CO_2 FLUXES AND CONCENTRATIONS OVER AN URBAN SURFACE IN CAIRO/EGYPT

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1. INTRODUCTION

While the surface-atmosphere exchange of CO_2 has been studied for many different natural surfaces, the exchange over urban surfaces has come into focus only in recent years. As the amount of fossil fuel combustion in cities is large, the CO_2 emissions are considered to be equally high. Cities therefore act as local CO_2 sources. Most of the earlier urban CO_2 studies took place in cities of developed countries in Europe, Northern America or Asia. However, studies from less developed countries are rare. Therefore, this study is of special interest, as it shows results of Cairo, a city of a less developed country within an arid environment.

The measurements of CO_2 fluxes and concentrations analyzed in this study were taken in the framework of the CAPAC project (Cairo Air Pollution and Climate) carried out by the Institute of Meteorology, Climatology and Remote Sensing of the University of Basel/Switzerland.

The objective of this study was to provide insight into the CO_2 fluxes and concentrations of Cairo. Due to the location of the measurement site, it was possible to divide the surface around the station into different land use sectors, similar to the way it was done by Vesala et al. (2007). Therefore, the study also aimed at investigating the influence of different urban surfaces on the CO_2 fluxes and concentrations. A question always kept in mind was if and to what extent vegetated areas were capable of reducing urban CO_2 emissions by photosynthesis.

2. METHODS AND MATERIAL

CO_2 fluxes were measured by applying the eddy covariance (EC) method. The set-up consisted of an ultrasonic anemometer (CSAT3, Campbell) and an open-path infrared gas analyzer (LI-7500, LI-COR). The instruments were fixed on top of a 12 m mast which was erected on the flat roof of a building of the campus of the University of Cairo. This resulted in a total measurement height of 35 m above ground. The measurement site was operated from Nov 10, 2007 to Feb 26, 2008. The fluxes were calculated online including corrections for density fluctuations.

The surroundings of the station showed different surface properties depending on the wind direction. The area to the north and north-west of the station was mainly urban built-up area. In a distance of about 300 m a street with several lanes in both directions and very intense traffic was located. Eastwards from the station, the zoological garden of Cairo was located, while, also in about 300 m distance, another street with intense traffic was situated in between the campus area and the zoological garden. To the south and south-west, the area consisted of agricultural fields as well as sports areas. The agricultural fields reached almost 1 km into the south. The closest street to the west and south-west was located about 500 to 800 m away.

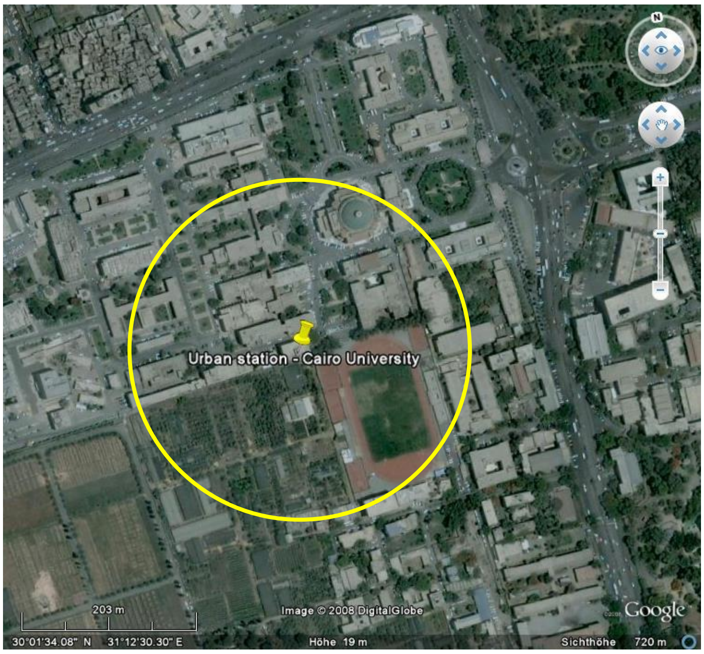

Fig. 1: Surroundings of the station in Cairo. Circle ∅ 200m

Due to the spatially varying surface covers, three land-use sectors were defined: A north sector (270-40°, predominantly urban, buildings and roads with heavy traffic), an east sector (40-135°, including the zoological garden) and a south sector (135-270°, agricultural fields and sports field). A stability dependent analysis of the CO_2 fluxes and concentrations was performed for each sector. Additionally a flux footprint estimation was carried out (Hsieh et al., 2000), which gave an estimate of the peak location of the flux as well as of the 90%, 75% and 50% flux fetch requirements depending on stability.

