

ENERGY BALANCE AND THE PRIESTLEY-TAYLOR PARAMETER FOR FORESTED AREAS IN THE AMAZON REGION¹

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1. INTRODUCTION¹

Micrometeorology of forests is always difficult in many aspects. Energetically, the large biomass and volume of air trapped by the canopy poses difficulties to the energy balance methods for estimating heat fluxes. A forest can be represented by a box of large volume being its depth determined by the height of the trees. Its energy balance is primarily through the top face of the box since the large biomass restricts the energy exchange at the bottom face. Even under advective conditions the exchange of energy is through the upper face. The energy balance of such box can be expressed as

$$Q_n = LE + H + G + P + S \quad (1)$$

being Q_n the net radiation, LE the latent heat, H the sensible heat, G the soil heat, P the net photosynthetic energy, and S the change in canopy heat storage. S represents the sensible and latent heat stored in the canopy air, and sensible heat stored in the vegetation (THOM, 1975). Some authors include also G in the storage term (JARVIS et al., 1976; McCAUGHEY & SAXTON, 1988). S represents gain or loss of stored energy and for the Amazonian forest it can exceed 10% of Q_n (MOORE & FISCH, 1986), sometimes it is comparable to H (FITZJARRALD et al., 1988). As such, S cannot be neglected from the energy balance equation of forests (SAXTON & McCAUGHEY, 1988), mainly on short time scales (i.e., minutes, or hours).

Energy balance is used to study the partitioning of the available energy into LE and H . A very simple way to estimate LE is by the PRIESTLEY & TAYLOR (1972) approach (P-T72), or

$$LE = \alpha [s / (s + \gamma)] (Q_n - G) \quad (2)$$

being α a coefficient; s the slope of the saturation vapor pressure-temperature curve; and γ the psychrometric coefficient. Results with shorter, smoother vegetation with plenty of soil water indicate α in the range 1.2 to 1.3 for daily estimates. Smaller α values have been reported for forests, or 1.05 by McNAUGHTON & BLACK (1973), 0.72 ± 0.07 by SHUTTLEWORTH & CALDER (1979), and 1.03 ± 0.13 by VISWANADHAM et al. (1991).

One objective here is to investigate the energy balance and the effect posed upon α by S , at the hourly time scale, in two areas of the Amazon forest. Another objective is to test two approaches to estimate LE using the P-T72 model, being one proposed by VISWANADHAM et al. (1992) with $\alpha = 0.93$ assuming $G = 0.1 Q_n$, and another from PEREIRA & VILLA NOVA (1992) with the hourly variation of α as a function of H .

2. MATERIAL AND METHODS

Data were obtained from energy balance measurements at the Amazon forest (ABRACOS project). One site was inside the Reserva Jarú, RO (10°5'S, 61°55'W, 120m), and mean

tree height of 33m. The other site was at the Reserva Vale do Rio Doce, Marabá, PA (5°45'S, 62°22'W, 150m), with mean tree height of 25m. Turbulent flux instruments (eddy correlation system Hydra, IH, UK) and an AWS were at the top of a 52m tower in both sites. Hydra gave independent values of LE and H . Q_n and G were also measured. Rainfall hours and the next 3 hours after a rain were excluded. S was a residue of eq(1) discarding P .

"Measured" α , given by eq(2), was compared with $\alpha = 1.33 + 0.00278 H$ (PEREIRA & VILLA NOVA, 1992). Hydra LE was compared with $LE = 0.93 [s / (s + \gamma)] (0.9 Q_n) + 20$ (VISWANADHAM et al., 1992).

3. RESULTS AND DISCUSSION

Hourly variation of the energy balance components indicated that G was negligible. For several hours, $S \geq H$ showing that it has to be considered in the energy balance of the Amazon forest. Large values for S ($\pm 100 \text{ W m}^{-2}$) was also detected by MOORE & FISCH (1986) at the Reserva Ducke, and by KELLIHER et al. (1992), in a New Zealand forest. The relationship between S and Q_n is not well defined for the Amazon forest. Hourly change in S was associated with the change in above canopy net radiation ($\Delta Q_n = Q_{n,t} - Q_{n,t-1}$), being t the time, with $S = 0.1748 \Delta Q_n + 36.439$ ($r^2 = 0.5207$; $n = 876$). Large negative ΔQ_n occurred mostly in late afternoon, with Q_n decreasing. Large positive values occurred between 10 am and 2 pm. Presence of cumulus clouds was the determinant factor of sudden changes in Q_n . Negative values are associated with their shades, and the positive changes are determined by the sudden burst of radiation reflected downwards by their brilliant walls.

