CLIMATIC ASPECTS OF THE AMAZONIAN TROPICAL FOREST.

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SUMMARY

The purpose of this study is to analyse the climatic aspects of the data collected in a forest site in comparison with conventional data obtained at different sites, such as clearing, rural and urban areas. The results showed that diverse climatic conditions do exist among the sites: the urban site showed higher temperature and lower relative humidity. In addition, evapotranspiration (potential and actual rates) was computed from the forest data set, using the classical Penman-Monteith's equation. The actual evapotranspiration is 30% of the potential value during dry period and seems to be almost constant during the whole year (tipically 2.0 to 2.5 mm day^{-1}).

INTRODUCTION

All data collected in the Amazon Basin have been taken from standard or conventional meteorological stations, most of them set up at clearings or farms. These sites may significantly alter the surface heat budget and, consequently, disguise the actual data fluxes over the forest canopy.

The energy budget of a forest can be expressed as:

$$A = R_N - S - G - P_H = H + LE \qquad (W.m^{-2}) \quad (1)$$

where the available energy (A) for partition between sensible (H) and latent (LE) heat fluxes is obtained from the net-radiation (R_N), minus the soil heat (G), the photosyntesis energy (P_H) and the air, water vapour and mainly biomass storage (S). In a long-period average (daily or longer), advection of energy can be neglected and the horizontal homogeneity is assumed (Fisch (1986) and Fitzjarrald **et al**. (1987)). The energy budget and evapotranspiration of the forest have been studied by others methods (eddy-correlation and Bowen ratio), as discussed in some of recently published papers (McCaughney (1985), Aston (1985), Verma **et al**.(1986)) or specifically dealing with tropical forest (Shuttleworth **et al**. (1984), Moore and Fisch (1986) and Fitzjarrald **et al**.

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(1987)). Nevertheless, none of them have shown data in a long-term basis (monthly and yearly) or presented a model to evaluate evapotranspiration (EVT) using standard meteorological data.

DATA SET AND INSTRUMENTATION

The data were measured at the top of a 45 m scaffolding tower at a site choosen in order to represent the native tropical forest: R. F. Ducke ($2^o57'S$, $59^o57'W$), 25 Km NE from Manaus (Amazonas, Brazil). A good description of the vegetation was given by Takeuchi (1961), Shuttleworth **et al**. (1984) and Moore and Fisch (1986).

An Automatic Weather Station (ASW) was used to measure the air and wet-bulb temperature, wind speed and direction, rainfall and solar and net-radiation fluxes. Measurements were taken each 5 minutes, averaged for a one-hour period (12 values) and stored hourly values in a cassette tape media. Strangeways and Smith (1986) discussed the development and performance of this equipment in comparison with conventional instruments.

The turbulent fluxes were measured with a "Hydra" equipment installed at the top of the tower (48.4 m). The Hydra's system, described in details by Shuttleworth **et al**. (1984) and Lloyd **et al**. (1985), comprises a vertical sonic anemometer, an infrared absortion hygrometer, a thin thermocouple and two Gill propellers.

Meteorological measurements from the automatic weather station were collected continuously from September 1983 up to September 1985. Meteorological data from conventional stations, R. F. Ducke (clearing site), UEPAE (crop production area) and INEMET (urban area) were obtained at synoptic hours (1200, 1600 and 2400 GMT) and converted to daily and monthly average. Energy fluxes were measured in fine days (total of 49 completed days) during September 1983, July to August 1984 and March to September 1985.

RESULTS

The results will be presented in two sections: the conventional meteorological data in section A and the estimates of monthly evapotranspiration in section B.

a) **Conventional Meteorological Data**

Figure 1 presents a map of the region including the four sites of interest. They are: A-AWS Tower (R. F. Ducke), B-Meteorological Station (R. F. Ducke), C-UEPAE and D-INEMET.

