Dear Dennis, Joe, and Siyan,

Thank you for hosting the AmeriFlux tech team at the Tonzi ranch site from April 12-25, 2016. In addition to the PECS system we also deployed the new portable profile system (PPS). The purpose of this deployment was to provide a high quality reference measurement of storage, provide diagnostic data and analysis of the site characteristics with regard to layer heights and inlet placement, to verify the function of recent upgrades to the PPS, and lastly, to promote the importance of the storage term within AmeriFlux.

While it is widely understood in the flux community (and certainly in the Baldocchi group!), it is worth reinforcing that the storage term is an important component of the mass conservation equation and quantifying it reduces errors when conditions are not steady state as well as allowing correct interpretation of diurnal physiological and ecological processes such as calculating GPP or R_{eco}. What follows is a detailed report of the site visit.

Key recommendations

During the site comparison the Tonzi Profile system was down for maintenance so this report focuses on portable profile system results.

Tonzi showed strong diurnal patterns of CO_2 storage during the site visit. While storage tends to average close to zero over longer periods, and thus may have smaller impacts on long term NEE values, this imbalanced diurnal pattern can have important impacts on GPP and other estimates where night-time flux values are used relative to daytime measurements.

Based on the data collected during this visit, the ideal sampling configuration for Tonzi would use a minimum of 7 inlets to measure storage with the following heights:

Inlet #	Inlet height m
1	0.23
2	0.92
3	2.87
4	5.75
5	8.28
6	11.27
7	23.00

Thanks again for hosting this site visit. As with our EC reports, please provide feedback about the site visit and the results of this report. We are always looking for ways for improve and provide the most value to sites.

Cheers,

-Chad, Hyojung, and the rest of the AmeriFlux Tech Team

Detailed report

Measurement description

The PPS utilizes 10 measurement heights that are spaced according to an exponential function:

$$h_i = ({n_i}^b * Z) * {n_t}^{-b}$$

Where h_i is the height of the inlet, n_i is the number of the inlet from the ground, *Z* is the eddy covariance measurement height, n_t is the total number of inlets and b is an exponent, which was set to 2 for the Tonzi deployment yielding the following inlet locations:

Inlet #	Inlet height (m)
1	0.23
2	0.92
3	2.07
4	3.68
5	5.75
6	8.28
7	11.27
8	14.72
9	18.63
10	23.00

Table 1. PPS inlet heights AGL for Tonzi deployment

Inlets are placed on 1 meter booms to minimize tower influence, and are co-located with an aspirated temperature sensor for each height (Apogee st-110 thermistors in TS-100 shields). Inlets are constant flow to the PPS, and are sub-sampled by a LI-840 IRGA via a valve switching manifold for 30 seconds every 5 minutes. The first 15 seconds of every interval is discarded to eliminate any valve switching effects and to allow the manifold to purge. This yields six whole column measurements for each half hour period. Pressure is measured at the base of the tower and corrected for each height. Water vapor pressure is derived from the IRGA H_2O values and used in combination with the temperature and pressure data to correct the IRGA CO_2 values to density in dry air. Whole column averages of CO_2 density are calculated by weighting each inlet's contribution according to the thickness of the layer it represents. Finally storage (S_c) is calculated as the change in column density between 30 min periods. For convenience when relating to EC data, S_c is reported in µmol m^2 s^{-1}.

$$S_{c=}\int_0^h \frac{\partial c}{\partial t}\,\mathrm{d}h$$

where c is CO_2 density, t is time, and h is the height of eddy covariance system. S_c is evaluated in a discrete format:

$$S_{c=}\left(\frac{\Delta c}{\Delta t}\right)_{i=1}\cdot h_{i=1}+\sum_{i=2}^{n}\left[\left(\frac{\Delta c}{\Delta t}\right)_i+\left(\frac{\Delta c}{\Delta t}\right)_{i-1}\right]\cdot\frac{h_i-h_{i-1}}{2}$$

where i is the index for vertical levels.

Uncertainty of Profile measurements

The uncertainty of the profile measurement system is largely driven by the precision of the LI840 30 minute averages and the short term (<1hr) drift of the sensor.

Variable	Ensemble Uncertainty	unit
Air temp	± 0.1	°C
LI-840 CO_2	± 1.0	µmol mol^{-1}
LI-840 H_2O	± 0.15	mmol mol^{-1}
Air pressure	± 0.1	kPa

Table 2. PPS measurement uncertainty

Photo 1. Main system at base of the Tonzi tower during deployment (grey box on front right leg). Inlets are located behind white aspirated temperature sensors, heights 1-4 visible. Site profile inlet 1 and 2 visible on left leg of tower.

Photo 2. Birds eye view of profile inlet system with PECS EC system visible on back left leg of the tower.

