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A GCM SIMULATION OF IMPACT OF LAND COVER CHANGES IN THE AMAZONIA ON REGIONAL CLIMATE

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1. INTRODUCTION

Amazonia is a major source of heat and water vapor for the global atmosphere. It covers a vast area and is positioned in the tropics, where the exchange of energy between the land surface and atmosphere is at a maximum. Changes in Amazonia are thus likely to have an impact on atmospheric circulations and the hydrological cycle, not only over South America but in other parts of the world as well (Dirmeyer e Shukla, 1994; Sud et al, 1996; Hahmann e Dickinson, 1997; Voldoire e Royer, 2004). The Amazon rain forest has experienced dramatic changes in the past 50 years due to active deforestation, particularly in the southeastern part of the Amazon Basin (Brazilian arc of deforestation). Due to land cover changes in Amazonia, this raises key scientific questions, such as: Could these changes have an impact on regional climate? What kind of impact? Using the general circulation model from the Brazilian Center for Weather Forecasting and Climate Studies (GCM/CPTEC) this study evaluated how the land cover changes (deforestation) in Amazonia affect the regional climate, considering deforestation scenarios for current and potential future conditions.

2. MODEL DESCRIPTION

The Center for Weather Forecasting and Climate Studies - Center for Ocean-Land-Atmosphere Studies (CPTEC-COLA) atmospheric general circulation model (AGCM) is a modified version of the spectral COLA GCM. It was used for the numerical simulations. Its main features are described in Cavalcanti et al. (2002). Model resolution is T62L28, that is, 28 levels and horizontal resolution of about 2^o. The land surface scheme coupled to the AGCM is the SSiB (Xue et al., 1991). The dynamical and physical processes in the COLA model are described in Kinter et al. (1997). The CPTEC-COLA model dynamical processes and physical parameterizations are the same as those of the COLA model, with Kuo scheme for deep convection (Kuo 1974), shallow convection following Tiedtke (1983), and the Mellor and Yamada closure scheme applied for the vertical diffusion in the planetary boundary layer (Mellor and Yamada 1982). The shortwave radiation is based on Lacis and Hansen (1974), modified by Davies (1982), and the longwave radiation formulation was that developed by Hashvardhan et al. (1987).

3. EXPERIMENT DESIGN

Four simulation runs were performed, referred to as CONTROL, PROVEG, CEN2033 and DESFLOR. In the CONTROL and PROVEG experiments, the South American vegetation map includes land cover representations of Legal Amazon with (PROVEG) and without (CONTROL) deforested areas, as elaborated by the ProVeg Project (Sestini et al. 2002) for the base year 1997 (Figure 1). In the CEN2033 experiment, a deforestation scenario for year 2033 was developed using a landscape dynamic model (Soares-Filho et al. 2004). Finally, the DESFLOR experiment assumed that all of Amazonia's tropical forest area was replaced by degraded pasture, similar to what has been done in other Amazonia deforestation impact studies (Hahmann and Dickinson 1997). Each simulation run consists of three years numerical integrations, named members (each member is related to a 3-yr run). The AGCM was integrated starting at 0000 UTC on December 1, 1997. The first month of integration was neglected due to soil moisture *spin up*. Climatology sea surface

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temperature (SST) was used in all experiments. Except for the land cover changes, all other initial and prescribed boundary conditions were kept identical in all simulations.

