574: Quantifying the CO_2 storage flux term in urban eddy-covariance observations

Ben Crawford, Andreas Christen

Department of Geography, University of British Columbia, Vancouver, Canada

Abstract

An experiment was conducted to evaluate the role of the CO_2 storage flux term in urban areas when performing eddy covariance measurements. The experiment used CO_2 concentration measurements at 2 heights: i) in the surface-layer on an eddy-covariance tower and ii) in the canopy-layer using a mobile measurement system. Results show that in this urban neighborhood, the rate of change of storage (storage flux term) is small relative to the measured vertical flux (<2% on average) and that using concentration measurements at one height in the surface-layer is a reasonable approach to estimate the storage flux term. Several issues remain when considering the storage term including the indoor air volume and differing scalar and flux source areas.

Keywords: urban CO_2 flux, storage flux, mobile measurements, eddy covariance

I. Introduction

The CO_2 storage flux term is generally recognized as a potential source of uncertainty for eddy covariance (EC) measurements on temporal scales of typical flux averaging periods of 30-60 minutes [1]. The storage term (ΔF_S) represents build-up (or depletion) of CO_2 in the measurement volume from ground to measurement height that is unaccounted for during measurements of the net vertical flux at the top of the measurement volume (F_C) by EC systems. Therefore, the 'true' net ecosystem exchange is expressed as:

$$NEE = F_C + \Delta F_S \qquad (1)$$

In urban areas treatment of ΔF_S has largely been neglected. Compared to forest or agricultural ecosystems, surface forcings in an urban area affecting storage (via stability and mixing) are expected to differ due to anthropogenic heat sources, greater mechanically generated turbulence, and a more open canopy structure. Furthermore, the magnitude and variability of surface emissions processes may change the relative importance of ΔF_S.

To measure ΔF_S in forest or agricultural sites, researchers often use a vertical profile measurement system to integrate changes in CO_2 concentration across the flux-averaging period through the depth of the storage volume [2]. A vertical profile is used because of the potential for different rates of CO_2 buildup (or depletion) at different heights. When a profile system is unavailable, researchers can use the change in CO_2 concentration at one height to calculate storage, with the assumption that the rate of change is constant throughout the depth of the measurement volume (z) [3]:

$$\Delta F_S = \frac{\Delta[\mathrm{CO_2}]}{\Delta t} \cdot z \qquad (2)$$

The objective of this study is to evaluate calculation of ΔF_S in an urban ecosystem based on concentration change measurements from a single location at the tower top. To accomplish this, the assumption that the rate of storage increase is constant throughout the measurement volume is tested using canopy-layer mobile CO_2 measurements. These measurements also enable examination of micro-scale spatial variability of CO_2 concentrations in the study area.

2. Methods

2.1 Experimental set-up

The study area is the source area of the Vancouver Sunset flux tower where local-scale CO_2 fluxes and concentrations have been continuously measured since May, 2008 on a tower at a height of 28.8 m [4]. To test the viability of ΔF_S calculated from this single point in the surface-layer, CO_2 concentrations were also measured within the canopy-layer using vehicle-mounted mobile measurements to obtain representative local-scale horizontal averages at screen level. The entire transect route occurs within a 2 x 2 km area and 15 runs were conducted over a 26-hour period to allow observation of CO_2 concentration patterns at high temporal and spatial resolution.

Ambient CO_2 concentrations were measured with a Li-800 GasHound closed- path infrared gas analyzer (Li-Cor Biosciences, Inc., Lincoln, Nebraska, USA) from an intake port mounted at 2.5 m height on the outside of the measurement vehicle. The port was placed near the front of the vehicle so as not to measure it's own exhaust. Air was drawn to the gas analyzer located inside the truck and CO_2 concentrations were sampled every 1 s. Potential air temperature (θ) measured with a fine-wire thermocouple was also recorded and data were synced with a GPS receiver recording time, latitude, longitude, elevation, and ground speed.

The transect route was designed to sample along major arterial roadways, residential side-streets, alleys, in urban parks, and be completed in approximately 1 hour so that assumptions of atmospheric stationarity could be plausibly applied. The 2 x 2 km transect domain is centered on the Sunset flux tower and encompasses over 80% of the tower's long-term flux source area.