Results

CO_2 Concentration data

The 10 inlets of the PPS allowed a detailed characterization of the concentration gradient during the site visit. Figure 1 shows the whole time series of CO_2 data for the site visit. Figure 2 shows a contour plot of the 12-day ensemble average concentration of CO_2 for each 5 minutes of the day for each height. Build-up of CO_2 at night and rapid depletion after sunrise are clearly observed. At night the gradient displayed a strong decrease from ~485 ppm at 0.23 meters to ~445 ppm at 11.27 meters, and a relatively uniform concentration from 11.27 meters to the top of the column. During the day the column was well mixed and uniform. The vvertical gradient in CO_2 concentration shows unequal contributions of CO_2 storage at different heights.

To quantitatively assess differences among means of CO_2 concentration at each level, we conducted a Tukey-Kramer pairwise multiple comparison with a tolerance (α) of 0.05 to compare different pairs of means and see which are significantly different from each other [*Kirk*, 1982] (Figure 3). The procedure conducted pairwise testing of means in a one-way analysis of variance with unequal sample sizes, and a single critical difference, which is estimated from the Studentized range statistic, is calculated for each pair of means. The means below the canopy height (<7.5 m) significantly differed from those above the canopy height. CO2 concentration significantly differed among the inlet heights of 0.23, 0.92 and 5.75 m below the canopy, whereas it significantly differed at the inlet heights of 8.28, 11.17, and 23.00 m above the canopy. No significant difference was found between the top three levels (14.72, 18.63, and 23.00 m).

Temperature profile

The temperature profile showed a consistent gradient during night time and became relatively uniform during morning and evening periods when incoming radiative heating is low but conditions are unstable (Figures 4 and 5). Radiative heating at the ground appears to cause a warmer zone near the ground (< 3 m) during the afternoon.

H_2O profile

The water vapor profile showed consistently drier values at night with a rapid increase propagating from the ground shortly after sunrise (Figure 6 and 7). This appears to be the result of dew evaporating as air temperatures rise shortly after sunrise. During the afternoon there is a consistent release of water vapor close to the ground and elevated concentrations overall consistent with evaporation and evapotranspiration contributions.

CO_2 Storage

During the 12 day site visit, 30 minute storage values were relatively consistent day to day and ranged from a minimum of-12.06 to a maximum of 11.69 µmol m^{-2} s^{-1}, with 95% of values falling between 8.71 and -8.81 µmol m^{-2} s^{-1} (Figure 8). DOY 105, 113, 114 had the smallest amplitude of storage fluxes.

The lowest values for storage occurred during the early morning hours, approaching zero during mid-day and peaking in the evenings. Figure 9 highlights this diurnal pattern (e.g., storing CO_2 at nighttime and losing CO_2 during the day) by showing the average values of storage for each half hour period of the day. Figure 10 presents CO_2 storage based on inlet height and time of day for a single day of the comparison, while Figure 11 presents storage by height and time of day as the average values for the 12 day site visit. Figures 10 and 11 both highlight the diurnal dynamics, as well as the influence of the canopy on storage.

Contribution of CO_2 Storage to NEE

Figure 12 shows the magnitude of storage (F_s) relative to CO2 flux from the EC (F_c) throughout the day as measured by the Portable Eddy Covariance System (PECS) during the site visit. Storage tends to play a reinforcing role, making significant contributions in the early morning and evening. When storage is added to F_c, NEE increases the amplitude throughout much of the day with a disproportionate effect on early morning uptake before and after sunrise, as well as increasing the release beginning in early evening.

