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THE SENSIBLE AND LATENT HEAT FLUXES FOR GURUPI RIVER BASIN - AMAZÔNIA - AND SOME LOCATIONS OF NORTHEAST REGION OF BRAZIL

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This paper describes an investigation of the heat fluxes over a period of three months (May to July) in Austral Autumn/Winter of 1983 in the Gurupi River Basin, Amazônia - and some locations of the Northeast Region of Brazil. A portable self-contained reversing instrument was constructed for measuring the Bowen ratio. The Amazon Region at this time was experiencing its "dry" season, so that high Bowen ratios, usually around unity, were found. In regions of Sobradinho Dam (Northeast Region), under drought conditions, the Bowen ratio was usually in the range 3 - 10. The Northeast Region (Recôncavo and Contas River Basin, the wet coastal zone) with abundant moisture, the Bowen ratio was found to be between 0.10 and 1.0. It is concluded that in this part of the Amazon Region the latent heat flux accounted for only 30 to 50% of the net radiation during the dry season. In the arid Sobradinho Dam region, the sensible heat accounted for about 80% of the net radiation. In the coastal wet region (part of Contas River Basin and Recôncavo), the latent accounts for more than 80% of the net radiation.

FLUXOS DE CALOR SENSÍVEL E LATENTE PARA A BACIA DO RIO GURUPI - AMAZÔNIA - E ALGUMAS LOCALIDADES DA REGIÃO NORDESTE DO BRASIL *Os resultados de uma pesquisa sobre os fluxos de calor sensível e calor latente, realizada na Bacia do Rio Gurupi - Amazônia Oriental - e em alguns locais do Nordeste Brasileiro, durante um período de três meses (maio a julho) no ano de 1983, são apresentados. As medidas mostram uma Razão de Bowen próxima a 1, enquanto que em volta da Barragem de Sobradinho, no Polígono das Secas do Nordeste Brasileiro, mostram a citada razão entre 3 a 10. Esse resultado inesperado na Amazônia, característico de áreas com limitado suprimento de água, é devido ao período em que medidas foram feitas, quando a região estava na sua época de seca. Em outras áreas estudadas no Nordeste (Recôncavo e na parte úmida da Bacia do Rio de Contas), áreas de alta umidade, os valores da Razão de Bowen ficaram entre 0,10 e 1,0, como esperado. Conclui-se que nesta parte da Região Amazônica apenas 30 a 50% da radiação líquida é utilizada pelo fluxo de calor latente. Nas proximidades da Barragem de Sobradinho, o calor sensível contribuiu com aproximadamente 80% do fluxo total da radiação líquida. Nas outras áreas do Recôncavo e Bacia do Rio de Contas houve inversão nesses fluxos.*

INTRODUCTION

The evaporation of water from the earth's surface to the atmosphere has been the subject of much research owing to its importance in hydrology, which encompasses studies of evaporation over lakes, channels and reservoirs. Evapotranspiration consumes much of the water and energy than is available to the land surface of the earth and consequently influences all hydrological and most meteorological processes. There is now a need for regular measurements over larges areas, if possible the synoptic network. However, this is not simply an instrumental problem, but also involves a through consideration of the interpretation of measurements made over heterogeneous areas.

An established technique for evaluating the evaporation is the energy budget method, which consists of estimating the partition of net radiation used in evaporation. Bowen (1926) showed that the partition of sensible and latent heat at a water surface could be determined in a relatively simple manner from gradients of temperature and humidity near the surface. Several types of instruments exist to measure the Bowen ratio (e.g. Black and McNaughton, 1971; Lourence and Pruitt, 1969; McCaughey, 1981 and Spittlehouse and Black, 1980), but none of them is easy to use, particularly in remote areas such as Amazonia and Brazilian Northeast.

The Amazon Basin plays an important role in the atmosphere circulation. In spite of its importance, relatively little is known about evaporation and energy and water balance of the region (Shuttleworth et al., 1984, and Shuttleworth et al., 1987). We have performed more than fifty Bowen ratio measurements at this tropical rain forest. The second area of interest is the Brazilian Northeast. This region is well-known as the "drought polygon". On this area, we have performed more than one hundred Bowen ratio measurements from the humid area close to the coast (sugarcane, cocoa plantation and cattle activity) to the drought region in the vicinity of the recent artificial lake of Sobradinho, with an area of 4,214 km^2 of water. This study gives an opportunity to understand the effect of fetch on the temperature and humidity gradients in the downwind of a discontinuity surface. The results show that the new equilibrium is achieved in the downwind distance at about 200 times the height of the upper sensor.

The objective of this work is to estimate the Bowen ratio to assess the sensible and latent heat fluxes in some locations of Amazon and Northeast regions of Brazil. An economical and light-weight instrument of Novaes and Bignell (1989) is used.

