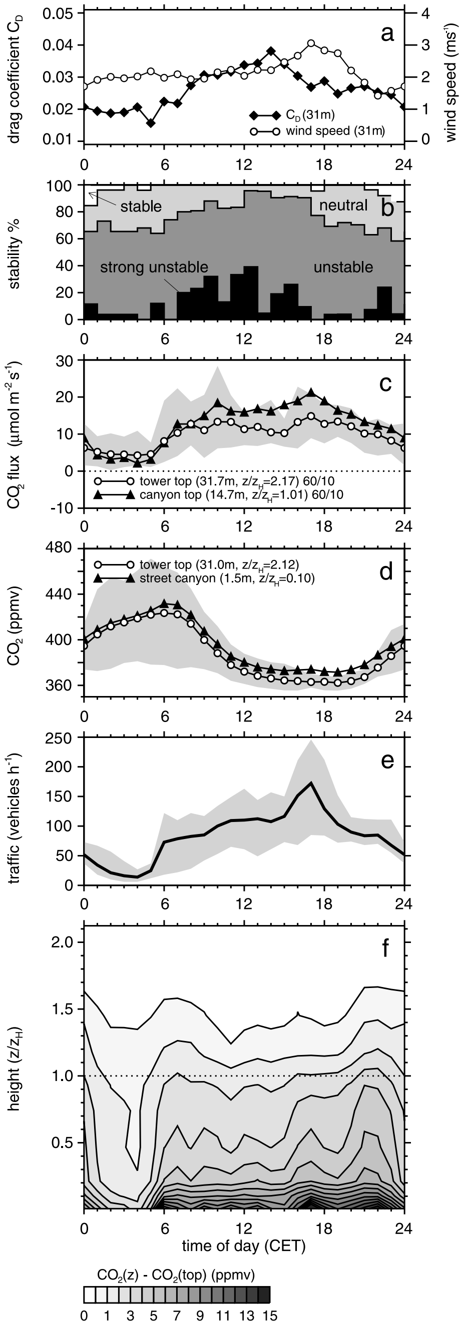

Fig. 3. Average diurnal courses of **a** wind speed in and above the canyon and the drag coefficient derived from measurements at the top level. **b** stability derived from measurements at tower top. **c** CO_2 fluxes from eddy covariance. **d** CO_2 concentrations inside and above the street canyon (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) for which data were available only during 3 weeks in June/July 2002. The grey bands contain 90% of the data

(9:00), which they attribute to CO_2 uptake by the vegetation. A contrasting result is reported by Nemitz et al. (2002). They presented average diurnal cycles from 33 days measured at ≈34 m above street level. The average diurnal courses are stratified according to city center and non-city center wind directions. Observations for the latter course are 2–4 ppmv lower, have a larger amplitude (11 ppmv) and show a minimum of 365 ppmv at around 14:00. As the measurements are taken in November, the minimum is explained with atmospheric boundary layer growth and/or dilution with air from the lower troposphere.

Comparison of urban diurnal courses in CO_2 concentration with rural ones (e.g. Buchmann and Ehleringer, 1998; Bernhofer et al., 2003) reveals few differences. As long as the observations are taken during the vegetation period, are not too far from the surface and are affected by mixed layer dynamics, rural and urban courses of CO_2 concentrations are quite similar both qualitatively and quantitatively.

It is necessary to compare the urban measurements with the regional background concentration of CO_2. The urban values at Sperrstrasse are compared with those from the Schauinsland station of the Global Atmosphere Watch network (Fig. 4). The Schauinsland station is classified as regional and is located 60 km north of Basel on a peak (1205 m) of the Black Forest mountains. More details and data can be found at the World Data Center for Greenhouse Gases (WMO, 2003). The average CO_2 concentration at the Schauinsland site for the 28 days is 369.6 ppmv and is considered the regional background concentration. The average diurnal amplitude is 8.7 ppmv with a minimum of 365.5 ppmv. During daytime urban and regional background concentration are very close. At night the CO_2 concentrations at Sperrstrasse show the typical large excursions, which are related to the build-up of local (shallow) inversions which lead to the corresponding accumulation of CO_2. Exceptions are the nights, when passages of fronts occurred (marked with a triangle in Fig. 4). Here mixing is primarily tropospherical and urban CO_2 concentration levels do not rise much above regional background levels. Further support for this is given when CO_2 concentrations are related to wind direction at Sperrstrasse. It is obvious from Fig. 5, that the nocturnal high-concentration periods are primarily related to flow from South-East. Under autochtonous conditions the wind comes typically from this direction as part of a regional cold air drainage system. At such

