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The impact of data gaps and quality control filtering on the balances of energy and carbon for a Southwest Amazon forest

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ABSTRACT

Fluxes of CO_2, water vapor, sensible heat and several heat storage terms were used to characterize the dependence of the energy balance closure and carbon balance on gaps introduced by screening for high quality or turbulent conditions. The current work is the first study where a sensitivity analysis was applied to the carbon balance and energy balance closure for an Amazonian forest site. The measurements were part of the RACCI/DRY-TO-WET Experiment, within the framework of the Large Scale Biosphere–Atmosphere Experiment in Amazonia (LBA). The energy balance closure varied from 88% to 98%, with an average intercept of $-5\,W\,m^{-2}$. The level of closure was dependent on the amount of data filtered out according to the quality control flag. A compromise between moderate data quality and good sampling of daytime periods was determined to be the best choice for this site. Different values of friction velocity threshold and data quality used in the screening of data resulted in a carbon balance ranging from -0.10 ± 0.15 to $0.31 \pm 0.25\,t\,C\,ha^{-1}$, where positive values indicate a net source of carbon in the period. Applying the screening based on friction velocity and quality control changed this ecosystem in the period analyzed from a sink into a source of carbon to the atmosphere. Year-round continuous measurements would be required to verify if the net release of carbon during this transition period is part of the natural cycle for this forest or if that was caused by disturbances in the ecosystem or local climatology. Our results show that the carbon sink strength associated with this forest site could have been overestimated in previous works due to underestimation of nocturnal respiration, caused by lack of filtering of low turbulence conditions.

1. Introduction

The Amazon forest has an important role in regulating the regional and global cycles of carbon, water and energy (Prentice and Lloyd, 1998; Andreae et al., 2002; Hutyra et al., 2007). Understanding the dynamics of such cycles in space and time is imperative to advance the knowledge about the exchange of matter and energy between the Amazon biosphere and the atmosphere. Moreover, measurements can be used as inputs in regional and global biogeochemical models that assess and predict the impacts of climate change on the forest and vice-versa (Pielke et al., 1998). Measurements can be made by satellite, airplanes, balloons or at the ecosystem level by micrometeorological towers. The assessment of ecosystem characteristics can be made at even smaller scales by using soil chambers, by evaluating the soil microbiology and by studying fluxes at the cellular level. In this work, the ecosystem scale was studied by using data collected in a micrometeorological tower located at the Jaru forest site, located in the southwest part of the Brazilian Amazon forest. Sensible and latent heat fluxes as well as several heat storage terms were compared to net radiation, an important measure of how good all the inputs and outputs of energy are being measured.

Grace et al. (1995) studied the same forest before and found that the ecosystem was a carbon sink, sequestering $1\,t\,C\,ha^{-1}\,year^{-1}$. Malhi and Grace (2000) discussed the plausibility of this value by considering the impact of several sinks and sources in the carbon balance. Regarding the sink derived from eddy covariance studies, the authors stressed the importance the uncertainties associated with nocturnal measurements, when the low level of turbulence leads to underestimated vertical fluxes of CO_2. Kruijt et al. (2004) analyzed separately all the sources of error and uncertainties in the fluxes calculated for several Amazonian sites, including the Jaru forest ecosystem. The authors found that errors associated with spikes or corrections due to instrument limitations were lower than 3% on an annual basis. However, the error for the annual carbon flux could reach up to 32% for the Jaru

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site, likely caused by terrain heterogeneity and gaps in the data coverage.

Lack of closure in the energy balance is a common problem reported in many studies that use the eddy covariance technique over agricultural ecosystems or forests (Twine et al., 2000; Araujo et al., 2002; Wilson et al., 2002; Vickers and Mahrt, 2003; Foken et al., 2006). von Randow et al. (2004), using data measured in 1999 at the Jaru forest site, found that the energy balance closure was approximately 74%. The authors hypothesized that the missing energy could be associated with mesoscale motions with time scales much larger than the usually used 30 min averaging period. However, averaging the fluxes up to 500 min still resulted in a lack of 15% in the balance found in that study. On the other hand, Malhi et al. (2002) found a closure of 100% using averages of 1–6 h for a forest site near Manaus, Brazil (central Amazon forest). Therefore, the contribution of low frequency motions to the energy balance closure could be site dependent, influenced by local characteristics of the flow, canopy structure and topography. In fact, this is a controversial subject, as discussed by Vickers and Mahrt (2003). They suggested that low frequency contributions for eddy covariance might be incorporated in flux calculations instead of be filtered out.

Convective clouds play a very peculiar role during the Amazon wet season, acting in a way to enhance inter scale motion interactions, what has been called “perturbated atmospheric state” by Garstang and Fitzjarrald (1999). Indeed, during the wet season campaign in 1999, the South Atlantic Convergence Zone (SACZ) was present, just above the western Amazon. It is interesting to mention that von Randow et al. (2002), in their analysis of low-frequency contributions for turbulent fluxes measured at the Jaru experimental site, have observed contributions on scales even greater than 1 h, corroborating the findings of Malhi et al. (2002). Such results show that Amazon forest flux calculations have to be estimated carefully, taking in account compromise relationships between sampling time and accuracy of flux computation (Shuttleworth et al., 1984). More discussion about the contribution of low-frequency motions to the fluxes in the Amazon region can be found in Malhi et al. (1998) and von Randow et al. (2002).