EXPERIMENTAL SITES

The experimental measurements were performed at five sites in the Northeast Region of Brazil during the period May 2 to June 25, 1983 and two sites in the Gurupi River Basin, Amazon Region from July 5 to July 9, 1983 (Novaes, 1985).

The Northeast Region of Brazil lies between 3°S to 17° and 35°W to 45°W and it has an area of 1.6 X 10^3 km^2. This is the hottest part of the country and its dry season is from May to November with a range of temperature 34° - 36°. The region is characterized by variable rainfall sometimes experiencing extreme drought conditions (Kousky, 1979; Hastenrath and Heller, 1977). The Northeast Region is normally divided into three main subdivisions from the coast to the interior, based on precipitation, soil and vegetation. The humid coastal lowland ("Zona da Mata") varies in width from 100 to 150 km. It is a very fertile and humid zone with deep soil and receives up to 2000 mm of rain distributed uniformly throughout the year. An upland transitional zone ("Agreste") gets an average annual precipitation of 800 mm to 100 mm. The "Sertão" is a semiarid plateau. In this area the annual average precipitation is less than 600 mm (Fig. 1).

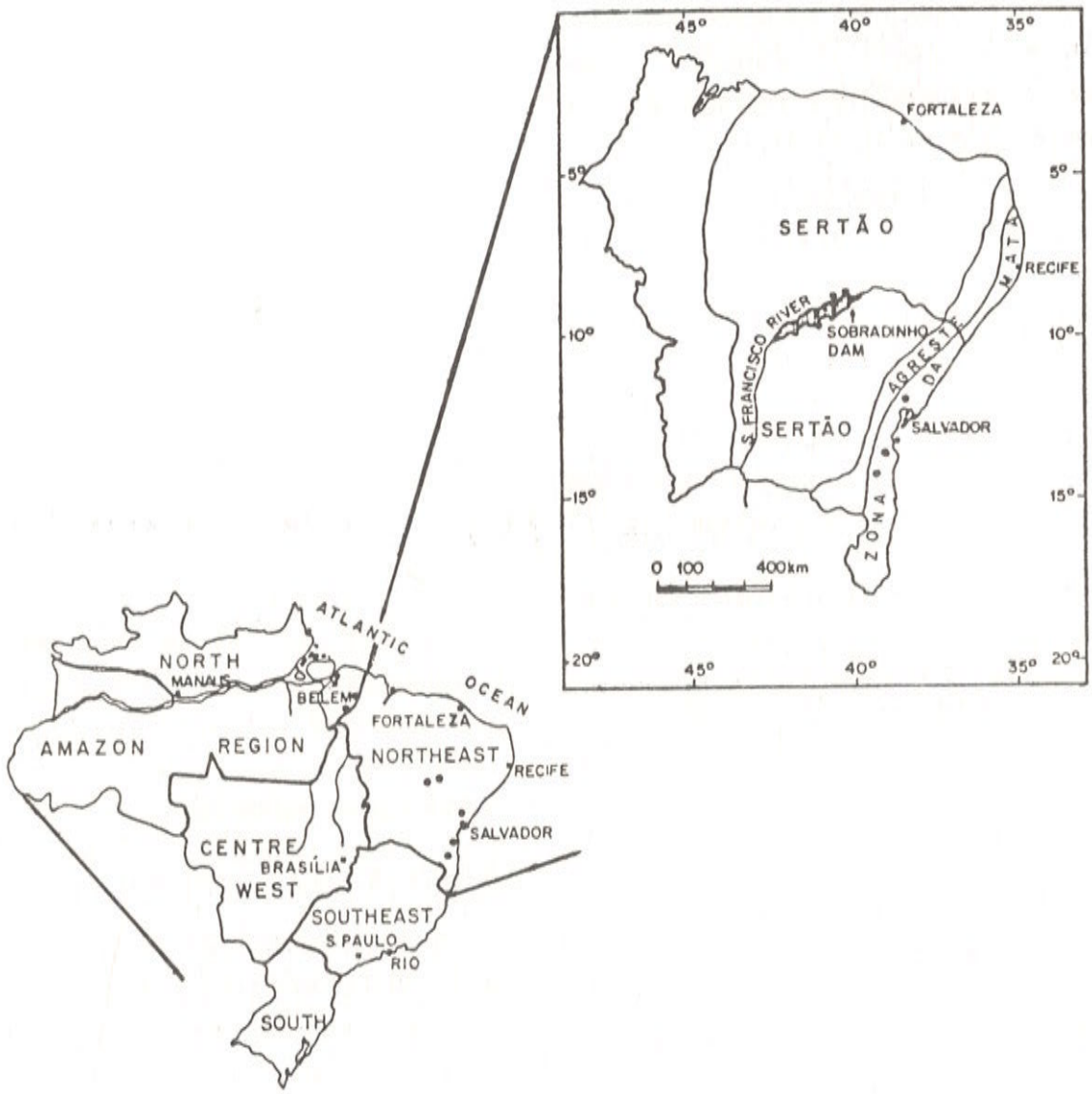

Figure 1. The three subdivisions from the coast to the interior of the Northeast Region. "Zona da Mata" is a wet coastal zone, "Agreste" an intermediate zone and "Sertão" a semiarid zone. The dots indicate the measurement sites locations.

