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INCORPORATING HYDRAULIC REDISTRIBUTION (HR) INTO THE SIMPLIFIED SIMPLE BIOSPHERE MODEL (SSiB)

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Introduction

Hydraulic redistribution (HR), the nocturnal transfer of water by root systems from moister to drier regions in the soil, has been recently documented in an Amazonian tropical forest (Oliveira et al. 2005; Rocha et al. 2004). Several observational studies have showed that HR plays an important role in maintaining plant transpiration during drought (Caldwell et al. 1998). Because of its importance, HR has been gradually incorporated into Land Surface (Parameterization) Models, LSM (Ren et al., 2004; Lee et al., 2005). Our aim here was to incorporate HR into the “Simplified Simple Biosphere Model” (SSiB; Xue et al., 1991) – the LSM used by the Atmospheric General Circulation Model – CPTEC AGCM to investigate the influence of HR in maintaining plant transpiration in a scenario of extreme drought in the Amazon. HR is represented in an extremely simple form to facilitate the inclusion in the SSiB code, therefore justifying the preliminary character of this study.

Incorporating HR in SSiB

HR is usually parameterized directly in the Richards equation as a flux or additional sink/source term. For example, Ren et al. (2004) considered HR as an additional term dependent on the matric potential, the rates of transpiration and root density. Lee et al. (2005) considered an additional flux dependent on the vertical difference of soil matric potencial, hydraulic conductivity, leaf area index and root density. These approaches are adopted because LSMs usually do not represent the hydraulic transport by the root system explicitly.

In this study, we have adopted a much simpler scheme. SSiB considers only 3 soil layers (Fig. 1): the surface (a few centimeters), root and drainage layers. We have considered that HR is a flux from the drainage layer (3rd layer) to the root layer (2nd layer) during the night when the degree of water saturation of the second layer is less than a threshold value (W_c); at each hour, a fraction (F) of the total water stored (in mm) in the third layer would be transferred to the second layer. The parameters W_c and F were calibrated by running SSiB for tropical forest biome. It was found that the effects of soil moisture deficit on plant transpiration became important when the root zone degree of saturation dropped below 60%, and that an hourly transfer of 0.1% of the total water stored in the third layer would be enough to keep the forest high evapotranspiration rates. Therefore, it was assumed that W_c = 60% and F = 0.1%.

[Explanation:
- Water availability of the 3rd layer (4 m thickness) = 150 mm/m x 4 m = 600 mm;
- Degree of saturation of the 3rd layer in the dry season = 70%;
- Dry season water availability = 600 x 0.7 = 420 mm (= S);
- Daily evapotranspiration ~ 4 mm ~ 1% S
- 1% in 12 hours ---> ~ 0.1% per hour]

For tropical forests, the SSiB (in the way it is implemented in the CPTEC AGCM model) considers 2 m as the depth of the third layer. To increase its storage capacity, the thickness of the layer is doubled, i.e., 4m. Even though this procedure may seem apparently arbitrary, this increase in thickness is justified by the following: for tropical forests, SSiB considers the total rooting depth as 1 m. This rooting depth can be considered as the effective one for transpiration. In the Amazon, it is well known that roots can be much deeper than 1m (Nepstad et al., 1994). But it is also known that more than 95% of the roots are found within the first meter of the soil profile, therefore transpiration derived from deep soil can be limited by lower densities of roots. Roots are present in all 3 layers of SSiB – but, for transpiration purposes, this model considers only the first two. The idea here is that roots deeper than 1 m, even though not directly related to the transpiration process during the

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day, will optimize transpiration by HR means [if we simply double the thickness of the third layer without including HR, there is no impact in transpiration – (test now shown)]

Data and Methodology

To asses the influence of HR in maintaining plant transpiration in a scenario of extreme drought in the Amazon, we carried out two simulations using the SSiB (Xue et al., 1991), one control and one with HR. For both runs, we specified the climatological forcings of SSiB (hourly radiation, precipitation, temperature, humidity, wind and pressure) by using data collected at the micrometeorological tower in the Jarú Reserve (Ji-Paraná, Rondônia, Brasil, 10° 05' S, 61° 55' W) for the period of January 1992 to December 1994, during the ABRACOS Project (Gash et al., 1996).

