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Gap-filling measurements of carbon dioxide storage in tropical rainforest canopy airspace

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Abstract

For the determination of biotic fluxes of carbon dioxide (CO_2) or other trace gases to or from a forest canopy, it is important to measure the storage of the trace gas within the forest canopy in addition to the net vertical flux above the forest canopy. However, the data continuity of within-canopy storage measurements can be poor because these measurements are subject to frequent equipment breakdowns. We here explore methods for gap-filling within-canopy CO_2 storage, using the data derived from an Amazonian rainforest (Caxiuanã). Our first approach was to estimate hourly storage from hourly CO_2 concentration measured above the canopy at the tower top. This proved unreliable, since at this hourly time scale the variations in above-canopy CO_2 are often decoupled from local changes in within-canopy storage. We then explored a second approach based on determination of the *total* CO_2 accumulation over a night. This was found to be adequately correlated with a time-weighted friction velocity (u_{*w}) averaged over a night ($R^2 = 0.42$). The total night-time storage was then used to model daytime depletion of CO_2 within the canopy. The gap-filling model was validated against independent data from the same site, and also applied to another tropical forest (Jarú) with similar results. The modelled storage is in good agreement with the measured storage, and by reducing susceptibility to advection error it is in some ways superior to the direct storage measurements. This suggests at the possibility of a general method for estimating storage in forest canopies, with re-calibration for each site.
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Keywords: Within-canopy CO_2 storage; Gap-filling method; Tropical rainforest; Friction velocity; Eddy covariance method

1. Introduction

Over the past decade, there has been a proliferation of studies utilising micrometeorological methods to quantify the flux of carbon dioxide (CO_2) and other trace gases between vegetation canopies and the atmosphere (Baldocchi et al., 2001). Whilst the focus of these studies has been on above-canopy fluxes, there was an early realisation that there can be significant storage of trace gases within the canopy airspace. The degree of storage varies with the intensity of boundary-layer turbulence and thus over the diurnal cycle. For CO_2 and other trace gases with nocturnal, sub-canopy emissions, there is a tendency of accumulation of the trace gases within the canopy airspace at night, and a depletion of this store in the early morning as thermal convection sets in.

Whilst the net effect of the storage of CO_2 over a full diurnal cycle is approximately zero (night-time accumulation = daytime loss), it can be important to measure this storage if our interest is to estimate the

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Nomenclature

C	CO_2 concentration (μmol m^{-3})
C_{top}	CO_2 concentration measured by the eddy covariance instrumentation at the top of the tower (μmol m^{-3})
d	zero-plane displacement (m)
h	the height of eddy covariance instrumentation (m)
LW	above-canopy downward long-wave radiation (W m^{-2})
R^2	coefficient of determination
RMSE	root mean square error
S_c	accumulated storage during night (g (C) m^{-2} $night^{-1}$)
S_c/F_{biotic}	ratio of night-time storage to night-time biotic flux
S_c/F_c	ratio of night-time storage to night-time above-canopy flux
T_a	air temperature at tower-top (°C)
T_s	soil temperature (°C)
u_*	friction velocity at tower-top (m s^{-1})
u_{*w}	time-weighted friction velocity averaged over a night (ms^{-1})
z	height above the ground surface (m)
$(z-d)/L$	Monin–Obukhov stability parameter (dimensionless)

"biotic" flux of the trace gas, and understand its physiological controls. The biotic flux (or net ecosystem exchange, NEE) is defined as biotic flux = above-canopy flux + storage flux. Measurement of within-canopy storage is now standard in many canopy flux measurement studies, with the most common approach using a gas analyser to measure gas concentrations from a sampling system that automatically cycles between intakes at various heights within the forest canopy. The mechanical nature of these measurements, however, means that there can often be problems of equipment breakdown (e.g. pump failure and solenoid switch failure), especially in challenging environments such as remote tropical forests (with problems with insects and humidity) or boreal forests (with problems with insects and icing). Therefore, the data continuity of storage measurements may often not match those of the above-canopy measurements. A reliable method of "gap-filling" measurements for within-canopy storage would clearly be desirable.

In this paper we explore the potential of various approaches to gap-filling measurements of storage in tropical forest canopies, utilising either data from the above-canopy flux measurements or from meteorological observations. In addition to describing a technical procedure, this paper is also of more general value in its exploration of the determinants of within-canopy CO_2 storage. We first explore the potential of utilising hourly or 30-min observations of above-canopy turbulence and CO_2 concentration. This approach is demonstrated to be unreliable, because at this time scale the variations in above-canopy CO_2 are often decoupled from local changes in within-canopy storage, and more influenced by advection from nearby regions.

In homogeneous canopies, advection problems are often related to limited sampling times, and we then explore an approach of utilising the mean meteorological or turbulence conditions over the entire night to estimate the total storage over the night. Total night-time storage is found to be more consistently predictable, and we then develop empirical relationships between total storage and the daytime evacuation of CO_2 from the canopy. Our aim here is to present an approach to site-specific gap-filling of CO_2 storage, but we also present evidence that there may be generalities in the storage phenomenon that are consistent across forest sites.

In summary, the questions that we address in this paper are:

(1) can the accumulation of CO_2 in a forest canopy be predicted from standard turbulence or meteorological variables?
(2) which variable is the best predictor of CO_2 storage?
(3) is the relationship between storage and turbulence invariant between forest sites?

2. Methods

2.1. Sites and measurements

The data used in our main analysis were collected in the Caxiuana National Forest (1°43′S, 51°27′W, 20 m above mean sea level), approximately 350 km to the west of the city of Belém, Pará, Brazil. This is an extensive, undisturbed, dense lowland tropical forest with a mean annual rainfall of 2400 mm, a mean canopy height of 35 m, an above-ground dry biomass of 330–430 t ha^{-1} (Wood et al., submitted for publication) and a leaf area index of 5–6 (P. Meir, unpublished data). Further site details are given in Carswell et al. (2002). The Edisol eddy covariance system (Moncrieff et al., 1997) was mounted above a 51.5 m tall aluminum tower. Eddy covariance sensors were mounted 4 m

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