Available online at www.sciencedirect.com
ScienceDirect
Agricultural and Forest Meteorology 142 (2007) 25–34
AGRICULTURAL AND FOREST METEOROLOGY
www.elsevier.com/locate/agrformet

The effect of canopy gaps on subcanopy ventilation and scalar fluxes in a tropical forest

Scott D. Miller[a,b,*], Michael L. Goulden[a], Humberto R. da Rocha[c]

[a] *Department of Earth System Science, University of California, Irvine, CA, United States*
[b] *Atmospheric Sciences Research Center, State University of New York, Albany, NY 12203, United States*
[c] *Department of Atmospheric Sciences, University of Sao Paulo, Brazil*

Received 5 April 2006; accepted 12 October 2006

Abstract

Forest gaps may provide conduits that preferentially vent moist, CO_2-rich subcanopy air to the atmosphere. We measured the above-canopy fluxes of momentum, sensible heat (H), CO_2, and water vapor (E_t), and the vertical profiles of CO_2 and water vapor, from two 67-m meteorological towers in a selectively logged Brazilian rainforest. The logging removed ~3.5 trees ha^{-1}, and increased the incidence of gaps by a factor of 3 over nearby undisturbed forest. One tower was located in an intact patch of forest within the selectively logged area; the other was 400 m upwind in a large gap created by the logging. During daytime the subcanopy air in the intact patch of forest had more CO_2, more water vapor, and was cooler than the air at comparable altitudes in the gap. Meanwhile, the daytime CO_2 flux was less negative (reduced CO_2 uptake) above the gap than above the intact forest, the daytime E_t was greater above the gap than the intact forest, and the daytime H was lower above the gap than the intact forest. These patterns cannot be explained fully by the local loss of canopy gas exchange in the gap, but are consistent with the horizontal transport into the gap, and subsequent vertical transport out of the gap, of high-CO_2, humid, cool air from the forest understory. The understory was drier and warmer during daytime after the logging, which would be expected to increase flammability. Further measurement and modeling efforts are needed to better understand the effect of canopy gaps on the local CO_2 and energy exchange, as well as the flux footprint.

Keywords: Canopy gaps; Carbon dioxide exchange; Eddy covariance; Tropical forest; Microclimate; Ventilation; Tropical logging; LBA-ECO

1. Introduction

Forest gaps, caused by the death of canopy trees due to disease, stress, age, strong winds, lightning, or selective logging, may provide conduits that preferentially vent moist, CO_2-rich subcanopy air to the atmosphere. Winds penetrate more easily into the lower forest near gaps, increasing subcanopy ventilation and drying (Laurance, 2004). Gaps alter the microclimate as more solar energy reaches the understory. The temperatures in gaps may be higher than those in intact forest areas (van Dam, 2001), creating the possibility of buoyant air motions and a ''chimney-effect''. Venting has the potential to dry and warm the subcanopy air, with implications for forest flammability (Uhl and Kauffman, 1990; Holdsworth and Uhl, 1997; Nepstad et al., 1999; Cochrane, 2003). Venting also has the potential to redistribute the flux of CO_2, with implications for the use of eddy covariance to determine ecosystem carbon balance (Acevedo, 2001). The tall

* Corresponding author at: Atmospheric Sciences Research Center, State University of New York, Albany, NY 12203, United States. Tel.: +1 518 437 8799; fax: +1 518 437 8758.
E-mail address: smiller@albany.edu (S.D. Miller).

0168-1923/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.agrformet.2006.10.008

trees, dense canopy, and common occurrence of an atmospherically stable subcanopy layer in tropical forest (Fitzjarrald et al., 1990; Goulden et al., 2006) may enhance the importance of gap venting in the tropics compared to other regions.

