Microclimatic Characteristics of a Primary Tropical Amazonian Rain Forest, ACEER, Iquitos, Peru

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ABSTRACT. The micrometeorological profile of a primary rain forest in northeastern Peru was monitored during 1995–1998. Specifically, the study was conducted to obtain high-resolution meteorological data to establish the cyclical relationships that exist within the forest on a daily, weekly, monthly, and yearly basis. Temperature and relative humidity were measured throughout a canopy walkway system at the Amazon Center for Environmental Education and Research (ACEER), Iquitos, Peru. Programmable data loggers were strategically employed along the walkway at 4, 18, 24, and 32 m above the forest floor. Rainfall was measured daily for four years (January 1, 1995, to December 31, 1998). Distinct seasonal variation in rainfall was encountered. Most rainfall occurred April–June, with the least occurring July–September. Typically, temperature was stratified vertically in the forest with higher readings recorded within the upper reaches of the canopy. On predictable occasions, stratification was lost for extended periods because of frontal systems that moved through the forest. Humidity profiles were cyclic with lower reaches of the forest at nearly 100% relative humidity much of the year. A greater degree of daily/weekly variation in humidity was noted throughout the upper canopy.

Key words: micrometeorological, Amazon, data logger, tropical forest, stratification

INTRODUCTION

The relation of the Earth's tropical rain forests to local, regional, and global climate has become an essential area of contemporary environmental research. The recent quest to understand the significance of spatial and vertical variation within tropical forests has produced various images of canopy dynamics (Baker 1996, Molion et al. 1985, Kira & Yoda 1989, Shuttleworth 1989, Shuttleworth et al. 1992, Smith et al. 1992, Fitzjarrald & Moore 1995, Terbough 1985, Cabral et al. 1996, Culf et al. 1996, Williams-Linera & Dominguez-Gastela 1998). Much of this work has focused on short-term variation relative to canopy microclimate; however, a long-term approach is warranted to ascertain vital associations between abiotic and biotic cycles within the forest.

Until recently, such an approach was made difficult by the inaccessibility of the canopy and the lack of quality instrumentation to perform during the prolonged high temperatures and humidity associated with rain forest environments. New advances in canopy walkway construction and computer technology now enable the acquisition of high-resolution meteorological infor-

mation, vertically and spatially, throughout some of the most remote canopy systems on the planet. Data loggers that measure temperature, light intensity, relative humidity, rainfall, and barometric pressure can be programmed and deployed to monitor forest conditions at high sampling rates for prolonged periods of time (e.g., half-second intervals for several years) with the use of a single battery. This technology, which is proving to be an invaluable tool for acquiring data from remote localities, will provide a better understanding of the daily-yearly cycles that characterize distinct rain forest environments.

To this end, we present excerpts of 4-year data collected in a remote Amazonian forest located on a small tributary of the Napo River in northeastern Peru. The objectives of our study were to acquire high-resolution meteorological data within an undisturbed rain forest environment; to assess the differences that exist within a well-defined vertical/spatial profile in the intracanopy environment, as they relate to temperature and relative humidity; and to assess long-term seasonal variation within a restricted forest locality.

METHODS AND MATERIALS

A series of data loggers were employed throughout the canopy walkway system at the Amazon Center for Environmental Education
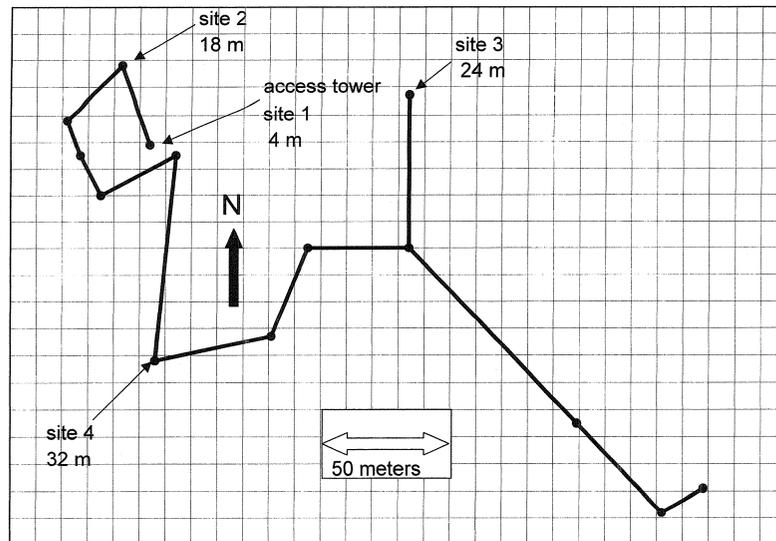
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FIGURE 1. Study sites 1–4 along the canopy walkway at the Amazon Center for Environmental Education and Research (ACEER), Iquitos, Peru, 1995–1998. Solid lines represent walkway spans, and solid circles represent platforms. Each square in the grid represents 10 m².

