CONTINUOUS NET CO_2 FLUX MEASUREMENTS IN COMPLEX URBAN ENVIRONMENT IN HELSINKI, FINLAND

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Abstract

Direct measurements of CO_2 fluxes with the eddy covariance (EC) technique have been made in Helsinki, Finland, since Dec 2005. Purpose of this study was to analyze the temporal behaviour of the CO_2 fluxes, and their dependence on surface cover. Besides, the necessary correction procedures, were studied with simultaneous measurements made with open- and closed-path CO2/H2O gas analyzers.

The surroundings acted as a source for CO_2 reaching 19 μmol m^2 s^{-1} in the direction of the road in winter. In direction with high vegetation cover, the flux remained below 7 μmol m^2 s^{-1}, and in summer, vegetation uptake exceeded the anthropogenic emissions and downward flux of 8 μmol m^2 s^{-1} was observed in daytime. CO_2 fluxes measured with the different analyzers correlated well (R^2 = 0.93), but on annual scale the open-path analyzer gave 17% lower net surface exchange (NSE) than the closed-path analyzer. This systematic difference can be explained with the open-path sensor heating causing apparent uptake of CO_2. The applied corrections decreased the difference in NSE down to 2%.

Key words: CO_2 flux, eddy covariance technique, land use, sensor heating correction

1. INTRODUCTION

Carbon dioxide (CO_2) has been recognized to be one of the major compounds affecting the radiative forcing of climate (IPCC 2007). Its emissions are largely affected by human activity via land use changes and fossil fuel combustion from which especially road traffic is know to contribute CO_2 emissions in urban areas. Even though many of the CO_2 sources have been indentified, there is still lot of uncertainty in the exact magnitude and distribution of sources. In Helsinki, Finland, the direct measurements of CO_2 fluxes with the eddy covariance (EC) technique were started at the urban measurement station SMEAR III in December 2005. The complex measurement surrounding enabled us to study the effect of different urban covers on CO_2 emissions, while the northern location provided information about the fluxes during pronounced seasons. In addition, purpose was to examine differences between the CO_2 fluxes measured with the open- and closed-path infrared gas analyzers and the effect of sensor heating of the open-path CO_2 fluxes.

2. MEASUREMENTS AND METHODS

The CO_2 flux measurements were carried out at the urban measurement station SMEAR III (*Station for Measuring Ecosystem – Atmosphere relations*) in Helsinki, Finland. The measurements were made on top boom of a 31 m high lattice tower situated on a hill (26 m above sea level, 60°12'N, 24°57'E) 5 km north-east from the Helsinki City Centre. The surrounding of the measurement tower is heterogeneous consisting of different kind of surface covers from vegetative areas to paved parking lots. Thus it can be divided into urban, road and vegetation sectors according to the typical land use on each sector. Urban sector is mainly covered with the University of Helsinki buildings and Finnish Meteorological Institute (mean height of 20 m) and roads and parking lot. In the road sector, one of the main roads (45 000 vehicles workday^{-1}) leading to the Helsinki City Centre passes the measurement tower with a distance of 150 metres. The space between is covered with deciduous forest. University Botanical gardens and allotment garden are situated in the vegetation sector, where the fraction of vegetated area is high (85%). In this study data between Dec 2005 and 2008 was analyzed. The measurement period was divided into four seasons: winter (Dec-Mar), Spring (April-mid-May), summer (Mid-May-Aug) and fall (Sep-Nov).

The measurement set-up consisted of a Metek ultrasonic anemometer (USA-1, Metek GmbH, Germany) to measure all three wind components and sonic temperature, and open- and closed infrared gas analyzers (LI-7500 and LI-7000, respectively, LI-COR, Lincoln, Nebraska, USA) to measure CO_2 densities and mixing ratios, respectively. Measurement resolution of 10 Hz was used.

