ASSESSMENT OF THE ENERGY BALANCE FOR THE FOREST AND “CAATINGA” SITES IN BRAZIL OBTAINED FROM SSIB AND IBIS MODELS

P 1.3

Ana Paula M. A. Cunha*, Regina C. dos Santos Alvalá, Vanessa Canavesi, Gilvan Sampaio
National Institute of Spatial Research, São José dos Campos, Brazil

1. INTRODUCTION

Land surface processes are among the most important components in a climate system. The state of land surface determines the energy and water balance at the interface of land and atmosphere to a great extent (Taylor, 2002; Oyama, 2002; Xue et al., 2004; Souza, 2006; Sampaio 2008). Changes in land surface properties, often associated with changing vegetation and soil characteristics, have dramatic effects on the climate simulated by general circulation models (GCMs). These changes in the surface characteristics may include modifications in surface albedo, the surface roughness, the leaf area index, the root depth, and the availability of soil moisture (Prentice et al, 1992).

Currently, there is a diversity of soil-vegetation-atmosphere schemes. The objectives of these models are mainly in the improvement of the bottom boundary condition of the atmospheric models by accurately evaluating the ground-surface impact on the atmosphere. The surface schemes range from those that simulate only the exchange of momentum, energy and water vapor between vegetated surface and atmosphere, as the "Simplified Simple Biosphere Model" – SSiB (Xue et al., 1991), even more sophisticated models, as, for example, the "Integrated Biosphere Simulator Model" – IBIS (Foley et a., 1996; Delire et al., 1999), which includes, in addition to processes listed above, the terrestrial carbon and nutrient cycling, and vegetation dynamics.

The SSiB is coupled to the global and regional meteorological models of the Brazilian Center for Weather Forecasting and Climate Studies/Brazilian National Institute for Space Research (CPTEC/INPE). It includes a complex treatment of the albedo, the energy balance of the surface, and the soil moisture. The SSiB Model parameters were calibrated for the Brazilian ecosystems rain forest (Correia et al, 2005) and caatinga (Cunha, 2007).

Recently, the IBIS-2.6 model of dynamical vegetation was also coupled to the GCM/CPTEC to make it able to diagnose the loss of biomass and its impact on storage of energy and water (Kubota and Bonatti, 2009). Previously, Imbuzeiro (2005) used micrometeorological measurements collected in four experimental sites of the LBA project to calibrate the IBIS-2.6 model.

In recent years, there have been a number of Land Surface Models (LSM) intercomparison projects on an international level. This type of intercomparison has increased the understanding of LSMs, and it has lead to many model improvements (Boone et al., 2009). To better understand the mechanisms controlling interactions and gain better simulations of energy balance, it is desirable to further examine the different parameterizations of vegetation and soil in different biosphere models.

To test the surface model´s performance, different simulations have been proposed. The goal of this work is evaluating the energy balance simulated by SSiB and IBIS models against two sets of measurements. This study focuses on the tropical rain forest and semi-arid in Brazil, those regions have a very sensitive climate system (Correia, 2005; Oyama, 2005; Souza, 2006; Sampaio, 2008).

---

* Instituto Nacional de Pesquisas Espaciais. *Av dos Astronautas, 1.758. Jd. Granja - CEP: 12227-010, São José dos Campos – SP, Brasil; e-mail:ana.paula@cptec.inpe.br*

2. DATA

2.1 Description of the sites

The proposed experiment was carried out at two different sites located within the semi-arid Northeast region of Brazil and the Amazonian forest (Fig. 1). The first site is situated at the Agricultural Research Center of the Semi-Arid Tropic – CPATSA, Petrolina, Pernambuco, Brazil. It represents an area of 600 ha of native caatinga, which presents a thorny vegetation with small leaves, with trees of approximately 4,5 m of height, pertaining to the Leguminosae family (mostly Mimosa tenuiflora), but with some trees with heights up to 8 m.

The *caatinga* is a type of vegetation adapted to the semi-arid conditions, with varied physiognomy, and covers the northeast portion of Brazil. It occupies an extension of about 800,000 km^2 that corresponds to 70% of the region. The micrometeorological and hydrological data were collected from July 2004 to June 2005. Measurements include sensible and latent fluxes. The soil of the experimental area is classified as argisol, which low water retention and poor fertility.