and Research (ACEER), Iquitos, Peru, (3°14′44″S, 72°55′28″W). The ACEER occupies 50 ha of land within the 250,000-ha Amazon Biosphere Reserve situated adjacent to the Sucusari, a small tributary of the Napo River in northeast Peru. The walkway system at the ACEER, which spans more than 576 m of primary terra firma rain forest, offers a superb opportunity to explore forest micrometeorology in an undisturbed setting.

Data loggers were positioned at various locations and heights throughout the canopy walkway system. Instruments by Onset Computer Corporation that measure temperature (stowaway TM XTI) and relative humidity (stowaway TM RH) were placed at 4, 18, 24, and 32 m above the forest floor. Instruments at each study site monitored the above parameters at 5-minute intervals 24 hours a day. Rainfall data were collected in a small clearing at the base of the walkway using a standard rain gauge. We report here four years of continuous rainfall data extending from January 1, 1995, to December 31, 1998.

Representative temperature and relative humidity (RH) data are reported from 1996–1997 seasons. Site 1 (at a height of 4 m) was located at the access tower of the walkway (FIGURE 1). Site 2, located 43 m west by northwest of the access tower, was 18 m above the forest floor. At a height of 24 m, site 3 was juxtaposed 110 m east by northeast of the access tower, and site 4, at 32 m in height, was placed 70 m south of site 1.

The initial set of data loggers that measured

temperature and RH were placed within a protective white polyvinylchloride (PVC) pipe, 13 cm long with a 7.5 cm diameter. The pipe was divided into two compartments of equal size, each 6.5 cm in length. A tiny hole was drilled through the side of the upper compartment to accommodate a thermocouple probe that extended 30 cm below the canister. The RH sensor was contained within the lower compartment of the canister. This compartment was fitted with a 7 mm² mesh over the opening of the pipe to assure proper gas exchange. Canisters, strapped to trees throughout the canopy walkway system with black electrical ties, were periodically evaluated and changed when necessary.

Study sites were selected to sample a variety of structural conditions within the canopy, because forests are not spatially uniform but rather horizontally heterogeneous at various scales (Parker 1995). The data logger at site 1 (4 m) was in a thickly vegetated area with well-established ground cover and understory vegetation and an established emergent canopy. This site received little direct light and remained darkened most of the day. The site 2 data logger (18 m) was sheltered by several levels of emergent trees but received intermittent light from light gaps created by dominant trees that had recently fallen. Although the site 2 data logger was positioned much higher on a tree than the site 1 apparatus, the actual elevation difference (altitude above sea level) between the two sites was minimal because of a drop in elevation relative to site 1. The data logger at site 3 (24 m) was
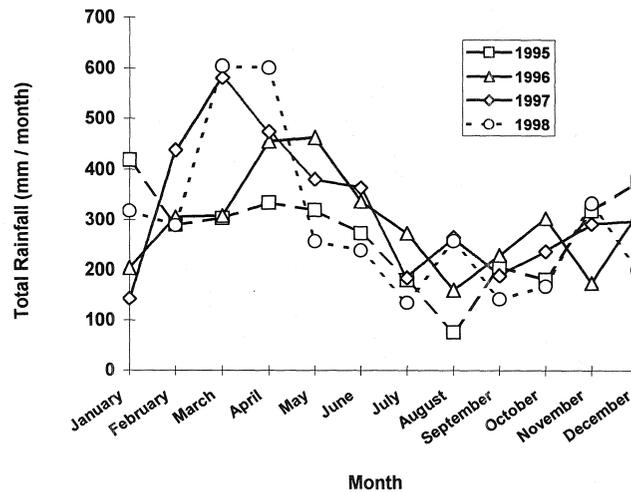
FIGURE 2.   Total monthly rainfall at the ACEER, Iquitos, Peru, 1995–1998.

