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SIMULATIONS OF TROPICAL RAINFOREST ALBEDO: IS CANOPY WETNESS IMPORTANT?

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1. Introduction

Surface albedo is the main factor that affects the land radiation balance. Accurate surface albedo information is essential for climate modeling, especially for regions, such as Amazonia, where the response of the regional atmospheric circulation to the changes on surface albedo is strong ((Nobre et al., 1991; Dirmeyer and Shukla, 1994; Costa and Foley, 2000).

Berbet and Costa (2003), demonstrates that an uncertainty of 10 $W \cdot m^{-2}$ in the seasonal solar radiation balance translates into an uncertainty of 30 mm/month in the simulated rainfall, a very significant uncertainty, especially in the dry season of that region. Previous studies have indicated that models are still unable to correctly reproduce details of the seasonal variation of surface albedo at both the hourly and monthly time scale (Berbet and Costa, 2003).

At the monthly time scale, Culf et al. (1995) analyzed the surface albedo at forest sites in Amazonia. The authors report that albedo seasonality at these sites is not related to the variation of solar elevation angle nor to cloudiness, but suggested a relationship to soil moisture. Although soil moisture affects ground albedo, most likely the changes in forest albedo are related to soil moisture-correlated variables: smaller soil exposure, darker leaves (associated with the leaf water potential) and higher canopy wetness (Berbet and Costa, 2003). Canopy wetness, in particular, is a strong candidate for changing canopy albedo, because reflectance of liquid water varies, depending on the wavelength, between 0 and 5%, much lower than the 12-13% usually measured above tropical rainforest canopies. Hence the presence of liquid water on the canopy increases the absorption of solar radiation, reducing the canopy overall albedo.

Here, we investigate the role of canopy wetness in the simulated albedo of a tropical rainforest. In this study, we run simulations using three versions of the land surface/ecosystem model IBIS: the standard version using the original calibration used by Delire and Foley (1999), the same version recalibrated to fit the tropical rainforests albedo data, and a modified version that incorporates the effects of canopy wetness on calculated surface albedo.

2. Sites, Instrumentation and Data

Field data used in this paper were measured at three sites in the Amazon: Ducke and Cuieiras (K34) Reserves are INPA (Instituto Nacional de Pesquisas da Amazônia) protected forest reserves, about 25 km north-east and 70 km north of Manaus, respectively. Jaru Reserve is an IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) forest reserve and is located about 80 km north of Ji-Paraná.

At the Cuieiras Reserve a piranometer (Kipp & Zonen, Delft, Netherlands), connected on a datalogger model (21X, Campbell Scientific) measured incident and reflected solar radiation each minute, storing the averages every 20 minutes. For the remaining sites, the incident and reflected solar radiation were measured using two solarimeters (Kipp and Zonen, Delft, the Netherlands) and hourly-averaged data were recorded.

We used incident and reflected solar radiation and precipitation data, collected from June 1999 to September 2000 at Cuieiras Reserve, from January to

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December of 1995 at Ducke Reserve and from January to December of 1993 at Jaru Reserve.

3. Description of the IBIS model

To simulate the diurnal albedo of an Amazon tropical forest, we use the Integrated Biosphere Simulator–IBIS (Foley et al., 1996). It includes representations of land surface processes, like energy, water and momentum exchange between the soil-vegetation-atmosphere system, canopy physiology, vegetation phenology, vegetation dynamics, and terrestrial carbon balance. One of the processes simulated by IBIS, of central interest here, is the exchange of solar radiation between the soil-vegetation-atmosphere system. Solar radiation transfer is calculated following the two-stream approximation, with separate calculations for direct and diffuse radiation in both visible and near-infrared bands. In this study, we modify the IBIS canopy radiation transfer code to incorporate the effects of canopy wetness on the vegetation reflectance. Although IBIS already calculates the canopy wetness, in this work the parameters ω (scattering coefficient), β (upscatter parameter for diffuse radiation) and β_o (upscatter parameter for direct radiation) are modified to include the radiative effects of canopy wetness, according to Equations 1 to 4:

$$\omega = \omega^{dry} \cdot (1 - f_{wet}) + \omega^{water} \cdot f_{water} + \omega^{snow} \cdot f_{snow} \quad (1)$$

$$\beta = \omega^{dry} \cdot \beta^{dry} (1 - f_{wet}) + \omega^{water} \cdot \beta^{water} \cdot f_{water} + \omega^{snow} \cdot \beta^{snow} \cdot f_{snow} / \omega \quad (2)$$

