Comparison of ECOR, EBBR, and CO2FLX4m System Fluxes

D.R. Cook and D.J. Holdridge
Argonne National Laboratory
Argonne, Illinois

ML Fischer
Lawrence Berkeley National Laboratory
Berkeley, California

Abstract

Comparisons of surface fluxes and mean measurements are made between the EBBR, ECOR, and CO2FLX4m systems at the SGP CF from January through July 2005. The comparisons were performed for periods when wind directions generated similar flux footprints over similar land cover. Comparisons of the ECOR and EBBR systems were made for north winds (natural grass surface); comparisons of the ECOR and CO2FLX4m systems were made for south winds (nearly bare ground or corn crop). For north winds, ECOR and EBBR sensible heat flux agreed very well and ECOR latent heat flux was 30% smaller than the EBBR during daytime. For south winds, ECOR sensible heat flux was 30% larger than the CO2FLX4m and ECOR latent heat flux was 16% smaller than the CO2FLX4m during daytime. Friction velocity measured by the ECOR and CO2FLX4m was nearly identical, suggesting that similar vegetation structure was present in the fetch seen by both systems. Daytime energy balance closure was 100% for the EBBR (by definition of the technique) and was 90% for the ECOR for north winds. Daytime energy balance closure was 111% for the ECOR and 99% for the CO2FLX4m for south winds (excluding one unusual day). CO_2 flux for the ECOR was slightly smaller than for the CO2FLX4m. Since the CO_2 concentrations measured by the ECOR and CO2FLX4m were very similar, differences in CO_2 flux may have been caused by spatial heterogeneity in the flux footprint. The ECOR system had a substantial water vapor density offset, but this did not affect the measured latent heat flux. Temperature varied significantly among the three systems. Explanations for the observed differences in the measurements by the three systems are given. The value of having tools (comparison plots on HandS) to detect data differences and to diagnose instrument problems is clearly shown by this study.

Introduction

In this study we compared measurements of sensible heat flux (H), latent heat flux (LE), CO_2 flux (Fc), momentum (as friction velocity u*), and some mean measurements from the EBBR, ECOR, and CO2FLX4m systems located at the SGP Central Facility. To make such comparisons, the wind direction must be steady from the north to compare the EBBR and ECOR flux measurements (for a natural grass surface) and steady from the south to compare the ECOR and CO2FLX4m flux measurements (for a nearly bare soil or corn crop surface). These wind directions are required so that the systems being compared make measurements of fluxes from very similar vegetation and terrain (similar flux footprint). The importance of making flux comparisons over similar vegetation surfaces is demonstrated by the large difference in available energy (net radiation plus soil surface heat flux) that occurred for the grass and corn crop areas; the ratio of north to south available energy for the 8 days studied averaged 0.71, indicating that less energy was available for H and LE over the corn crop surface than was available over the natural grass surface.

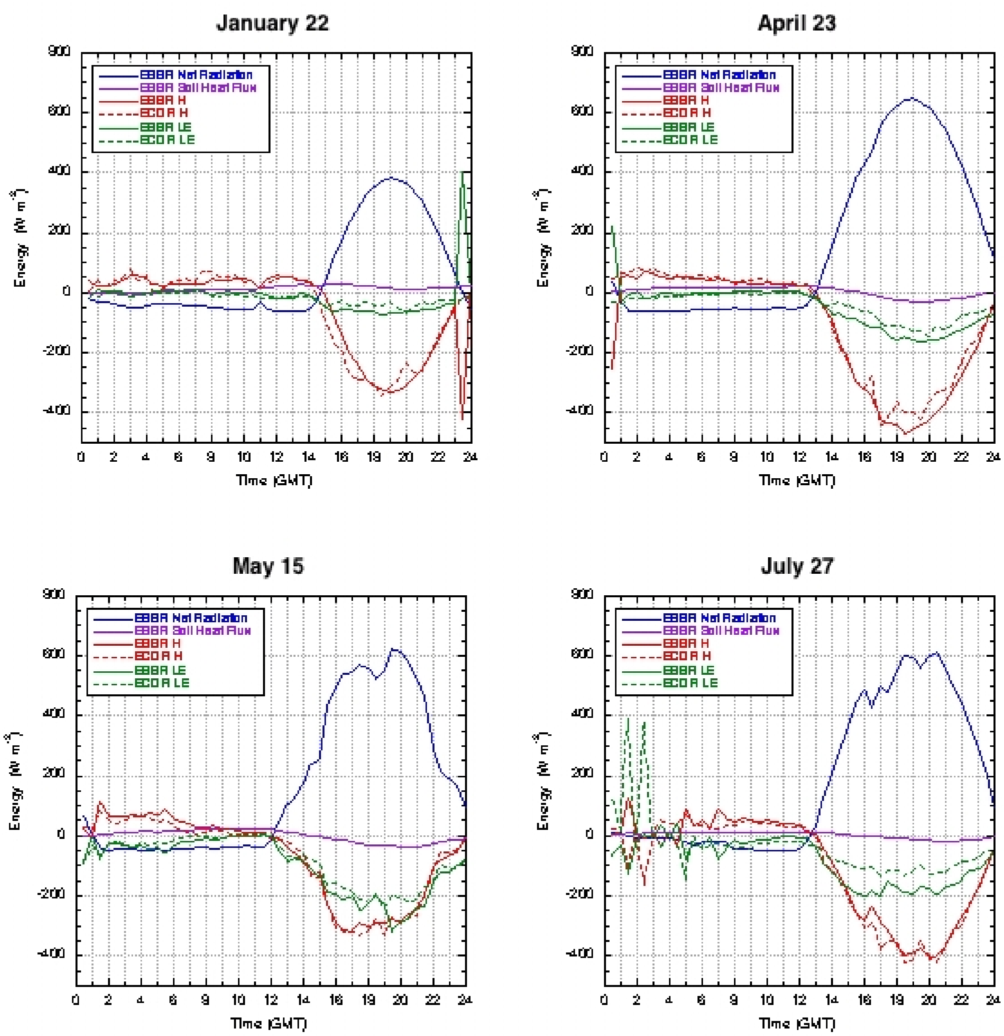
Four days in early 2005 are used for the EBBR-ECOR comparison and four other days in early 2005 are used for the most of the ECOR- CO2FLX4m comparisons. Means of temperature, CO_2 concentration, and water vapor density are compared for January through July 2005. The comparisons are summarized in Table 1; Comparisons Summary Table.

