Challenges of a Coupled Climate-Biosphere Model to Reproduce Vegetation Dynamics in Amazonia

Mônica Carneiro Alves Senna[1], Marcos Heil Costa[1]

[1]Department of Agricultural Engineering, Federal University of Viçosa, Av. P. H. Rolfs, s/n, Viçosa – MG, 36570-000, Brazil, monica@vicosa.ufv.br

INTRODUCTION

Vegetation and climate interact through several complex feedbacks. The global pattern of vegetative land cover is governed by climate through precipitation, temperature, solar radiation and CO_2 concentration. Changes in climate alter competitive relationships among species, and thus alter the structure and biogeography of ecosystems. On the other hand, terrestrial ecosystems affect climate through exchanges of energy, water, momentum, CO_2, and other atmospheric gases. Changes in community composition and ecosystem structure alter these fluxes and consequently, alter climate. The interactive coupling of climate and terrestrial ecosystems has been examined with fully integrated dynamic global vegetation models.

Here we investigate how well a fully coupled atmosphere-biosphere model, CCM3-IBIS, can reproduce vegetation dynamics in Amazonia. The simulated vegetation dynamics depends strongly on the simulated climate. So, we focus on precipitation (P) and incident solar radiation (S_{in}) because they are the most important climate variables for Amazon vegetation. The vegetation dynamics variables analyzed are land cover, net primary production (NPP), leaf area index (LAI), and above ground live biomass (AGLB).

METHODS

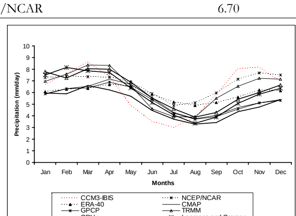
In this study we use the coupled climate-biosphere model CCM3-IBIS. CCM3 operates at a spectral resolution of T42, 18 vertical levels, and a 20-min time step. The oceans are represented by monthly averaged fixed sea-surface temperatures that serve as boundary conditions for the atmosphere. IBIS simulates land surface processes, plant phenology and vegetation dynamics, and represents vegetation as two layers (trees and grasses). Land surface physics and canopy physiology are calculated with the time step used by CCM3. The plant phenology algorithm has a daily time step and the vegetation dynamics is solved with an annual time step. It operates on the same T42 spatial grid as the CCM3, and with dynamic vegetation component enabled, so vegetation structure and biogeography change in response to climate. We have updated the rainforest representation in IBIS with new calibration against flux data from four different Amazonia flux tower sites, using data from the Large-Scale Biosphere Experiment in Amazonia (LBA). We conduct an experiment with three ensembles for a period of 30 years; the last 20 years are averaged to analyze the results. The first 10 years are left for the model to approach an equilibrium state, specifically with respect to soil moisture.

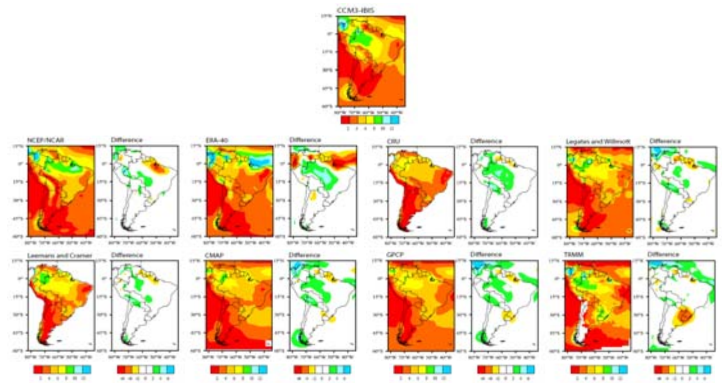
Two climate variables and four vegetation dynamics variables are compared to observations. Precipitation is compared to eight databases: NCEP/NCAR and ERA-40 reanalysis, CRU, Legates and Willmott (1990), Leemans and Cramer (1990), CMAP (CPC Merged Analysis of Precipitation), GPCP (Global Precipitation Climatology Project), and TRMM (Tropical Rainfall Measuring Mission). Incident solar radiation is compared with GOES algorithm GL1.2. Land cover is compared with potential vegetation dataset from SAGE-UW (Center for Sustainability and the Global Environment – University of Wisconsin). NPP and LAI are compared with in situ measurements done by LBA researchers in several Amazon sites. AGLB is compared with the recent map by Saatchi et al. (2007).