$$\beta_o = \omega^{dry} \cdot \beta_o^{dry} (1 - f_{wet}) + \omega^{water} \cdot \beta_o^{water} \cdot f_{water} + \omega^{snow} \cdot \beta_o^{snow} \cdot f_{snow} / \omega \quad (3)$$

$$\omega^{water} = \nu \cdot \omega^{dry} \quad (4)$$

where f_{wet} is the total wet (water and snow) fraction of the canopy ($f_{wet}= f_{water}+f_{snow}$), f_{water} is the fraction of the canopy wet by liquid water and f_{snow} is the fraction of the canopy wet by snow. The superscripts *dry, water* and *snow* denote dry, wet by water and wet by snow canopies, respectively. ν is the ratio of the scattering coefficients of the canopy surfaces wet by water and dry canopy surfaces, applied individually to leaves and stems.

4. Experiment Design

In this study, we conduct three simulations of the diurnal surface albedo for each of the three Amazon forest sites using the off-line IBIS version, as follows:

1) DF99: for reference to previous studies, this simulation uses the set of optical parameters used by Delire and Foley (1999);
2) DC_i, the dry-canopy (control) simulations: use the original code, without modifications to incorporate the effects of wetness on canopy reflectance. The subscript *i* may be equal to *M* for the Manaus-nearby sites (Ducke and Cueiras Reserves), or *J* for Jaru Reserve.
3) WC_i, the wet-canopy simulations: similar to DC_i, but including the modifications described in Equations (1) through (4).

The terms dry-canopy (DC) and wet-canopy (WC), when referring to versions of the IBIS code, denote only the status of the canopy during the radiative transfer calculations. It should be noted that both versions simulate the interception of water by the canopy, and the evaporation and dripping of the canopy-stored water. To calibrate the DC simulations, initially we do a sensitivity analysis of the simulated albedo to several canopy optical parameters. The most sensitive parameters are the upper and lower canopy leaf orientation ($\chi_{leaf\text{-}up}$ and $\chi_{leaf\text{-}lo}$, respectively), and upper and lower canopy visible and near-infrared (NIR) leaf reflectance (α^{Leaf}_{VIS-up}, α^{Leaf}_{VIS-lo}, α^{Leaf}_{NIR-up} and α^{Leaf}_{NIR-lo}, respectively).

5. Results and Discussion

Figure 1 shows the diurnal profile of the surface albedo for Cuieiras Reserve, for the three IBIS versions, for selected days of the year. To facilitate the interpretation, the days selected represent either no-rain days – charts on the left side (a, b, c) of the figures – or days with a single daytime rainfall event – right side (d, e, f) of the figures.

The DF99 simulations overestimate the surface albedo, particularly when zenith angle is high. The albedo simulated by the calibrated model (DC_M and DC_J) fit better to the observed data in days without precipitation occurrence (left side of Figures 1), but the DC version of the model does not represent the observed albedo drop during precipitation events (right side of Figures 1).

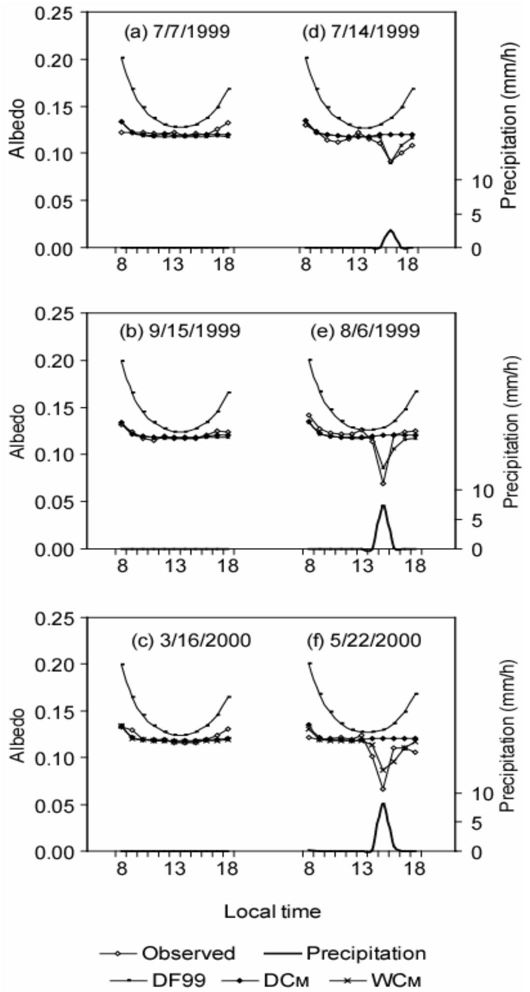

Fig. 2. Diurnal variation of the simulated and observed surface albedo in the Cuieiras Reserve for selected days.