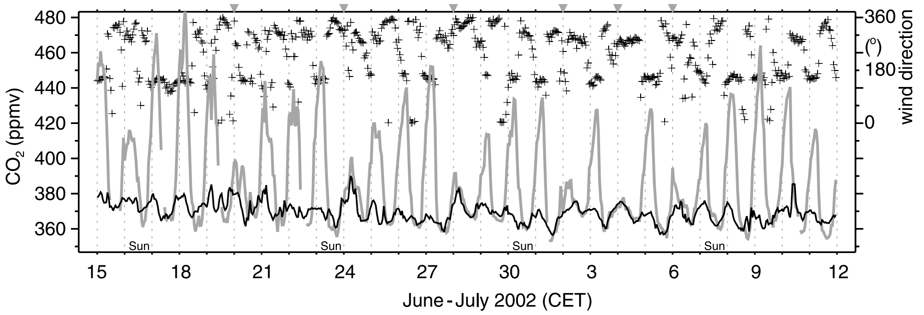

Fig. 4. 1 h averages of CO_2 concentrations for the period June 15 to July 12, 2002. Black line: GAW station Schauinsland. Grey line: tower top Sperrstrasse, Basel. + = wind direction. Triangles mark days with frontal passages. Sundays are indicated by "Sun"

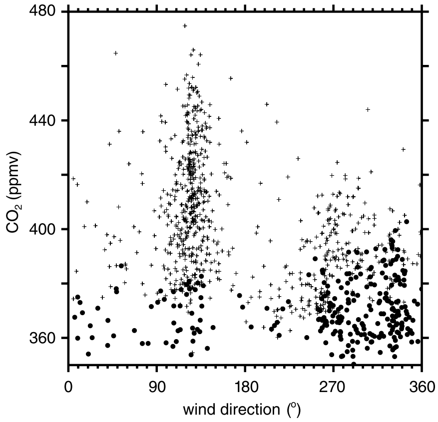

Fig. 5. 1 h averages of CO_2 concentrations versus wind direction between March 1 to July 12, 2002. + = night-time values (22:00–6:00), ● = daytime values (9:00–18:00)

times shallow inversions of depth 100 and 200 m can be expected, which was confirmed by tethered balloon soundings carried out during BUBBLE (Rotach et al., 2004). With winds from westerly directions such high CO_2 concentrations are usually not observed. The fetch towards both South East and West is urban for at least 3 km and it is unlikely that differences in advected CO_2 cause these systematic variations in nocturnal CO_2 concentrations.

During BUBBLE a LIDAR was operated from which it is possible to derive an aerosol mixing layer (aML) height (Rotach et al., 2004). As an example for one day, these values are plotted together with the CO_2 concentrations from two heights at Sperrstrasse (Fig. 6). The aML heights appear somewhat high, but a tethered balloon which escaped at 15:52 on June 26 measured the base of the inversion at 1850 m. Until 18:00 the aML height is around 1900 m dropping to 1500 m at 21:00. The aML heights during nighttime from 21:00 to 7:00 represent rather the height of the residual layer than the height of the surface layer and are less indicative for the mixing processes close to the ground. During a similar night, when the tethered balloon system was available, an inversion developed up to 250 m in depth in the early morning and was eroded from below after 6:00. It is not possible to detect the effects of such a shallow ground based inversion with a LIDAR. However, using a combination of LIDAR and tethered balloon information the daily course of the CO_2 concentration can be explained

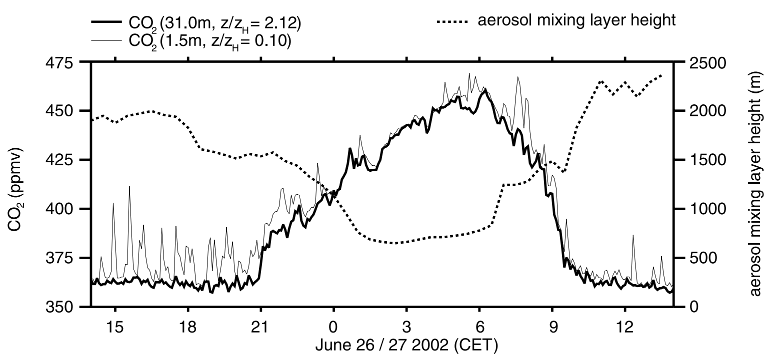

Fig. 6. Aerosol mixing layer derived from LIDAR measurements (dashed line). 10 min averages of CO_2 concentration at tower top (thick line) and in the street canyon at 1.5 m (thin line) between June 26, 14:00 and June 27, 2002, 14:00