Rainfall: The rainfall distribution depicted by figure 2a, clearly show two different periods: a rainy season from December to May (monthly precipitation higher than 300 mm) and a dry season from June to November (precipitation lower 100 mm). This distribution governs the climate in the tropical region. The rainy season, popular knows as "winter", is associated with lower temperatures and higher relative humidity, while the dry season, local "summer", correlates with higher temperatures and lower relative humidity. The rainiest month (AWS=50 mm) was June 1984. There is a good agreement between all the sites in a rainy season, although some significant difference can occur in the dry season due to convective rainfall.

Temperature: The temperature time series of the sites (figure 2b) are similar, but INEMET's temperatures are persistently higher, occasionaly 2.0°C. The data collected from the AWS presents a strong seasonality: during the rainy season temperatures are lower than the sites B and C, while an opposite situation is observed for the dry season. The amplitude of temperature cycle is 2.5°C, with a maximum near 27.0°C (September) and a minimum in June (24.0°C).

Relative Humidity: The time series of RH (figure 2c) are similar although UEPAE's data (crop conditions) are always higher and INEMET's data lower. The AWS site presented a seasonal cycle with the dry season registers of 75-80% RH and the rainy season has 85-90% RH. The amplitude of the RH cycle is 10%.

The relationship among the rainfall, temperature and relative humidity, during the year agrees with the expected behaviour: high rainfall figures happens simultaneously with low climatic temperature and high relative humidity, while low rate of monthly precipitation induces high climatic temperature and low relative humidity. This fact can be clearly observed by comparing the time series in figures 2 a, b, c.

b) **Evapotranspiration Estimates**

The daily evapotranspiration was computed using Penman-Monteith's equation:

$$EVT = \frac{s(R_N - S - G - P_H) + C_p VPD/r_A}{(s+\Delta)(1 + r_S/r_A)} \quad (W.m^{-2}) \quad (2)$$

where VPD (specific humidity deficit), r_s and r_A (stomatal and aerodynamic resistances) and R_N were measured by AWS in MKS units. The fluxes of G, S and P_H were negleted because their daily contribution is almost null (Stewart, 1983). The aerodynamic resistance was estimated from the equation below, derived by Shuttleworth **et al.** (1984) for tropical forest:

$$r_A = \frac{33.0}{U} \quad (s.m^{-1}) \quad (3)$$

where the wind speed (U) was measured by AWS.

Typical values of stomatal resistance (r_S= 0,50, 100, 185 and 200 $s.m^{-1}$) were used.

The results (Table 1) show some interesting features:

- the highiest values of actual evapotranspiration occured during the dry season 1984 (EVT > 4.0 $mm.day^{-1}$) because the trees are able to extract water from deeper layers Also, the values of April 1985 were higher because the end of rainy period.

- the ratio of actual and potential evapotranspiration (r_S= 0) is extremely constant (f = 0.31 ± 0,05).

Under the same assumptions, monthly EVT was calculated and presented in figure 3:

a) the amplitude of the potential evapotranspiration ($r_S = 0$) annual cycle is 4.0 mm.day^{-1}. If r_S = 185 or 200 s.m^{-1}, this range is only 1.0 mm.day^{-1}.

b) assuming a stomatal resistance ranging from 150 (rainy period) to 200 s.m^{-1} (dry season), the EVT is almost constant with typical figures between 2.0 and 2.5 mm. day^{-1}

CONCLUSIONS

The results presented here showed that diverse climatic conditions do exist among the forest, rural and urban areas. Thus, care must be taken when extrapolating urban climatic conditions to large uninhabited areas.

In addition, the actual evapotranspiration is 30% of the potential EVT during dry period and seems to be almost constant during the whole year (typically 2.0 to 2.5 mm.day^{-1}).

Finally, the data set used here, the first integrated measurement of the energy and turbulent fluxes over the Amazon Forest, offers a good opportunity to study and understand the complex interactions between the forest and atmosphere.

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RESUMO

Este trabalho analisa os aspectos climáticos de dados coletados em uma área de floresta tropical nativa e compara-os com dados convencionais obtidos em situações de clareira, condições rural e urbana. Os resultados mostram que diversas condições climáticas existem entre os sítios escolhidos: a condição urbana apresenta os maiores valores de temperatura e os menores valores de umidade relativa. Além disso, taxas de evapotranspiração real e potencial são calculadas com o conjunto de dados obtidos na área de floresta tropical, utilizando a equação clássica de Penman-Monteith. A evapotranspiração real é de 30% da taxa potencial durante o período seco e aproximadamente constante durante o ano todo (valores típicos de 2.0 a 2.5 mm.dia^{-1}).