The rain forest site is located about 105 km North of Ji-Paraná, Rondonia (Reserva Biológica do Jaru). The Jaru forest is classified as a *Floresta Ombrófila Aberta* (palm-rich open tropical rain forest). At this site, a 60 m tall Micrometeorological Tower was installed for the measurement of the radiation balance, the turbulent fluxes of momentum, sensible and latent heat, the soil heat flux, the wind profile, and of the rainfall. The data were collected during 2001, as part of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia – LBA.

Table 1 presents the coordinates of the sites and the annual values of meteorological parameters.

Site	Longitude	Latitude	Elevation [m.a.s.l]	Precipitation [mm/year]	Temperature [ºC]
Petrolina - Caatinga	40º19’45,1”W	9º03’30,6”S	350	298,7	26,2
Reserva Biológica de Jaru – Rain forest	62º22’W;	10º45’S	120	2512,48	25,12

Table 1: The principal description of the sites

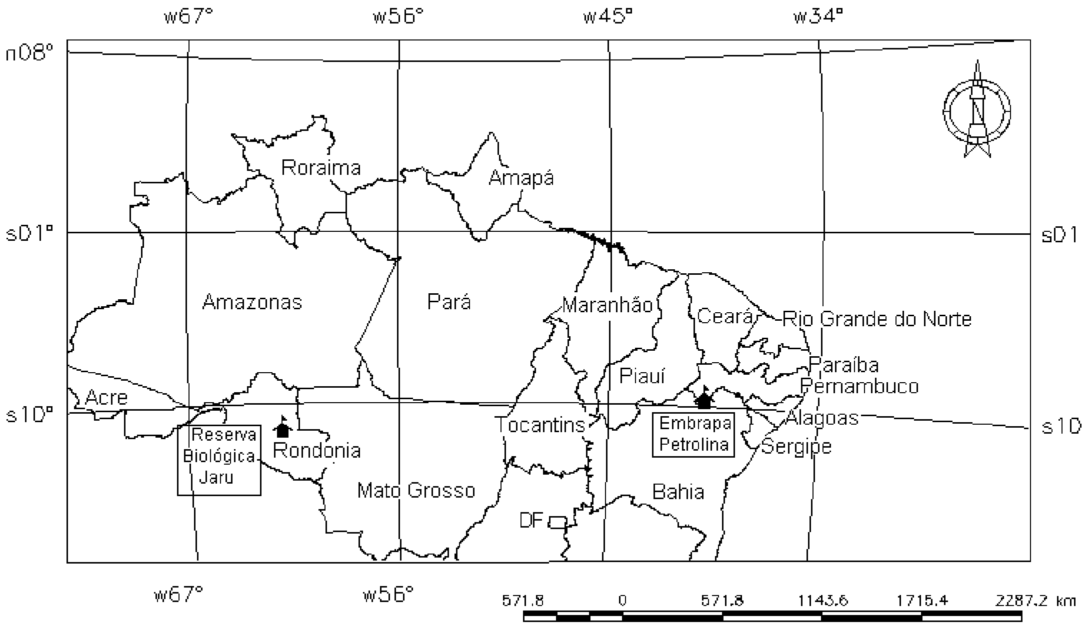

Figure 1: The location of the observation towers sites in Brazil

3. Land Surface Models

The experiments in this study were conducted to evaluate the energy balance simulated by SSiB and IBIS models. The SSiB model used is a simplified version of the Simple Biosphere Model – SiB (Sellers et al., 1986), which is a biophysically based model of land-atmosphere interactions and is designed for global and regional studies. The SSiB is more complex than other schemes of surface in the treatment of the albedo, the energy surface and soil moisture. It describes the surface in terms of one vegetation layer (reduced from two in SiB) and three soil layers. The water stored by the soil may be evaporated by bare soil or transpired through the canopy. The total amount of water and energy entering and leaving the system will always remain balanced (Kahan et al., 2006). Three aerodynamic resistances are introduced to control the heat and water fluxes between the canopy layer air space and canopy leaves, soil surface, and the reference PBL height. These resistances are obtained as a function of the morphology of vegetation, soil type, wind speed and corresponding potential difference of temperature. The surface albedo has diurnal variations based on the change of net solar radiation in the canopy layer due to vegetation properties (Ma et al., 2010). The interception, reflection, transmission and absorption of radiation by the canopy and ground are handled by the “two stream method” in SSiB (Misra et al., 2001). The parameters of the SSiB were validated and subsequently calibrated for the Reserva Biológica do Jaru forest site (Correia, 2005) and monthly calibrated for the Brazilian Northeast Caatinga (Cunha, 2007).