WC simulations, however, show that the modified version of IBIS is able to reproduce the considerable decrease in surface albedo during precipitation hours (right side of Figure 1). This reduction in the surface albedo is consistent with an increase of the absorption of the incident solar radiation by the liquid water deposited on the leaves, increasing solar radiation absortance and reducing solar radiation reflectance, but also brings an improvement to the simulation of the entire period.

We also compare the model results at the monthly time scale for the three sites studied (Figure 2). In all cases, the WC albedo is smaller than the DC albedo, but the changes introduced do not substantially modify the simulated albedo. As seen in Figure 1, because of evaporation and dripping, the effect of canopy wetness on the surface albedo is restricted to the duration of a rainfall event plus one or two hours. Although Amazonia is one of the rainiest climates on Earth, the frequency of rainfall events (7.1% at Ducke, 14.2% at Cueiras, 17.0% at Jaru) is relatively low for a more significative effect of canopy wetness on albedo seasonality.

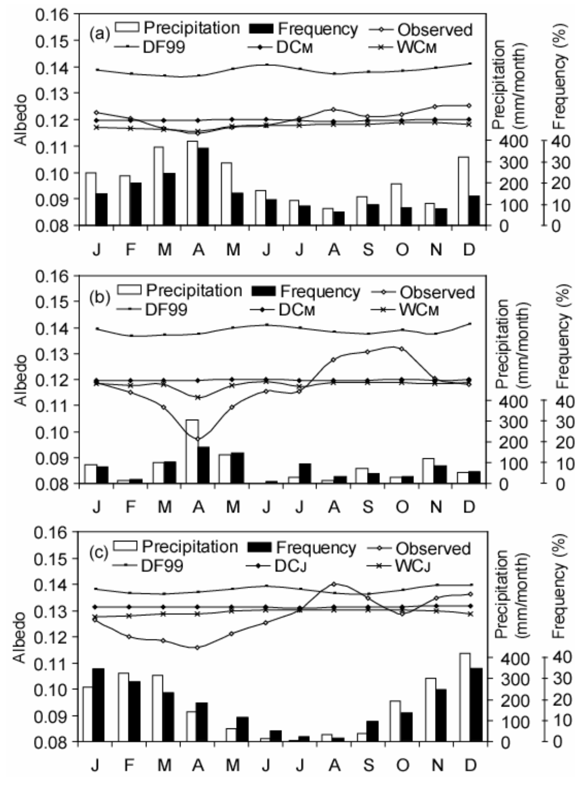

Fig. 5. Monthly profile of the observed and simulated surface albedo, monthly precipitation and frequency of rainfall events, at three Amazon rainforest sites: (a) Cuieiras Reserve, from June 1999 to September 2000, (b) Ducke Reserve, from January to December of 1995 and (c) Jaru Reserve, from January to December of 1993.

An exception is observed at the Ducke Reserve (Figure 2 b), where a more pronounced drop in the WC-simulated albedo is observed in April. Even in this extreme case, the simulated decrease in monthly albedo accounts for less than half of the observed change, which let us conclude that canopy wetness alone is not sufficient to represent correctly the seasonal variability of the albedo of a tropical rainforest.

6. Summary and Conclusions

The incorporation of canopy wetness on the radiative transfer calculations improves the simulation results at the hourly time scale, reproducing the observed decrease in surface albedo during precipitation hours, when the canopy is wet. Although the canopy wetness has an important effect, this effect is restricted to the times when the canopy is actually wet, a relatively short period of time at the monthly or longer time scales. Therefore, the changes introduced are not sufficient to substantially improve the representation of albedo seasonality.

While these results exclude the role of canopy wetness as a main source of seasonal variability of tropical rainforests albedo, this study narrows the choice of sources of albedo seasonal variation. Following the discussion of Culf et al. (1995) and Berbet and Costa (2003) on the subject, we recommend that future studies investigate the role of photoinhibition and leaf water potential on the seasonality of the tropical rainforest albedo. The clear definition of these roles, and their incorporation into climate models, will eventually allow us to do much more detailed studies of the climatic effects of tropical deforestation.

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