The transects were driven over a continuous 26-hour period from 0500 LST September 7, 2011 - 0700 LST September 8, 2011. Clear-sky, calm conditions during a mid-week period were chosen to select for greatest overnight thermal stability and traffic emissions, and therefore greatest storage. Transects were driven every second hour, except during sunrise when they were driven every hour to better resolve CO_2 venting from the canopy-layer, and were timed to sync with the 30-minute flux-averaging period of the tower.

2.2 Spatial averaging

A spatial average of CO_2 concentrations is preferable to a temporal average due to variable transit times throughout the day. To accomplish this, first a 20 x 20 m grid approximating residential street-width was overlaid on the study area and sample points falling within each grid-cell are averaged. This resolution is used for analysis and visualization of micro-scale variations in temperature and CO_2 (Section 3.1). In a second step, the 20 x 20 m grid cells are averaged to make 200 x 200 m grids. This resolution ensures an equal number of data points for each run and is used to determine the average CO_2 concentration for the canopy-layer during the transect run and change in concentration between runs (Section 3.2). The route was designed to pass through each of the 200 x 200 m grid cells at least once and measurements of both arterial road and residential side-street segments were required within grid cells that contained both road types.

To take into account affects of changing wind directions and atmospheric stability on tower observations, the surface flux source area affecting tower measurements was calculated for each transect period [5]. The flux source areas are calculated at 2 m resolution and each pixel is weighted by its contribution to the measured tower signal. The spatial averages of canopy-layer CO_2 concentration were then overlaid and multiplied by the source area weights to determine the average CO_2 concentration for the flux source area.

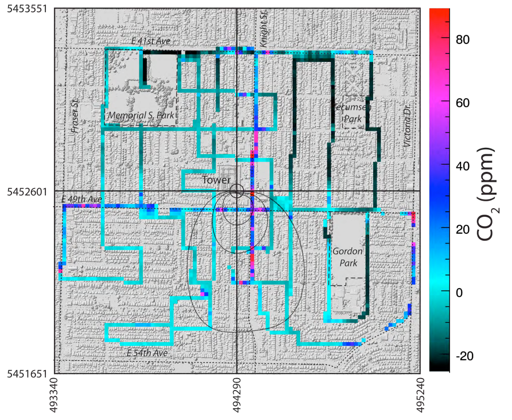
3. Results and Discussion

3.1 Spatial patterns

The transect route was mapped and visualized at a spatial resolution of 20 m for each of the 15 runs. During the daytime, highest CO_2 concentrations were observed along arterial roads, particularly at intersections (Figure 1). Average daytime concentrations measured above arterial roads were 5% higher than above residential side-streets.

Overnight, average CO_2 concentrations measured above residential streets surpass concentrations measured above arterial roads, reflecting the diminished traffic volume and the influence of emission processes such as soil respiration.

a) Day CO_2 departure from run mean (900-1000 LST)



b) Night CO_2 departure from run mean (300-400 LST)

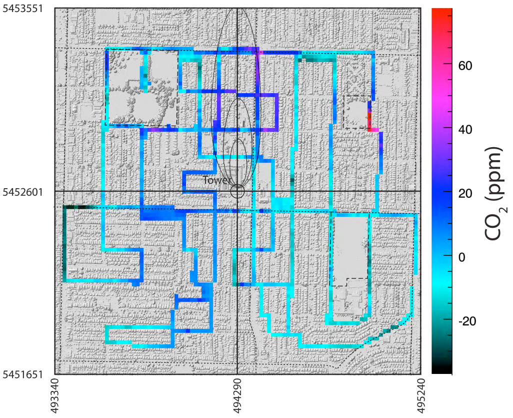
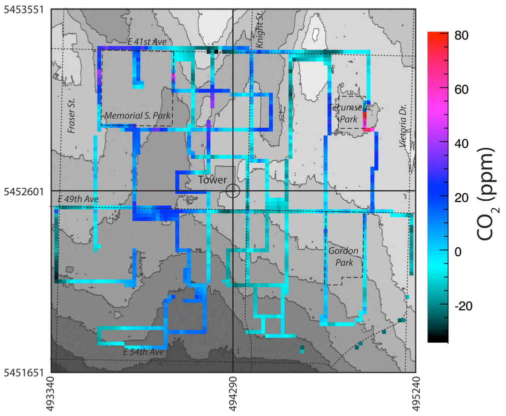


Figure 1. CO_2 concentration departures from mean for daytime (a) and nighttime (b) runs. The flux source area during the transect run is superimposed in black isolines (contours are 50%, 75%, and 95% source area contribution levels).