Table 1. EBBR-ECOR Comparisons

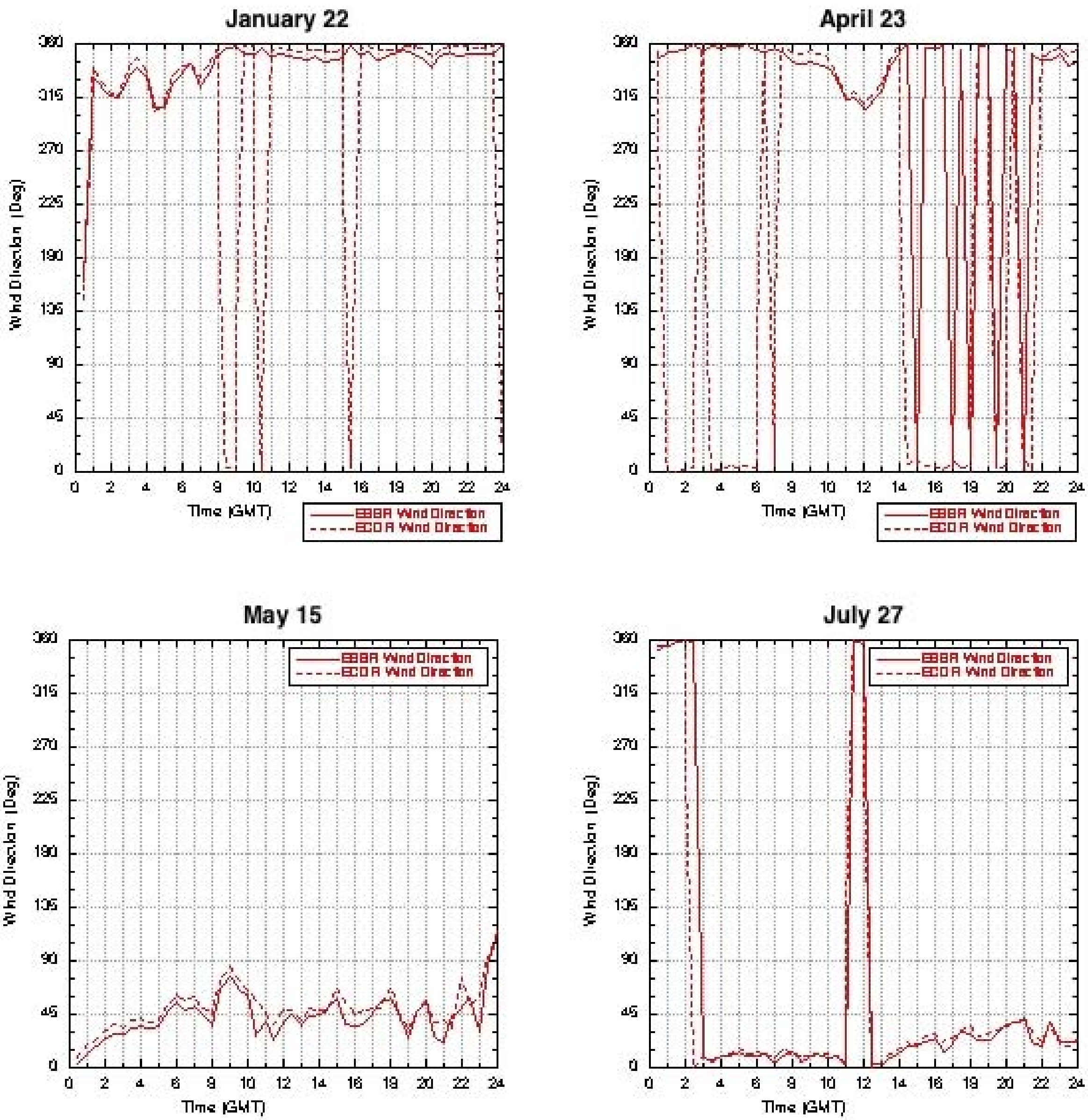
Period	ECOR/EBBR Ratio		ECOR/CO2FLX4m Ratio	
	H	LE	H	LE
Daytime	1.00	0.70	1.30	0.84
Daily	0.99	0.76	1.31	0.90
	EBBR, ECOR Closure (%)		ECOR, CO2FLX4m Closure (%)	
	EBBR	ECOR	ECOR	CO2FLX4m
Daytime	100	90	111	99
Daily	100	90	107	95
	Bowen Ratio			
	EBBR, ECOR		ECOR, CO2FLX4m	
	EBBR	ECOR	ECOR	CO2FLX4m
Daytime	1.77	2.53	2.03	1.31
	ECOR/CO2FLX4m Ratio		Friction Velocity (m s^{-1})	
	CO2 Flux	CO2 Conc.	ECOR	CO2FLX4m
Daytime	-0.02	0.98	0.44	0.45
Daily	-0.34	0.98	0.30	0.31

Table 1. (contd)				
	Water Vapor Density Difference (mmol m^{-3})		Temperature Difference (°C)	
	ECOR-EBBR	ECOR-CO2FLX4m	ECOR-EBBR	ECOR-CO2FLX4m
Daytime	279.4	250.6	+0.89	-2.22
Daily	280.1	256.4	+1.57	-1.78
			ECOR-mean T	CO2FLX4m-mean T
Daytime			-0.10	2.12
Daily			-1.64	0.14

Please refer to the data plotted in Figures 1a through 1d and the comparisons in Table 1 when reading the discussion below.