One important aspect is to check the impact S might have upon α . Positive S induced a decrease in α because the above canopy LE at that time does not take into account the corresponding LE stored in the canopy air. Therefore, the above canopy LE is less than the overall conversion of the Q_n into latent heat, resulting in α as low as 0.65. Conversely, as the canopy air enthalpy increases, it becomes more buoyant and more likely to be expelled resulting in negative S . Consequently, in this condition the above canopy LE is enhanced by the stored canopy latent heat, thus erroneously representing a larger proportion of Q_n conversion, resulting in larger α (> 1.6). Sometimes the larger above forest canopy LE is wrongly believed to be caused by advection.

The grass relationship $\alpha = 1.33 + 0.00278 H$ (PEREIRA & VILLA NOVA, 1992), did not differ significantly from the fitted $\alpha = 1.245 + 0.0023 H$ ($r^2 = 0.7580$; $n = 1003$). The grass function had a tendency to overpredict α in forest when H was in the range between -20 W m^{-2} and -80 W m^{-2} , but for H values outside this range the prediction can be considered as good. This is an apparent indication that the dependence of α on H is not accidental. The combined effect of $H + S$ on α showed the same tendency observed for the independent effect of H , with the same slope but a smaller interception coefficient, or $\alpha = 1.143 + 0.002 (S + H)$, with $r^2 = 0.6422$ ($n = 1003$).

To further test the applicability of the α function given by PEREIRA & VILLA NOVA (1992), LE was estimated with $LE = (1.33 + 0.00278 H) [s / (s + \gamma)] (0.9 Q_n)$, here called "modified

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Priestley-Taylor (MPT)", assuming $S = 0.1 Q_n$, as proposed by VISWANADHAM et al. (1992). The use of this assumption for S allows comparison of performance of the two approaches (variable versus fixed α values). The results show that the estimates with the MPT did not differ significantly from the measured values, with the points falling along the perfect fit line (1:1), having a standard deviation of $\pm 27.3 \text{ W m}^{-2}$ and $r^2 = 0.9690$.

Similar results were obtained with the parameterization proposed by VISWANADHAM et al. (1992), or $LE = 0.93 [s / (s + \gamma)] (0.9 Q_n) + 20$, with the points falling also along the 1:1 line, but with a larger spread of the points giving a standard deviation of $\pm 33.9 \text{ W m}^{-2}$ and $r^2 = 0.9079$; however, its performance can be considered as good in predicting the hourly latent heat flux (Figure 8). The present data set, with a much larger number of points analyzed ($n = 1003$), indicates that a slightly better fit would result if the intercept value of the above equation was 32.6 instead of 20, giving a $r^2 = 0.9319$ and standard deviation of $\pm 30.8 \text{ W m}^{-2}$.

Finally, if the actual value of S is incorporated into equation 2, then the best fit with a fixed value of α will be obtained with $LE = 1.02 [s / (s + \gamma)] (Q_n - G - S)$, which gave a $r^2 = 0.9194$ and standard deviation of $\pm 33.5 \text{ W m}^{-2}$.

4. CONCLUSIONS

The hourly energy balance of two forested areas of the Amazon region indicated that daytime S is a significant term of the exuberant vegetation, being sometimes larger than H , and as such it cannot be discarded from the budget. There was not a definite relationship between S and the above canopy Q_n as suggested elsewhere; however, the assumption that $S = 0.1 Q_n$ resulted in good performance of the Priestley-Taylor model. Negative S enhances the above canopy latent heat flux and it is sometimes interpreted as contribution of local advection. The large mass of vegetation restricted G to a negligible value. Confirming previous work in forested areas, LE consumed about 70% of Q_n , and this is the simplest way to estimate forest evapotranspiration when soil water is not limited.

The parameter α was primarily determined by H , but also by S . The fitted α versus H function for the forest did not differ significantly from the previous grass function. However, α was negatively affected by S , with larger S values resulting in smaller α . The combined effect of S and H over α had the same tendency as that determined independently for H . This helps to explain why α is much smaller for forests than for shorter vegetation.

The above canopy LE given by the Priestley-Taylor model either with α estimated by the PEREIRA & VILLA NOVA (1992) function or by the VISWANADHAM et al. (1992) parameterization, both assuming that $S = 0.1 Q_n$, did not differ significantly from the measured flux. These results substantiate both approaches. VISWANADHAM et al. (1992)

equation should be preferred because it needs only Q_n and above canopy air temperature as input variables.

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