Table 1. Actual (HYDRA) and calculated evapotranspiration rates using typical values of stomatal resistances. All numbers in $mm.day^{-1}$

Date	HYDRA	EVAPOTRANSPIRATION RATES				
		0	50	100	185	200
07/09/83	3.4	14.0	7.7	5.3	3.5	3.3
09/09/83	2.8	9.6	6.1	4.5	3.1	2.9
10/09/83	1.4	5.2	3.2	2.3	1.5	1.4
17/09/83	3.3	12.3	7.9	5.9	4.0	3.8
18/03/83	3.2	8.6	5.6	4.2	2.9	2.8
25/09/83	3.0	10.3	6.8	5.0	3.5	3.3
27/09/83	2.8	7.3	5.3	4.1	3.0	2.9
29/06/84	3.3	12.8	7.5	5.3	3.5	3.3
30/06/84	2.9	9.7	6.5	4.9	3.4	3.2
07/07/84	3.7	10.6	5.9	4.1	2.7	2.5
08/07/84	3.3	9.3	6.0	4.4	3.1	2.9
09/07/84	2.8	8.9	5.9	4.4	3.1	2.9
30/07/84	3.2	15.0	9.0	6.4	4.3	4.1
31/07/84	2.9	10.3	6.9	5.1	3.6	3.6
09/08/84	4.3	12.9	7.2	5.0	3.2	3.0
11/08/84	3.5	10.9	6.5	4.6	3.1	2.9
13/08/84	2.8	5.8	3.9	2.9	2.0	1.9
20/08/84	3.0	7.7	5.0	3.6	2.5	2.4
21/08/84	3.9	10.9	6.5	4.6	3.1	2.9
22/08/84	4.4	12.1	6.9	4.8	3.2	3.0
23/08/84	4.2	12.7	7.1	5.0	3.2	3.1
24/08/84	4.2	12.7	7.3	5.1	3.4	3.2
25/08/84	2.7	9.2	5.4	3.8	2.6	2.4
06/04/85	3.5	11.0	6.5	4.6	3.0	2.9
15/04/85	4.2	12.2	7.0	4.9	3.2	3.0
16/04/85	3.7	12.4	6.6	4.5	2.9	2.8
10/06/85	2.8	9.7	5.5	3.8	2.5	2.4
11/06/85	1.6	7.4	4.2	2.9	1.9	1.8
22/06/85	2.8	8.2	4.8	3.4	2.3	2.1
04/07/85	3.7	11.5	6.3	4.3	2.8	2.6
05/07/85	3.3	11.3	6.3	4.4	2.9	2.7
24/07/85	2.3	6.1	4.0	2.9	2.0	1.9
25/07/85	2.8	7.9	4.3	3.0	1.9	1.8
28/07/85	3.1	9.2	5.4	3.8	2.5	2.4
29/07/85	3.8	12.7	6.8	4.6	3.0	2.8
31/07/85	3.8	12.2	6.4	4.3	2.8	2.6
02/08/85	2.6	9.8	6.0	4.3	2.9	2.8
03/08/85	2.6	9.6	6.3	4.8	3.2	3.0
06/08/85	2.1	11.4	6.9	5.0	3.3	3.2
08/08/85	2.4	9.4	5.6	4.0	2.7	2.5
20/08/85	2.9	9.3	5.3	3.7	2.5	2.3
01/09/85	2.7	9.6	6.1	4.5	3.1	2.9
02/09/85	3.1	9.5	6.0	4.4	3.0	2.8
14/09/85	3.8	10.2	5.9	4.1	2.7	2.6
20/09/85	3.1	10.6	6.8	5.0	3.4	3.2
21/09/85	3.2	11.1	7.3	5.4	3.8	3.6
26/09/85	3.0	12.5	7.8	5.7	3.9	3.7
28/09/85	2.5	5.9	4.0	3.0	2.1	2.0