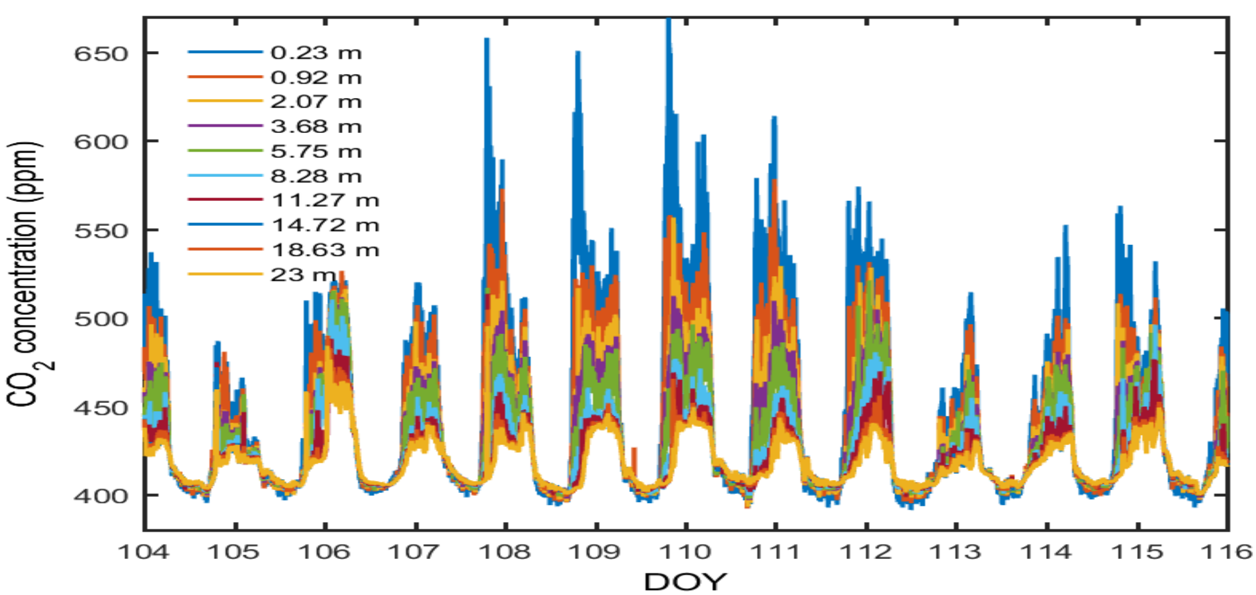

Figure 1. Time series of CO_2 concentration data by height

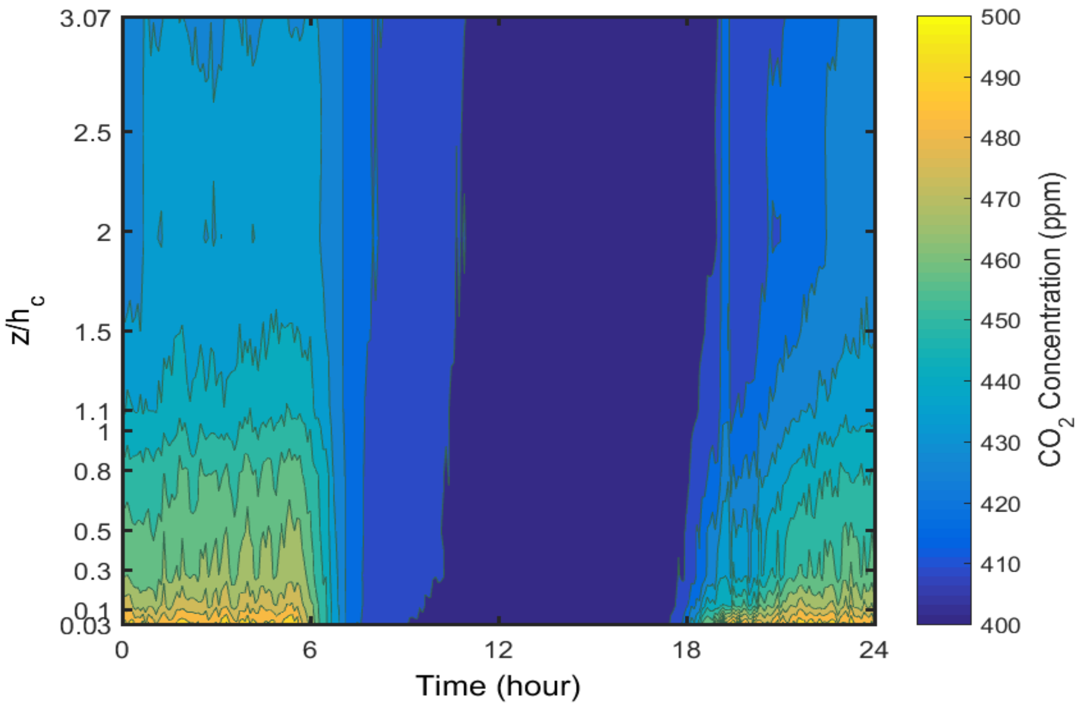

Figure 2. CO_2 concentration gradient, average values based on time of day.