The global terrestrial biosphere model IBIS (version 2.6) is a comprehensive model of terrestrial biospheric processes, representing two vegetation layers (i.e., trees and short vegetation) and six-layer soils. The IBIS model represents the physical, physiological, and ecological processes occurring in vegetation and soils. The land surface processes, plant phenology, and vegetation dynamics are simulated. IBIS simulates the exchange of both solar and infrared radiation between the atmosphere, the vegetation canopies, and the surface. Solar radiation transfer is simulated following the two-stream approximation, with separate calculations for direct and diffuse radiation in both visible and near-infrared wavelengths (Kucharic et al., 2000). Micrometeorological measurements collected in four experimental sites of the LBA project (Flona do Tapajós km 83 and km 67, Reserva do Cuieiras (km34) and Rebio Jaru) were used to calibrate the IBIS model (Imbuzeiro, 2005).

In IBIS, a grid cell can contain one or more plant functional types (PFTs) that compose a vegetation type (Foley et al., 1996; Kucharik et al., 2000; Costa et a., 2007). Although IBIS also includes a dynamic vegetation component, in this study it is disabled, so vegetation land cover is fixed.

4. Experiments

In this study, off-line tests are conducted, meaning that the SSiB and IBIS models are not linked to any GCM or regional model—the prescribed atmospheric conditions are already determined for each time step of the models run. These variables, known as forcings, are obtained from field measurements from CPATSA/Petrolina caatinga site and the Reserva Biológica do Jaru forest site and are used to drive the models. The forcings include measures of incident radiation, air temperature, specific and relative humidity of air, wind speed, air pressure and precipitation. The same forcings were used in all runs to caatinga and rain forest in both models.

In the SSiB run for caatinga were employed parameters for standard type-8 vegetation, shrubs with ground-cover (Dorman and Sellers, 1989), as well as in IBIS run were employed parameters for open scrubland vegetation type, which are normally used in GCMs for the caatinga of Northeast of Brazil. Both models were run for one year.

5. Results

The results of the energy balance simulated by both models and for each vegetation type were compared. Figure 2 shows the comparison of latent heat flux (LH) and sensible heat flux (SH) between observations in the caatinga region and the calculated value from both SSiB and IBIS models. The points come from the one year simulations (from July 2004 to June 2005). It is observed that in both models the sensible heat flux is better simulated than the latent heat flux, as well as the correlations coefficients are higher in simulations with the SSiB. The latent heat flux was overestimated by the SSiB model for caatinga.

In the rain forest runs, the points also came from the one year simulations, however there are fewer points due to many gaps in data observed. Even in simulations for the forest, the correlation higher than the one obtained for the IBIS (Figure 3).

The results showed that the latent heat flux was overestimated by SSiB for both seasons (dry season - JAS and wet season – JFM) for caatinga (Figure 4). The calculated sensible heat flux by both models was agreed fairly well with observations. The root-mean-square (RMS) error for both IBIS and SSiB are 28,74 Wm^{-2} and 17,14 Wm^{-2} (Table 2), respectively.

Figure 5 shows the comparison between SSiB and IBIS for rain forest. In wet season (JFM) the results are very close to latent heat flux for both models. While both fluxes are close to observations during the night hours, most of the inconsistency occurs during the day, when net radiation (not shown) is greatest.