The average CO_2 fluxes were calculated with EC technique as a co-variance between the vertical wind speed *w* and respective scalar. Commonly accepted procedures were used in the flux calculation (Aubinet *et al.* 2000) with linear de-trending and 2-dimensional coordinate rotation. In addition to the traditional WPL correction (Webb *et al.* 1980), the density fluctuations generated by the open-path sensor itself should be taken into account when calculating open-path CO_2 flux (F_{OP})(Burba *et al.* 2006, 2008). Three different methods to correct the effect of this sensor heating were tested over one year of measurements from Jul 2007 to Jun 2008. In the first method, the fitting method, sensor heating correction is added on the traditionally corrected F_{OP}. The correction itself is determined with a non-linear fit in a least square sense to F_{OP} and closed-path CO_2 flux (F_{CP}), the latter representing the actual flux. In the other two methods, the multiple linear regression (MLR) and linear methods, the heat flux generated by the open-path analyzer is added to the heat flux used in the traditional WPL correction (Burba *et al.* 2008). The surface heat fluxes are calculated with resistance approach where the surface temperatures have been calculated with multiple linear regression from meteorological parameters and with linear regression from air temperature, respectively, according to Burba *et al.* (2008). Details about the correction methods can be found from Järvi *et al.* (2009).

3. RESULTS

The seasonal behaviour of the CO_2 fluxes showed medians ranging between -10 and 20 μmol m^2 s^{-1} with the downward fluxes occurring during summer (Not shown). The diurnal behaviour of fluxes followed the traffic patterns in Helsinki area especially in the road sector, where the fluxes reached 19 μmol m^2 s^{-1} in winter (Fig. 1). Clear relationship between the CO_2 fluxes and road traffic in the road sector was evident and emissions from other sources were found to be 1 μmol m^2 s^{-1} (Vesala *et al.* 2008).

In the vegetation sector, the fluxes stayed below 7 μmol m^2 s^{-1}, and in summer, the vegetation uptake exceeded the anthropogenic emissions and downward flux of 8 μmol m^2 s^{-1} was observed. The effect of vegetation was also distinguishable in other land use sectors in summer around the noon. Nocturnal fluxes in the vegetation sector were 2-3 µmol m^{-2} s^{-1} higher in summer than during other seasons due to increased vegetation respiration. This agrees with the respiration level 1-3 µmol m^{-2} s^{-1} measured with soil chambers from treeless vegetation around the measurement tower (Vesala *et al.* 2008).

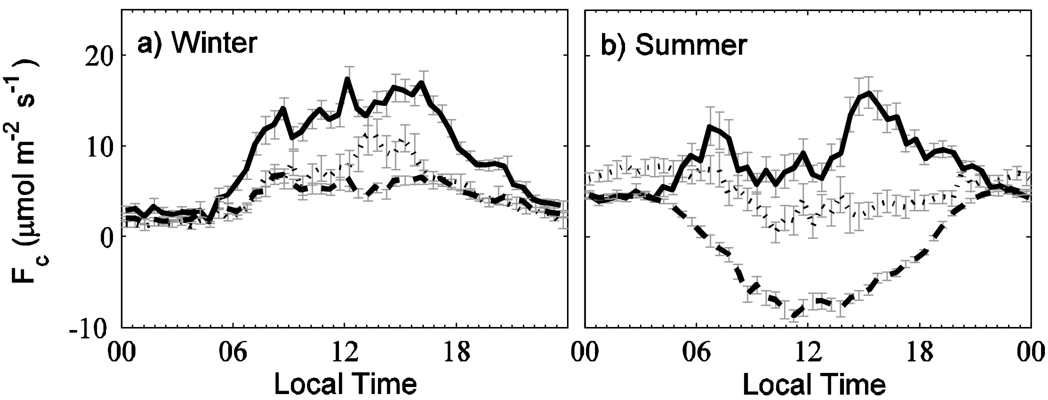

Fig. 1. The diurnal behaviour of CO_2 flux (F_c) for a) winter and b) summer in Helsinki, Finland, measured with the open-path infrared gas analyzer. Separation to different land use sectors was made solid line representing the road sectror, dotted line the urban sector and dashed line the vegetation sector. Error bars show the respective quartile deviations.