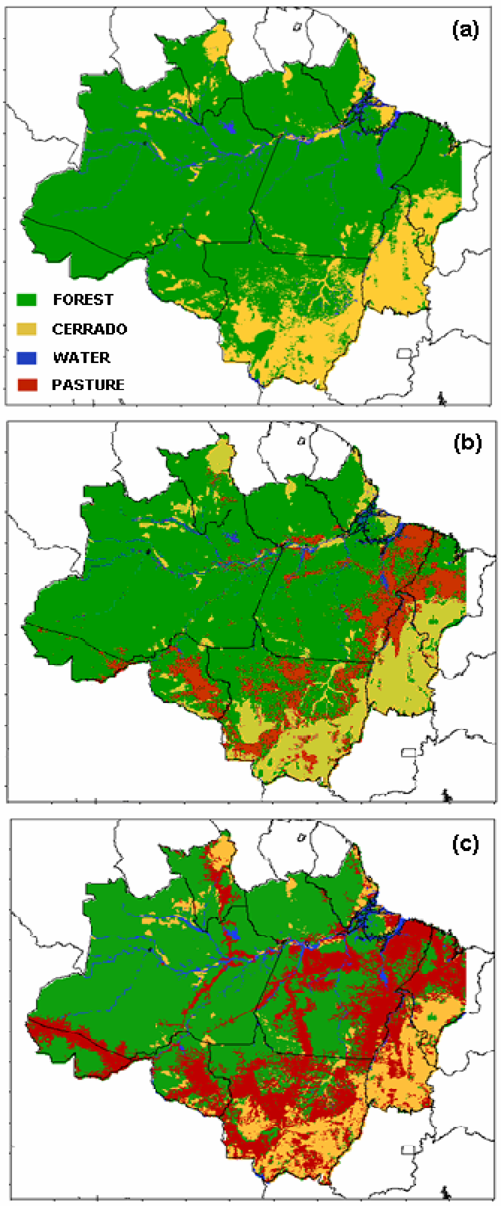

Fig. 1. Deforestation scenarios on a horizontal resolution of 1 km x 1 km. (a) no deforestation scenario used in CONTROL simulation; (b) current deforestation scenario produced by the ProVeg Project (Sestini, 2002) and used in PROVEG simulation; (c) deforestation scenario for year 2033 used in CEN2033 simulation. On the maps green means tropical forest, yellow - cerrado ("a type of savanna"), blue - water and red - degraded pasture.

4. RESULTS

An increase of the surface temperature was observed in all of the scenarios, with annual mean values ranging from 1.0 to 1.6°C and with the most significant temperature impacts observed during the dry season, when the soil was under hydrological stress. A reduced surface net radiation was observed in all scenarios (from 24.4, 23.9 and 26.9 W m^{-2} for the PROVEG, CEN2033 and DESFLOR scenarios, respectively). The cloud mechanism, in which the increase of the surface reflected solar radiation is balanced by an increase of the incoming solar radiation, was observed in the two last scenarios. In general, both the increases in albedo and in upward longwave fluxes were primarily responsible for the reduced surface net radiation for the PROVEG scenario. The climatic impacts that these scenarios have on the annual averages of precipitation are assessed here. For the PROVEG scenario, there was an increase (1.2 mm day^{-1}) of the precipitation in southern Amazonia (Figure 2), and decreased precipitation was observed in the north of South America. This result indicates that deforestation, as simulated by PROVEG, contributed to the modifications of the dynamic atmospheric structure and, consequently, created mesoscale circulation, as a result of differential heating related to the heterogeneity of the surface, once the thermal and radiative characteristics of the vegetation cover have been modified. Analytical and numerical studies using mesoescale models have shown that the horizontal heterogeneity of the turbulent surface sensible and latent heat fluxes can produce strong mesoescale circulations (Silva Dias and Regnier, 1996; Wang et al. 2000). These circulations significantly affect the structure of the Planetary Boundary Layer (PBL), the heat, moisture and scalar fluxes (Li and Avissar, 1994), and cloud and precipitation organization (Wang et al., 2000). Durieux et al. (2003) showed experimental evidence of the increased cloud cover and precipitation over the deforested areas in Amazonia. Examining the climate effects of changes in the vegetation cover over the arc of deforestation, they observed that during the dry season there were more low clouds present in the afternoon, while for the rainy season the convection was stronger over pasture during the night, leading to an increase of the local precipitation. Different from previous simulations, decreased precipitation was observed in the CEN2003 and DESFLOR scenarios, with significant reductions in the east and northeast of Legal Amazonia (Figure 3).