(1a)

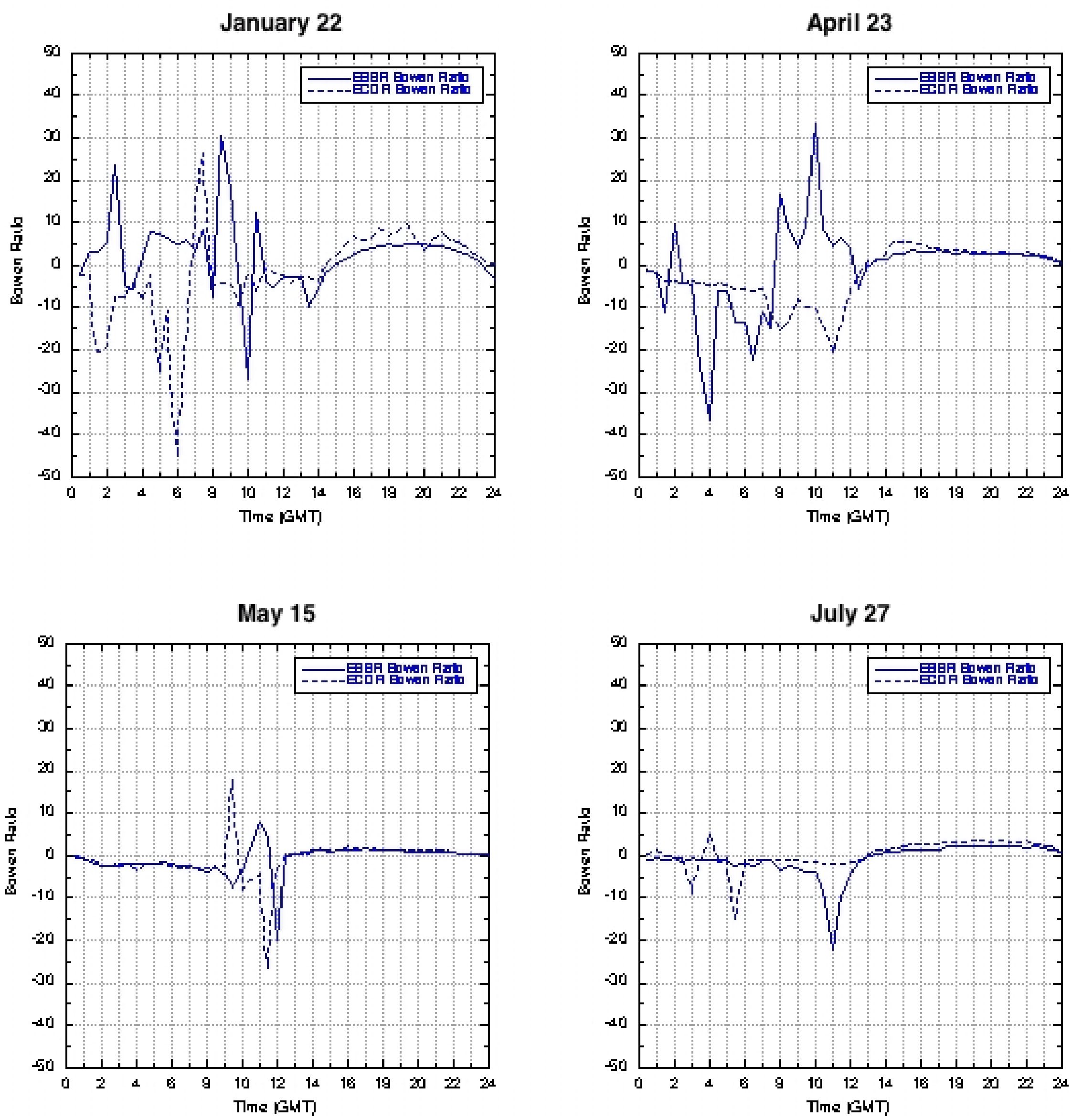


(1b)

Figure 1. Energy Balance: Net radiation (Rn) and soil surface heat flux (G) measured by the EBBR system are representative of the natural grass surface seen by the EBBR and ECOR for north winds. H and LE are displayed for both the EBBR and ECOR in Figure 1a. The plot of wind direction (see Figure 1b; Wind Direction) shows that the EBBR and ECOR were measuring the same wind directions and therefore the same flux footprint.

ECOR and EBBR H agreed within 1% on average both during daytime conditions (defined as having positive net radiation) and on a daily basis.

ECOR LE averaged 30% smaller than that for the EBBR during daytime and 24% smaller on a daily basis. The EBBR technique assumes that the eddy diffusivities for heat and water vapor are the same, but in the unstable atmospheric conditions that tend to occur during the daytime, the water vapor diffusivity is actually about 12% to 30% smaller; this could explain some of the EBBR-ECOR LE daytime difference and may suggest that the EBBR may overestimate LE, as is sometimes implied in the literature. A comparison of the ECOR/EBBR and ECOR/CO2FLX4m LE ratios suggests that this overestimate would be around 15% at most. Consequently, daytime Bowen ratio (ratio H/LE) was normally larger for the ECOR measurements than for the EBBR and CO2FLX4m systems (see Figure 1c; Bowen Ratio).