As três subdivisões do território, da costa para o interior do Nordeste. A **Zona da Mata**, *que é uma região úmida da costa, o* **Agreste**, *que é uma região intermediária, e o* **Sertão**, *que é uma região semi-árida. Os pontos indicam a localização dos sítios de medida.*

The Amazon climate is always hot and humid, with daytime temperatures ranging from 21°C to 32°C. There are no seasons in the normal sense - it is either the dry season or the rainy season. To the north of the Equator, the rainy season is generally from March to July and to the south, from October to April. The annual rainfall in the region is between 1700 mm and 3000 mm (Figueroa and Nobre, 1990).

The field measurements in the Amazon Region were carried out in the Gurupi River Basin in two separate sites about 300 km southeast of Belém. Both sites (Veneza Farm) are approximately 5 km^2 and are located in areas where the forest has been partially removed and cattle activities have been started (Fig. 2). The measurements were made near the center of each square. The surrounding generally flat terrain was predominantly forest about 25 meters tall.

EXPERIMENTAL AND TECHNICAL DETAILS

The Bowen ratio were obtained with the psychrometer system, which is a portable unit, weighting approximately 2.0 kg (Novaes and Bignell, 1989). The main components of this unit area electric package (four sensors, Wheatstone bridge and amplifier), shields and aluminum framework. The temperature sensors used to measure the gradients of wet and dry bulb temperature were placed at 2.1 m and 0.50 m above the surface (Nordon and Brainbridge, 1962).

3.1 Net Radiation

The net radiation was measured using two metched 1N914 diodes as sensors. The effects of wind were reduced, but not entirely eliminated by shielding the flux plate with a thin film of polyethylene. The diodes were connected to a bridge circuit fed by two 9 V batteries and the temperature difference across the plate, measured by the voltage output representing, was amplified by a 741 operational amplifier and displayed on the same digital voltmeters used the differential psychrometer. The radiometer was calibrated with a standard ventilated net radiometer on the roof of Imperial College, London (Novaes, 1985).

Net radiation was measured at a height of 1.0 m above the surface at the same places, where the Bowen ratio was performed.

3.2 The Bowen Ratio Method

The Bowen ratio (β) was calculated from vertical gradients of temperature measurements. Fluxes of latent heat (LE) and sensible heat (H) were determined from the formulae

$$LE = (F_N - G)/(\beta + 1) \; and$$
$$H = \beta(F_N - G)/(\beta + 1) \qquad (1)$$

We need the net radiation (F_N), ground heat flux (G) and β to obtain LE and H. The order of magnitude of G is very small compared to F_N, i.e., $G=0.1F_N$ (De Bruin and Holtslag, 1982; Fuchs and Hadas, 1972). So, we did not consider G values in the computation of results.

RESULTS AND DISCUSSION

The work described here was conducted during the period from May 2 to June 25, 1983 at the Brazilian Northeast and from July 5 to July 9, 1983 at the Gurupi River Basin in the Amazon Region (Novaes, 1985). During this period in the Amazon Region the winds were mainly from east or northeast, and in the Northeast Region they were from the east. The diurnal temperature range was about 22° C to 33° C and 21° C to 32° C in the Amazon and Northeast Regions, respectively. In both regions, the period was intermittently cloudy even in the Northeast area, where a long drought was taking place. The Amazon Region at this time was experiencing its "dry" season and high Bowen ratios, at the selected sites were, surprisingly, around unity, due to substantial soil moisture