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3. RESULTS AND DISCUSSION

3.1 Meteorological Conditions

The temperature decreased from November to January and increased again in February (monthly averages: 19.3°C, 16.2°C, 13.0°C, 14.1°C). The wind speed showed a clear diurnal pattern. The maximum wind speed was usually observed between 2 and 3 pm and the minimum at around 7 am. The predominant wind directions were NE and SW. There was no obvious difference between diurnal and nocturnal wind directions; winds from the north were more frequent and normally also stronger. Rain was very rare during the observation period.

3.2 CO_2 Fluxes

The mean CO_2 flux over the entire measurement period was 6.18 µmol m^{-2} s^{-1}, while 50 percent of the data lay between 1.19 and 9.86 µmol m^{-2} s^{-1}. Thus, on average the fluxes were always positive and directed away from the surface. Median peak values ranged between 15 and 20 µmol m^{-2} s^{-1}. Surprisingly, the average CO_2 fluxes measured in Cairo were not higher than those reported from previous studies in other cities. On average, they were even lower than the fluxes reported from Basel by Vogt et al. (2006) or from Chicago by Grimmond et al. (2002). We expected to find higher CO_2 fluxes due to the heavy traffic in Cairo and the relatively low technology of cars. Moreover, the CO_2 fluxes showed only a single maximum between 1 and 3 pm, which differs from previous studies (Velasco et al. (2005), Vogt et al. (2006)), where often two rush-our peaks (in the morning and in the late afternoon) were observed. The CO_2 fluxes showed a distinct weekly cycle (Fig. 2). On Fridays (Sabbath in Cairo with strongly reduced traffic intensity), they were remarkably lower, while on Saturdays, the fluxes were higher again but on average still lower than the fluxes on the subsequent weekdays.

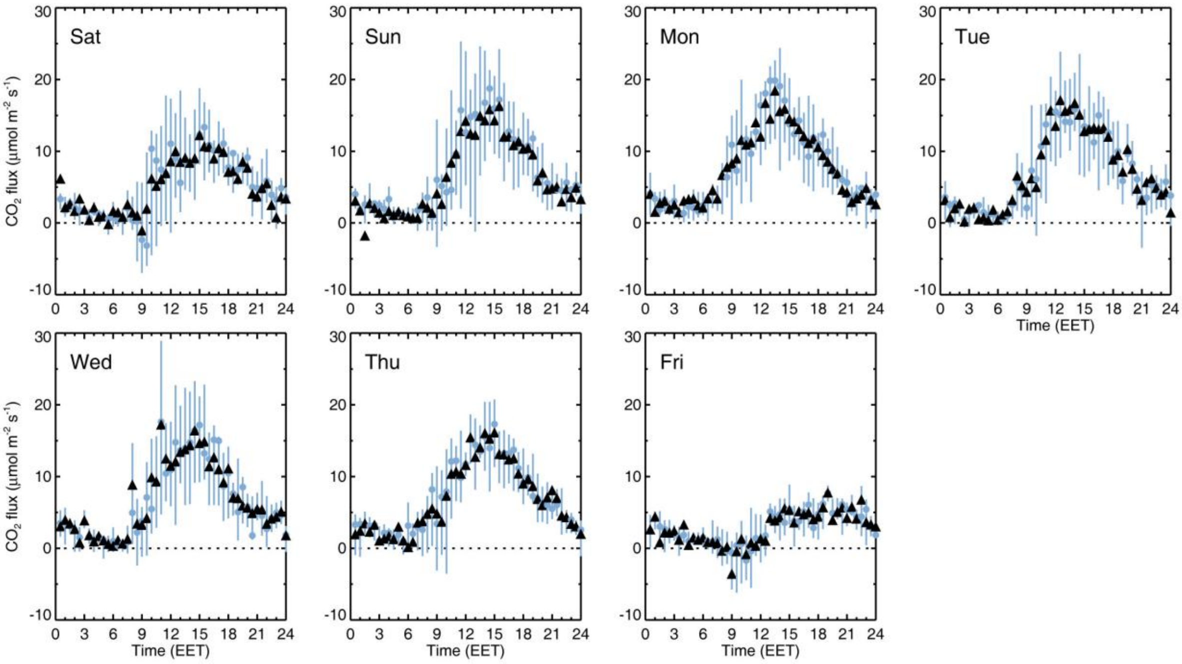

Fig. 2: Average diurnal courses of CO_2 fluxes per weekday. Triangle: mean, circle: median ±25%.

