# Monitoring Carbon, Heat, and Water Vapor turbulent fluxes over an Agricultural Field in Western Amazon.

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**Introduction.**

The interest of the impact of deforestation on climate in Amazon has been shown in several models and projects. Most of those studies indicated the transformation from a forest to a pasture field. However, during the past years, there has been an increase of the area of rice and soybean plantation. In the Large scale Biosphere-Atmosphere experiment in Amazonia (LBA) there is a continuing effort to understand the effects of this type of deforestation with a continuous data set. This study presents the results of turbulent flux measurements of carbon, heat, and moisture using the eddy correlation system over an agricultural site in the Eastern Amazon region. During the last 5 years this field has been transformed from a pasture to a rice and soybean plantation. The emphasis in this study is to show the detection of the vegetation phenology and its relationship with carbon exchange and the turbulent kinetic energy partition. We will show the changes in turbulent fluxes ($CO_2$, $H_20$, and heat), radiative parameters (albedo and PAR-albedo), and other parameters due to changing landscape from a pasture to crop fields.

**Instrumentation, methods, and land use.**

The site is located in the Western Amazon, in the Santarém region (3.012$^0$S, 54.537$^0$W). A 20 m tower was installed in an agricultural field to monitor standard micrometeorological variables and carbon dioxide concentration. The site is open, with the closest trees in the direction of the predominant easterly wind lying a kilometer from the tower. An eddy covariance system (EC), comprised of a 3D sonic anemometer (Applied Technologies, Inc, SATI/3K), and an infrared gas analyzer (IRGA, Licor 6262) to measure $CO_2$, and $H_2O$ concentrations, was installed at 8.75 m. Inlets and anemometers in the EC system faced east to accommodate predominant easterlies. Profile observations included temperature and humidity sensors in aspirated radiation shields (Vaisala Humitter, CS500, at 6.1, 4.1, 2.2 m), and $CO_2$ (Licor 6262, with sampling inlets at 11.8, 5.3, 2.7, and 0.5 m). Near tower top (17.8 m), incident and reflected global solar radiation (Kipp and Zonen, CM11/14) and 'photosynthetically active radiation' (PAR, 400-700nm), downwelling and upwelling global long-wave (CG2) radiative fluxes were collected at 0.2 Hz. Soil temperatures (Campbell, Inc. 108 at -0.10, -0.24, -0.50, -1.50, and -2.0 m), soil heat flux (Campbell HFT3 at -0.30 m), and soil moisture (Campbell CS615 at -0.30 m) were also installed. Data collection started on September 2000 and continues to the present. Just before the harvest, aboveground and belowground biomass measurements were performed.

Analog signals are digitized by dataloggers, and a PC linux machine collects the serial streams from the instruments and datalogger outputs. Averages, second, third, fourth moments, and flux covariance are calculated at 30 minute intervals. Turbulent fluxes are calculated from deviations of a 30 minute centered running mean filter. A 3D rotation and density corrections are applied to perform flux calculation. The gap-filling strategy for daytime fluxes of $CO_2$ is to use carbon assimilation light curves and the vapor pressure deficit. Nighttime fluxes are estimated through the nocturnal boundary layer budget method (Acevedo et al., 2004; Sakai et al., 2004) due to the lack of mechanic turbulence at night.

Land use history is shown in table 1. The data collection started on Sept 2000, and the field was a pasture. On 2000 the field was converted to an agricultural field. The agricultural practice involves the use of machines to plow and to till the soil, and heavy fertilization of the soil. In some years there are two crops, the rice plantation that usually starts at the beginning of the rain season (about January), and the soybean plantation that starts at the middle of the rainy season (May), and it ends at the beginning of the dry season (August or September).

Table 1: land-use history.

| Year | Description |
|---|---|
| 1984 | The original forest was cleared (burning). Pasture field. |
| 1990 | Burning (?) |
| 2000 | Sept 15: Started data collection.<br>pasture grass, *Brachiaria brizantha*<br>1 animal(buffalo or cow)/ha |
| 2001 | January to November: pasture<br>November 14 till 20: burning & plowing |
| 2002 | February 24 till June 13,14: rice<br>July 1 till July 5: burning<br>July 5 till December: fallow. |
| 2003 | January 2 till May 5 - rice<br>May 15 till September 1st - soybean<br>September till December: fallow |
| 2004 | January 14 to Apr 3 - rice<br>May 1 till Aug 31 – soybean |
| 2005 | May 1 till August 23 – soybean |
| 2006 | Fallow |

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**Discussion.**

PAR-albedo is sensitive to changes in vegetation cover and can be used to monitor the plant phenology of this site. We note that the PAR-albedo exhibits behavior inverse to that of the NDVI (the normalized difference vegetation index). Thus, a greener canopy corresponds to lower PAR-albedo. The wet season can be seen by the high values of the soil moisture content. Rice crop starts at the beginning of the wet season and it is harvested in the middle of the wet season. The soybeans are seeded in the middle of the wet season, and it is harvested after the start of the dry season. Notice that the PAR-albedo increases at the end of the soybean crop, indicating the change of color of the foliage, from green to dry yellow.