in a relatively open area of vegetative cover. This apparatus was placed 7 m below a sparsely vegetated crown and thus was exposed to direct sunlight throughout the day. The highest site at 32 m (site 4) had characteristics similar to those of site 3 but was slightly more open. Conditions at site 4 were characteristic of conditions at the top of the canopy found throughout the forest surrounding the ACEER.

RESULTS AND DISCUSSION

Total rainfall received at the ACEER during 1995–1998 was 327, 352, 384, and 354 cm per year, respectively. Distinct seasonal variation as to rainfall distribution was observed within the forest (FIGURE 2). In general, rainfall is most pronounced during the 6-month January–June period, with several peaks observed during March–April. The 1997–1998 seasons were especially wet during March and April, although a dramatic drop in rainfall was recorded April 1–July 31, 1998. In all years and in nearly all instances, rainfall diminished sharply during April, with further declines observed during the next two months. Lowest periods of rainfall

were observed July–September for all four years (average of 572 cm/year). Several instances occurred during the 4-year period when no rainfall was recorded for 7 consecutive days. In one instance, September 1998, data indicated nine consecutive days without rain, except for a minor episode. During the dry season, 10–20 days/month without rainfall can be expected. In contrast, in the rainy season (January–June), dry spells are typically much shorter and may last only two days. Although unusual, instances occur even in the wet season when rainfall is intermittently absent for as many as 15 days (TABLE 1).

Each of the four years monitored was divided into trimesters that exhibited distinct rainfall patterns (FIGURE 3). Rather than use trimesters representing a calendar year, we analyzed multiple sets of trimesters based on rainfall patterns. For example, a set of trimesters yielding similar results was December–February, March–May, June–August, and September–November. Regardless of how the data is parsed, two distinct seasons are apparent.

Most annual rainfall occurred during the first two trimesters (January–March and April–June).

TABLE 1.   Total days per month without rainfall at the Amazon Center for Environmental Education and Research (ACEER), Iquitos, Peru, 1995–1998.

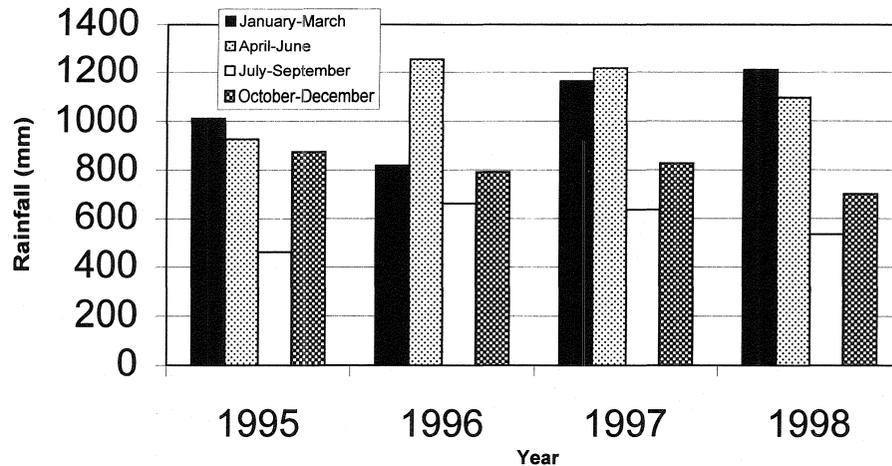| Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	12	11	8	7	7	12	18	23	13	13	4	13
1996	11	6	7	7	2	10	18	14	18	17	17	9
1997	16	8	16	10	6	11	20	17	15	12	11	6
1998	7	6	10	7	14	10	7	16	18	12	6	14

FIGURE 3.　Seasonal variation of rainfall at the ACEER, Iquitos, Peru, 1995–1998.