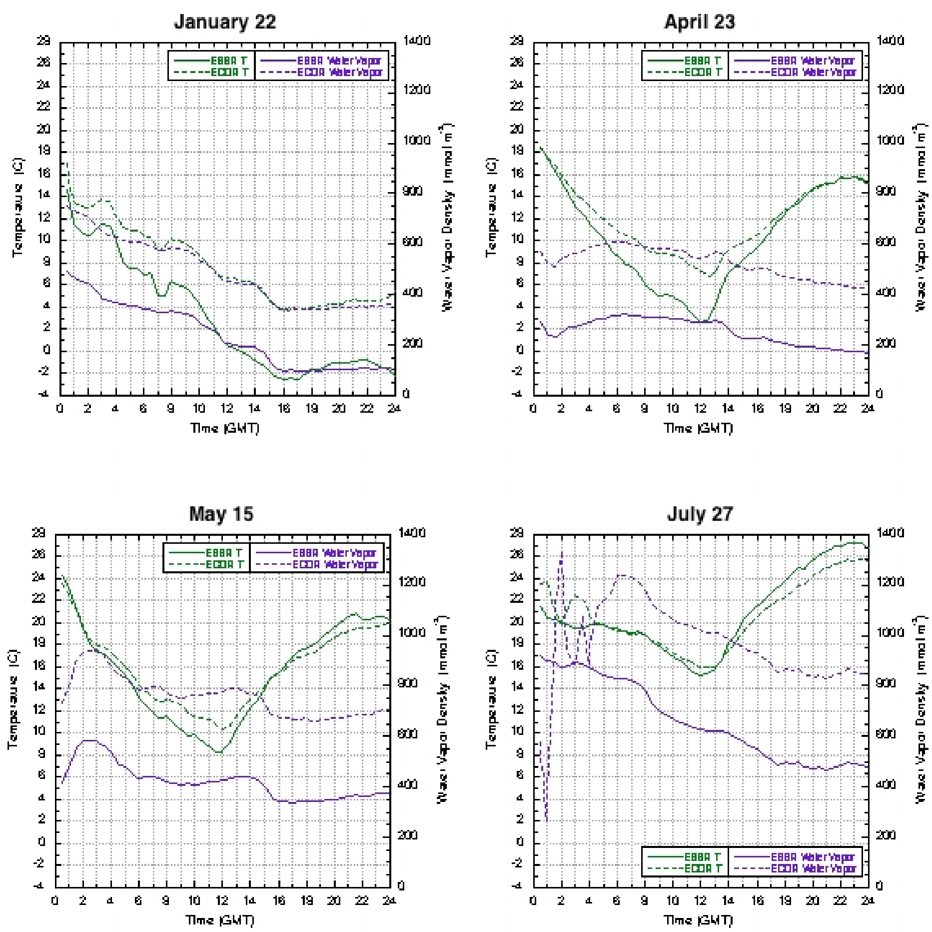


(1c)

By definition, the EBBR technique assumes that energy balance closure is 100%; both daytime and twenty-four hour average energy balance closure for the ECOR was 90% (based on the availability of energy as EBBR net radiation plus surface soil heat flux); this is a very normal closure for an eddy correlation system.

The ECOR sonic anemometer temperature and EBBR top level temperature generally agree within about 1°C during the daytime (see Figure 1d; Temperature). However, during colder temperatures, the sonic anemometer indicates higher temperatures than the EBBR, especially on January 22. The ECOR sonic anemometer was calibrated for temperature; however, the calibration curve lessens in slope with decreasing temperature. For simplicity, a straight line slope was fitted to the calibration data, causing the sonic anemometer to overestimate temperature at colder temperatures.

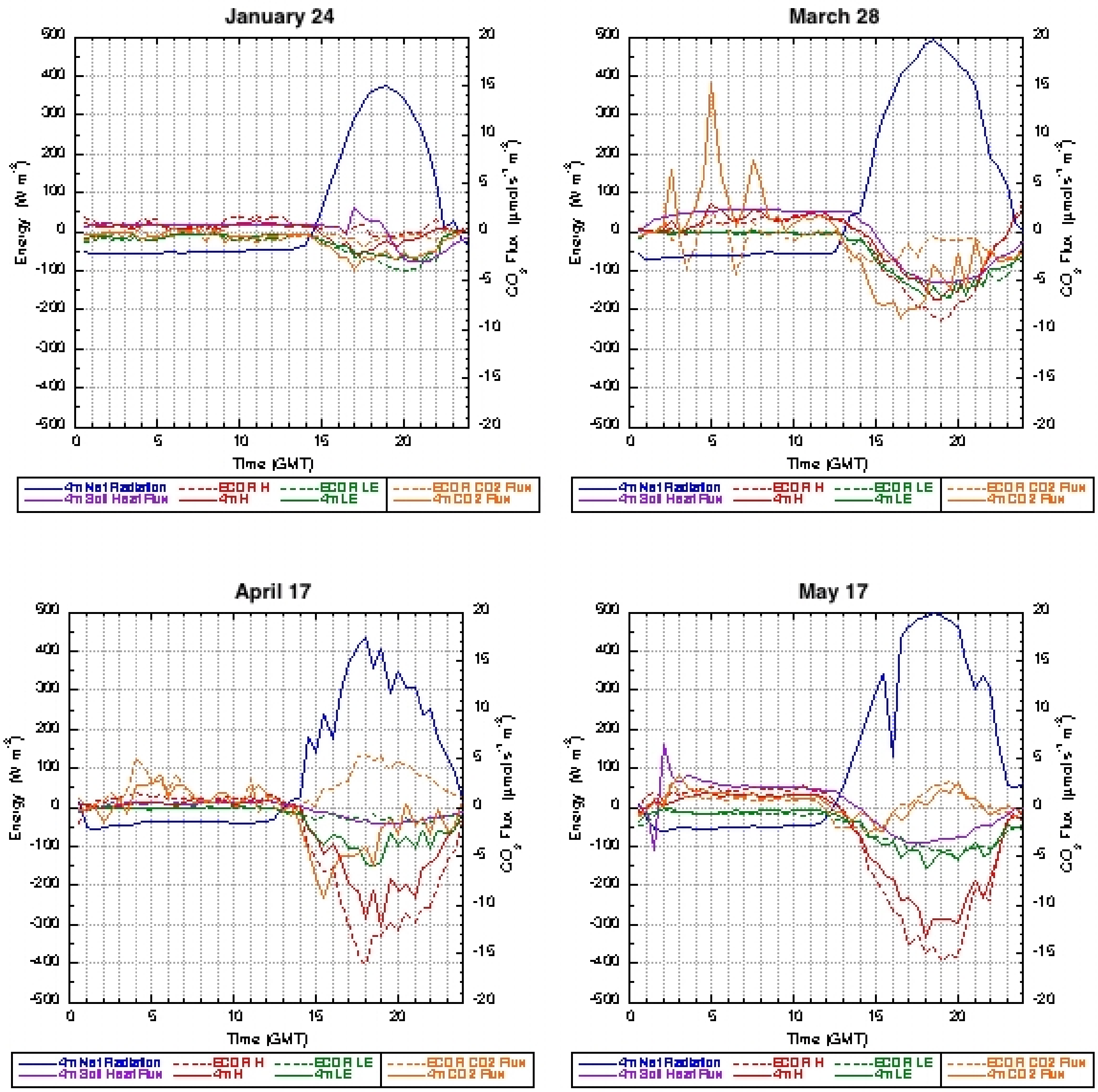
The water vapor density reported by the ECOR is much greater (280 mmol m^{-3}) than that measured by the EBBR top level (see Figure 1dc; Water Vapor Density). The ECOR LI-7500 CO_2/H_2O sensor has a very large water vapor offset. Fortunately, the offset does not affect the measured water vapor flux.