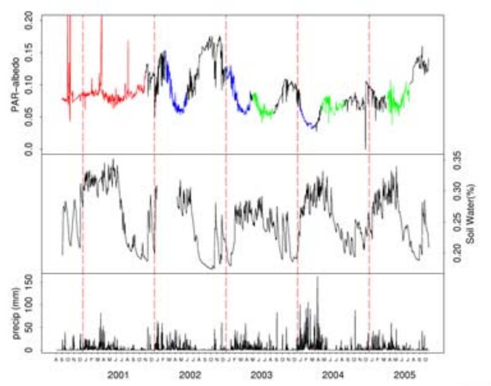


Figure 1: PAR-albedo (PARup/PARdw) time series for the entire experiment. Red line correspond when the field was a pasture, blue the rice crop, and green represents the soybean crops, (middle) soil moisture, (bottom) precipitation time series.

There is also a strong correlation between the canopy phenology and the $CO_2$ flux *NEE* values change according to the agricultural practice. Biomass measurements indicate the accuracy of the EC systems. The EC accumulation curves indicate that they underestimate the carbon uptake, principally for the rice crop (fig. 2). During the bare soil period, we hypothesize that the *NEE* should approach the soil respiration rate (since there is no vegetation) even during the daytime (fig. 3). Nearly constant efflux of $CO_2$ from the soil is indeed observed during daytime for the bare soil period, indicating that the soil respiration rate is approximately constant. Even though the nearby forest presents a bigger uptake during the daytime, it is offset by the high respiration rate thus the annual carbon uptake will be less than this site (Miller et al, 2004, Sakai et al, 2004).

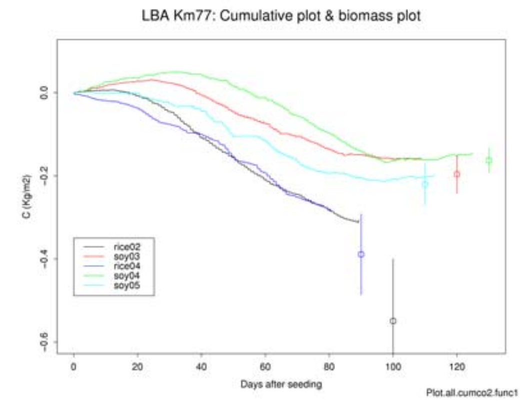


Figure 2: Cumulative plot of the Net Ecosystem Exchange (NEE) from the EC system. A negative indicates an uptake of carbon from the atmosphere. The circles at on the right side represents the biometric values sampled just before the harvest (check color table in the graph), error bars denote the standard deviation.

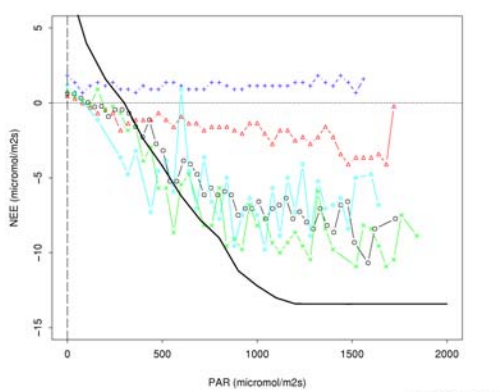


Figure 3: Light curves (NEE vs PAR) for the pasture wet (circles), pasture wet (triangles), bare (pluses), rice (crosses), and soybean (diamonds) periods. The thick curve represents the light curve for the nearby primary and cut forest sites (personal communication, Drs. Scott Miller and Scott Saleska).

Phenological changes are also manifested in changes in the partition of the available energy into sensible and heat flux. Lower Bowen ratio ($ß=H/LE$) values, associated with growing vegetation, are found during the wet periods (fig. 4). When a canopy is present or when the bare soil is wet, the Bowen ratio is approximately constant during the day. This contrasts with the situation in the nearby forest, where the highest evaporation rate measured during the dry season (Rocha et al., 2004). One interesting observation is the fact that evaporation rates at the end of the rice plantation show values lower than its equilibrium evaporation values.

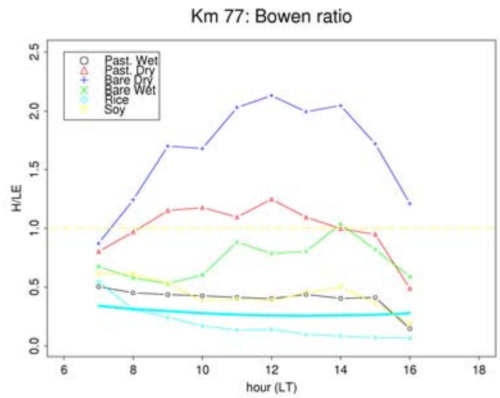


Figure 4: Hourly plot of the Bowen ratio for several vegetation covers. The thick blue line indicates the equilibrium evaporation.

