JP4.18 THE REGIONAL EVAPOTRANSPIRATION OF THE AMAZON

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1. INTRODUCTION

Several datasets of Amazonian evapotranspiration (ET) have been developed (e.g., Shuttleworth, 1988). The annual cycles of ET in these datasets tend to vary in magnitude and phase. Global Climate Models (GCMs) tend to produce ET cycles that follow the modeled precipitation cycle: more in the rainy austral summer (December through February) and less in the drier austral winter (June through August) (Dickinson and Henderson-Sellers, 1988; Henderson-Sellers et al., 1993; Werth and Avissar, 2002). These GCMs seem to be responding more to the drier soil in winter as an impetus for reduced ET.

In an apparent contradiction with these results, however, Shuttleworth (1988, henceforth S88) used measured net surface radiation and atmospheric humidity to model ET, and found that Amazon ET undergoes a weak annual cycle that is out of phase with that of precipitation and in phase with the net radiation at the ground surface. ET is strongest in late winter (July-September) and weakest in the rainy summer (December-February).

2. AMAZON ET DATA

We have evaluated two independent methods that have been used to produce the annual cycle of ET at the scale of the Amazon. Both are similar in that they are based on the energy and water balance equations at the land surface. However, the representation of the water transfer at the surface is different in these methods.

2.1 *Net Radiation Method*

In his study, S88 used the measured surface net radiation data recorded for the Amazon Region Micrometeorological Experiment (ARME). That project involved surface measurements during the period from September 1983 to September 1985 at a single site in the Ducke Reserve (2° 57’ S, 59° 57’ W) near Manaus in the Brazilian state of Amazonas. As recorded in S88 (and as expected at this location) the ARME net surface radiation undergoes an annual cycle that has two peaks, one during April (fall equinox) and one in September (spring equinox). During the relatively clear winter in between (May through August), the surface net radiation values are higher than during the cloudy summer (December through February).

Figure 1 shows the resulting ET. It reaches a low point (3.0mm/day) during the rainy season (December through February), as recorded in S88. It rises during the autumn and peaks (4mm/day) during the winter dry season (July through September), falling again as summer approaches, giving an annual range (i.e., annual maximum – annual minimum) of 1.0mm/day. Evidence of a weaker peak is seen in April (the second equinox). As given in S88, the annual cycle of ET is strongly related to the cycle in net available radiation, with the two cycles in phase, correlating at 0.82. This implies that evaporation is largely radiation limited and is at or near its maximum (as determined by radiation) rate throughout the year, with minimal control by the vegetation. This can also be seen when the S88 values of mm-equivalent net radiation are compared to the derived values of ET. The ratio of evaporation to net radiation is about 0.89 (+/- ~.035) throughout the year.

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2.2 *Global Climate Modeling Method*

The Goddard Institute for Space Studies (GISS) Model II GCM (Hansen et al., 1983) was adopted as an example to demonstrate how ET over the Amazon is simulated with a fully-interactive climate model. This model has been applied extensively to simulate current and future climate under various scenarios (Hansen et al, 2000; Shindell et al., 1999), and has a land-surface scheme that is conceptually typical of most GCMs (Rosenzweig and Abramopoulus, 1997).

The Amazon-averaged GISS modeled ET (Fig. 1) has a summer maximum (3.5mm/day), and reaches its minimum (1.2mm/day) in late winter (September), when the ground is driest. Unlike ET calculated by S88, the GISS model ET is out of phase with the net available energy, correlating at 0.1, and the ratio between ET and maximum ET (mm/day equivalent of net radiation) is much lower than seen in S88, varying from a February value of 0.7 to a September value of 0.2. Also, the net annual variation of ET is around 2.4 mm/day, which is much larger than the 1 mm/day amplitudes of the S88 annual ET cycle.

In general, one might expect ET to correlate with net longwave radiation, since a reduction in ET (say, through drying) would yield a warmer surface that would radiate more longwave upward, reducing the net longwave. For example, the GISS Amazon ET correlates with net longwave at .99 (assuming a net downward flux is positive). Through their variable control of transpiration, however, the model stomata can alter the cycle of net longwave radiation so that it is no longer in phase with net shortwave radiation. The GISS GCM ET does not correlate well with the *net* radiation (sum of net longwave and net shortwave radiation), suggesting that, unlike in S88, the model stomatal control has a strong effect on the model transpiration. Therefore, the GISS simulated Amazon can be technically described as water-limited, but not in the usual sense of there being no water available for ET. Rather, the vegetation impedes ET during the dry season. The ET produced in the GISS GCM near where S88 measured radiation (Fig. 1) depicts increased rates of ET (relative to the GISS-GCM ET for the entire Amazon) but a similar annual cycle, with the minimum shifted to October, still different from S88. This suggests that the different vegetation models used in S88 and the GISS GCM, not only the different locations considered for the analysis, explain the differences in ET.

3. DISCUSSION AND CONCLUSIONS

The methods of estimating ET in the Amazon evaluated here exhibit different annual cycles, with a large difference among the various techniques obtained in the winter dry season. The two major controls on ET are the available energy at the surface and the way that vegetation regulates transpiration through its stomata. As the methods studied vary in the way they incorporate this regulation, the resulting ET cycles vary as well.

The ET dataset developed by S88 depicts high annual ET and a relatively weak annual cycle, implying a weak vegetation control of ET. The minimum of ET occurs in summer, with the maximum in winter. The GISS model experiences a wintertime minimum in Amazon ET and the low ET persists well into spring. The model reacts to the natural reduction of soil moisture in winter by sharply cutting off ET.

We conclude from this study that there are not enough available ground observations of ET to evaluate which of the two methods considered here best represents the regional ET in the Amazon. In their description of the LBA project, Avissar and Nobre (2002) indicate that "Multiyear ground-based measurements of carbon stores and fluxes are being made at sites strategically located along gradients of land use intensity, vegetation, and climate, complemented by observations from aircraft campaigns and by modeling". Therefore, we expect that the ET and other hydrological data to come from this extensive field campaign will greatly contribute to this key issue.

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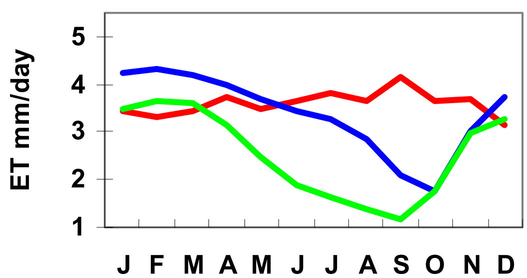

Fig. 1 Figure 1: Annual cycle of evapotranspiration in the Amazon at the Ducke Reserve in Manaus (2° 57’ S, 59° 57’ W), as calculated by Shuttleworth (1988), based on a two-year average (red), simulated by an ensemble mean of six realizations of eight years each with the GISS GCM near Manaus (blue), and throughout the Amazon (green).