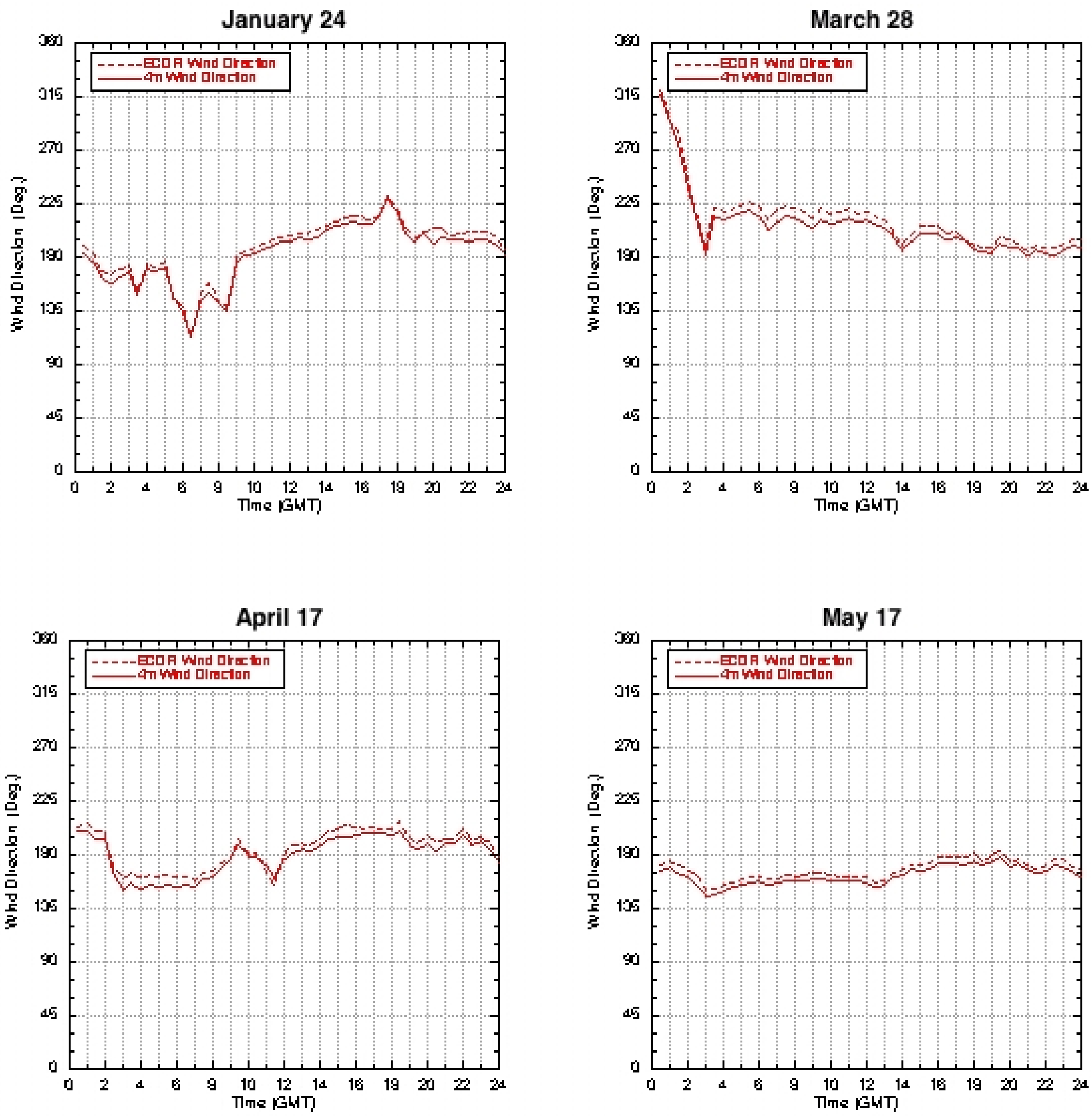
(1d)

ECOR-CO2FLX4m Comparisons

Please refer to the data plotted in Figures 2a through 2e and 3a through 3c when reading the discussion below.



(2a)

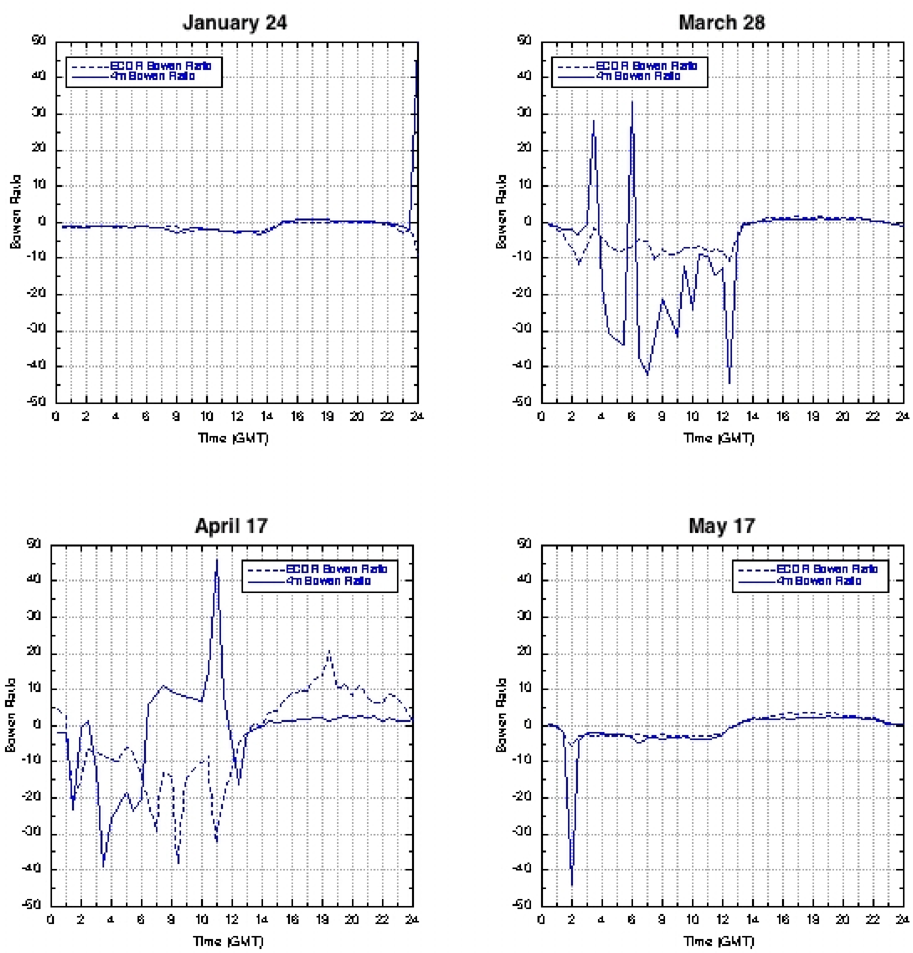


(2b)

