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Micrometeorological aspects of a tropical mountain forest

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Abstract

Photosynthetically active radiation, air temperature, humidity and wind speed were registered along a vertical profile within and above a steeply sloped lower tropical montane rain forest in southern Ecuador. The upper canopy layer accounted for the absorption of more than 90% of incident photosynthetic photon flux density (PPFD); on an average only 5.5% reached the forest floor. Forest floor PPFD was modelled for the whole plot using hemispherical images, analysed with the Software HemiView 2.1. Model performance could be enhanced considerably when taking the narrowed horizon and a PPFD-adjusted atmospheric extinction coefficient into account. However, the simulation revealed high temporal variability of light conditions at the forest floor; modelled PPFD transmission ranged from 5.5% to 10.5% on an average and so was higher than measured values. Daytime temperature and water vapour gradients within the forest were weak, and the understory stratum appeared not to be decoupled from the atmospheric conditions above the forest. Even if methodology was insufficient with respect to quantification of turbulent structures, the measured gradients and the low wind deceleration within the forest indicates an efficient turbulent mixing of the stand air volume during typical daytime conditions. The importance of regional wind characteristics became evident under the influence of exceptionally strong, persistent, and dry mountain winds resulting in steeper aero-dynamic gradients throughout the measured profile. Thus, compared to level sites, forest meteorology of sloped mountain forests must be considered of higher complexity, due to the topography-influenced light conditions and the impact of complex local wind and turbulence patterns on the mountainous landscape.

Keywords: Light penetration; Rainforest; Thermal stratification; Wind profile

1. Introduction

The effective interaction of climate and plant stands has been well established since the early stages of micrometeorological research (Geiger, 1942). Thus, knowledge of biophysical exchange processes at the vegetation–atmosphere interface and its influence on forest microclimate is of great importance in ecological research since microclimate affects ecological processes such as plant regeneration and growth, soil respiration, nutrient cycling, and habitat formation, to name only a few. Furthermore, basic data on microclimate provide important input for ecological field studies, ecosystem modelling and management decision-making (Jones, 1992; Chen et al., 1999).

The general physical theory of energy, mass and momentum exchange and transfer is well-established for ideal conditions (Thom, 1975; Stull, 1988; Kaimal and Finnigan, 1994). However, knowledge of these processes in more complex mountainous terrain still remains quite limited (Kaimal and Finnigan, 1994; Staebler and Fitzjarrald, 2004), while applying micrometeorological theories to sites with non-ideal conditions may result in serious errors of unknown magnitude (Bernhofer, 1992; Baldocchi et al., 2001).

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Montane forest environments exhibit vast changes in soil characteristics, vegetation structure and climatic conditions within short horizontal and altitudinal distances. The rugged terrain produces small-scale heterogeneity in forest and canopy structure and variation in slope inclination and orientation, which primarily implicates drastic differences in solar energy influx. In addition, the diurnal rhythm of local wind systems, the topographically modified flow patterns, advective fluxes and gravitationally induced processes strongly influence forest climate (Whiteman, 2000; Staebler and Fitzjarrald, 2004). Field data on the highly complex mountain surface climates is scarce, even if some extensive studies on turbulence structures and energy exchange over steep mountainous terrain were recently performed in temperate regions (e.g. the MAP-RIVIERA project, in the Italian Alps; cf. Rotach et al., 2004).

However, even less information is available on forest microclimate in tropical montane environments. Besides the pioneering work of Troll (1968) on climate and ecology of Andean mountains and, more specifically the works of Grubb and Whitmore (1966, 1967) in Ecuador or Huber (1976) in Venezuela, few studies exist which include meteorological aspects of neotropical montane rain forests. Experimental set-ups have varied considerably depending on the particular object of investigation, ranging from studies on epiphytes (Pentecost, 1998; Catchpole, 2004), tree physiology and transpiration (Zotz et al., 1998; Santiago et al., 2000), energy and water budgets (Steinhardt, 1979), to forest hydrology (Hafkenscheid, 2000; Schellekens et al., 2000) and land use change (van der Molen, 2002).

The present study contributes to the understanding of micrometeorological conditions in a sloped lower montane rain forest and was integrated with ecophysiological research on water relations and forest microclimate (Motzer et al., 2005), forming part of a multidisciplinary ecological project conducted in the southern Ecuadorian Andes. The following paper focuses on spatio-temporal patterns of light, vertical temperature and water vapour profiles within the forest, and the influence of turbulent wind movement.

2. Methods and material

The study area is located within a native lower tropical montane rain forest on the eastern slope of the southern Ecuadorian Andes (3°58′S, 79°04′W; Fig. 1). The area is part of the "Reserva Biológica San Francisco" at the northern fringes of the Podocarpus National Park. Measurements were taken from a 480 m^2 forest plot situated on a N-NNW-facing 40–45° slope at 1975 m a.s.l. The average canopy height of the forest plot was 18 m. Its canopy could be divided into an overstory (>13–14 m height) and a mid-subcanopy stratum (2.5–14 m height). Any further separation into a midcanopy and a subcanopy layer remained dubious due to the non-continuous boundary at about 6–8 m height. The understory consisted of herbs, ferns, seedlings and juvenile trees below 2–2.5 m growth height. Leaf area index (LAI), inferred from optical measurements using a LAI2000 plant canopy analyser (Li-Cor Inc., Lincoln, NE), displayed an average of 6.4 (for further details on stand structure see Motzer, 2003).

A standard weather station ("met-station") operated by the University of Erlangen, Germany (Emck, personal communication) was located 320 m north-east of the research plot on a non-forested ridge at 1950 m a.s.l. (see Fig. 1). The data were used for comparison of the measured forest climate with regional climatic conditions. According to the met-station data, annual precipitation amounted to 2067 mm (period 1998–2002). A marked rainy season occurs from April to June with maximum rainfall in May (up to 257 mm), while a drier period occurs between November and January (minimum in November 90 mm). Mean annual air temperature was 15.5 °C (1999–2002), varying from 14.5 °C (July) to 16.2 °C (November). Under dry and bright conditions, temperature might exceed 25 °C. Generally, air humidity was high and night-time saturation was the norm. Low clouds or dense fog were infrequent and horizontal precipitation contributed to less than 5% of the annual precipitation at altitudes between 1800 and 2000 m a.s.l. (personal communication R. Rollenbeck, University of Marburg, Germany).

Forest microclimate was measured along a vertical profile within and above the forest between September 2000 and February 2002. Air temperature and humidity (HMP35, Vaisala, Helsinki, SF), photosynthetically active radiation (PAR; SKP215, Skye Instruments, Powys, UK) and horizontal wind speed (Vector Instruments, Alfreton, UK) were measured at three heights above the forest floor (4, 8, 13 m height) using a custom-made steel wire suspension system with variably fixable aluminium frames supporting the sensors. This system was suspended from a branch of the dominant canopy tree *Trichilia guianense* Klotzsch (Meliaceae, 18 m height) and wired to the ground. Additionally, above-canopy climate within the vegetation boundary layer was recorded by a set of sensors on a telescoping crossbar mount attached to the uppermost robust branch of the same tree. The sensors measured conditions at a height of approximately 2 m above the