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SPATIAL DISTRIBUTION OF PRECIPITATION RECYCLING IN THE AMAZON BASIN

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ABSTRACT

Precipitation recycling is the contribution of evaporation within a large region to precipitation in that same region. The rate of recycling is a diagnostic measure of the coupling of land surface hydrology and regional climate. Here we describe the spatial and seasonal variability of the precipitation recycling process over the Amazon basin. The results are based on data of evaporation and water vapor fluxes from the European Center for Medium Range Weather Forecast (ECMWF). We estimate that 25% of all the rain that falls in the Amazon basin is contributed by evaporation within the basin. The contribution of recycled water vapor increases westward and southward with significantly different spatial distributions in the different seasons.

INTRODUCTION

Hydrology affects climate in many different ways. Evaporation provides the water vapor necessary for precipitation processes. Latent heat fluxes associated with evaporation and condensation provide an important energy transport mechanism in the Earth's atmosphere. Because land surface hydrology plays such a significant role in maintaining the equilibrium of regional climate, many recent studies[1,2,3] suggest that anthropogenic changes in surface hydrology, e.g., deforestation of the Amazon basin, may result in serious impacts on climate. The precipitation recycling rate is a diagnostic measure of the current degree of coupling and the potential interactions of land surface hydrology and regional climate.

Previous studies suggested different ways for computing precipitation recycling. Budyko[4] provides a spatially lumped estimate of precipitation recycling. It describes the seasonal but not the spatial distribution of the recycling rate. Lettau[5] describes precipitation recycling along a single streamline. We study both the spatial and seasonal variability of the recycling process.

We consider two species of water vapor molecules; those which evaporate outside the region and molecules which evaporate within the region. The definition of the word 'region' includes all the area under study which is the Amazon basin. It is not restricted to the area of a single grid point. For a finite control volume of the atmosphere, conservation of mass requires the following relations.

$$\frac{\partial N_w}{\partial t} = I_w + E - O_w - P_w$$
$$\frac{\partial N_o}{\partial t} = I_o - O_o - P_o \tag{1}$$

where w denotes molecules which evaporate within the region and o denotes molecules which evaporate outside the region. N is the number of water vapor molecules. I and O are the inflow and outflow, respectively. P is precipitation and E is evaporation. N, I, O, P, and E are variable in space and time. It is assumed that the two species are well mixed which implies that

$$\rho = \frac{P_w}{(P_w + P_o)} = \frac{O_w}{(O_w + O_o)} = \frac{N_w}{(N_w + N_o)} \tag{2}$$

ρ is defined as the precipitation recycling ratio. Mixing of water vapor in the atmosphere is primarily achieved by dry thermal convection near the surface of the Earth. It is observed that the change in total precipitable water is small relative to fluxes over an appropriate time period, like a month. We will then assume that both derivatives in Equation (1) are zero. Substituting from Equation (2) into Equation (1) and rearranging we then get

$$\rho = \frac{I_w + E}{I_o + I_w + E} \tag{3}$$

The spatial resolution of the data should be small enough to resolve significant spatial variability in evaporation and fluxes. The temporal resolution should be large compared to the travel time across the basin.

The evaporation and fluxes data for the Amazon basin are part of the ECMWF global data set. The data assimilation system at the ECMWF combines data from surface meteorological stations, upper air observations and satellite data. Although the frequency and spatial coverage of the observations in the Amazon basin is limited, the ECMWF global data set is regarded as one of the best available data sets[5]. The data covers the period 1985–1990 inclusive. It has a twelve-hour resolution for the flux data and six-hour resolution for the evaporation data. It has a spatial resolution of 2.5° latitude by 2.5° longitude.

Figure 1 shows the spatial distribution of the precipitation recycling ratio in the Amazon basin. The annual recycling map indicates that ρ increases westward and southward. These directions are consistent with the directions of water vapor fluxes in the basin. Previous studies of recycling in the Amazon assumed that the variability of the process is mainly in one direction from east to west[6]. The results in Figure 1 suggest that ρ has a significant southward gradient. This gradient dominates the recycling map in the month of December consistent with the southward migration of the Inter-Tropical Convergence Zone (ITCZ) and the resulting southward flux of moisture over most of the Amazon basin in that month.