Canopy parameterizations for turbulent fluxes, such as canopy resistance ($r_c$), also follow the phenological changes in the agricultural field (fig. 5). The lowest $r_c$ values are observed in the wet season, principally during the rice plantation. However, $r_c$ values for other cultures have bigger value than the aerodynamic resistance ($r_a$, fig. 6). This indicates that the exchange between the above mixed layer and air the canopy is more dominant than the local evaporation when $r_c$ is greater than $r_a$.

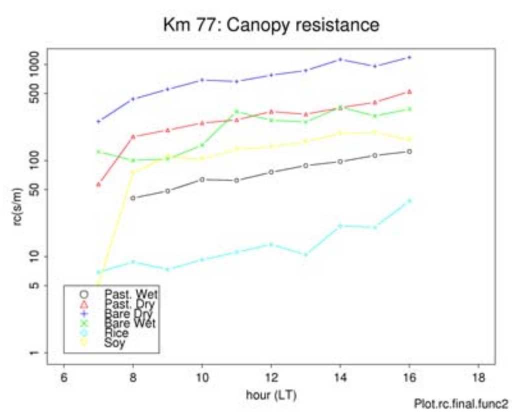


Figure 5: Hourly plot of the canopy resistance ($r_c$) for several vegetation covers. Note that the y-axis is logarithmic.

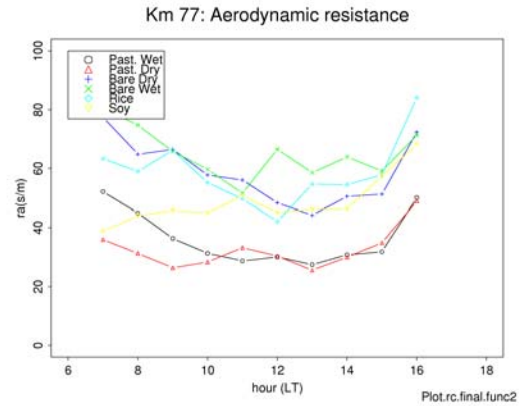


Figure 6: Hourly plot of the aerodynamic resistance ($r_a$) for several vegetation covers.

The $\Omega$ factor (McNaughton and Jarvis, 1983) measures the degree of coupling between the surface layer (SL) and the above mixed layer (ML). Low values of $\Omega$ indicate that the system SL/ML is well coupled such that turbulent mixing prevents the formation of strong SL/ML gradients. This connects the evaporation in the canopy with water vapor deficit in the mixed layer. High values of $\Omega$ indicate that the surface is isolated from the atmosphere because of relatively inefficient turbulent transport. In this scenario, the actual evaporation is strongly coupled with the available radiation energy in the daytime. There is a clear distinction between the dry and wet periods (fig. 7). During dry periods there turbulent mixing is more intense; for the wet season for both bare soil and pasture there is more of a balance between the radiative forcing with the turbulent exchange. The rice period is characterized by more complete domination of the net radiative forcing.

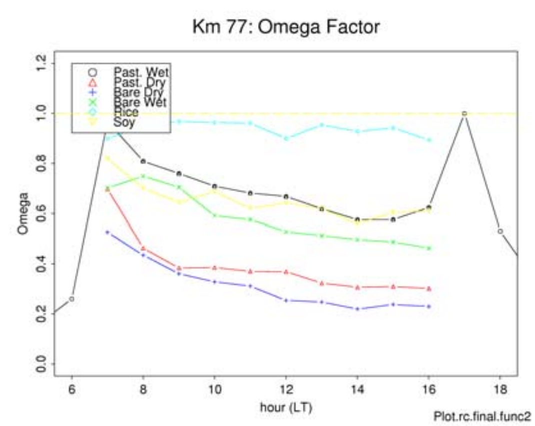


Figure 7:Hourly plot of the omega factor ($\Omega$) for several vegetation covers.

**Summary:**

Greenness of the vegetation, and differences in land cover type are clearly detected from changes in the PAR-albedo. Seasonal changes in these parameters are follow those of the daytime evaporation and carbon uptake. These changes in the albedo do not only indicate changes the net radiation regime, but they also mirror changes in energy partition and $CO_2$ fluxes. Lowest values of the Bowen ratio ($\beta$) were observed during wet periods, principally during rice plantation. During this period, $\beta$ values were lower than the equilibrium value, probably due to the fact that the rice roots were taking more ground water than do grass roots. Variation of the $\Omega$ factor separates the dry and wet regimes, showing that in wet periods local net radiation is the principal forcing in the evapotranspiration. There is net uptake of carbon in this field and it is bigger than adjacent forest. Carbon exchange depends on the agricultural practices. For instance, after plowing and tilling there is a small efflux of $CO_2$, rice crops have the highest carbon uptake. Therefore, the decision to have one or both crops or none, rice and soybean, and its fallow in one year will impact on the carbon uptake.

**Acknowledgements.**

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