Also during the night transect runs, a negative correlation (correlation coefficient = -0.76) was found between θ and CO_2 concentration and spatial patterns generally conform to the micro-scale topography of the study area (Figure 2). This suggests micro-scale processes such as cold-air pooling are a significant determinant of nocturnal canopy-layer CO_2 (and possibly other pollutant) distribution.

a) Topography and CO_2 departure from run mean (100-200 LST)



b) Topography and θ departure from run mean (100-200 LST)

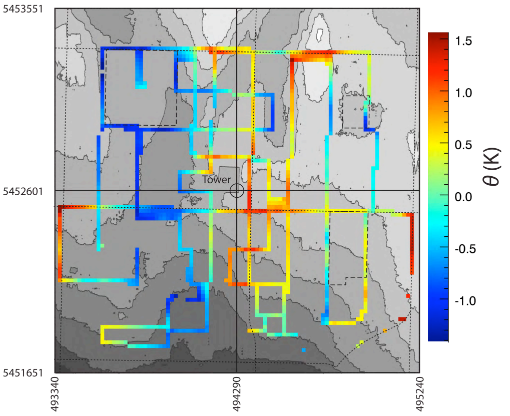


Figure 2. Departures from mean for CO_2 concentrations (a) and potential temperature (θ) from 0100-0200. The transects are superimposed on ground elevation contours (5 m intervals, min = 40 m (dark), max = 85 m (light)).

3.2 Storage flux

Throughout the measurement period, observed canopy-level (2.5 m) CO_2 concentrations are higher than concentrations measured at the flux tower (28.8 m) (Figure 3a), reflecting both the presence of surface CO_2 sources and a measurement bias towards roads. Overall, the source area-weighted CO_2 concentrations match the concentrations determined for the entire canopy-layer.

Before ΔF_S is calculated, the $\Delta CO_2/\Delta t$ term from eq. 2 can be examined separately for the canopy-layer and surface-layer (Figure 3b). Initially at 07:00 LST, the canopy-layer (Transect measurements) CO_2 concentration has increased more from the previous hour than the surface-layer (Tower measurements), presumably from early morning traffic emissions injected into the still relatively stable surface layer. By the next run at 08:00 LST, canopy-layer concentrations have decreased while surface-layer concentrations have increased. This negative canopy-layer $\Delta CO_2/\Delta t$ is likely due to CO_2 venting as the surface warms and atmospheric stability decreases. At the same time, $\Delta CO_2/\Delta t$ in the surface-layer is positive from a combination of increased traffic emissions and the addition of the vented CO_2 from below.

By 10:00 LST, both levels show a decrease in CO_2 concentrations as the traffic morning rush hour wanes, cleaner air from the residual mixed layer and free atmosphere is mixed downward, and vegetation photosynthesis increases. By 12:00 LST both levels appear well-coupled and remain so for the duration of the day. After sunset, the surface-layer shows an initial increase in CO_2 relative to the surface-layer (20:00-22:00) and a small buildup again in the early morning (04:00-07:00).

To calculate ΔF_S, the $\Delta CO_2/\Delta t$ values were scaled by the depth of the measurement volume (z, Eq. 2). Three methods of calculating ΔF_S were then compared (Figure 3c). The first method uses the $\Delta CO_2/\Delta t$ measured at the tower top integrated over the entire measurement height (z = 28.8 m). The second method divides the measurement volume into two layers: canopy-layer (surface to mean building height, 5.1 m) and surface-layer (5.1 m to 28.8 m) and uses the corresponding $\Delta CO_2/\Delta t$ measured from the transects and the tower top, respectively. The third method is identical to the second and uses source area-weighted $\Delta CO_2/\Delta t$.