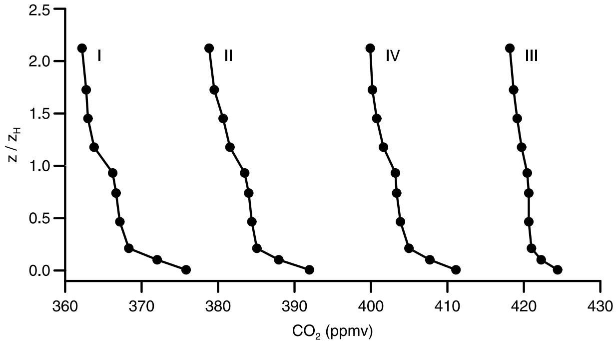

Fig. 7. Average CO_2 concentration profiles for stages (i) to (iv) based on measurements between June 15 and July 12, 2002. (i): 16:00 to 20:00, lowest concentrations, highest traffic load, good mixing. (ii): 21:00 to 24:00, rising concentrations, reduced traffic, low mixing. (iii): 3:00 to 7:00, concentration maxima, starting traffic, low mixing. (iv): 8:00 to 11:00, decreasing concentration, moderate traffic, good mixing

fairly well. Accumulation starts with the build-up of the ground based inversion and maximum concentrations are reached just before the inversion starts to become eroded at the surface. At the same time the morning rush hour occurs, but because mixing processes also become more efficient, concentrations drop and reach below regional background values already before noon on June 27.

From ground level up to two times the mean building height the concentrations of CO_2 are – on average – always decreasing with height (Fig. 3f). Smallest gradients are observed during the second half of the night, when the traffic load is lowest. The average concentration profiles for stages (i) to (iv) are shown in Fig. 7 and one can discern a street layer up to $z/z_H \approx 0.2$, where gradients are strongest, followed by a canyon layer up to z_H and an above canopy layer. The absolute values of CO_2 concentration are not related to local traffic load, while the gradients in the street layer (and also at z_H) are dominated by the latter.

3.2 CO_2 fluxes

This results in CO_2 fluxes which are closely related to traffic load and directed away from the urban surface almost all the time (Fig. 3c). Smallest fluxes with values around 3 and 5 $\mu mol\, m^{-2}\, s^{-1}$ at canyon and tower top occur in the second half of the night from 1:00 to 5:00 when also the smallest traffic load occurs. With the onset of traffic, the CO_2 fluxes rise to around 16 and 12 $\mu mol\, m^{-2}\, s^{-1}$ at canyon and tower top, respectively. They stay in that range until about 19:00 with a minor peak at 9:00 (17.9 and 13.3 $\mu mol\, m^{-2}\, s^{-1}$) and the maximum at 17:00 (21.2 and 14.9 $\mu mol\, m^{-2}\, s^{-1}$). After this peak, CO_2 fluxes decrease in phase with the traffic load to their daily minimum values at around 4:00. The 24 h averages are 12.5 and 9.9 $\mu mol\, m^{-2}\, s^{-1}$ for canyon and tower top, respectively.

The average diurnal courses of CO_2 flux measurements at the two heights show some interesting features: during the second half of the night, when the traffic is low in the street canyon, the fluxes at tower top are larger than those at canyon top (Fig. 3c). During this time, concentrations at tower top and in the street canyon are also very similar. During the rest of the day the CO_2 fluxes at canyon top are higher. This pattern can be explained by the different source areas seen by the sensors at different heights. While the fluxes at canyon top are dominated by the local traffic in the Sperrstrasse, the measurements at the tower top see larger areas, i.e. emissions from other street canyons, the emissions related to domestic heating and also the assimilation and respiration effects of the sparsely vegetated backyards. Blending of the various sources and sinks leads to smaller fluxes at tower top, which, however, better represent the local urban area. As mentioned already, during the second half of the night the fluxes at tower top are slightly larger. This is probably due to the fact that vegetation now is a relevant source seen only by the upper level.