3.3 CO_2 Concentrations

The mean concentration over the whole measurement period was 403 ppmV and 50 percent of the data lay between 388 and 411 ppmV. The CO_2 concentrations showed the maximum in the morning (Fig. 3) with median values around 430 ppmV. Also Grimmond et al. (2002), Nemitz et al. (2002), Velasco et al. (2005) and Vogt et al. (2006) had already found the highest concentrations in the early morning. The peak values in Cairo, however, occurred later than expected, at around 8 to 9 am. This delay could be assigned to the daily course of stability, as the change from stable to unstable conditions usually happened only at about 8 am. The CO_2 concentrations were clearly influenced by the diurnal course of stability i.e. the height of the planetary boundary layer, while no influence of traffic on the CO_2 concentrations could be detected.

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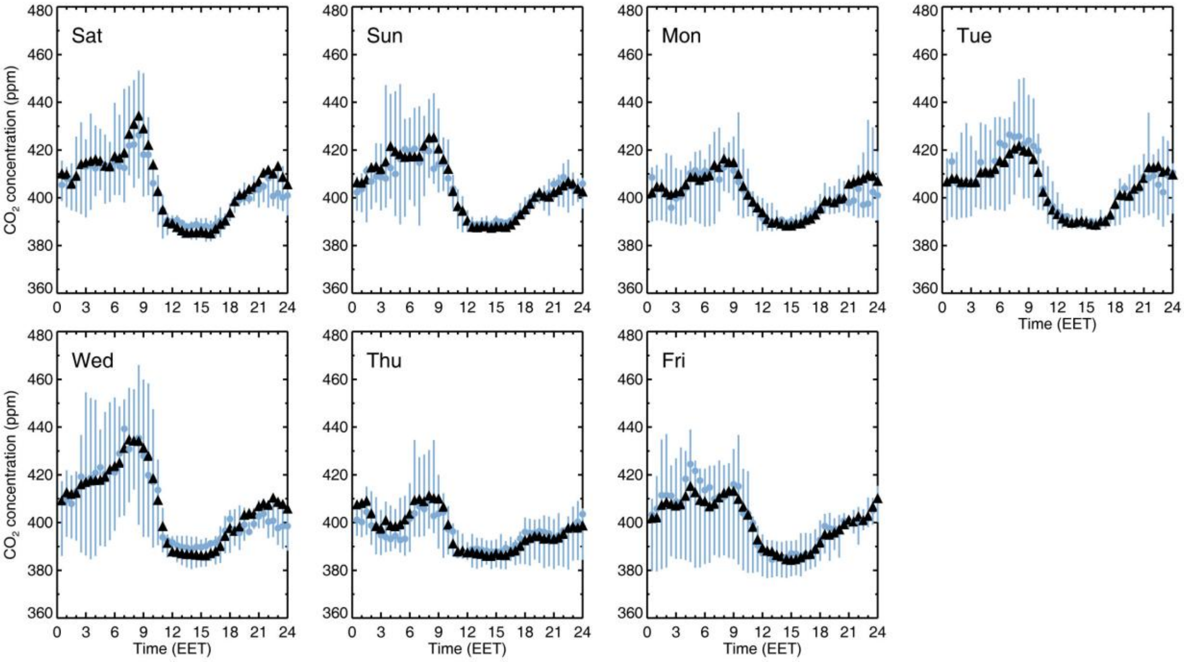

Fig. 3: Average diurnal courses of CO_2 concentrations per weekday. Triangle: mean, circle: median ±25%.