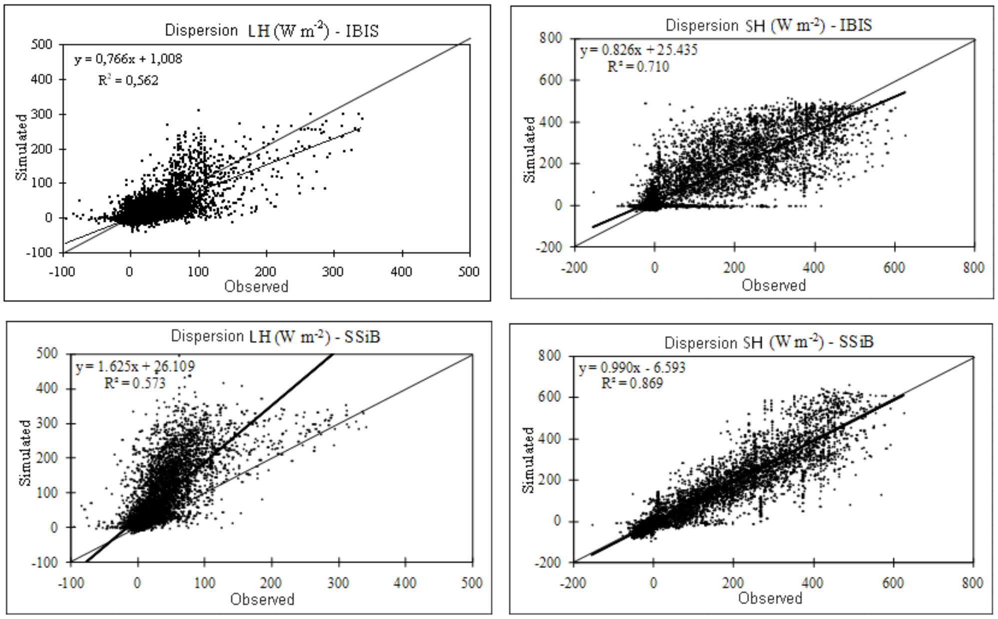

Figure 2: Comparison of latent heat flux (LH) and sensible heat flux (SH) between observations in the caatinga region and the simulated value from SSiB and IBIS

The Table 2 summarizes the simulated averages for rain forest and caatinga runs in comparison to observations and the corresponding RMSE, based on daily averages. The values of RMS error infers that the values of latent heat flux from IBIS for the caatinga site was better, whereas the values of sensible heat flux from SSiB was better. For the rain forest site, the values of latent heat flux from SSiB were better, and for sensible heat flux the best simulation is not clearly defined. It is highlighted that the simulations with the SSiB model were made considering the parameters previously calibrated for both rain forest and caatinga sites.

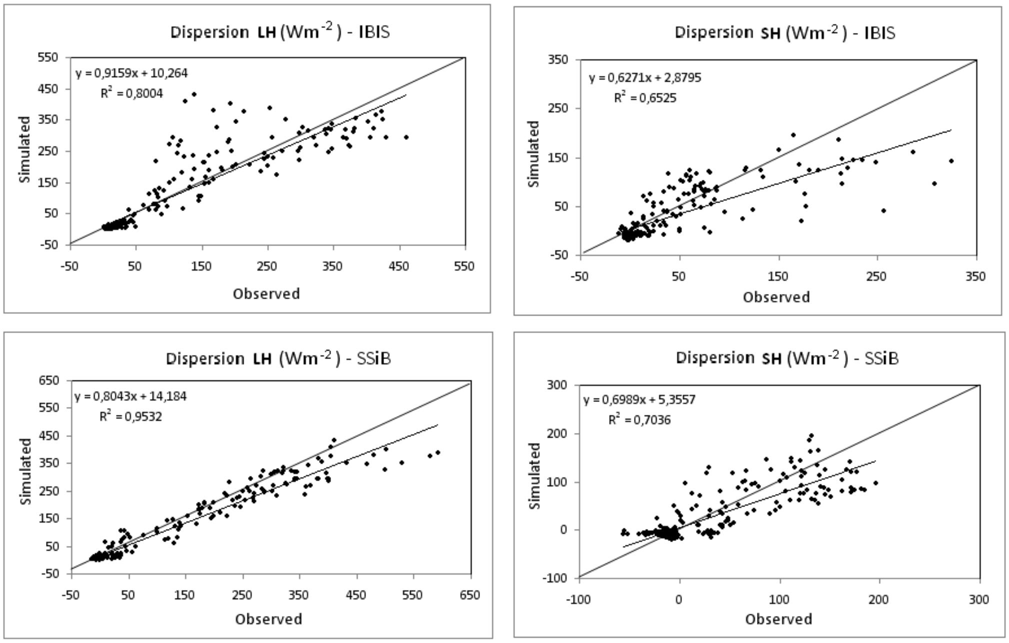

Figure 3: Comparison of latent heat flux (LH) and sensible heat flux (SH) between observations in the rain forest region and the simulated value from SSiB and IBIS