These trimesters had similar amounts of precipitation (unpaired Student t-test, $P > 0.5$). When these trimesters were compared to the third trimester (July–September), however, marked differences were apparent ($P < 0.05$). Rainfall in the third and fourth trimesters statistically differed from one another and from the first two trimesters ($P < 0.05$ in both instances). Total rainfall at the ACEER was similar to that ob-

served in other neotropical forests (Windsor 1990), including forests in Peru (Rudloff 1981).

Temperature Profiles

Daily temperatures varied within a narrow 10°C range throughout the study. Early morning hours averaged 21–22°C, and afternoon temperatures climbed to 31–32°C (FIGURE 4). Much of
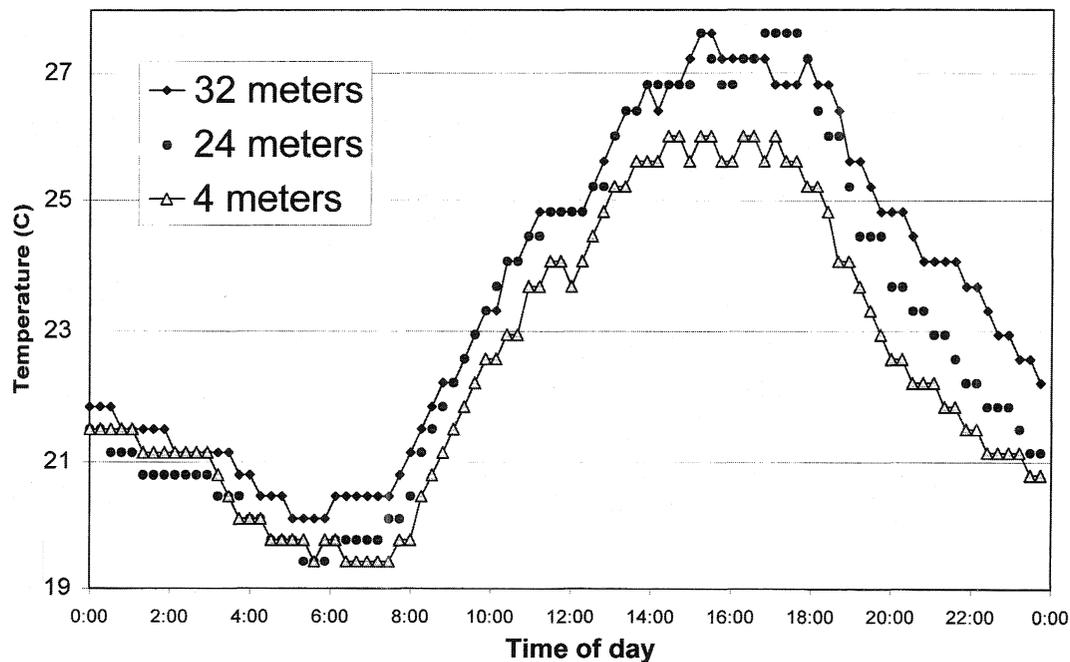

FIGURE 4.　Daily temperature profile at elevations of 4, 24, and 32 m recorded at study sites 1, 3, and 4 along the canopy walkway at the ACEER, Iquitos, Peru (see FIGURE 1).

the fluctuation depends on the incidence of unreflected solar radiation, the amount and duration of rainfall, and the duration of cloud cover over the canopy. Most unreflected solar radiation is absorbed by the upper canopy, with the remainder transmitted to surrounding vegetation within the upper reaches of the canopy and, to a lesser extent, within ground and understory vegetation (Shuttleworth 1989). The architecture of the upper canopy, therefore, becomes less decisive; and the total leaf area plays a larger role in directing the remaining radiation. The effect of this scattering is a reduction of incoming radiation to lower regions of the canopy; consequently, ground level temperatures can be expected to be slightly lower. Typically, the temperature at ground level remains 0.5–2.5°C lower than that found at the top of the canopy. This finding is similar to temperature profiles in other tropical forests (Shukla et al. 1990, Baker 1996, Cabral et al. 1996, Culf et al. 1996). Temperature profiles correspond with reduced light at lower reaches.