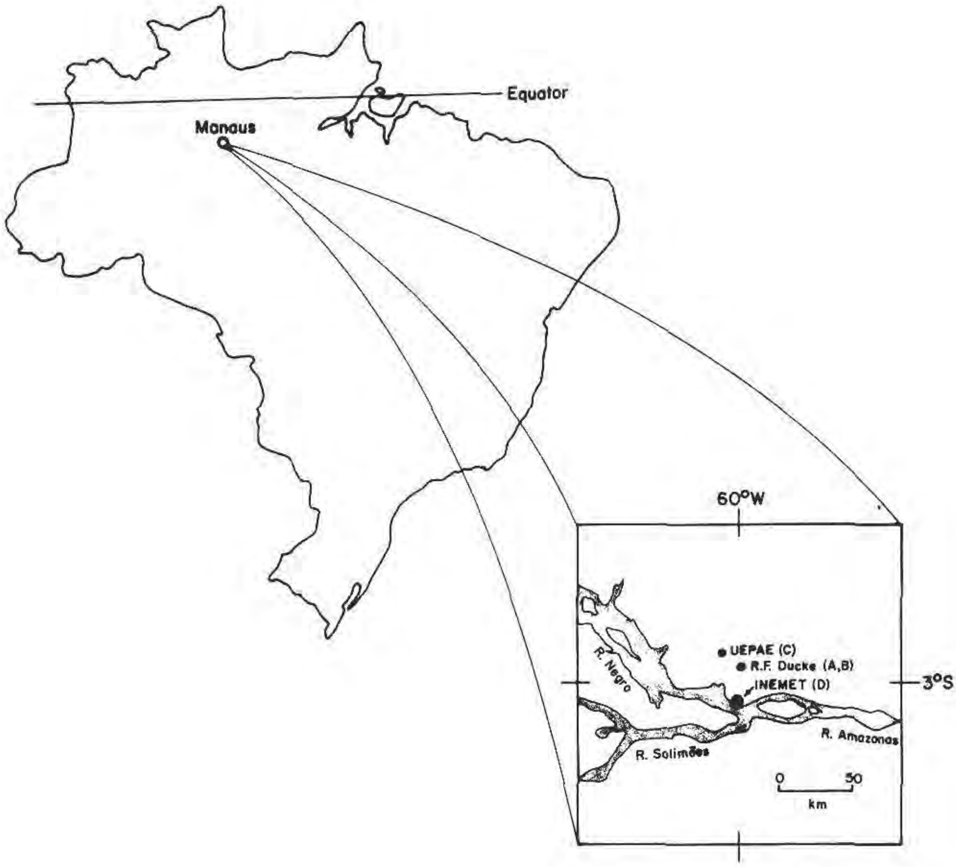

Figure 1. Geographic map of interested area: forest (A), clearings (B), rural (C) and urban area (D).