The three methods track closely through the day, though the tower method underestimates storage overnight and in the early morning due to CO_2 buildup in the canopy-layer, and overestimates storage when the canopy-layer is vented at 0800. Overall, the combination method of the source area-weighted and tower storage is judged to be the best-estimate of the storage flux. This method takes into account the different rates of $\Delta CO_2/\Delta t$ above- and in-canopy and is spatially more aligned with the tower measurements through use of the source area.

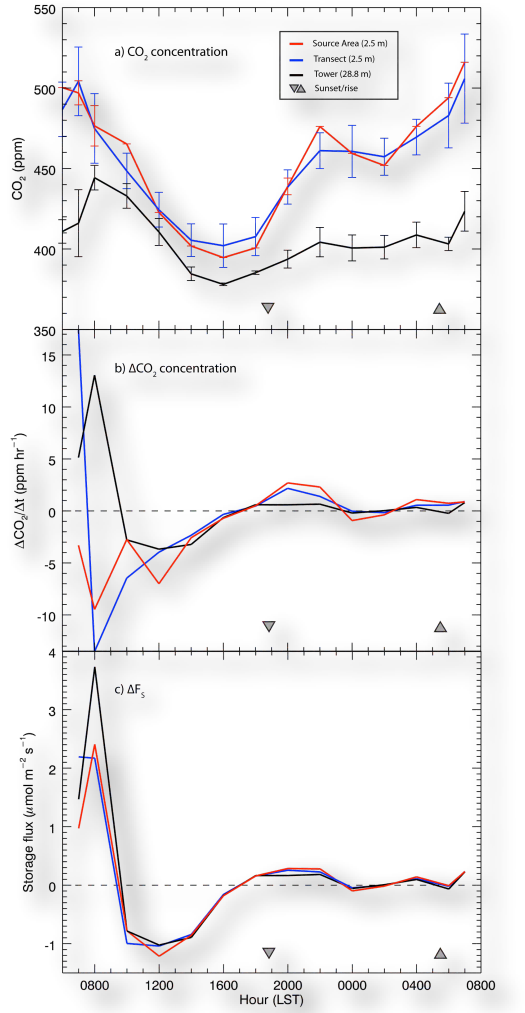


Figure 3. CO_2 concentrations (a), $\Delta CO_2/\Delta t$ (b), and ΔF_S (c) measured during the study period. Error bars are omitted from (b) and (c) for clarity.

4. Conclusions

The assumption that $\Delta CO_2/\Delta t$ is constant throughout the measurement volume appears to be reasonable in this urban setting for most hours. During transition periods between night and day, however, there is potential for error as the canopy and above-canopy layers adjust to new surface forcings.

Practically, in terms of storage calculations the importance of these differences is reduced due to the small volume of the canopy-layer relative to the entire measurement volume. Over the course of the study period, the best-estimate and tower-based methods of calculating ΔF_S differ by an average of 16%. This translates to an average difference between *NEE* (Eq. 1) calculated using the two methods of 0.2%.

ΔF_S is also relatively small compared to F_C. On average, the best-estimate ΔF_S is 1.8% of measured F_C, while the tower-method is 2.8%. Given the large magnitude of F_C in measured in urban environments, ΔF_S is relatively minor, and determining ΔF_S from $\Delta CO_2/\Delta t$ concentrations measured at a single height is a reasonable simplification.

Several caveats remain. One issue is that of different surface source areas affecting CO_2 concentrations and CO_2 fluxes. Source areas for concentrations are often an order of magnitude larger than those for fluxes [6] so the processes influencing ΔF_S are likely different that those of F_C. Additionally, this study neighborhood is a relatively low-density residential area and ΔF_S may be quite different in a densely packed environment with deep canyons. Finally, the measurements here do not account for emissions processes and storage inside buildings. Emissions that occur indoors will eventually be vented to the surrounding atmosphere and measured by tower-based eddy covariance systems, but the actual timing of the emissions is obscured.

5. Acknowledgments

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6. References

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