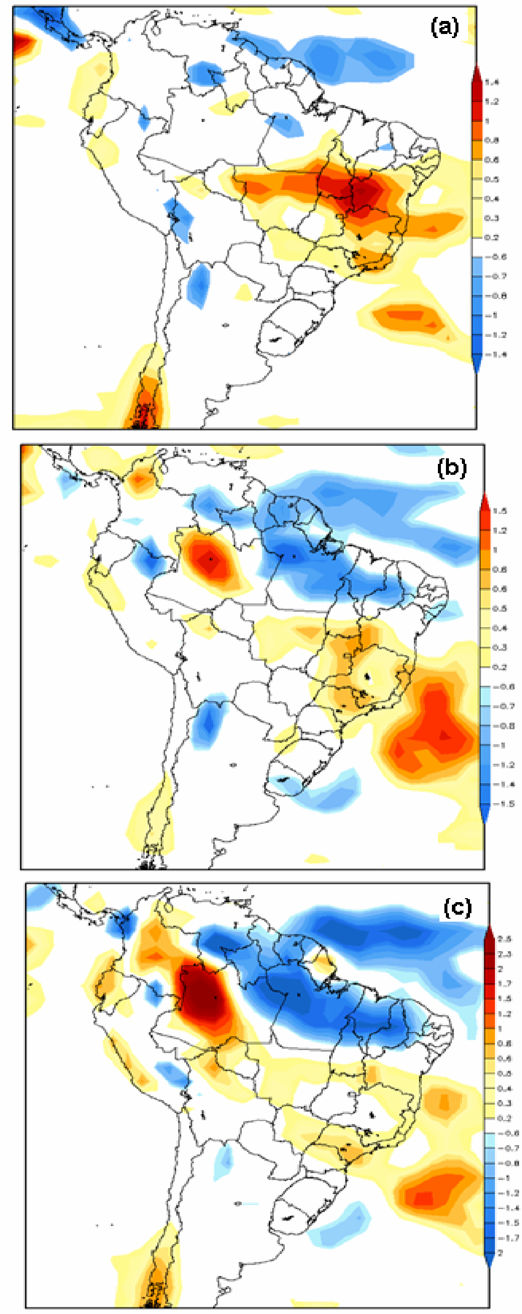

Fig. 2. Modeled annual mean difference in precipitation (mm day^{-1}): (a) PROVEG-CONTROL; (b) CEN2033-CONTROL; (c) DESFLOR-CONTROL. Blue (red) color represents negative (positive) anomalies.

A significant increase of the precipitation was observed in the extreme western part of the South American continent resulting from the increase of the moisture convergence over this region. Evapotranspiration from the tropical forest is one of the most important water vapor sources feeding into precipitation in Amazonia; thus, it was initially expected that a reduction in evapotranspiration would lead to a reduction in precipitation. The changes of the hydrological cycle differed in each of the deforestation scenarios. In all three scenarios, a negative feedback mechanism was observed in the hydrological cycle, with greater amounts of moisture being carried to the deforested areas. The increase of the moisture convergence was greater than the reduction of the evapo-transpiration for the PROVEG scenario (Figure 3). This result, as well as the mesoescale thermodynamic processes, caused an increase of the precipitation. The negative feedback mechanism of Sud and Fennessy (1984) may be used to explain this result. According to this mechanism, a reduction in evapotranspiration would lead to increases in surface temperature and sensible heat flux, which, in turn, would heat the lower troposphere. This would generate a low thermal surface relative to its neighbors. So, a low-level moisture convergence would occur, creating favorable conditions for precipitation. In addition, warming of the lower troposphere (due to the increase of the sensible heat flux) would create a more unstable vertical profile, thus promoting convection.