Correlation between the CO_2 fluxes measured with the open- and closed-path infrared gas analyzers (F_{OP} and F_{CO}, respectively) was found to be good (R^2=0.93) yielding a linear fit of $F_{OP} = 0.96F_{CP} - 0.61$. The apparent small negative offset of the fitting resulted a difference of 17% in net surface exchange (NSE) over the studied period (Fig.2). This represents the effect of the open-path sensor heating correction which has been observed to cause apparent CO2 uptake over vegetative surfaces (e.g. Grelle and Burba 2006; Burba *et al.* 2008). The difference in NSE was substantially decreased by taking the effect of the sensor heating into account. Three tested correction methods MLR, linear and fitting reduced the difference in NSE to 11, 2 and 4%, respectively. Despite the lowest difference obtained with the linear method, the fitting method should be used in the correction since it gave the best linear fit between the open- and closed-path CO_2 fluxes and most efficiently removed systematic dependencies on meteorological variables (Not shown). The fitting method provides a site-specific approach to correct F_{OP}, but the downside of the method is that it requires a period of simultaneous measurements made with open-path and closed-path gas analyzers and an assumption that the closed-path analyzer gives the correct CO_2 flux. If simultaneous measurements are not possible to made, the linear method should be used in the correction. By ignoring the open-path sensor heating causes systematic error in F_{OP} resulting with lower/higher CO_2 fluxes when the flux is upward/downward. This causes bias in the emission inventories of carbon at both urban and non-urban sites.

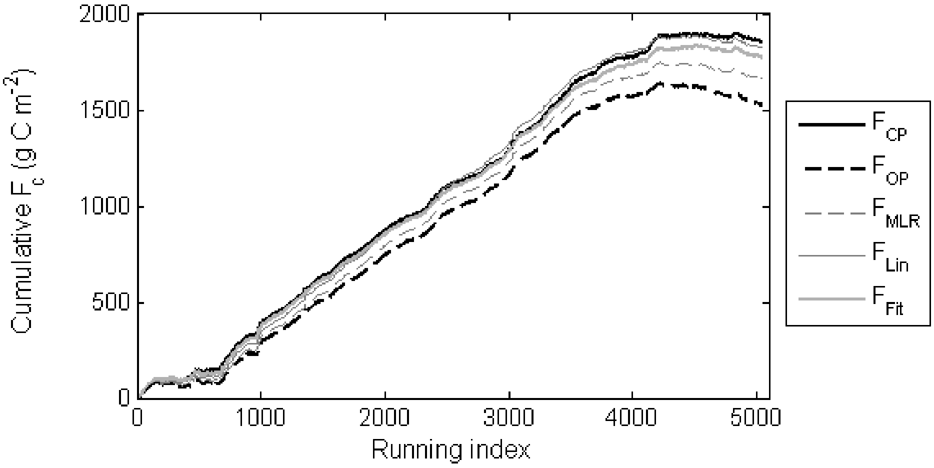

Fig. 2. The cumulative CO_2 fluxes (No gap filling was made) measured with closed- and open-path infrared gas analyzers between Jul 2007 and Jun 2008. F_{CP} is the closed-path flux, F_{OP} is the open-path flux corrected with traditional WPL correction, and F_{MLR}, F_{Lin} and F_{Fit} are the open-path fluxes corrected with the different sensor (MLR, linear and fitting methods, respectively).

4. CONCLUSIONS

The temporal behaviour of the CO_2 fluxes and dependencies of fluxes on land use cover were studied in Helsinki, Finland, between Dec 2005 and Mar 2009. In addition, comparisons between the CO_2 fluxes measured with the open- and closed- path infrared gas analyzers were made, and the effect of the open-path sensor heating on measured flux was examined. Three different methods to correct the effect of the sensor heating were tested based on Burba *et al.* (2006) and (2008).

The surroundings acted as a source for CO_2 reaching 18 μmol m^2 s^{-1} in the direction of the road (45 000 vehicles weekday^{-1}) leading to the Helsinki City Centre. In the direction with high vegetation cover, the flux remained below 7 μmol m^2 s^{-1} through the year, and in summer, vegetation uptake exceeded the anthropogenic CO_2 emissions and downward flux of 8 μmol m^2 s^{-1} was observed in daytime. CO_2 fluxes measured with the different analyzers correlated well (R^2 = 0.93), but on annual scale the open-path analyzer gave 17% lower NSE than the closed-path analyzer. This systematic difference can be explained with the open-path sensor heating causing apparent uptake of CO_2. The applied corrections decreased the difference in NSE down to 2%. The site-specific approach (the fitting method) gave the best results and if possible should be used in the correction.

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