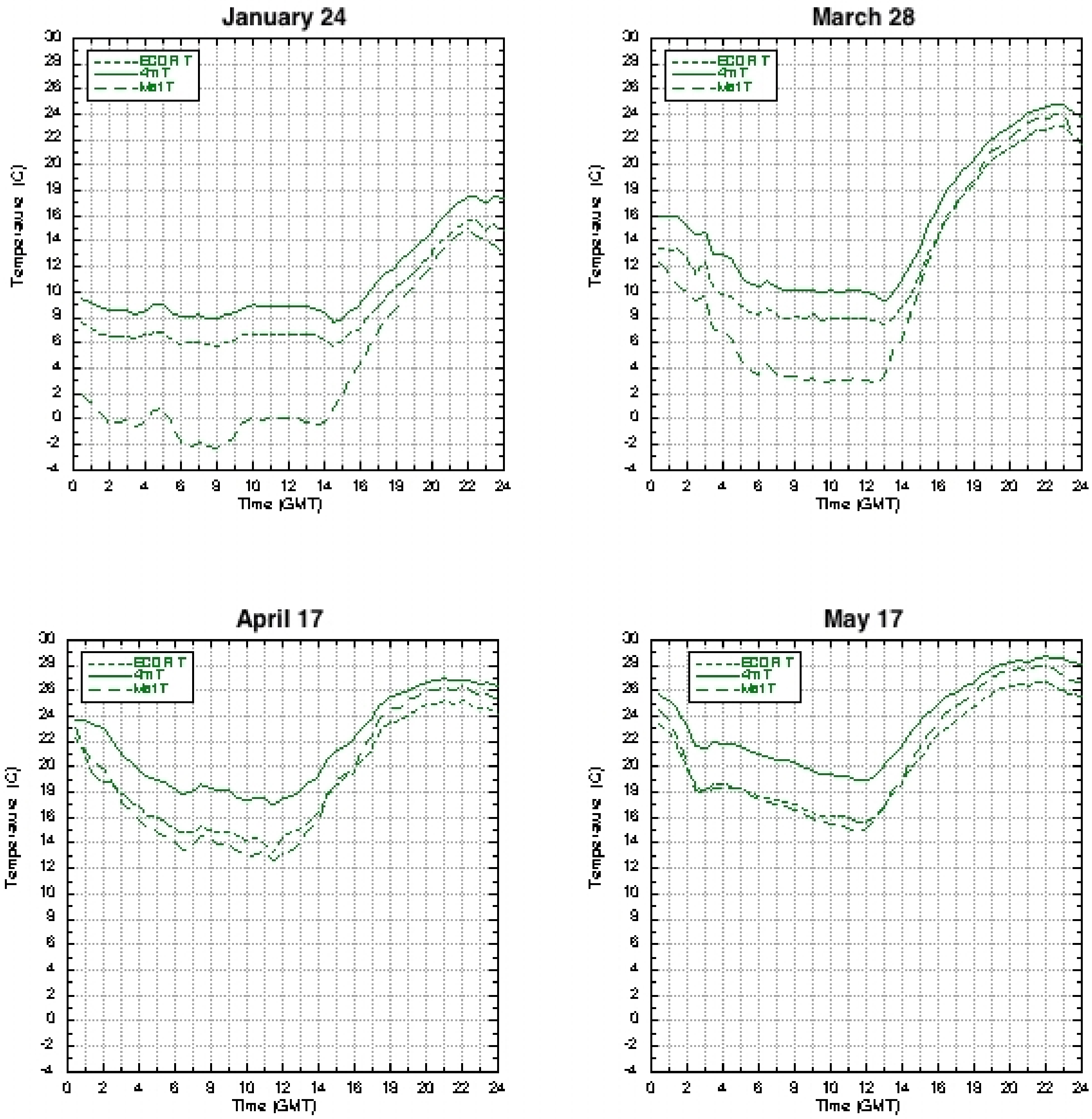
Figure 2a. Energy Balance and CO2 Flux: Net radiation and soil heat flow measured by the CO2FLX4m system (augmented by an estimate of soil heat storage) are representative of the nearly bare surface and weeds or young corn crop seen by the ECOR and CO2FLX4m for south winds. Storage of energy in the soil above the soil heat flow plates was not measured. Therefore, the EBBR ratio of soil surface heat flux to soil heat flow was used to adjust the CO2FLX4m soil heat flow plate measurements up to an estimated soil surface heat flux. H and LE are displayed for both the ECOR and CO2FLX4m in Figure 2a. The plot of wind direction (see Figure 2b; Wind Direction) shows that the ECOR and CO2FLX4m were measuring the same wind directions and the friction velocities measured by the two systems (see Table 1) were nearly identical, indicating that the two systems were seeing similar vegetation structure.

On average, ECOR H was 30% greater than H measured by the CO2FLX4m during daytime and 31% greater on a daily basis. ECOR LE was 16% smaller than that measured by the CO2FLX4m during daytime and 10% smaller on a daily basis.

