Effects of Deforestation in Amazonia on the Local Hydrological Cycle: The Scale-Dependence Issue

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Figure 1
Mean Rate of Gross Deforestation Estimated by the PRODES Project (INPE, 2002).

Abstract

Despite all the concern from the scientific community on major impacts of Amazonian deforestation (Figures 1 and 2), its effects on the local hydrological cycle are still uncertain. While many modeling studies have observed that large-scale conversion of the Amazonian rainforest into pastures, or croplands tend to induce an overall reduction in precipitation (Table 1), there are also meso-scale experiments that predicted the establishment of enhanced rainfall over deforested areas (Dias and Regnier, 1996; Wang et al., 2000). These contrasting results suggest that the net effect of deforestation on precipitation might depend on the size of the clearing area.

However, precipitation in Amazonia follows more closely the fluctuations in the general circulation of the atmosphere, which seems to be still offsetting the effects of deforestation (Chen et al., 2001). Therefore, since runoff is not directly dependent on such remote forcings, it may, unlike precipitation, carry the signal of deforestation and permit a better assessment on the scale-dependence of its effects.

The present work apply different methods of Trend Analysis to historical discharge records in the Amazon Basin, to detect significant trends potentially associated with deforestation. Preliminary results indicate the existence of organized spatial patterns in the trends of non-filtered discharge records, indicating a potential association with deforested areas (Figure 3). Based on current and predicted deforestation scenarios, a numerical model representing the Water Budget Closure (WBC) system in Amazonia (Figure 4) is also applied, providing high-resolution gridded runoff and discharge outputs (Figures 6d and 6e). Following the conceptual model discussed here (lower box, on the right), the application of WBC as proposed will assess the coherence of deforestation and trend patterns, applying suitable soil parameters according to the gridded forest coverage observed (Figures 1 and 2)..

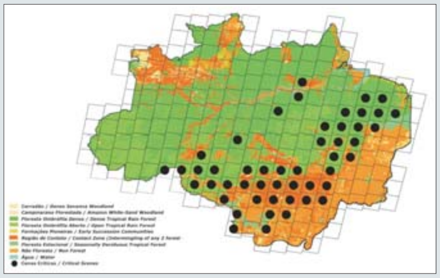


Figure 2
Forest Coverage and Critical LandSat Scenes Estimated by the PRODES Project (INPE, 2002)

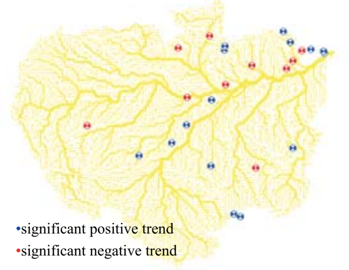


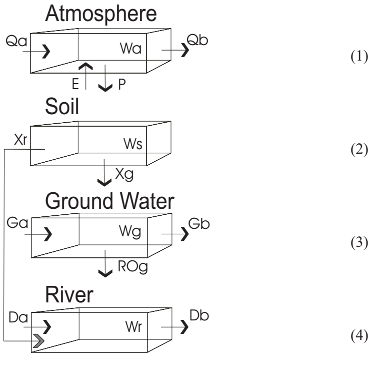
Figure 3
Set of discharge gauging stations (collected by ANA-Agência Nacional de Água) that showed either positive (blue) or negative (red) significant trends (at the 95% level of significance) during the last decades.

Evapotranspiration estimates by WBC

The Aerological Approach is one of the methods applied to WBC in order to estimate daily gridded values of evapotranspiration within the Amazon Basin. It requires the application of atmospheric observed data into Equation 1 and the results shown here refer to the application of analysis and short-range forecast data from the Mesoscale ETA Model, which is integrated bi-daily at CPTEC/INPE over 19 (p) pressure vertical levels and has a 40 km spatial resolution (Figure 6b). The (Q) horizontal water vapor flux over the air column up to 500mb is calculated by the vertical integration of the product between the (q) specific humidity and the (v) wind velocity, multiplied by the inverse of the ($g=9.81 m/s^2$) gravity acceleration (Brutsaert, 1982; Kuznetsova, 1990; Peixoto and Oort, 1992), while the precipitable water (Wa) and the precipitation (P) are taken directly from the analysis.

The other method applied refers to the calculation of evapotranspiration directly from the surface latent heat flux estimated by ETA Model (Figure 6c). It appears that this method is more suitable for the calculation of the actual evapotranspiration within the Amazon Basin, considering the more realistic values encountered. It is suggested here that the instabilities in the wind field might cause the instable evapotranspiration field obtained by the Aerological Approach.