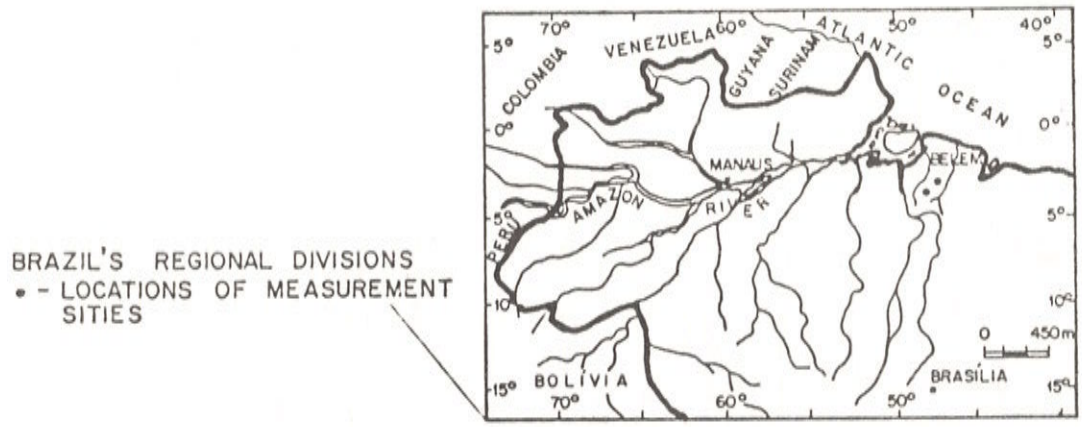

Figure 2. Amazon Region. The dots indicate the measurement sites.
A região Amazônica. Os pontos indicam a localização dos locais de medida.

deficit. On the other hand, the Bowen ratio exceeded 3 in regions of the Sobradinho dam, under drought conditions, since the measurements were performed close to the shore of the reservoir. The large values in the region are quite reasonable because the lake is located in the heart of the "drought polygon" of the Northeast Region. At the other sites of the Northeast Region ("Recôncavo" and "Contas" River Basin - the wet coastal zone) with abundant moisture, the Bowen ratios were found to be between 0.10 and 1.0.

Hourly heat fluxes and the Bowen ratio were measured on 20 May 1983 at "Santa Luzia" Farm ("Contas" River Basin) and they are illustrated in Fig. 3. The daytime Bowen ratio varied between 0.10 and 0.75. It appeared that soil water was not limiting evapotranspiration. Fig. 3 shows the daily cycle of the grassland radiation components. The maximum hourly net radiation over the grassland during daylight is observed around 11.00 hours. Similar energy balance results have been reported by Yap and Oke (1974) for a grass surface with high values of soil water potential.

The other sites of the "Zona da Mata" (Recôncavo and Gongoji River) have shown similar daily trends of the Bowen ratio and heat fluxes as in "Santa Luzia" farm, where the latent heat accounted for more than 80% of the radiation.

Fig. 4 shows the daily patterns of the Bowen ratio values and heat fluxes for 18 June 1983, at Sobradinho dam (semiarid zone). This site has an extensive gravel surface with sparse deciduous thorn vegetation 1 to 3 meters tall, and it is 300 meters away from the Sobradinho lake shores. At this location the lake is about 7 km in width. The wind direction was predominantly from the east or southeast, and the surface water temperature was 25° C. Because of the large bare soil exposure to solar radiation and the large water deficit, the daytime Bowen ratio value is always high and it is usually well in excess of unity. The energy partition of sensible and latent heat in Fig. 4 shows that the sensible heat flux accounts for about 80% of the net radiation and closely follows the net radiation diurnal cycle.