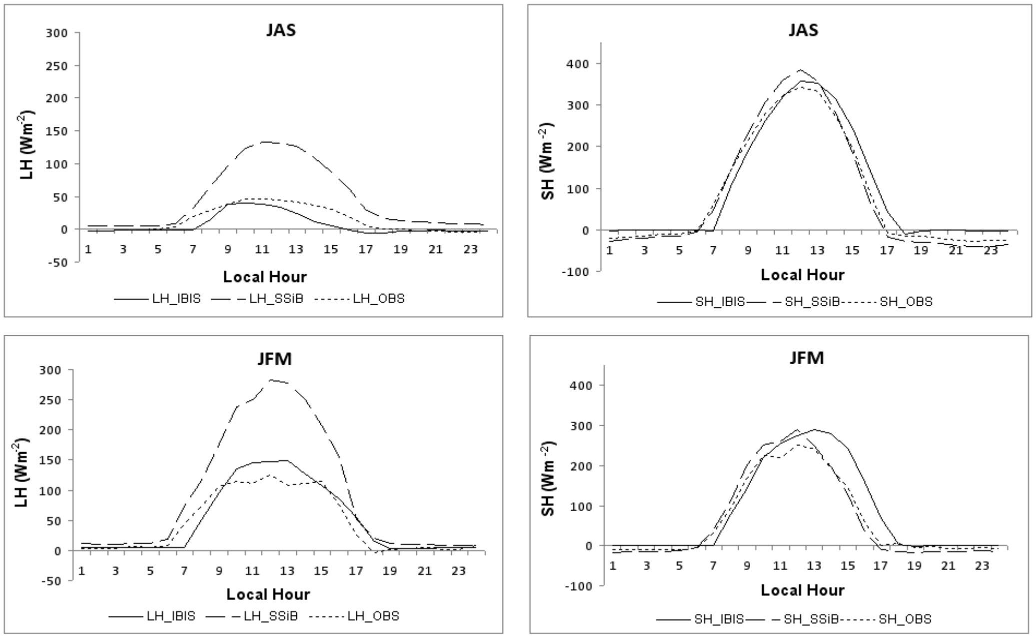

Figure 4: Diurnal cycle of the observed and simulated latent heat and sensible heat fluxes by SSiB and IBIS models – Caatinga. The forcing data are from July to September 2004 (JAS – dry season) and from January to March 2005 (JFM – wet season). Solid: IBIS, dashed: SSiB and dotted: observed

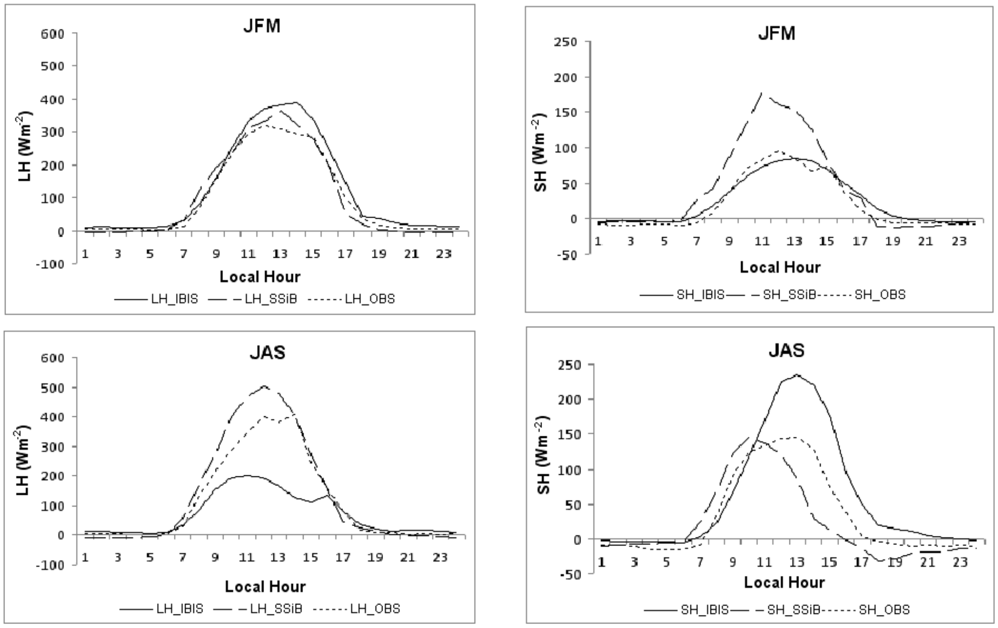

Figure 5: Diurnal cycle of the observed and simulated latent heat and sensible heat fluxes by SSiB and IBIS models – Caatinga. The forcing data are from January to March 2001 (JFM – wet season) and from July to September 2001 (JAS – dry season). Solid: IBIS, dashed: SSiB and dotted: observe.