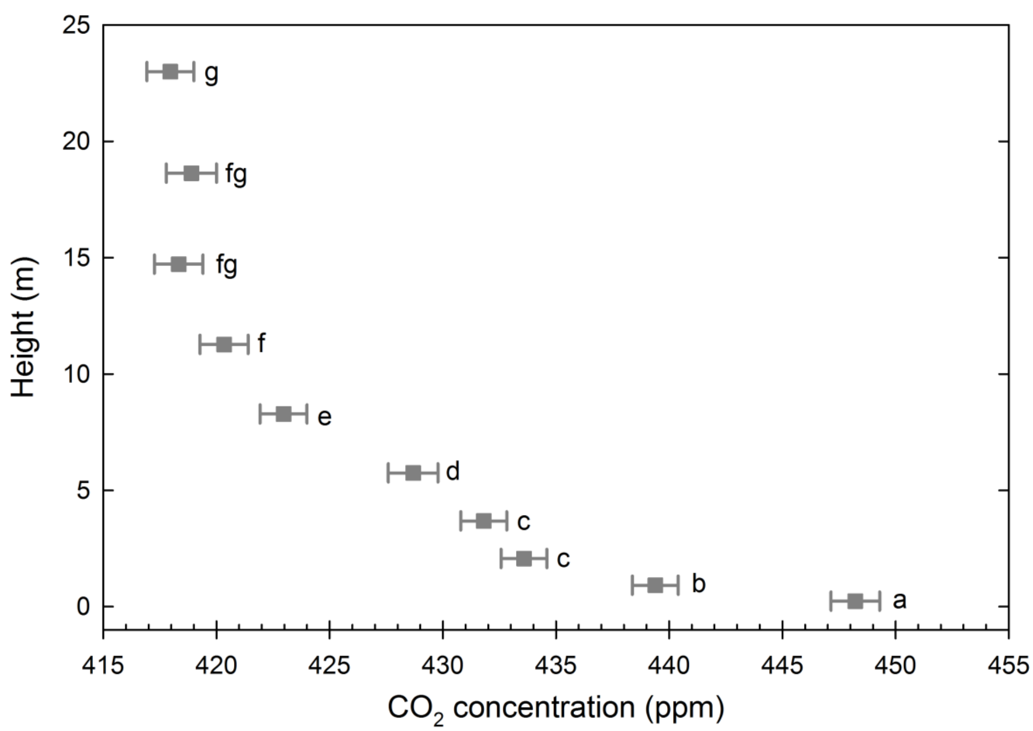

Figure 3. Variation of the 12-day means of CO_2 concentration and confidence intervals for each level. Intervals are computed by the Tukey-Kramer pairwise multiple comparison at α = 0.05. Means with the same letter are not significantly different from each other ($P>0.05$). Different letters indicate significant differences.