The variation of Bowen ratio as a function of the

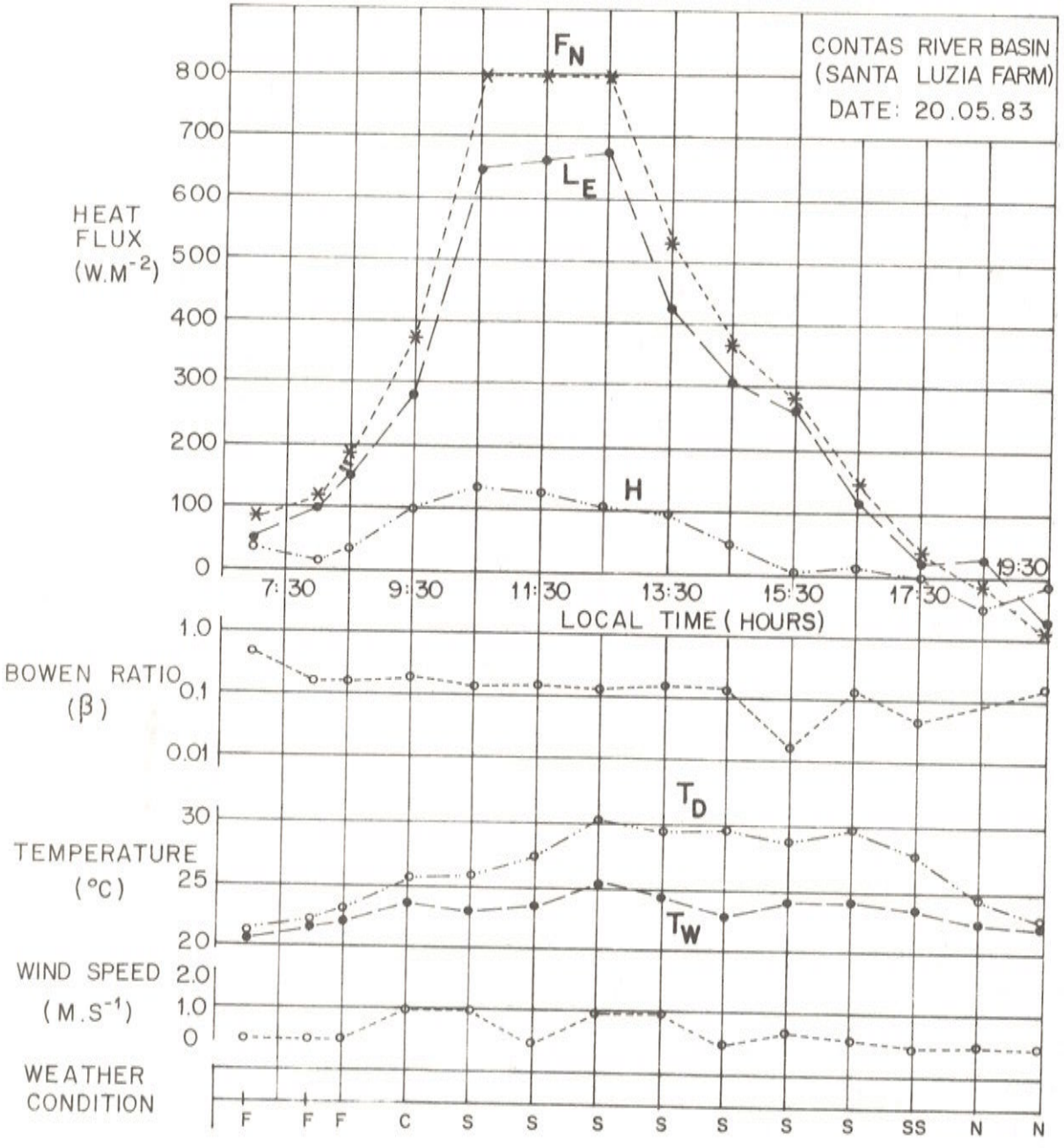

Figure 3. Energy flux diagram for May 20, 1983, at Santa Luzia Farm (Contas River Basin), a wet grassland region (14°15'S, 39°45'W). Latent heat (LE) and sensible heat (H) are calculated from β and F_N. The symbols are: F - fog, C - cloud, S - sunny, SS - sunset, N - night, T_D - dry bulb temperature and T_W - wet bulb temperature.

Diagrama de fluxo de energia para maio 20, 1983, na fazenda Santa Luzia (bacia do rio Contas), uma região úmida de cerrado (14° 15'S 39° 45'W). Calor latente (LE) e sensível (H) são calculados de β e F_N. Os símbolos são: F - para neblina, C - para nuvens, S - para tempo ensolarado, SS - para crepúsculo vespertino, N - para noite, T_D - para temperatura de bulbo seco e T_W - para temperatura de bulbo úmido.