Different patterns were observed in both the 2033 scenario and the large-scale deforestation scenario. One local increase of the moisture convergence was observed, but not sufficiently intense to generate an increase of the precipitation. The reduced evapotranspiration was the dominant factor in these scenarios. Therefore, the partial deforestation in Amazonia may actually lead to an increase in precipitation locally. However, as the deforestation increases, this condition becomes unsustainable, leading to drier conditions and, consequently, to reduced precipitation in the region. The moisture transport by the regional atmospheric circulation over the Amazon Basin was calculated for each of the deforestation scenarios (Figure 4). Overall, the more significant changes in moisture convergence over the basin as a whole were observed with the large-scale deforestation scenario. Different results, particularly the reduced moisture convergence, were obtained for the other deforestation simulations (Zhang et al., 1996; Voldoire and Royer, 2004). However, in this study we observed that large-scale deforestation could reduce the high precipitation regime of the Amazon Basin only through a reduction of the evapotranspiration, despite the increase of the moisture transport in the basin through the regional atmospheric circulation.

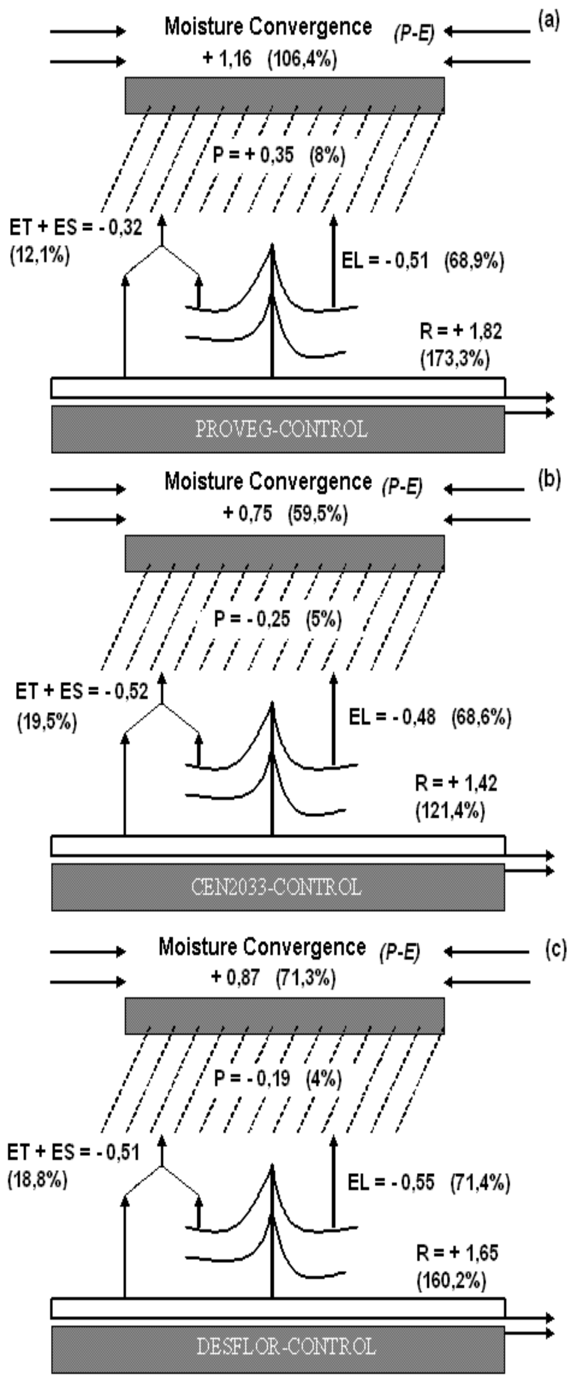

Fig. 3. Schematic illustration of the hydrological cycle changes for each deforestation scenario: PROVEG (a), CEN2033 (b) and DESFLOR (c), respectively. Here P is the annually averaged precipitation, ET is the transpiration, ES is the soil evaporation, EL is the rate of precipitation interception by foliage, R is the surface runoff. The percentages represent the contribution to the total precipitation. Numbers in parentheses are the percentage changes.
Units are in mm day^{-1}.