The micrometeorological technique eddy covariance is commonly used to measure the carbon dioxide and water vapor exchange by terrestrial ecosystems (Baldocchi et al., 1988; Wofsy et al., 1993). Eddy covariance provides a direct, high-precision flux measurement averaged over a relatively large footprint. For daytime measurements at ~10 m above a rough forest canopy, the upwind forest area that contributes to the flux is of order tens to hundreds of ha (e.g., Rannik et al., 2000). The forest–atmosphere exchange in a horizontally uniform (homogeneous) area is assumed to occur in the vertical direction only, and the net ecosystem exchange (NEE) of carbon dioxide is considered the sum of the vertical turbulent flux and the decline or accumulation of carbon dioxide in the air column beneath the flux sensors (storage). The formal expression for NEE over a heterogeneous surface includes additional terms in the mass conservation equation to account for horizontal gradients and advection. Simulations of turbulent flow over a forest gap predict spatial variations in scalar fluxes driven by local flow patterns, buoyant heating at the gap surface, and the entrainment of overlying air into the gap airspace (Acevedo, 2001). Key issues for the use of eddy covariance above forest are whether canopy gaps create local circulations that violate the assumption of horizontal homogeneity, and whether and how locating eddy covariance towers close to or within a gap effects turbulent fluxes (Sun et al., 1998).

We investigated the possibility that a large gap created by selective logging in an Amazonian tropical forest was a preferential vent for the evacuation of subcanopy air during the daytime. Our study took advantage of a selective logging operation within the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA-ECO; Keller et al., 2004). The logging created a mosaic of gaps and intact forest. We measured the carbon dioxide and water vapor exchange simultaneously from two nearby towers. The first tower operated for 3 years beginning 1 year before logging in an intact patch of forest that was within the selectively logged area. The second tower operated for 2 years beginning after logging, and was located in a large gap approximately 400 m upwind of the first tower. Our analysis focused on comparing the daytime fluxes of momentum, heat, carbon dioxide and water vapor, and the vertical profiles of carbon dioxide and water vapor between the towers.

2. Methods

2.1. Site

The measurements were made in the Floresta Nacional do Tapajos, near the 83 km marker on the Santarem-Cuiaba highway (BR 163), ~70 km south of Santarem in the state of Para, Brazil (3.010308°S, 54.581508°W). The vegetation was tropical humid forest on a broad, flat plateau, with a canopy height of ~20–40 m. The soil was yellow latosol clay (Haplic acrorthox). Additional details of the landscape and local topography are reported by Hernandez Filho et al. (1993) and Goulden et al. (2006). Details of the experimental design and the pre-logging meteorology and fluxes are described in Goulden et al. (2004), Rocha et al. (2004), and Miller et al. (2004).

A 700-ha area was selectively logged during 3 months beginning in September 2001 (Fig. 1). The logging included reduced-impact techniques such as pre-selection of the trees to be harvested, and the planning of felling directions, skid trails and log landings (Pereira et al., 2002). Six months before logging, vines of selected trees were cut to reduce canopy damage during felling. After the logging, gap location, size, and shape were mapped in a 600 m × 300 m intensively studied area that extended 500 m to the northeast of the intact tower and that encompassed the area around the gap tower. We also calculated the incidence of gaps upwind of the two towers and also in larger tracts of logged and unlogged forest using a classified IKONOS image (Fig. 1). We calculated the Normalized Difference Vegetation Index (NDVI) from the Red and near Infrared IKONOS bands. We then created a classified image of the occurrence of gaps using a NDVI threshold, where gaps had an NDVI < 0.4 and intact crowns had an NDVI ≥ 0.4.

2.2. Micrometeorological measurements

The meteorological measurements were made from two 67-m-tall, 46-cm-triangular-cross-section towers (Rohn 55G, Peoria IL) located within the selectively logged area (Fig. 1). The logging extended several kilometers to the east (the climatological upwind direction) of the towers. The first tower was installed and operating in June 2000, 15 months before the logging (Goulden et al., 2004; Miller et al., 2004; Rocha et al., 2004). The nearest gap created by the logging in the upwind direction was 50–75 m from the tower, and we refer to this tower as the 'intact' tower (Fig. 1). The second tower (the 'gap' tower) was installed and