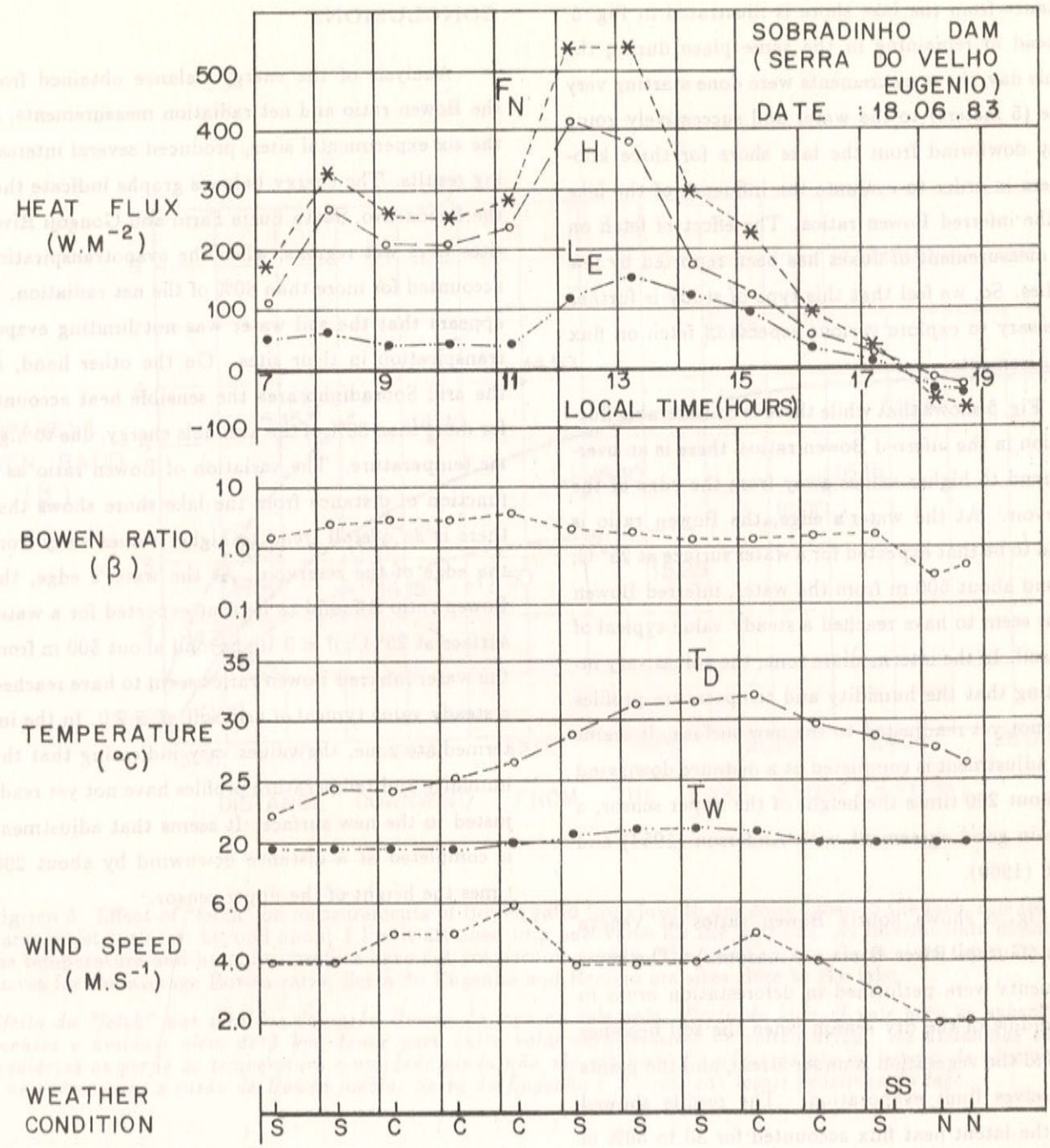

Figure 4. Energy flux diagram for June 18, 1983, at Sobradinho Dam (SERTÃO), a semiarid region (9°5'W, 40°48'W). Latent heat (LE) and sensible heat (H) are calculated from β and F_N. The symbols are as in Fig. 3.

Diagrama de fluxo de energia para junho 18, 1983, para a represa de Sobradinho (sertão), região semi-árida (9°5'S, 40°48'W). Calor latente (LE) e sensível (H) são calculados de β e F_N. Os símbolos são iguais aos da Fig. 3.

distance from the lake shore is illustrated in Fig. 5. Instead of remaining in the same place during the whole day, the measurements were done starting very close (5 meters) to the water and successively going away downwind from the lake shore for three kilometers in order to evaluate the influence of the lake on the inferred Bowen ratios. The effect of fetch on the measurement of fluxes has been reported by few studies. So, we feel that this type of study is further necessary to explore various aspects of fetch on flux measurements.

Fig. 5 shows that while there is considerable fluctuation in the inferred Bowen ratios, there is an overall trend to higher values away from the edge of the reservoir. At the water's edge, the Bowen ratio is found to be that expected for a water surface at 25° C; beyond about 500 m from the water, inferred Bowen ratios seem to have reached a steady value typical of arid soil. In the intermediate zone, the values vary indicating that the humidity and temperature profiles have not yet readjusted to the new surface. It seems that adjustment is completed at a distance downwind by about 200 times the height of the upper sensor, a value in good agreement with Anderson (1954) and Webb (1960).

Fig. 6 shows hourly Bowen ratios at Veneza Farm (Gurupi River Basin - Amazônia). The measurements were performed in deforestation areas in the middle of the dry season when the soil becomes dry and the vegetation is under stress, and the plants themselves limit evaporation. The results showed that the latent heat flux accounted for 30 to 50% of the net radiation. The behavior of H and LE is similar to that observed by Black (1979) over forest with a soil water deficit. He found that the Bowen ratios are in excess of unity, and a tendency of LE to reach its peak in the afternoon.