Site	Months		LH (Wm^{-2})	SH (Wm^{-2})	RMS error LH ($W\ m^{-2}$)	RMS error SH ($W\ m^{-2}$)
Caatinga	JAS	measured	13.86	84.07	-	-
		IBIS	6.84	95.62	11.12	28.74
		SSiB	45.86	83.16	43.49	17.14
	JFM	measured	44.08	64.29	-	-
		IBIS	48.92	84.03	17.63	39.83
		SSiB	92.96	65.35	74.06	17.42
Rain Forest	JFM	measured	99.35	19.54	-	-
		IBIS	123.04	23.94	34.11	9.26
		SSiB	100.88	40.24	22.92	35.84
	JAS	measured	115.27	32.29	-	-
		IBIS	69.54	58.69	96.17	42.68
		SSiB	132.81	22.59	48.95	32.43

Table 2: Average values of measured fluxes compared with the ones simulated from IBIS AND SSiB models. Observed and simulated averages from IBIS and SSiB models.
LH, latent heat flux; SH, sensible heat flux; RMS, root-mean-square.

6. Conclusion

To better understand the global climate processes and their effects on the biosphere, it is necessary to have a good knowledge of the partitioning of available energy between latent heat and sensible heat fluxes at the land surface. Such knowledge is essential to develop reliable tools for the study of both short-term and long-term ecosystem processes, and how these processes feedback and affect the climate system.

Thus, a series of numerical experiments was designed to understand the physics at the soil/vegetation-atmosphere interface to evaluate the performance of two different biophysical models to simulate the energy balance at the surface. Two observational data sets, CPATSA – caatinga and Reserva Biológica de Jaru – Rain Forest of Brazil, were used to to evaluate the results.

For caatinga site, both models had similar performance. The latent heat flux was better simulated by IBIS model and sensible heat flux was better simulated by SSiB. For the forest site, SSiB had a better performance for both fluxes. However, the turbulent flux measurements at the rain forest site had many gaps. Thus, few data was used in this study to evaluate the performance of both models.

Usually, the calibrated set of vegetation parameters produces better simulations of the energy balance. However, even in the simulations that has been considered using calibrated parameters for the caatinga, the SSiB still overestimating the latent heat flux. This may be related to possible limitations in the algorithm used for the calibration process or related to possible errors in the observed data. The simulated latent heat flux was best for the forest. Concerning tothe IBIS model, it was not calibrated for the caatinga, so it is expected that with the calibrated parameters the model can better represent the partition of energy at the surface for this vegetation type. Thus, these results are preliminary and other analyses are still necessary to better understand the biophysical processes involved.

Finally, better parametrization of surface conditions in these areas should help improve the reliability of GCM experiments.

7. References

Boone, A. and P. deRosnay, 2007: Towards the improved understanding of land-surface processes and coupling with the atmosphere over West Africa. iLEAPS Newletter, 3, 33-34.

Correia, F. W. S. Modelagem do impacto de modificações da cobertura vegetal Amazônica no clima regional. 421p. (INPE-14094-TD/1077). Tese (Doutorado em meteorologia) – Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, 2005.

Costa, M. H., S. N. M. Yanagi, P. J. O. P. Souza, A. Ribeiro, and E. J. P. Rocha (2007), Climate change in Amazonia caused by soybean cropland expansion, as compared to caused by pastureland expansion, Geophys. Res. Lett., 34, L07706, doi:10.1029/2007GL029271.

Cunha, A. P. M. A. Calibração do "Simplified Simple Biosphere Model – SSiB" para o bioma caatinga do Nordeste Brasileiro.135p. Dissertação (Mestrado em Meteorologia) – INPE, São José dos Campos, 2007.

Delire, C., & Foley, J.A., Evaluating the performance of a land surface / ecosystem model with biophysical measurements from contrasting environments. J. Geophys. Res., 104, 16.895-16.909, 1999.