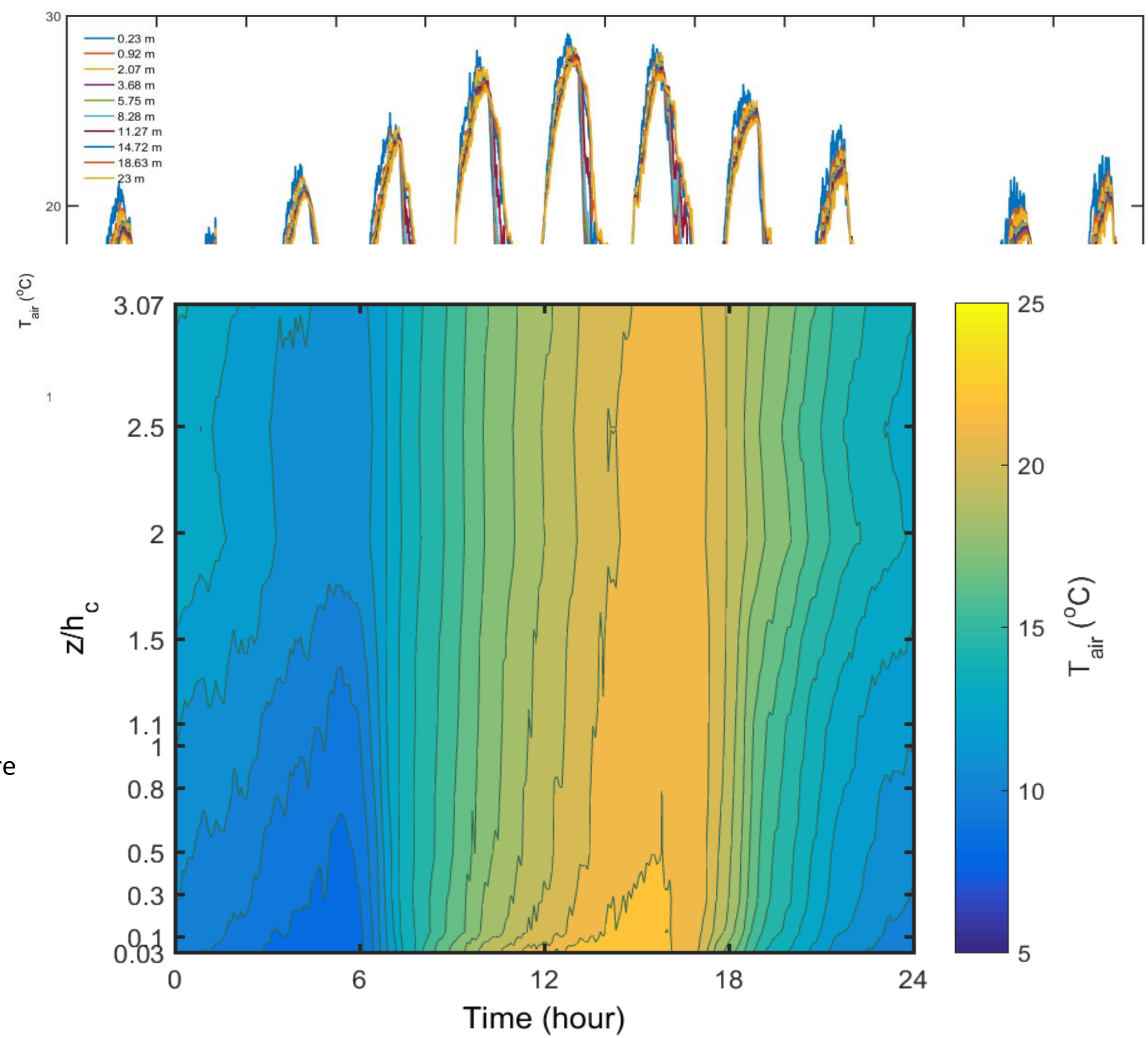

Figure 4.
Temperature

time series by height.

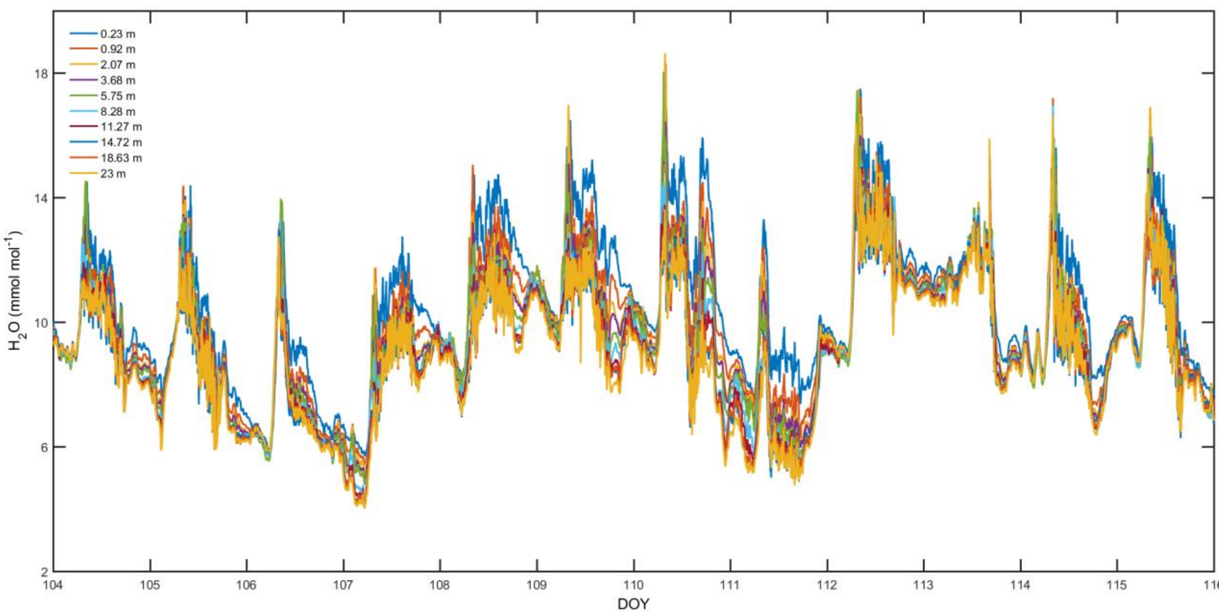

Figure 5. Temperature gradient, average values based on time of day

Figure 6. Water vapor time series by height.