CONCLUSIONS

Analysis of the energy balance obtained from the Bowen ratio and net radiation measurements, at the six experimental sites, produced several interesting results. The energy balance graphs indicate that the Recôncavo, Santa Luzia Farm and Gongoji River sites were wet regions, when the evapotranspiration accounted for more than 80% of the net radiation. It appears that the soil water was not limiting evapotranspiration in their sites. On the other hand, in the arid Sobradinho area the sensible heat accounts for more than 80% of the available energy, due to high air temperature. The variation of Bowen ratio as a function of distance from the lake shore shows that there is an overall trend to higher values away from the edge of the reservoir. At the water's edge, the Bowen ratio is found to be that expected for a water surface at 25° C, $\beta = 0.10$; beyond about 500 m from the water inferred Bowen ratios seem to have reached a steady value typical of arid soil, $\beta > 2.0$. In the intermediate zone, the values vary indicating that the humidity and temperature profiles have not yet readjusted to the new surface. It seems that adjustment is completed at a distance downwind by about 200 times the height of the upper sensor.

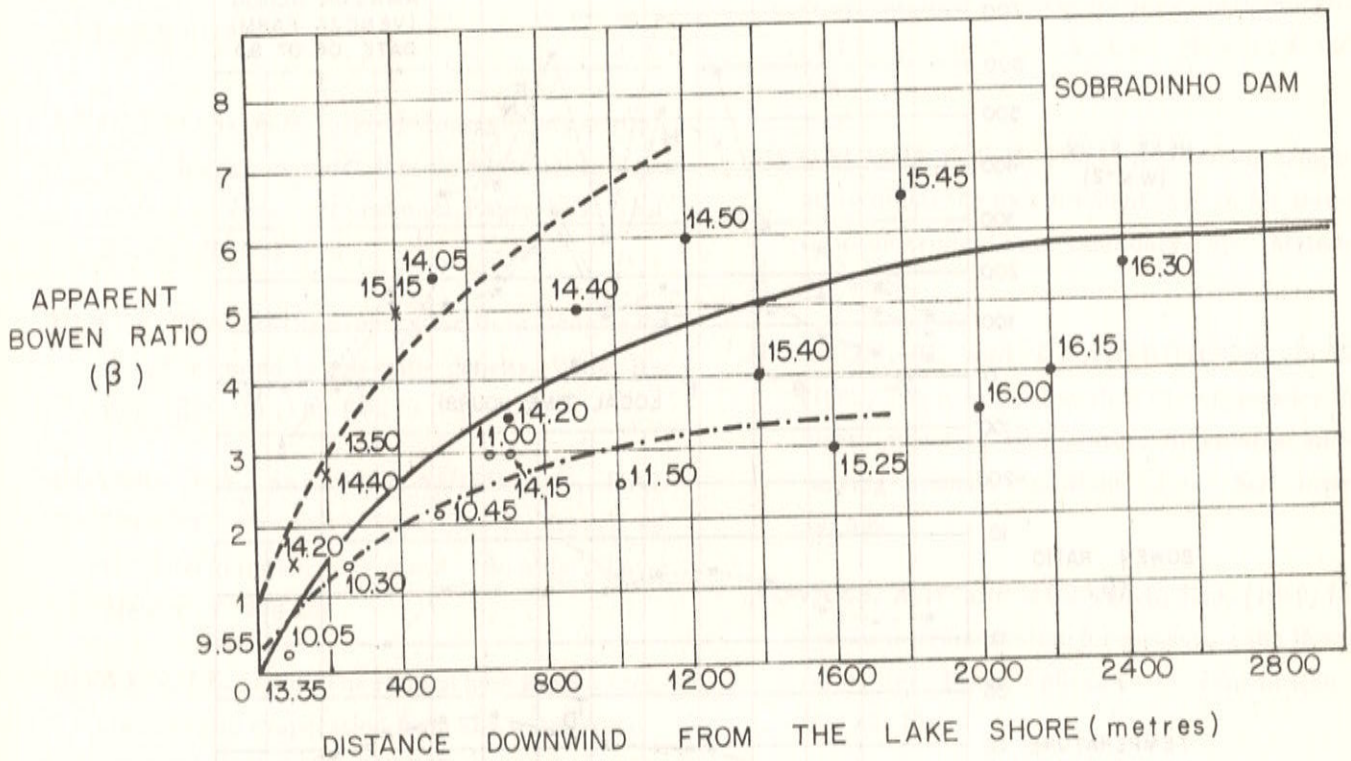

Figure 5. Effect of "fetch" on measurements of Bowen ratio from lake to dry soil. Close to the lake, β is for the warm moist surfaces; beyond about 1 km it attained to a new value for the arid soil. At intermediate distances the temperature and humidity profiles have not yet become steady. The numbers are observation times and the curves for the average Bowen ratio. Serra do Engenho and Recreio are sites close to the lake.