3.4 Sector-Dependent CO_2 Fluxes and Concentrations

The sector-dependent analysis provided insight into the influence of different urban surfaces on the CO_2 fluxes and concentrations. Of special interest was, if and to what extent the vegetation south of the measurement site and the zoological garden east of the measurement site would be able to reduce the CO_2 emissions.

Figure 4 shows the average diurnal courses of CO_2 fluxes and concentrations per land use sector. The CO_2 fluxes were higher over the north sector than over the south sector (while the values from east sector were in between). At around 9 am, the fluxes of the south sector were negative, whereas the ones of the north sector were positive. Thus, the vegetation of the south sector was able to reduce the CO_2 emissions as previously observed by Vesala et al. (2007). For the east sector, the question was whether the vegetation of the zoological garden some distance to the measurement site would show an effect on the CO_2 fluxes, even if a street with high traffic density was located between the measurement site and the zoological garden. It seems that the influence of the zoological garden on the CO_2 flux was not very large, and that the measurements were mainly influenced by the close-by street. This was confirmed by the estimation of the flux fetch requirements, as the zoological garden was only included in the 90% flux fetch requirement under unstable conditions. (Note, however, that the data availability for the east sector was very low, since the winds were rarely blowing from this direction.)

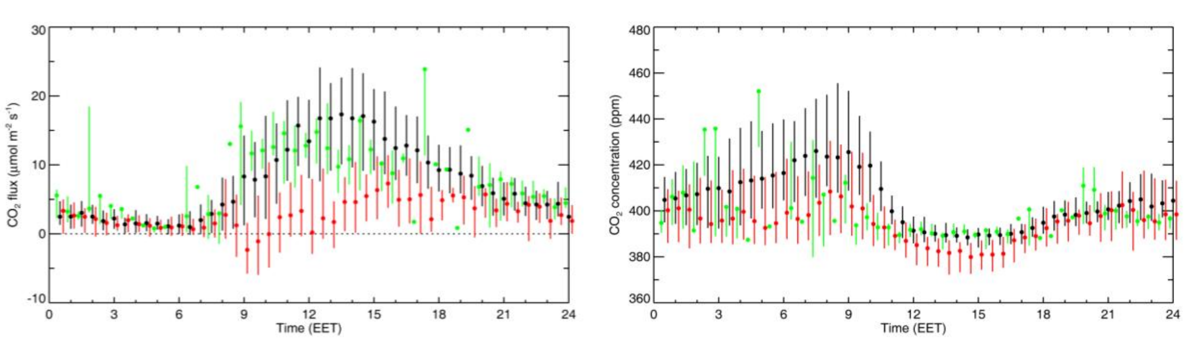

Fig. 4: Average diurnal courses of CO_2 fluxes (left) and of CO_2 concentrations (right) per land use sector. Circle: median ±25%. Black: north sector, red: south sector, green: east sector.

In general, the CO_2 fluxes were influenced more noticeably by the different source areas than the CO_2 concentrations. Differences induced by the different surfaces in the three land use sectors were more evident for the CO_2 fluxes than for the CO_2 concentrations. Nevertheless, the nocturnal concentrations were remarkably

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lower in the south sector than in the north sector. The nocturnal conditions during flow from the south sector were generally more stable which could have concentrated respired and emitted CO_2 in the layers below the measurement level while during flow from North this layer of accumulation reached above it.

3.5 Conclusion

The aim of this study has been to provide insight into the CO_2 fluxes and concentrations in Cairo, a megacity in an arid environment. In Cairo, with its high traffic density and high percentage of old cars as well as other CO_2 emitters, it was expected to measure higher CO_2 fluxes than in cities of more developed countries. However, the observed CO_2 fluxes and concentrations turned out not to be higher on average than those measured in other cities. This is probably due to the fact that the campus area is a significant part of the source area for the CO_2 fluxes and has much less traffic than the area adjacent to the North. A quantification is difficult but it is likely that the CO_2 fluxes are underestimated. The direct influence of traffic was not as obvious as it could have been expected based on previous studies; no distinct rush-hour peaks occurred. The influence of traffic, however, became evident on Fridays (Sabbath in Cairo), when the fluxes were considerably lower compared to the other weekdays. The CO_2 concentrations were clearly influenced by the diurnal course of stability, while the influence of the traffic on the CO_2 concentrations was not as obvious.

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