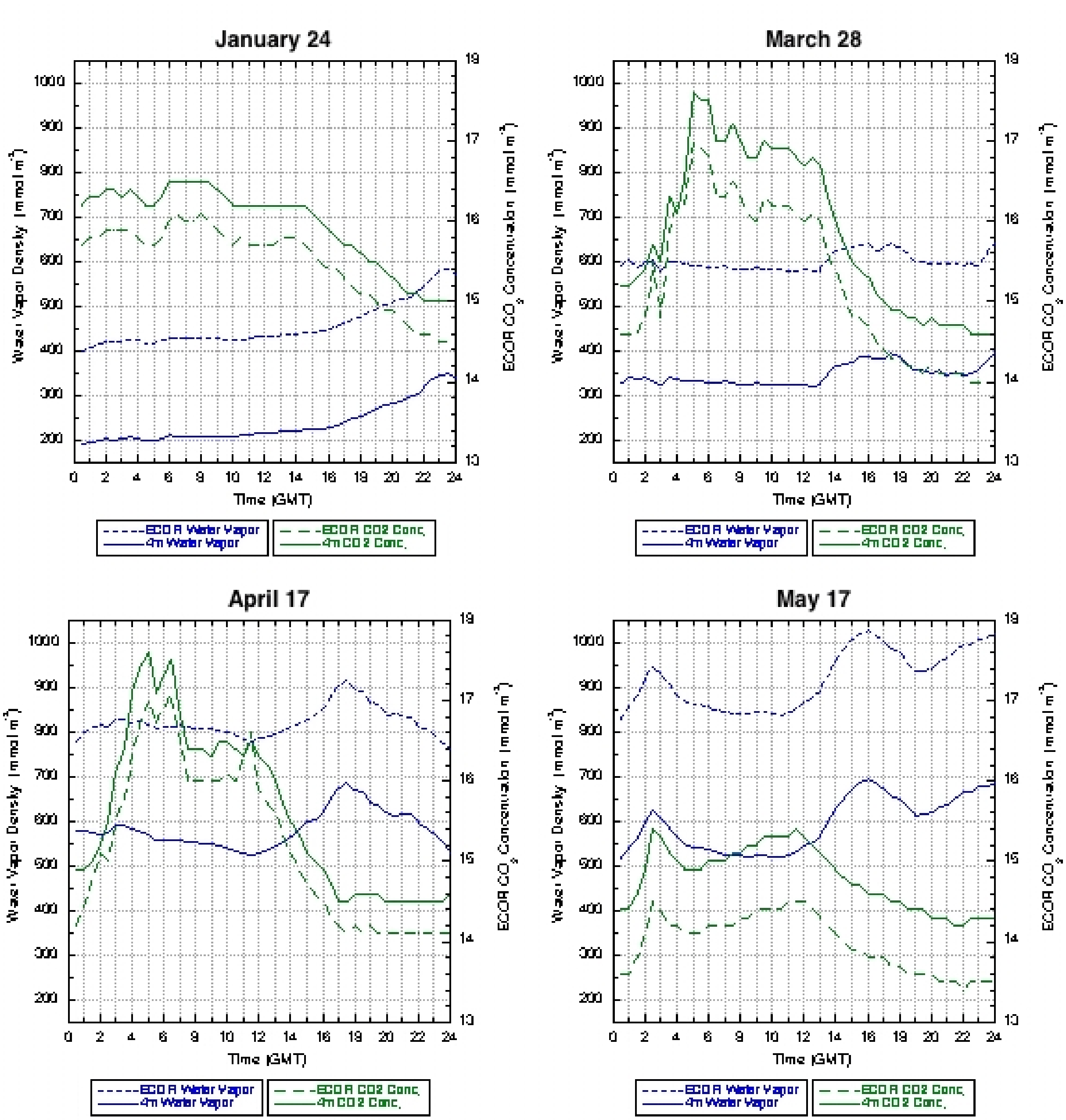
H was particularly small for the ECOR and CO2FLX4m on 24 January, much smaller than for the EBBR, apparently because of frozen soil. Neither system approached closure. It is suspected that the soil energy storage was underestimated; energy in the soil may have been lost to thawing of the frozen surface. Therefore, the available energy was apparently overestimated. This one day alone greatly reduced the average closure and therefore is not included in calculating the ECOR-CO2FLX4m comparison closures in Table 1. Daytime energy balance closure was 111% (based on the availability of energy as CO2FLX4m net radiation and soil surface heat flux) for the ECOR and 99% for the CO2FLX4m. The 24 January data shows the value of adding a soil energy storage measurement to the CO2FLX4m suite of measurements.



(2c)



(2d)



(2e)

The CO2FLX4m sonic anemometer temperature was normally greater than the ECOR sonic anemometer and CO2FLX4m mean temperatures (see Figure 2d; Temperature, and Figure 3a). The three temperature measurements only agreed well when the temperature was above about 24°C and differed greatly near 0°C. The ECOR temperature normally agreed quite well with the mean temperature, except at cold temperatures, where, as expected, the ECOR sonic temperature linear calibration slope causes the ECOR temperature to be greater. The CO2FLX4m sonic anemometer has not been calibrated for temperature and uses the default slope of 1.0. The comparison data suggests that the CO2FLX4m temperature measurement would benefit from an in situ temperature calibration of the sonic anemometer. It's difficult to reconcile the CO2FLX4m temperature being greater, and yet H being lower, than for the ECOR (except on 24 January).