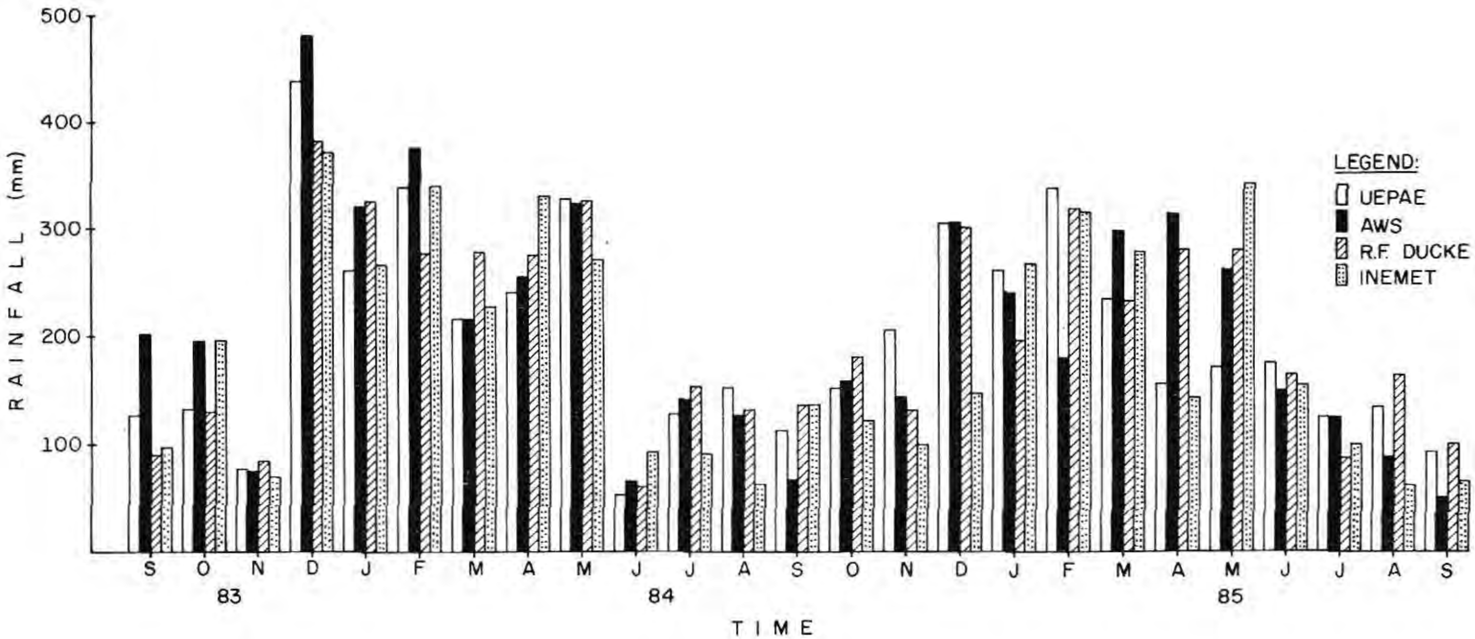

Figure 2a. Rainfall distribution: forest (AWS), clearings (R. F. Ducke), rural (UEPAE) and urban area (INEMET)

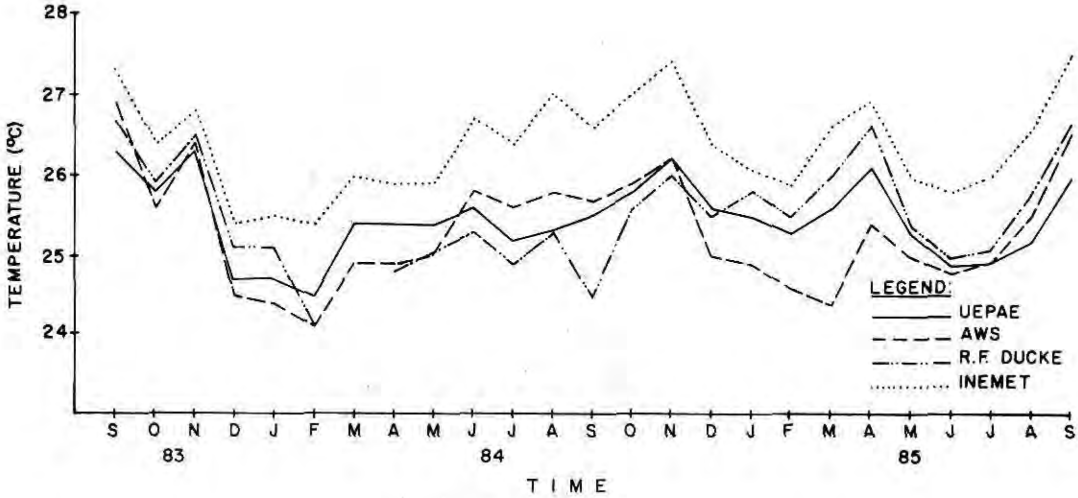

Figure 2b. Temperature time series: forest (AWS), clearings (R. F. Ducke), rural(UEPAE) and urban area (INEMET).

