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Energy dynamics and modeled evapotranspiration from a wet tropical forest in Costa Rica

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Abstract

The effects of albedo, net radiation (R_n), vapor pressure deficit (VPD), and surface conductances on energy fluxes and evapotranspiration (ET) were determined for a wet tropical forest in NE Costa Rica from 1997 to 2000. Sensible heat fluxes (H) were estimated by the combination of eddy-covariance and the change in below-canopy heat profiles. Above-canopy latent heat fluxes (λE) were estimated by the residuals from R_n and H, and below canopy λE fluxes. Surface reflectance (albedo) was $\sim$12% of incident solar radiation and did not differ seasonally. R_n was significantly different among years and explained $\sim$79% of the variation in H and λE fluxes. The effects of VPD did not explain any additional variation in heat fluxes. λE fluxes were always greater than H fluxes when $R_n > 40\ \mathrm{W\ m^{-2}}$. Understory heat fluxes were small and contributed little towards daily energy exchange, but may be significant when R_n is small. A dimensionless coefficient (Ω) was used to determine the relative importance of aerodynamic conductance (g_a) and bulk canopy conductance (g_b) on λE flux. During the day, Ω was >0.6 and peaked at 0.85 suggesting that the forest was decoupled from physiological controls, λE fluxes are more dependent on R_n than water availability, and g_a exerts more control on λE fluxes than g_b. Because of these results, both the Priestly–Taylor and the Penman–Monteith models performed well using only R_n. Because the canopy is wet $\sim$32% of the time, there was better precision in estimating λE fluxes using the Priestly–Taylor model (with an empirically estimated $\alpha = 1.24$), when the canopy was wet. Annual ET were 1892, 2292 and 2230 mm for 1998, 1999 and 2000, respectively. Annual ET ranged from 54 to 66% of bulk precipitation. Using a Rutter-type model, interception losses were 17–18% of bulk precipitation. The overall amount of energy needed for annual ET accounted for $\sim$88 to 97% of total R_n.

Keywords: Tropical wet forest; Evapotranspiration; Latent heat; Sensible heat; Penman–Monteith; Priestly–Taylor; Eddy covariance

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1. Introduction

The energy balance of tropical forests is complex due to feedback mechanisms among radiation, cloud formation and precipitation (Wielicki et al., 2002; Hartmann et al., 2001; Sohn and Smith, 1992). This complexity extends to the potential role of the tropical energy balance in affecting tropical and global climates and general and anomalous circulations (Kelly and Randall, 2001; Timmermann et al., 1999; Chen and van den Dool, 1999; Fasullo and Webster, 1999; Larson et al., 1999). Much of our understanding of these dynamics has relied on model results, which have shown large spatial and temporal variability in both sensible and latent energy budgets (Kelly and Randall, 2001; Raman et al., 1998; Hulme and Viner, 1998; Shuttleworth, 1988). In situ studies have either scaled leaf level measurements to whole canopies (Bigelow, 2001; Avissar, 1993; Roberts et al., 1993), or have estimated the energy balance components using eddy covariance over short periods (cf. 8 d, Shuttleworth et al., 1984; 1 yr, Malhi et al., 2002; 1 yr, da Rocha et al., 2004). Quantifying the variation of energy balance parameters and their biophysical controls over longer periods (e.g. years) should allow for better predictions of runoff and improved models of regional and global climate.

Both physical and physiological factors influence forest energy fluxes, including incident radiation, surface albedo, rain, interception, canopy capacity, and aerodynamic (g_a) and bulk surface (g_b) conductances. Incident radiation in the tropics varies less seasonally than that at higher latitudes, and values at the surface are more related to cloudiness than changes in solar zenith angle. General circulation models tend to underestimate net radiation in the tropics because of uncertainties in estimating surface albedo and cloud cover (Cramer et al., 1999; Ruimy et al., 1995). Forest surface albedos range from 0.1 to 0.2 (Monteith and Unsworth, 1990), with annual and seasonal differences affecting the available energy. Large variability in annual rainfall totals have been observed in the tropics and are thought to be influenced by El Niño-Southern Oscillation (ENSO) and other anomalous circulations (e.g. McKinley et al., 2004; Malhi and Wright, 2004; Bousquet et al., 2000). This in turn affects the amounts of water available for evapotranspiration. A general observation is that 50–60% of annual rainfall is recirculated to the atmosphere through transpiration and evaporation of intercepted water, with the other 50% as runoff from neotropical humid forests that receive 2400–3000 mm yr^{-1} (da Rocha et al., 2004; Malhi et al., 2002; Shuttleworth, 1989). The results from these studies imply that local hydrology is strongly affected by how energy is partitioned at the surface.

Canopy conductances for tropical forests are typically determined by estimating bulk surface conductance (g_b) by scaling leaf-level or sap-flow measurements to the canopy (Whitehead, 1998; Dolman et al., 1991) or by deducing g_b in relation to meteorological parameters and measured fluxes (Wright and Gash, 1996; Stewart, 1988). Aerodynamic conductance is generally calculated as a function of horizontal windspeed, zero-plane displacement, and roughness length (Denmead and Bradley, 1985). Unlike agronomic communities in which evapotranspiration is dominated by transpiration and controlled by the plant's canopy conductance, evapotranspiration from tropical forests is generally thought to be strongly dependent on aerodynamic conductance, because of the high rainfall and the significant proportion of the time when the canopy is wet, reducing the importance of g_b in evapotranspiration (Shuttleworth, 1989).

Our research objective was to define the surface controls on the energy fluxes from a wet tropical forest in Costa Rica, which included the temporal partitioning of R_n, below-canopy energy fluxes, conductances and overall surface energy fluxes, and to use these controls to model annual evapotranspiration.

2. Methods

2.1. Study site

This study was conducted as part of a long-term study of tropical forest carbon cycling, the CARBONO project, at the La Selva Biological Station, Puerto Viejo de Sarapiquí, Costa Rica (10°25′51″N, 84°00′59″W, elevation 80–150 m.a.s.l.). La Selva is located in northeastern Costa Rica in the Caribbean lowlands at the base of the central volcanic chain and was classified as tropical wet forest in the Holdridge