The availability of simultaneous measurement of fluxes and gradients of CO_2 allows to test the applicability of the flux-gradient-relationship as predicted from Monin-Obukhov similarity theory (MOST). We cannot expect to find a well developed relationship, because the measurements are taken within the roughness sublayer. This is especially true for the canopy top level, while the tower top level is possibly at the upper boundary of the roughness sublayer. The source and sink distribution is heterogeneous and sources are intermittent. The dimensionless gradients or stability functions for the two levels are calculated as

$$\phi_{CO_2} = k \frac{z - z_d}{C_*} \frac{\partial \bar{c}}{\partial z},$$

where $k = 0.4$ is the von Karman constant, z_d is the zero-plane displacement taken as $2/3 z_H$

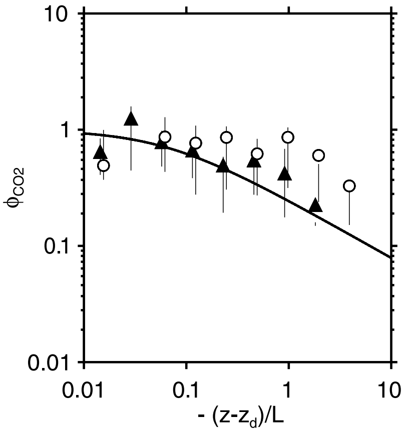

Fig. 8. Nondimensionalised CO_2 gradients for tower top (circles) and canopy top (triangles). Fluxes are from eddy covariance measurements and gradients are derived from the concentrations at 31.0/25.2 m and at 10.8/13.2/17.2 m sampled between June 15 and July 12, 2002. Displayed are class averages of 1 h values with a frequency of a least 3 per bin. Error bars enclose 50% of all data. The black line denotes the Dyer-Businger relation $(1\text{–}16(z\text{-}z_d)/L)^{-0.5}$ for sensible heat, with L the Obukhov length $L = -u_*^3 Tk^{-1} g^{-1} \overline{w't'}^{-1}$, where T is temperature, g is acceleration due to gravity and $\overline{w't'}$ is the kinematic heat flux

(Grimmond and Oke, 1999), C_* is the scaled CO_2 flux (i.e. divided by u_*, the friction velocity) and $\bar{c}$ is the average concentration of CO_2. According to MOST ϕ_{CO_2} is a function of the stability index $(z\text{-}z_d)/L$ only. Here we use local flux values to determine the Obukhov length L.

In Fig. 8 the ϕ_{CO_2} values are plotted versus stability index. Those from the canopy top follow – on average – the MOST prediction quite well. This was not expected, but may reflect the fact, that contributions from different sources are sufficiently mixed at canopy top level. The ϕ_{CO_2} values at tower top show larger scatter and seem not to depend on the stability index. Due to the horizontal heterogeneity in source and sink distribution, gradients and fluxes do not reach a stability dependent equilibrium.

Grimmond et al. (2002) present an average diurnal pattern of CO_2 fluxes from 13 days in Chicago. The fluxes are always positive in the range 0 to 10 $\mu mol\,m^{-2}\,s^{-1}$, but the timing of maxima and minima is quite different compared to observations from Basel. Nocturnal values are around 3 to 5 $\mu mol\,m^{-2}\,s^{-1}$ and minimum values slightly above 0 $\mu mol\,m^{-2}\,s^{-1}$ are reached at 8:00, which then slowly increase to 3 $\mu mol\,m^{-2}\,s^{-1}$ around 13:00. The flux maximum occurs at 18:00 and values remain relatively high at around 7 $\mu mol\,m^{-2}\,s^{-1}$ until midnight. The CO_2 fluxes at the Chicago site seem to be strongly influenced by the CO_2 uptake/release by the vegetation, which covers 39% of the local area. There is also large inter-diurnal variability as standard deviations of hourly fluxes vary between ± 10 and ± 20 $\mu mol\,m^{-2}\,s^{-1}$ during day and night, respectively.