The objective of the current study is to characterize the sensitivity of both energy balance closure and carbon balance to several levels of screening of bad data (friction velocity threshold, quality control), which to our knowledge has not been done before for an Amazon site.

2. Site and data

The measurement site is located at the Jaru Biological Reserve, about 100 km north of Ji-Paraná, Rondônia, Brazil, in the south-western part of the Brazilian Amazon forest. A 60 m tall tower was installed at approximately 600 m from the shore of Machado River (coordinates: 10 ° 4′ 42.36″ S; 61 ° 56′ 1.62″ W, at 145 m a.s.l.). The trees are 35 m tall, on average, but some of them reach up to 45 m. This tower was used in 1999 for two campaigns of the LBA project (Large-Scale Biosphere-Atmosphere Experiment in Amazonia, http://lba.cptec.inpe.br/lba) and measurements were continuous until November of 2002. More details about these campaigns and site location can be found in Silva Dias et al. (2002), Andreae et al. (2002) and Kruijt et al. (2004). The fluxes of carbon and energy from 1999 to September of 2002 were reported in von Randow et al. (2004) and convective boundary layer characteristics for this region were presented in Fisch et al. (2004). The data used in this work was measured at the same tower during the Dry-to-Wet/RACCI LBA campaign that took place in several locations in the Brazilian state of Rondônia from September to November of 2002. The objective of this experiment was to investigate the physical processes that controlled the dry to wet transition in this region, specifically by characterizing the interactions between atmospheric water vapor and aerosols from forest fires (Andreae et al., 2004; Sapucci et al., 2007). Data collection was made in several locations using rawinsounding balloons, radar, airplanes and micrometeorological towers. Measurements of dry and wet deposition of nitrogen performed at a pasture site 80 km distant were reported in Trebs et al. (2006).

The forest tower was equipped with an eddy covariance system installed at 62.7 m, consisting of a 3D sonic anemometer (model Solent 1012R2, Gill Instruments, UK) and a closed path infra-red gas analyzer (IRGA) model LICOR 6262 (LICOR Inc., Nebraska, USA), both operating at 10.4 Hz. On 11 October 2002, an open path IRGA was added to the system, measuring close to the sonic anemometer. Air pressure was measured at 40 m using a barometer model PTB100A, from Vaisala (Helsinki, Finland). Wind direction was measured using a wind vane placed at 60 m (model W200P, Vector Instruments, UK). Wind speed was measured at several heights above and below the canopy using cup anemometers (model A100R, Vector Instruments, UK) placed at 15, 25, 35, 37, 39, 41, 44, 50 and 60 m. For air temperature and relative humidity, a vertical profile of thermohygrometers (model HMP35A, Vaisala, Helsinki, Finland) was installed with sensors at the following heights: 3, 12, 22, 28, 33, 37, 42, 52 and 60 m. These three variables were averaged every minute.

3. Methodology

3.1. Flux calculation

The eddy covariance technique was used in the determination of turbulent fluxes (Aubinet et al., 2000; Lee et al., 2004). The high frequency data was processed using the Alteddy software[1] (created by Jan Elbers, Alterra Group, Wageningen, Netherlands). The software was set up to apply a double rotation scheme to the coordinate system in order to align the horizontal wind to the mean flow and make the average vertical velocity zero (Kaimal and Finnigan, 1994). The Schotanus correction was applied to correct the effects of humidity on the temperature measured by the sonic anemometer (Schotanus et al., 1983). The effects of air density on the measurements of the open path IRGA were corrected according to Webb et al. (1980) (WPL correction). The air had to be transported from the inlet close to the sonic anemometer into the closed path IRGA, what introduced a time lag between these measurements and that made by the sonic anemometer. These lags were determined and accounted for each half hour file before calculating the covariances. In addition, high frequency losses in the fluxes caused by both transport through the tubes and sensor separation were also corrected (Philip, 1963; Moore, 1986; Leuning and King, 1992). A time series is considered stationary if its statistical properties (mean, variance, etc.) do not change over time. Since stationarity is one of the fundamental assumptions of the eddy covariance method (Stull, 1988), it is important to estimate its value for each signal. Non-stationarity can be calculated by comparing the average of signal statistics (e.g., mean) within sub-sets of the signal with the overall statistic. A deviation between these two calculations is associated with non-stationarity. The software used in this work generated flags (1–9) based on the quality control proposed by Foken et al. (2004), which takes into account the stationarity of the time series. The higher the flag, the higher the level of non-stationarity in the fluxes (e.g., flag 3 denotes 50% of non-stationarity). In this work we also used flag 9 to mark missing records or data out of reasonable limits.

[1] http://www.climatexchange.nl/projects/alteddy/index.htm.