In the control run, the micrometeorological forcings were not modified. In the scenario of extreme drought, we opted to simulate the severe drought conditions observed in southwestern Amazonia in 2005 (70-80% less precipitation than the long-term average for the dry period). Therefore, we reduced precipitation to 25% of the total measured and maintained the other micrometeorological variables constant (Figure 2). This scenario is much more extreme than the one considered in climatic change studies (average reduction between 0-15% of the annual total and increase in drought frequency).

Results

Considering the scenario of extreme drought, starting on April 2004 (2 years after the beginning of drought), transpiration decreased abruptly as a consequence of the decrease in soil moisture availability (Fig. 3). In the HR run, transpiration was maintained very close to the control one, even after the extreme drought. This result suggests that HR may play an important role in supplying water for plant transpiration during periods of extreme water deficits. In a similar modeling exercise, Lee et al. (2005) showed that evapotranspiration increased significantly in the Amazon during the regular dry season, when plants were allowed to redistribute soil water. Both studies provided evidence that a refined parameterization of plant root functioning have a major impact in the hydrology and climate of the Amazon. However, our results need to be seen with caution because in the HR run, the drainage layer became very dry after 3 years and we do not know how long more transpiration could be maintained by hydraulic redistributed water. An improvement in the representation adopted here would be to decrease the flux from the third to the second layer as the third layer dries-out.

Future work

Incorporate hydraulic redistribution (HR) in both directions, upward and downward in the soil.

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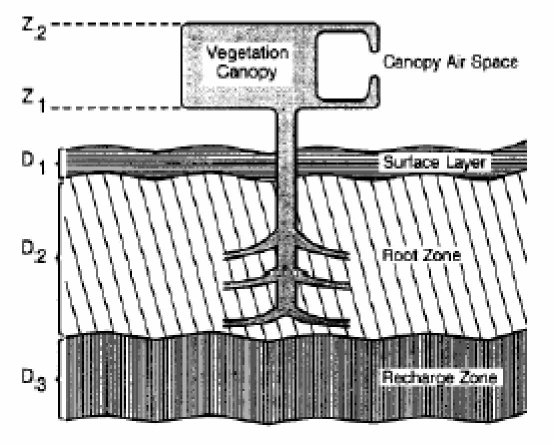

Fig. 1 – Scheme of soil layers used in SSiB

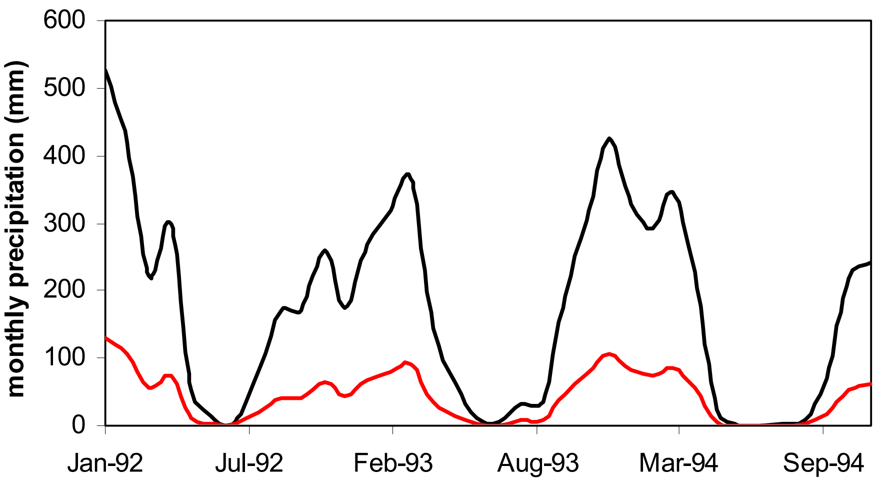

Fig. 2 – Precipitation in the forest site (Jaru Reserve). Black line represents measured precipitation; red line (lower line), ¼ of the measured value. The series in red was used to study the effects of a prolonged (and hypothetical) drought in the Amazon.