Despite only slight temperature differences, the forest becomes distinctly stratified. The greatest variation between ground and upper canopy temperatures usually occurred at 4–6 p.m., after incoming solar radiation had time to exert its maximum effect on the upper canopy, where direct exposure is greatest. The variation lessened as the sun set, and night temperatures at lower and upper reaches of the canopy were identical or differed by only 0.5°C. As the sun rose, the gradient became exaggerated, until it reached 2.5°C near 4 p.m. Plotted temperature profiles throughout the canopy conformed to a polynomial expression of third order or higher ($r^2 > 0.9$). Because incoming solar radiation varies little from season to season at this latitude, the temperature profile of the canopy remains relatively constant throughout the year. Minimum and maximum temperatures recorded throughout the canopy changed little seasonally (FIGURE 5).

In several instances, loss of temperature stratification occurred during intervals of a few days to several weeks in June; however, the phenomenon also was recorded in May and July. Loss of stratification is driven by massive frontal systems moving in from the south. These large cool-air masses envelop the forest and temporarily eliminate vertical differences (from ground to upper canopy) in temperature and relative humidity. Temperatures approaching 15°C or lower have been recorded over extended periods (FIGURE 6). In addition, rainfall also affects daily temperatures. Many days that remain relatively tepid (>26°C, FIGURE 3) are those that receive significant amounts of rain throughout the day (FIGURE 7). We currently are exploring the biological implications of these phenomena.
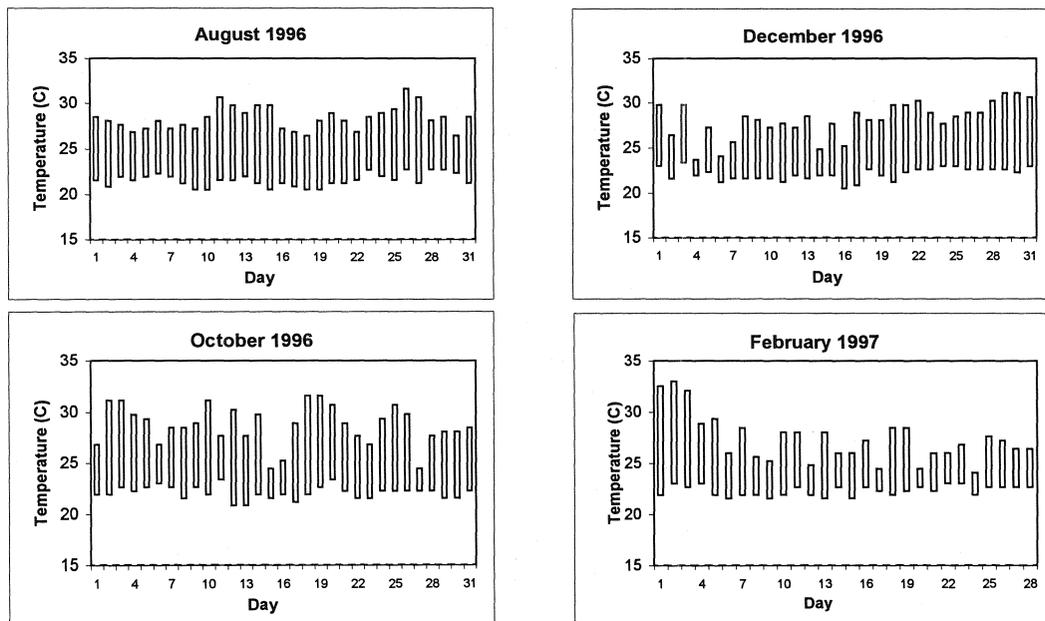