Efeito do "fetch" nas medidas da razão Bowen do lago ao solo seco. Perto do lago, β vale para as superfícies quentes e úmidas; além de 1 km, tende para outro valor característico de sólido árido. As distâncias intermediárias os perfis de temperatura e umidade ainda não são estáveis. Os números são os tempos de observação e as curvas para a razão de Bowen média. Serra do Engenho e Recreio são locais próximos do lago.

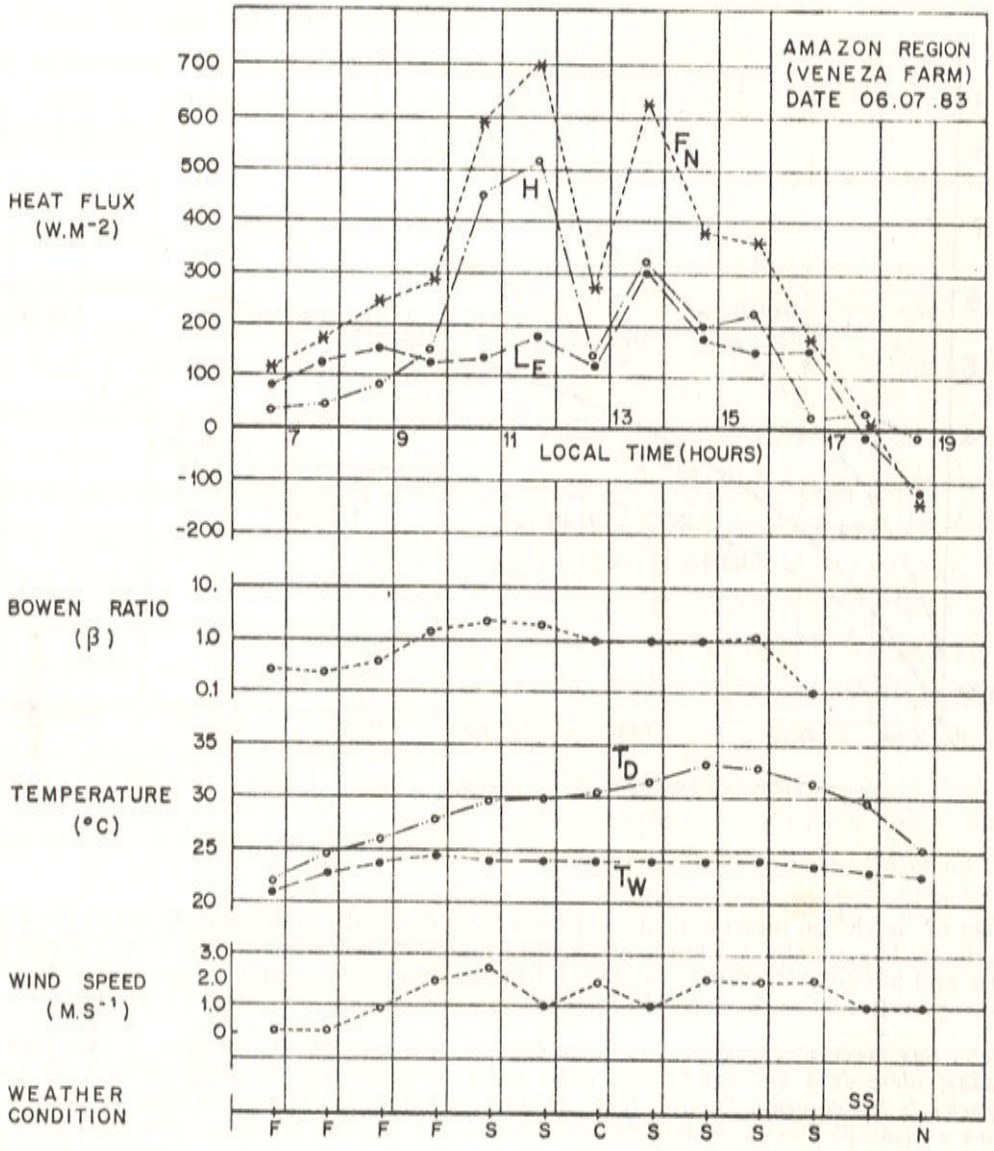

Figure 6. Energy flux diagram for July 6, 1983, at Veneza Farm (Gurupi River Basin - Amazonia) (2°45'S, 46°25'W). Latent heat (LE) and sensible heat (H) are calculated from β andF_N. The symbols are as in Fig. 3.

Diagrama de fluxo de energia para 6 de julho, 1983, na fazenda Veneza (bacia do rio Gurupi, Amazônia, 2º 45'S, 46º 25'W). Os símbolos são os mesmos da Fig. 3.

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