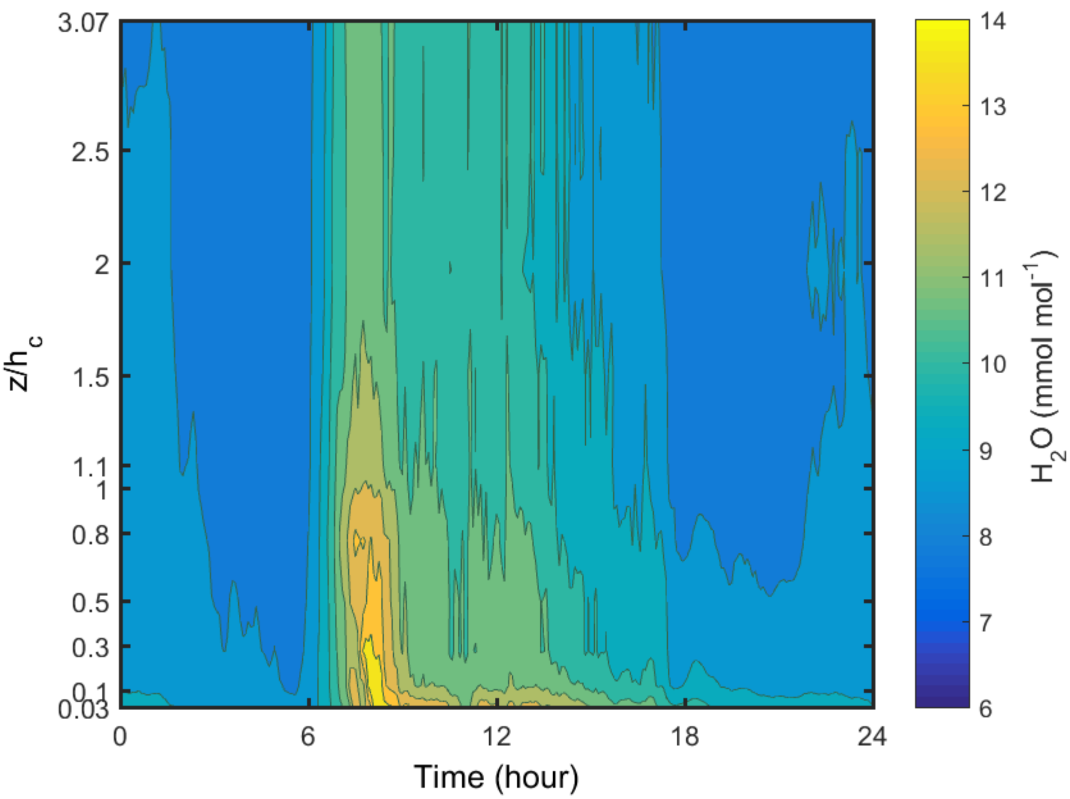

Figure 7. Water vapor profile concentration gradient, average values based on time of day.

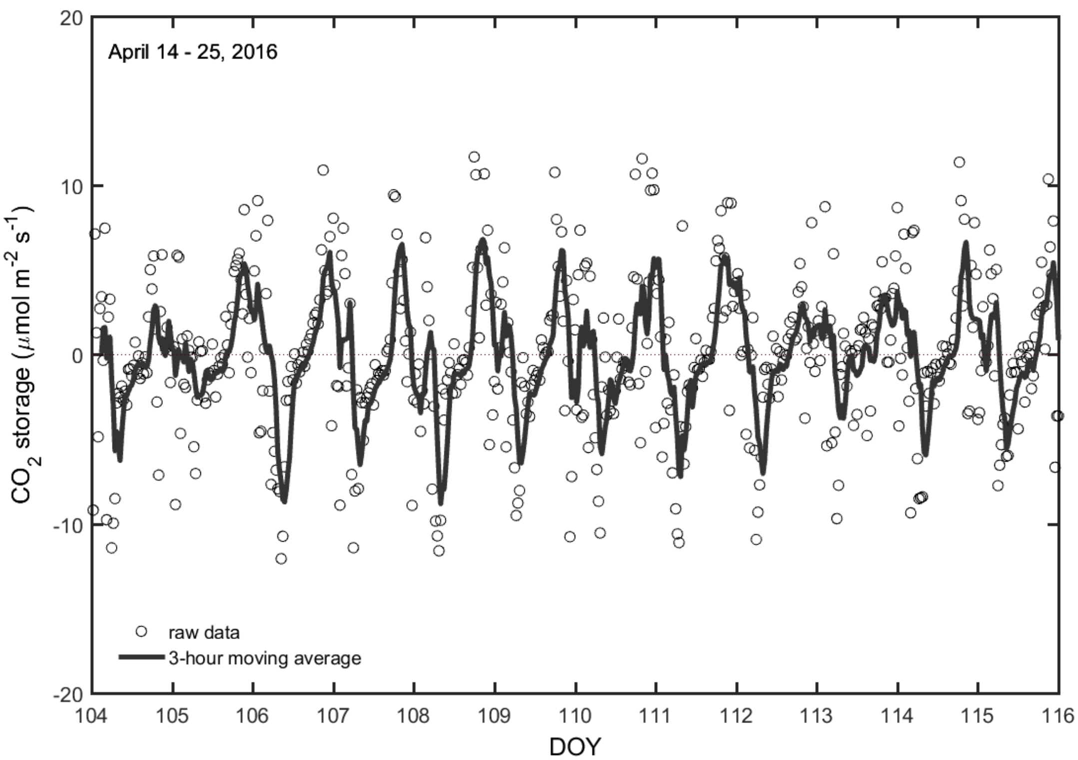

Figure 8. CO_2 storage time series, 12 days of 30 minute values.