The CO_2 fluxes presented by Nemitz et al. (2002) are also relatively high. The average diurnal cycle starts at 10 $\mu mol\,m^{-2}\,s^{-1}$, rises between 3:00 to 9:00 to 32, drops to 24 $\mu mol\,m^{-2}\,s^{-1}$, rises again to reach the maximum of about 38 $\mu mol\,m^{-2}\,s^{-1}$ shortly after 14:00 and decreases thereafter until midnight. Separating in city center and non-city center directions dramatically decreases the non-city values to around 10 $\mu mol\,m^{-2}\,s^{-1}$ and increases the city values by up to 8 $\mu mol\,m^{-2}\,s^{-1}$. The range of the fluxes was from -12 to 135 $\mu mol\,m^{-2}\,s^{-1}$ with a daily average of 22 $\mu mol\,m^{-2}\,s^{-1}$.

Soegaard and Møller-Jensen (2003) present the annual course of measured monthly averages of mean daily CO_2 fluxes for 2001. The values extracted from their Fig. 2 from June to November are 3.2, 1.6, 3.3, 5.9, 5.7 and 6.1 $\mu mol\,m^{-2}\,s^{-1}$, respectively. The measurements were taken at the top of a 40 m mast in an area with 20 to 25 m high buildings in the central part of Copenhagen.

Comparing average values of CO_2 fluxes between urban areas has its limitations. The distribution of sources and sinks is 3-dimensional and CO_2 concentrations are highly variable, vertically and – more important – horizontally. Additionally, concentrations over (not only) urban areas are largely dominated by mixed layer dynamics and advection, and depend, to a lesser extent, also on upwind conditions. A good example is the afternoon drop of the CO_2 concentrations close to or below background values. It would be difficult to explain it locally, when net CO_2 fluxes are directed upward. As a rough estimate we can calculate from Fig. 3d for the 14 daytime hours from 6:00 on the CO_2 accumulation from the measurements at tower top. If the average flux rate of 12.2 $\mu mol\,m^{-2}\,s^{-1}$ distributes CO_2 in a column with a height of 2000 m, this would lead to an increase of $\approx$7.4 ppmv. The daytime increase should even be higher, as the nocturnally accumulated CO_2 has additionally to be distributed in the column. Vertical mixing in terms of dilution in a larger volume can alone not be the reason, as the urban CO_2 input can not be ‘‘diluted away’’. There has to be entrainment of tropospheric air with low CO_2 concentrations and – probably more important, in order to get CO_2 concentrations close to or below regional background – advection of air with reduced CO_2 levels from sink dominated areas has to take place. A similar estimation for the remaining 10 night-time hours would give an increase in concentration of $\approx$28.6 ppmv, if accumulation is allowed into a 200 m high column. This corresponds well to the measured increase of 60 ppmv, as the latter value is certainly too high for the whole column. Contrary to daytime, the nocturnal courses can be explained locally.

Additional insight in the mixing process and how different sources contribute to average CO_2 concentrations can be gained by investigating the isotopic composition of the urban atmosphere. Pataki et al. (2003) reported from a year-long study in Salt Lake City where they were able to separate anthropogenic and biogenic effects by use of the isotope-tracer technology. They partitioned contributions into average CO_2 background concentration, gasoline combustion, natural gas combustion and respiration, and documented their seasonal changes. For the above background night-time concentrations in June/July gas combustion was identified as dominating source, while respiration was less important (about 10 to 20%). Widory and Javoy (2003) carried out a study in Paris, and although their ‘‘sampling was neither systematic nor extended over a sufficiently long period’’, they demonstrated the feasibility of combining isotope and concentration approaches. Even the signature of human respiration was recognised under certain circumstances. Finally, Takahashi et al. (2002) report from a one day experiment in and above an urban forest in Japan in winter. They document the diurnal course of the partitioning between fossil fuel and soil respiration above background CO_2.

No unique ‘‘urban’’ picture emerges based on the currently available CO_2 fluxes reported in the literature. The site to site flux variability reflects the real diversity of urban areas. This diversity is not yet adequately covered by experimental studies. Putting aside instrumental and methodical issues, the fluxes are valid for the point in space where they were measured. It is well known, that fluxes measured at a certain height are influenced by a certain source area. The extend of this area needs to be known, and detailed descriptions of surface properties are necessary, e.g. the vegetation fraction, in order to be able to better assess the influence of biospheric uptake or release of CO_2. Clearly, more long-term studies from a variety of cities are needed.

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