Water Budget Closure



Wa= precipitable water
Q = water vapor flux
E = evapotranspiration
P = precipitation
Ws= soil water
Wg= ground water

Xg = excess water to the ground
Xr = excess water to the river
G = ground water flux
ROg = runoff from the ground
Wr = river water
D = discharge

Figure 4
Water Budget Closure (WBC) applied to each single grid cell within the Amazon Basin and part of South America. The equations on the right represent the mass balance within each one of the boxes (reservoirs), which are connected by the arrows (water fluxes). Coupling between adjacent river cells is performed by the WTM (Water Transport Model) (Vörösmarty et al, 1996).

Table 1
Summary of results of some recent simulations of Amazonian deforestation on the expected changes on mean surface temperature (*T*) total daily rainfall (*P*), evapotranspiration (*E*) and runoff (*R*)(D'Almeida et al., 2002).

reference	*dT(°C)*	*dP(mmd^{-1})*	*dE(mmd^{-1})*	*dR(mmd^{-1})*
LW, 1989	+2.4	-1.43	-0.85	-0.40
N *et al*, 1991	+2.5	-1.76	-1.36	-0.40
HS *et al*, 1993	+0.6	-1.61	-0.64	-0.90
LR, 1993	+2.1	-0.81	-0.55	-0.20
PL, 1994a	+3.8	+1.08	-2.07	+3.70
PL, 1994b	+0.14	-0.51	-0.35	-0.16
S *et al*, 1996	+2.0	-1.48	-1.22	-0.26
MP, 1996	-0.5	-0.40	-0.31	+0.33
LR, 1997	+2.3	-0.27	-0.76	+0.51
HD, 1997	+1.00	-0.99	-0.41	-0.50
CF, 2000	+1.40	-0.70	-0.60	-0.10

Scale Dependence of the Hydrological Effects of Deforestation: A Conceptual Model

At the catchment level, the replacement of the original forest coverage by pastures tend to increase runoff, basically due to reductions in infiltration, water uptake and evapotranspiration, and increase in rainfall. This pattern is more commonly observed during the dry-season and it is induced by soil compactation, shallower roots under pastures, strong reduction of transpiration and interception, and enhanced convection activity.

However, as the cleared area becomes wider, the impact of deforestation seems to change, basically switching the predicted effects on precipitation and runoff. The change in the tendency of precipitation can be explained by two factors; namely, disappearance of land surface heterogenities encountered around small cleared areas, which are responsible for the increase in convection activity, and diminishing of the water recycling effect, which significantly feeds the local precipitation patterns. Therefore, since there are more than one factor that contributes to the reduction in rainfall, it actually tends to decrease faster than the increasing rate of deforestation. On the other hand, since the reduction in evapotranspiration depends only on the extent of forest that is cleared, as a result of spatially uniform reductions in transpiration, interception and water uptake, it tends to follow a fairly linear increment as the clearing gets wider. As a consequence, there is a point when the reduction in rainfall overcomes the reduction in evapotranspiration, making runoff - the difference between these two quantities - to decrease as well.

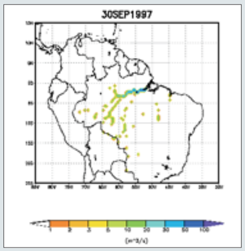


Figure 6a
ETA/CPTEC daily accumulated forecasted rainfall.

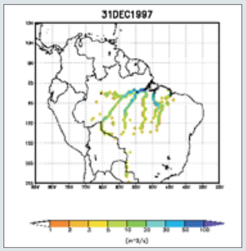


Figure 6b
Evapotransp. estimated by the Aerological Approach.

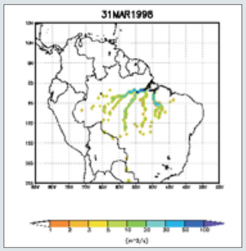


Figure 6c
Evapotransp. estimated by the surface latent heat flux.

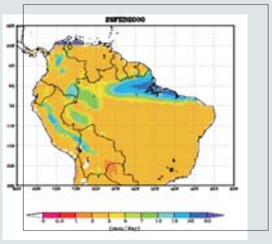


Figure 6d
Daily runoff simulated by WBC.

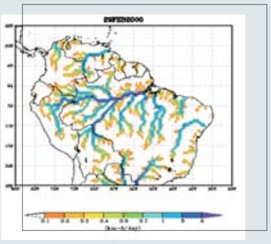


Figure 6e
Daily river discharge simulated by WBC.

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