Dorman, J. L.; Sellers, P., 1989: A global climatology of albedo, roughness length and stomatal resistence for atmospheric general circulation models as represented by the Simple Biosphere Model (SiB). Journal of Applied Meteorology, v.28, p.833-855.

Foley, J. A.; Prentice, I. C.; Ramankutty, N.; Levis, S.; Pollard, D.; Sitch, S.; Haxeltine, A, 1996: An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. Global Biogeochemical Cycles, v. 10, n. 4, 603–628.

Imbuzeiro, H. M. A. Calibração do modelo IBIS na floresta amazônica usando múltiplos sítios. 93 p. Dissertação (Mestrado em Agronomia) - Universidade Federal de Viçosa, 2005.

Kahan, D.; Xue, Y.; Allen, S., 2006: The impact of vegetation/soil parameters in simulations of surface energy and water balance in the semi-arid Sahel area: a case study using SEBEX and HAPEX-Sahel data. Jounal of Hydrology, v. 320, n. 1-2, p. 238-259.

kubota, P. Y.; Bonatti, J. P. Conseqüência do Acoplamento do Esquema de Vegetação Dinâmica IBIS ao MCGA-CPTEC: Aspectos Climatológicos de Precipitação e da Dinâmica de Carbono. In: III Simpósio Internacional de Climatologia (SIC), Canela. In Anais do III , 2009.

Kucharik, C. J., and Coauthors, 2000: Testing the performance of a dynamic global ecosystem model: Water balance, carbon balance, and vegetation structure. Global Biogeochem. Cycles, 14, 795–825.

Ma, H. Y.; Mechoso, C. R.; Xue, Y.; Xiao, H.; Wu, C. M.; Li, J. L.; Sales, F., 2010: Impact of land surface processes on the South American warm season climate. Clim. Dyn. Published onine: 22 April 2010. doi: 10.1007/s00382-010-0813-3.

Misra, V., P. A. Dirmeyer, and B. Kirtman,, 2001: The implementation of Simplified Simple Biosphere (SSiB) scheme in the Regional Spectral Model (RSM), COLA Tech. Rep. 95, Cent. for Ocean-Land-Atmos. Gen. Circ. (COLA), Calverton, Md., 29 pp.

Sampaio, G. Conseqüências climáticas da substituição gradual da floresta tropical amazônica por pastagem degradada ou por plantação de soja: um estudo de modelagem. 2008. 417 p. (INPE-15263-TDI/1346). Tese (Doutorado em Meteorologia) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos. 2008.

Oyama, M.D., 2002. Conseqüências climáticas da mudança de vegetação no nordeste brasileiro: um estudo de modelagem. Tese de doutorado em Meteorologia. Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 181p.

Oyama, M. D. Conseqüências Climáticas da Desertificação Total do Nordeste Brasileiro: Avaliação Preliminar com o Uso do Modelo Regional MM5. In: Simpósio Internacional de Climatologia, 2005, Fortaleza. Anais do Simpósio Internacional de Climatologia, 2005.

Prentice, I. C.; Cramer, W.; Harrison, S. P.; Leemans, R.; Monserud, R. A.; Solomon, A. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography, v. 19, n. 2, p. 117-134, 1992.

Sellers, P.J., Mintz, Y., Sud, Y.C., Dalcher, A., 1986. A simple biosphere model (SiB) for use with general circulation models. J. Atmos. Sci. 43, 505–530.

Souza, S. S. Impactos climáticos regionais da mudança de vegetação no semi-árido do Nordeste brasileiro. 209 p. (INPE-14432-TDI/1131). Tese (Doutorado em Meteorologia). Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, 2006.

Taylor, C.M., E.F. Lambin, N. Stephenne, R.J. Harding, and R.L.H. Essery, 2002: The Influence of Land Use Change on Climate in the Sahel. J. Climate, 15, 3615–3629.

Xue, Y., Sellers, P.J., Kinter III., J.L., Shukla, J., et al., 1991. A simplified biosphere model for global climate studies. J. Climate 4, 345–364.

Xue, Y.; H.-M. H. Juang, W.-P. LI, S. Prince, R. Defries, Y. Jiao, and R. Vasic, 2004: Role of land surface processes in monsoon development: East Asia and West Africa. J. Geophys. Res., 109, D03105, doi:10.1029/2003JD003556.