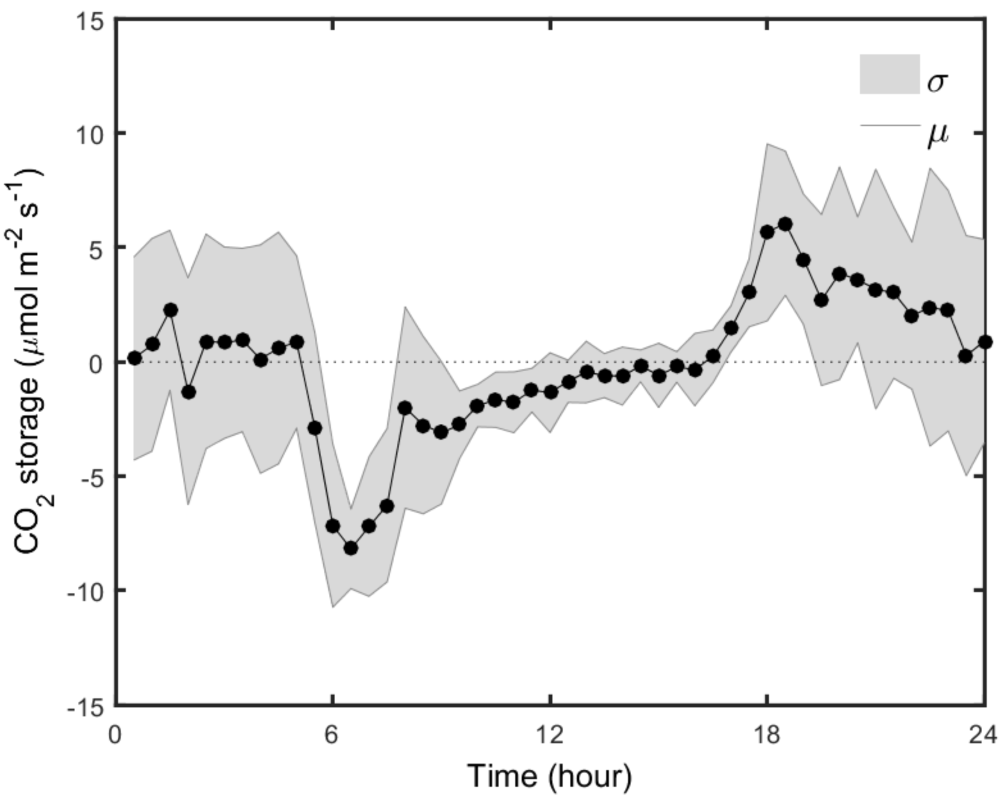

Figure 9. CO_2 storage, 12 days of 30 minute data average based on time of day. One standard deviation shown by shaded area.

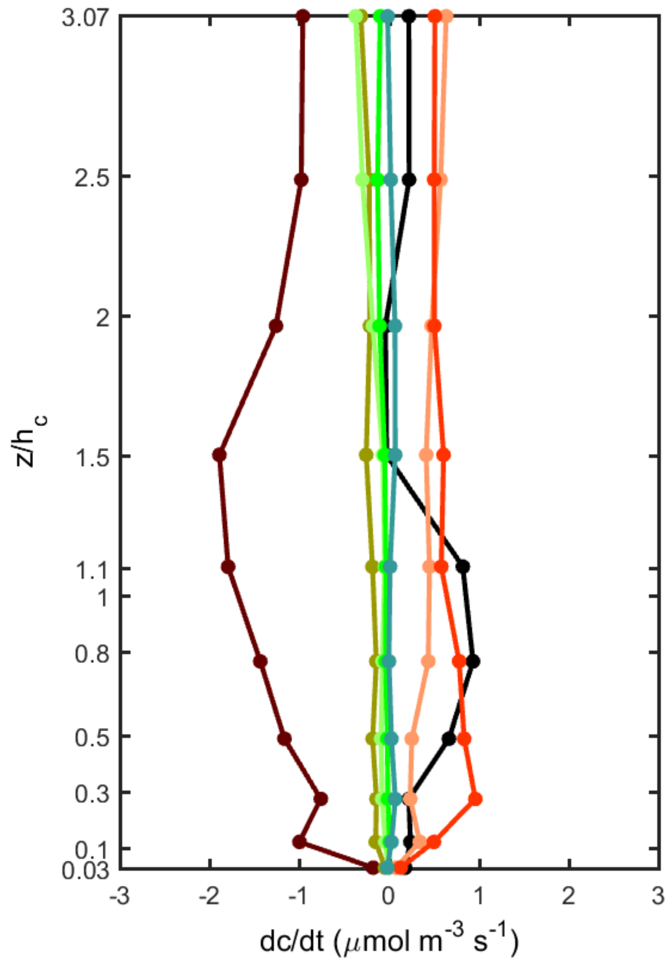

Figure 10. CO_2 Storage by individual heights during one day of comparison.