Figure 2 shows the estimated precipitation recycling ratio averaged over the basin and for the different months of the year. The seasonal variability of the averaged recycling ratio is small. The values for the Southern Hemisphere summer are slightly smaller than those for winter. The explanation of that result is in the high levels of rainfall in summer at the eastern subregion of the basin. Due to its location next to the

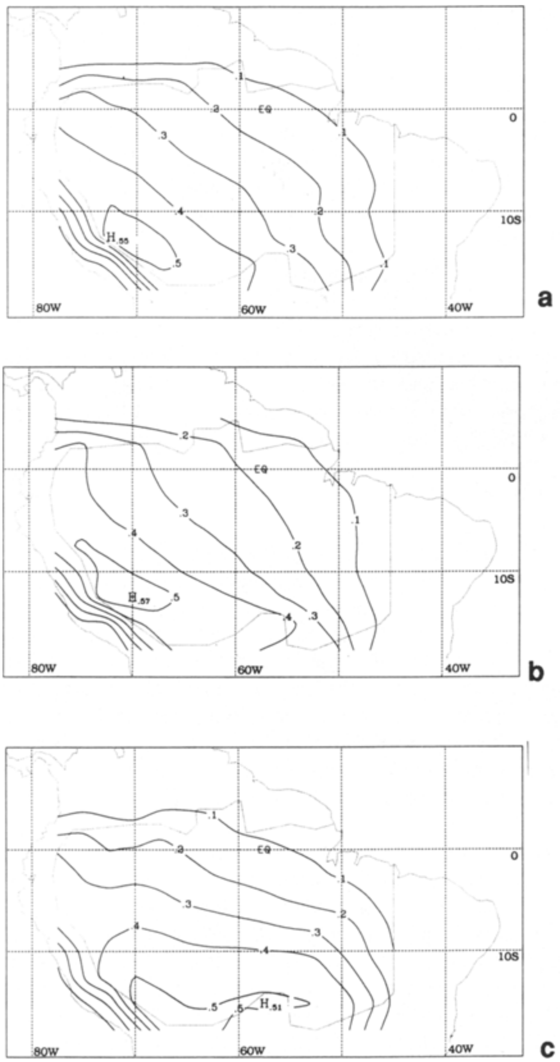

Figure 1. Spatial distribution of precipitation recycling ratio. a) annual, b) June, and c) December. The recycling ratio at each point in the basin is the ratio of recycled precipitation to total precipitation at that point. Recycling in a) is estimated by a weighed average of the recycling maps of all the months. The weighing function is the amount of precipitation for each month normalized by annual precipitation. This procedure is carried for each point in the basin.