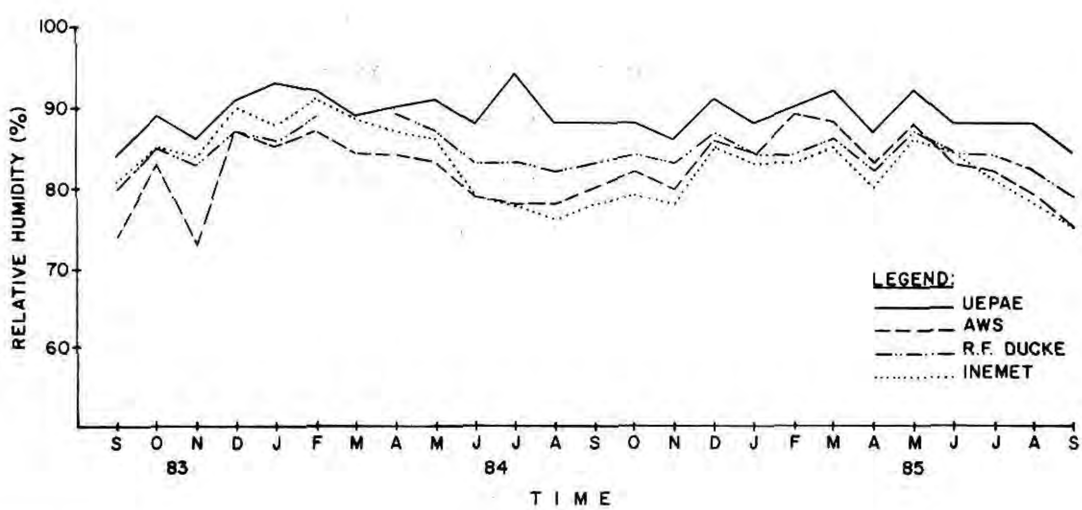

Figure 2c. Relative Humidity time series: forest (AWS), clearings (R. F. Ducke), rural (UEPAE) and urban area (INEMET).

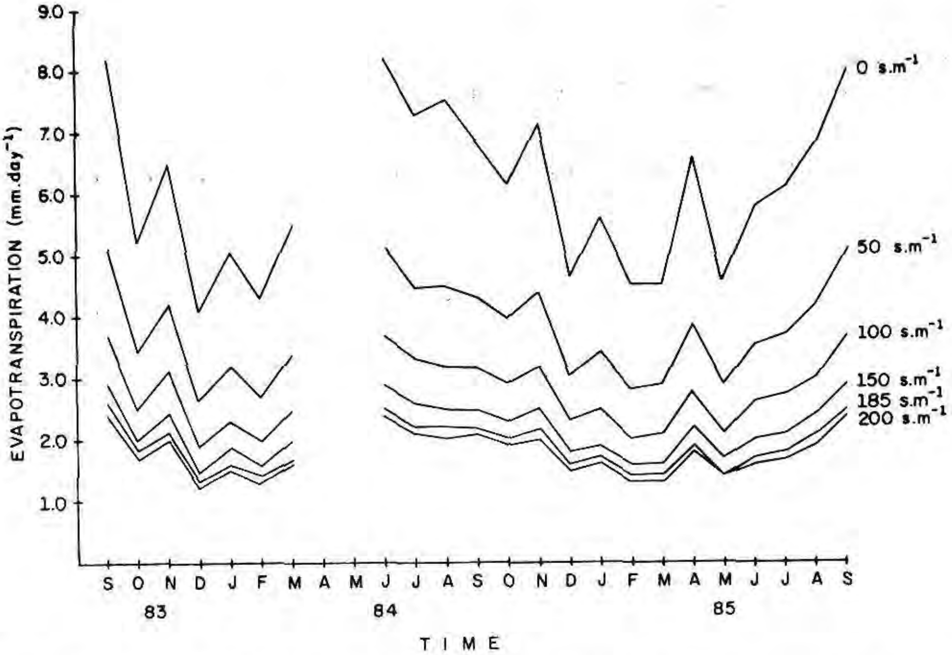

Figure 3. Estimates of evapotranspiration using typical figures of stomatal resistance.

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