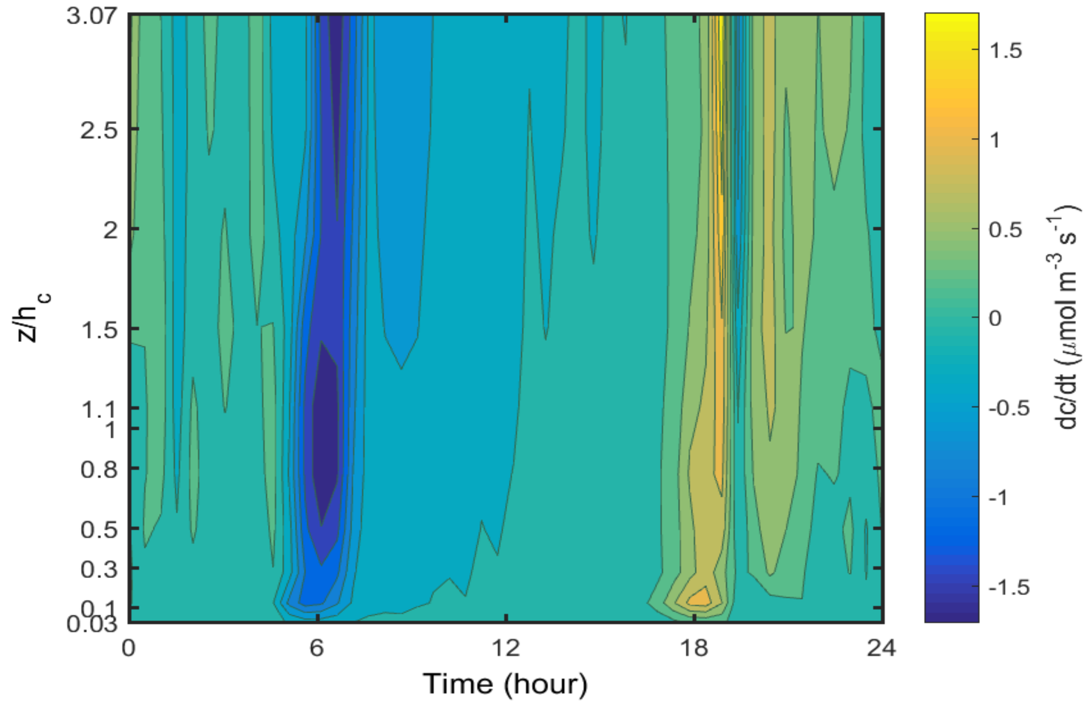

Figure 11. CO_2 storage gradient by height, average values based on time of day.

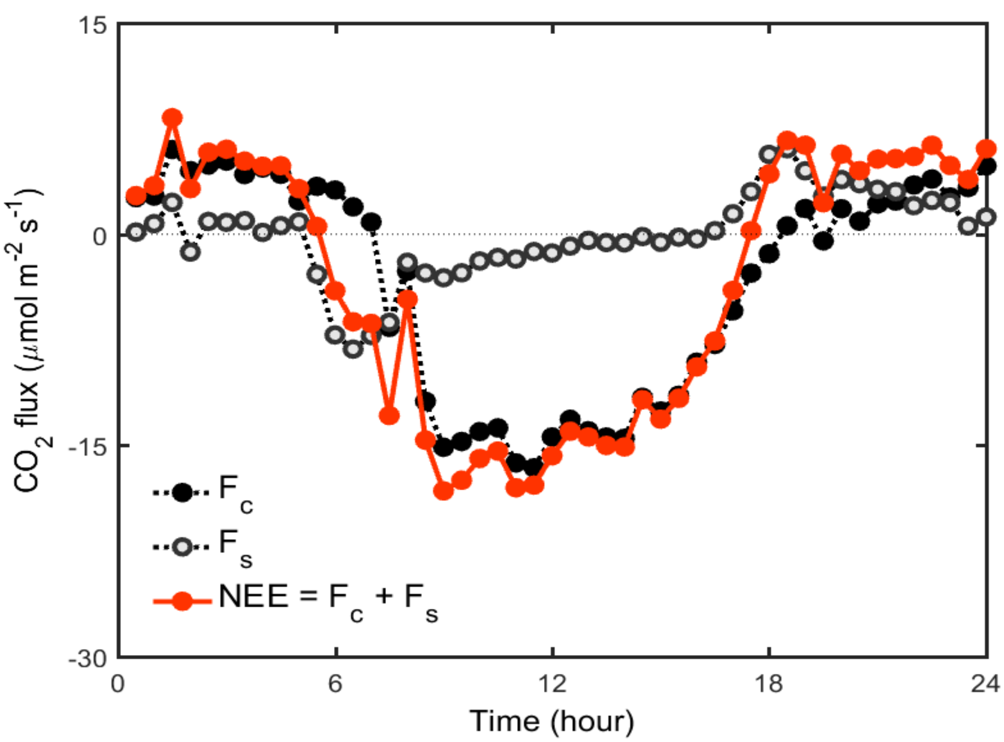

Figure 12. Comparison of the storage term (F_s), flux from the EC (F_c) and NEE (=F_c + F_s) based on time of day for 12 day period.