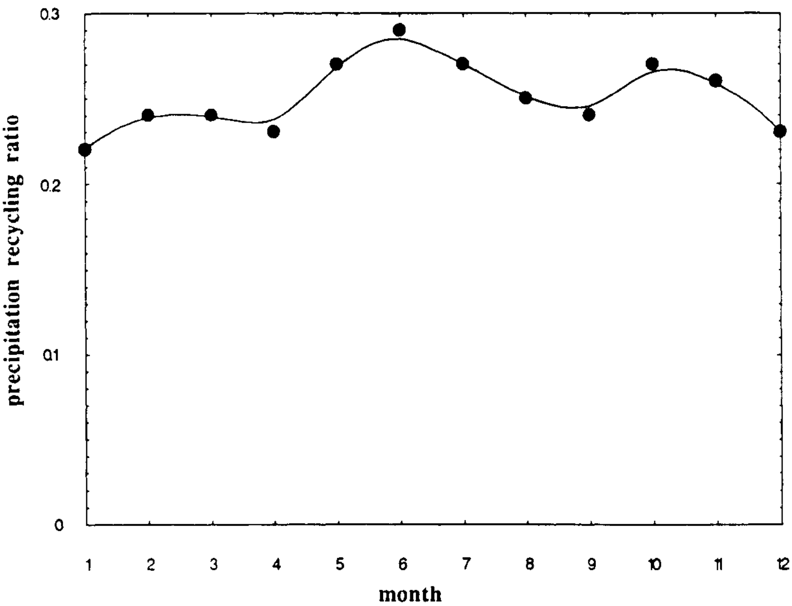

Figure 2. Seasonal distribution of precipitation recycling ratio. Recycling is estimated by a weighed average of the recycling spatial distribution. The weighing function is the amount of precipitation at each location normalized by the entire basin precipitation. This procedure is carried for each month of the year.

Atlantic Ocean, this subregion has a smaller ρ and hence the weighted average recycling ratio in summer is slightly smaller than that of winter.

The annual recycling ratio for the Amazon basin is estimated to be 25%. This ratio is significantly smaller than the frequently quoted estimate of around 50%[7,8]. The higher estimate of recycling was based on an inaccurate picture of atmospheric moisture flux over the Amazon which assumes that flux out of the basin is negligible. For a closed basin with no atmospheric water vapor outflow, the recycling ratio is given by the ratio of total evaporation to total precipitation. It was estimated that evaporation represents about 56% of precipitation in the Amazon[9], and hence it was concluded that the recycling ratio in the Amazon is about 56%[7]. But the Amazon is not a closed system, the data shown in Figure 3 indicate that the atmospheric water vapor flux out of the basin is significant. The flux out of the basin accounts for almost 70% of the flux into the basin. Although this ratio is significantly smaller than that for other rivers, e.g., 95% for the Mississippi basin[10], it is evident that the atmosphere above the Amazon basin is far from being a closed system. Most of the outflow occurs through

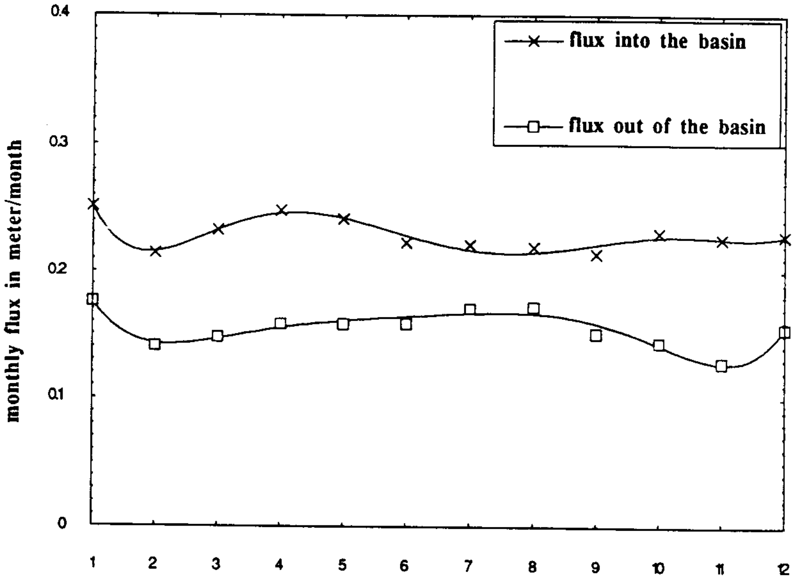

Figure 3. Atmospheric water vapor fluxes above the Amazon basin. Units correspond to depth of water over the basin area.

the Northern and Southern borders. This migration of moisture is confirmed by isotopic studies[11].

The east-west gradient of ρ as estimated by this study agrees with the results of Lettau et al.[6] ρ is comparable with $(1 - 1/\gamma)$ which is defined in their study. Our estimate of annual recycling of 25% is very close to a recent estimate of recycling in the Amazon using a modified Budyko's model[12]. We conclude by emphasizing that estimates of precipitation recycling provide a diagnostic measure of the coupling between hydrology and climate. It is inappropriate to make any prognostic statements regarding the effects of deforestation or any other disturbance of surface hydrologic parameters based solely on estimates of precipitation recycling and before studying the equilibrium of the disturbed climate system.

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