FIGURE 5. Minimum/maximum temperature profiles for select months at the ACEER, Iquitos, Peru, 1996–1997.
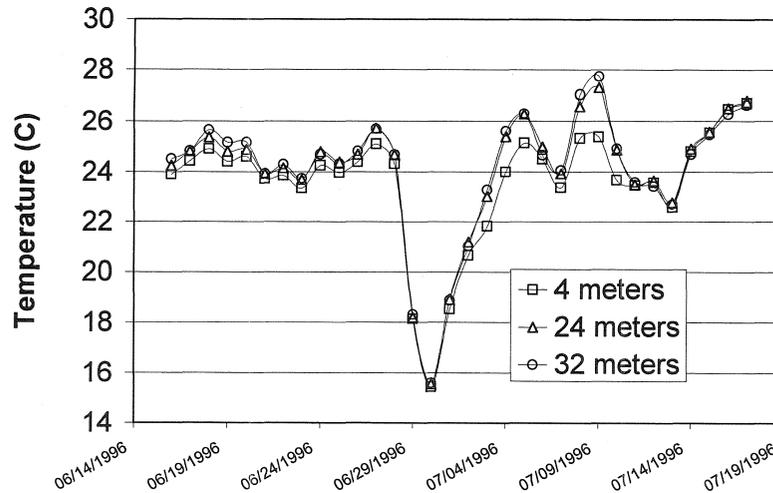
FIGURE 6.   Temperature profiles during a frontal system at the ACEER, Iquitos, Peru, 1996. Similar periods of depressed temperatures observed each year in June and July are called "El frio de San Juan."

Humidity Profiles

Humidity profiles throughout the ACEER canopy tend to stratify according to elevation above the forest floor (FIGURE 8). Levels at or near the ground remain near 100% RH for most of the year, although they may occasionally dip to 95% RH or slightly lower during periods of reduced rainfall and/or windy conditions (July–September). Because of the consistent abundance of moisture during most of the year, ground levels remain very moist under the cover of the canopy. At higher regions within the canopy, RH is somewhat lower. FIGURE 8 presents a typical RH profile throughout the canopy, with humidity levels fluctuating a great deal more at upper regions of the canopy than at lower regions. During relatively dry months (August–October 1996), a greater degree of daily RH variation was recorded throughout the upper reaches of the canopy. RH, however, remained well above 50% and was similar to reports from other tropical forests (Lauer 1989). In months experiencing more rainfall (December 1996–February 1997), less variation in RH was recorded, and RH profiles remained at nearly 100% for several weeks. During rainy months, temperatures correspondingly were lower throughout the canopy, although stratification tended to persist. This pattern was especially evident when comparing temperature and RH in February 1997 (FIGURES 5, 7). Very heavy rains were recorded for most of the month; temperatures remained relatively low; and daily RH profiles for the month remained at or near 100% in the upper reaches of the canopy.

CONCLUSION

The use of computerized data loggers is an inexpensive and effective way to retrieve valuable high-resolution meteorological data in remote areas such as those encountered at the ACEER, Iquitos, Peru. The information gathered at this locality provided a distinct picture of the microclimatic conditions found throughout various heights within this forest.

The meteorological parameter with the greatest variation was relative humidity. The lower reaches of the canopy remained at or near 100% RH for extended periods of a month or more, while RH in the upper reaches of the canopy shifted as much as 50% during the same period. Undoubtedly, these differences may effect secondary growth throughout the canopy as well as flowering and pollination events.