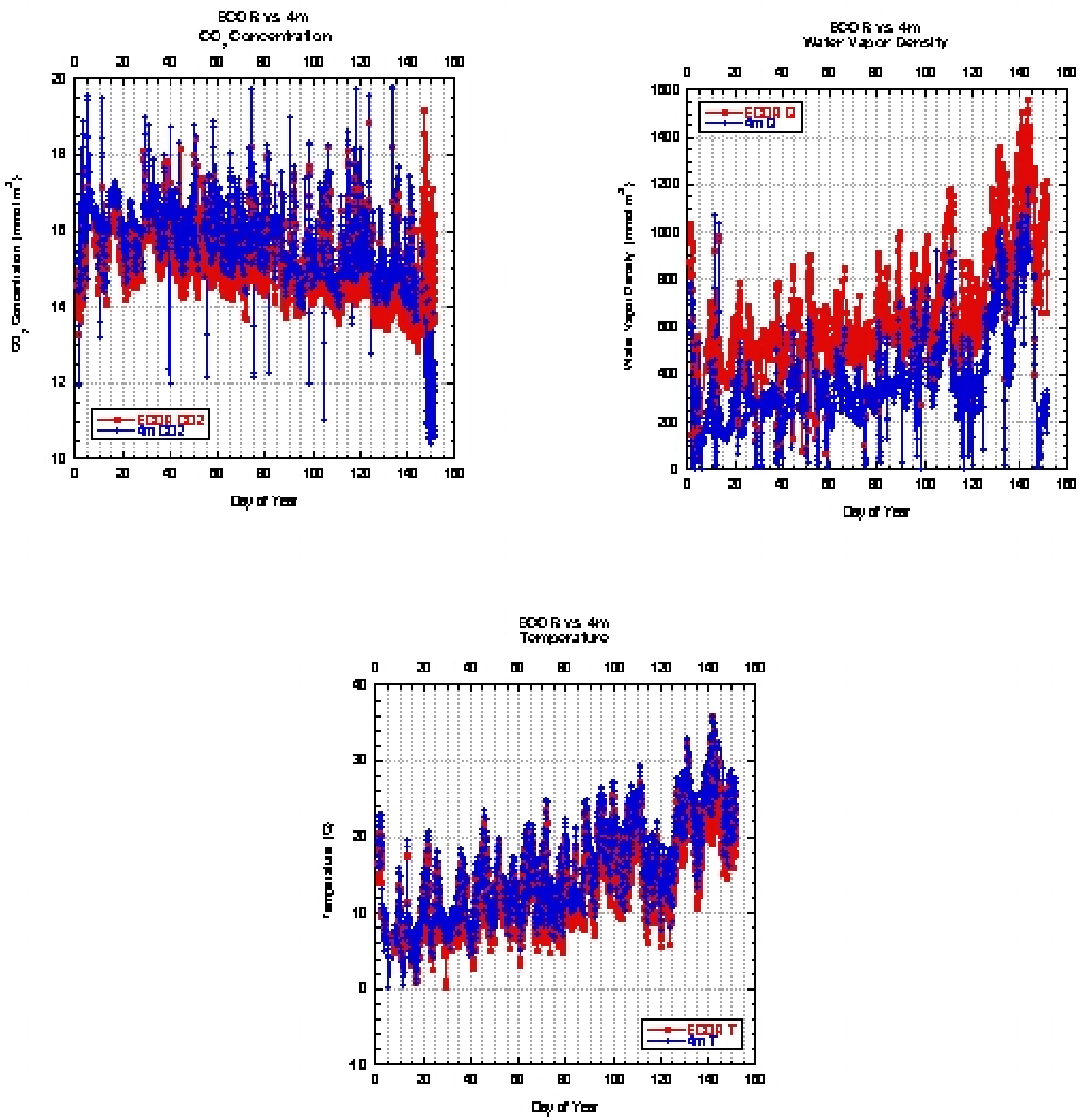


Figure 3a – 3c.

The water vapor density reported by the ECOR is much greater than that measured by the CO2FLX4m (see Figure 2e; Water Vapor Density and CO_2 Concentration, and Figure 3b). The ECOR LI-7500 CO_2/H_2O sensor has a very large water vapor offset (around 280 mmol m^{-3}). Fortunately, this offset does not affect the measured latent heat flux.

CO_2 concentrations measured by the ECOR and CO2FLX4m were nearly the same; with ECOR CO_2 concentrations being slightly lower (see Figure 2e; Water Vapor Density and CO_2 Concentration, and Figure 3c).

CO_2 fluxes measured by the ECOR and CO2FLX4m were similar on three days, but were quite different on 17 April (see Figure 2a; Energy Balance and CO_2 Flux). The ECOR CO_2 flux was positive most of 17 April, suggesting that even before WPL density corrections were applied the flux was significantly undermeasured.

Summary

Reasonably similar measurements of fluxes and means are given by the EBBR, ECOR, and CO2FLX4m systems when they are compared for the same vegetation surface. However, some measurement problems were identified in the process of conducting this study. Most of these problems have already been addressed by the authors, but others may need more consideration. A more rigorous LI-7500 CO_2/H_2O sensor calibration procedure has been implemented by the authors; this is expected to improve CO_2 and water vapor comparisons between the ECOR and CO2FLX4m systems. Lastly, the value of having tools (comparison plots on HandS) to detect data differences and to diagnose instrument problems is clearly shown by this study.

Tutorial of Flux Measurement Techniques

Energy balance Bowen ratio technique (EBBR): The Energy Balance Bowen Ratio (EBBR) system uses the gradient approach to produce 30 min estimates of the vertical fluxes of sensible and latent heat. Flux estimates are calculated from observations of net broadband radiation, soil surface heat flux, and the vertical gradients of temperature and vapor pressure. Other measurements include wind speed, wind direction, near surface soil temperature, near surface soil moisture, barometric pressure, and relative humidity. Data collected by the EBBR are also used to calculate bulk aerodynamic fluxes with the Bulk Aerodynamic Technique (BA) EBBR value-added product (VAP), to replace sunrise and sunset spikes in the flux data. A unique aspect of the system is the automatic exchange mechanism (AEM), which helps to reduce errors from instrument offset drift by switching the gradient instruments from upper to lower positions or vice versa every 15 minutes. Accuracy of the flux measurements is approximately +/-10%, with a tendency to overestimate latent heat flux. There are 14 EBBR systems installed in SGP and 1 proposed for the Darwin site in TWP.

Eddy correlation technique (ECOR, CO2FLX4m): The eddy correlation flux measurement systems provide half-hour average measurements of the surface turbulent fluxes of sensible heat, latent heat, carbon dioxide, and momentum. Other measurements include wind speed, wind direction, barometric pressure, sonic temperature (nearly virtual temperature), CO_2 concentration, CO_2/H_2O sensor internal temperature, and water vapor density. The fluxes are calculated by correlating the instantaneous differences from the means of vertical wind speed and the other measurements: horizontal wind speed, air temperature, water vapor density, and CO_2 concentration. Instruments used include the Gill WindMaster Pro sonic anemometer and the LICOR LI-7500 CO_2/H_2O sensor. The ECOR and CO2FLX4m systems employ different types of data acquisition systems and programming. Accuracy of the flux measurements is +/- 20%, with underestimation of fluxes being common. There are 9 ECOR systems installed in SGP and 1 in the AMF. There are three LBNL CO2FLX systems installed at the SGP CF, at 4, 25, and 60 meters height.