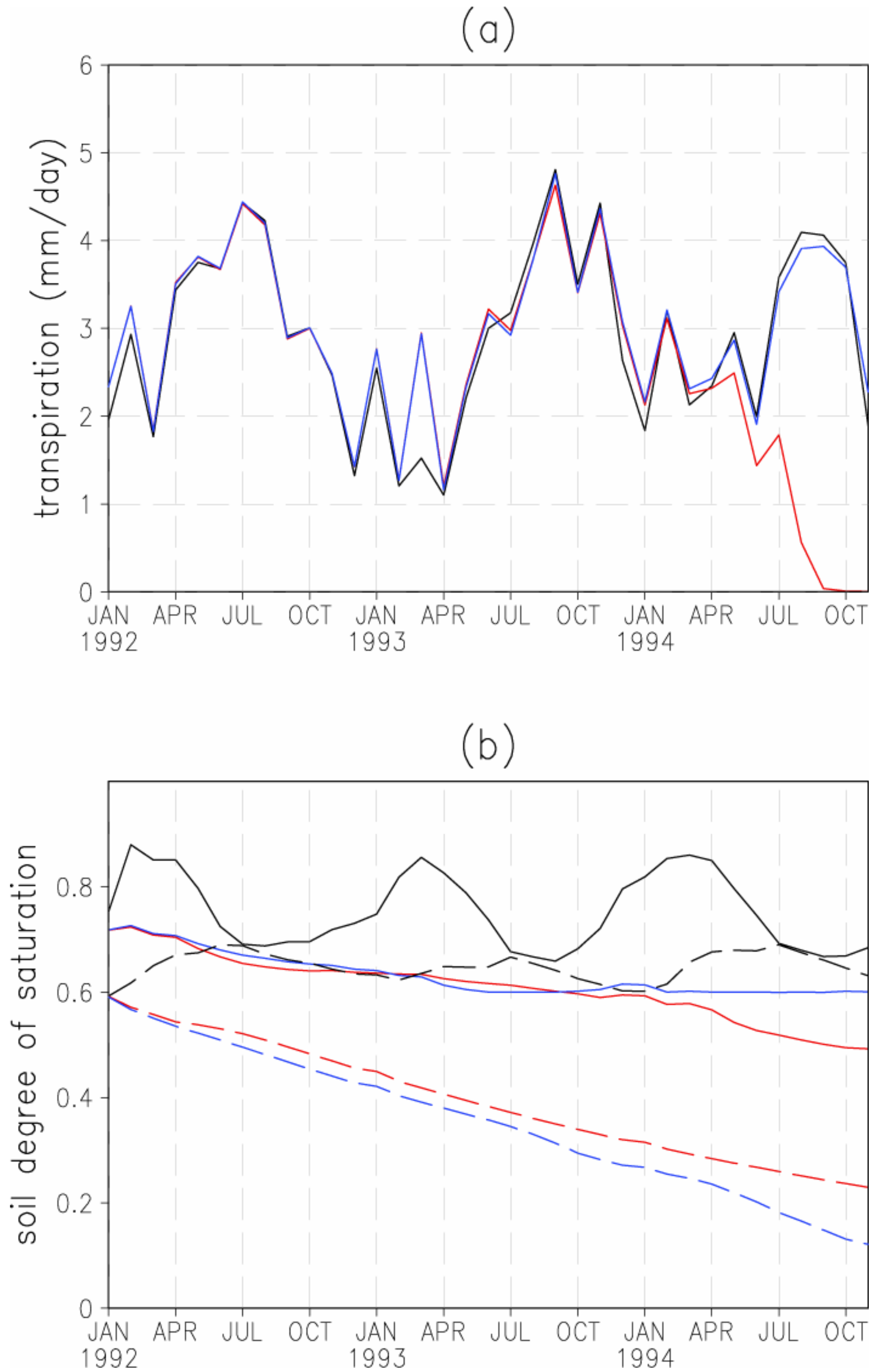

Fig. 3 – Monthly transpiration averages (a) and the degree of soil water saturation (b) for the SSiB run. Black lines represent the control run; red lines, reduced precipitation to ¼ of the measured value; blue lines, run with HR and drainage layer with doubled size. In (b), solid [dashed] lines represent the degree of soil saturation in the root [drainage] layer.