Of particular note is the distinct seasonal variation in rainfall. To our knowledge, seasonality has not been thoroughly investigated in this forest. Episodes of cooler temperatures recorded in June–July over several years are intriguing. In these instances, fronts pushed through and depressed temperatures to as low as 14°C throughout the entire canopy for periods of 5–12 days. During such periods, thermal stratification was lost. The possible regulatory effects of these climatic conditions on the biology of rain forest plants warrant further study.
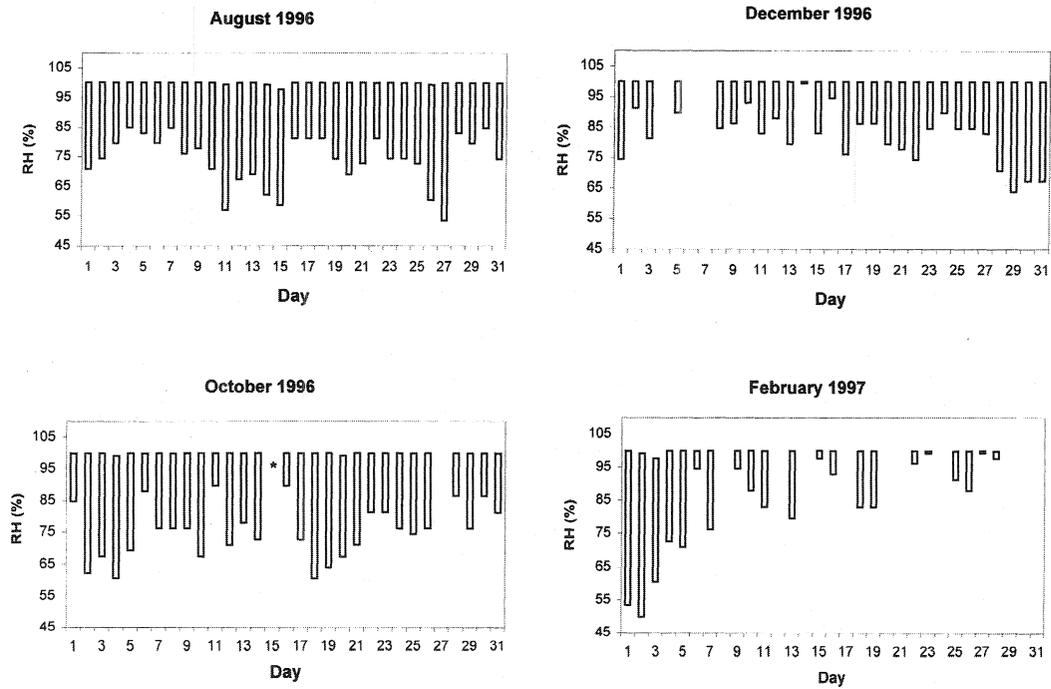
* The absence of a bar represents 100% RH

FIGURE 7. Minimum/maximum relative humidity profiles for select months at the ACEER, Iquitos, Peru, 1996–1997.
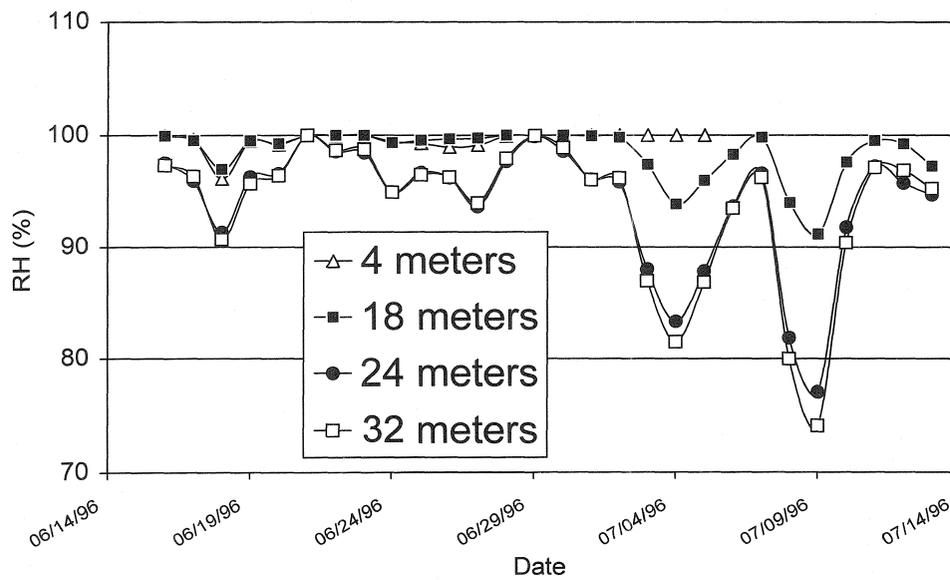

FIGURE 8. Daily relative humidity profiles at elevations of 4, 18, 24, and 32 m recorded at four study sites along the canopy walkway at the ACEER, Iquitos, Peru, 1996.

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