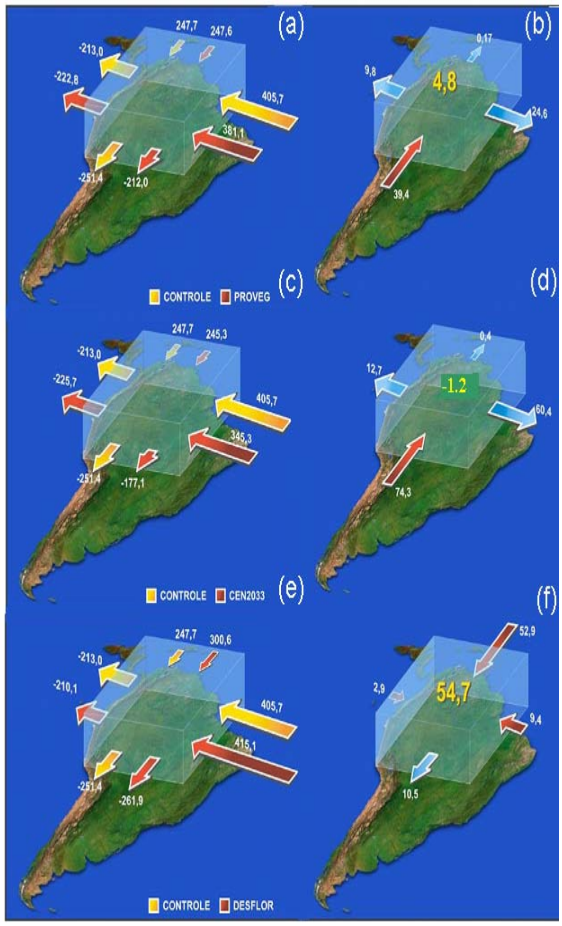

Fig. 4. Vertically integrated water vapor transport across the boundaries of the Amazon Basin for all deforestation scenarios (10^6 x kg s^{-1}): (a,b) PROVEG scenario; (c,d) CEN2033 scenario; (e,f) DESFLOR scenario. On the right side, the blue (red) arrow represents the moisture transport leaving (entering) the Amazon Basin.

5. SUMMARY AND CONCLUSIONS

A primary motive for conducting this study was to determine the consequences of deforestation on the regional climate, using four different scenarios for Amazonia: no deforestation, current scenario, a scenario for 2033, and a large-scale deforestation scenario, which considered that the tropical forest in South America had been replaced by degraded pasture. This was done using a CPTEC-COLA AGCM coupled with the SSiB surface scheme. The simulation results show that, for all scenarios, the most significant changes of the radiation and energy budgets occurred during the dry season. Also, the decreased root depth after deforestation plays an important role in this result. For the hydrological cycle, a negative feedback mechanism was observed for all scenarios, with an increase of the precipitation with the first scenario and decreased for the

2033 and with large-scale deforestation scenarios. Even though the total rainfall decreases for the last scenario, its reduction is much smaller than the reduction of the evapotranspiration. Indeed, if the rainfall reduction were larger than the evapotranspiration reduction, the biosphere could be expected to exert a positive feedback mechanism on the rainfall climatology. Likewise, a smaller reduction would create a negative feedback mechanism. Thus, the biogeophysical feedback mechanism of the deforested Amazonia is negative, being definitely a better scenario than the one with a positive feedback. A positive feedback mechanism creates an instability that could lead to further degradation of the biosphere, as inferred by Xue and Shukla (1993) for Sahel. On the other hand, a negative feedback promises recovery if the anthropogenic pressure is eliminated. However, if the anthropogenic activities do not permit regrowth, such as the construction of roads, buildings and parking lots or using the land for grazing and agriculture, the negative feedback mechanism would generate an excess of water at the surface, thus causing increased runoff, flooding in low-lying areas, and other hydrologic disasters.

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