RESULTS

Precipitation

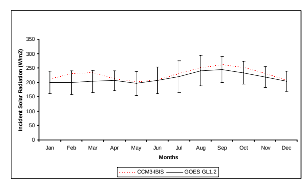
Precipitation products	Annual mean P over the rainforest area (mm/day)	Difference
CRU	4.98	24.5%
GPCP	5.36	15.7%
CMAP	5.45	13.8%
ERA-40	5.91	4.9%
Leemans and Cramer (1990)	5.95	4.2%
CCM3-IBIS	**6.20**	
Legates and Willmott (1990)	6.20	0.0%
TRMM	6.39	-3.0%
NCEP/NCAR	6.70	-7.5%

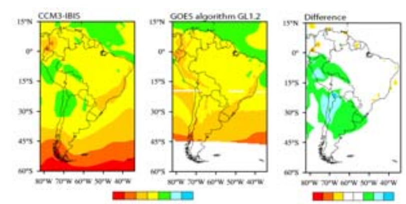




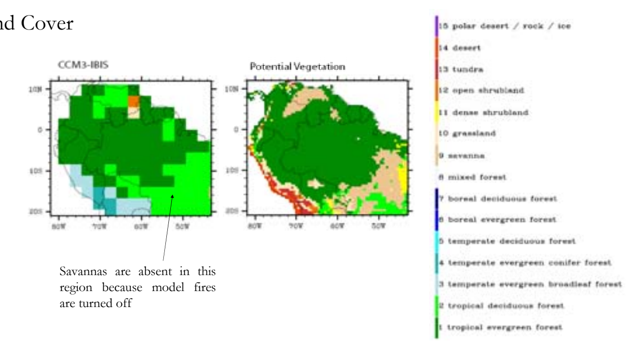
Incident Solar Radiation

Over the tropical rainforest area:
Simulated: 227.1 W/m² (CCM3-IBIS)
Observed: 214.5 W/m² (GOES GL1.2)





Land Cover



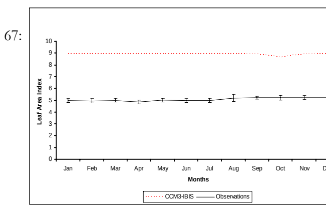
Net Primary Production

Site	Observed total NPP (kg m⁻² y⁻¹)	Simulated total NPP (kg m⁻² y⁻¹)	Difference	Observed above ground NPP (kg m⁻² y⁻¹)	Simulated above ground NPP (kg m⁻² y⁻¹)	Difference
Manaus	0.98	1.12	14.3%	0.70	0.89	27.1%
Caxiuanã	1.12	0.85	-24.1%	0.83	0.68	-18.1%
Tapajós	1.45	1.04	-28.3%	1.15	0.83	-27.8%
Mean	1.18	1.00	-15.3%	0.89	0.80	-10.1%

Observed total NPP and above ground NPP from Malhi et al. (submitted)

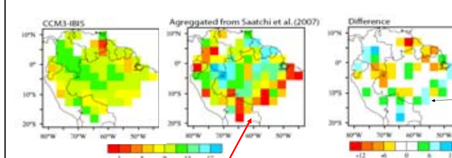
Leaf Area Index

Santarém, km 67:

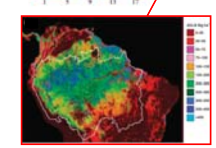


Observed LAI from Costa et al. (unpublished data)

Above Ground Live Biomass



Large positive errors occur on deforested land



Saatchi et al. (2007)

Correlation of Errors

	Error biomass
Error S_{in} (GOES)	-0.03
Error P (Leemans & Cramer 1990)	0.14
Error P (Legates & Willmott 1990)	0.18
Error P (TRMM)	0.23

CONCLUSIONS

The accurate representation of the coupled climate-biosphere dynamics require the accurate representation of climate (in particular P and S_{in}), NPP, and its partition among the several carbon pool components. The Amazon climate (annual mean and seasonality) is extremely well simulated for both P and S_{in}. CCM3-IBIS is successful in reproducing tropical evergreen forest in the Amazon. However, it reproduces the tropical deciduous forest biome in regions where there is savanna in potential vegetation map. This is because savannas depend on disturbances like fire or extreme weather events, neither of which are represented in the model. Simulated NPP averaged over three sites is underestimated by 15%, although NPP errors calculated at individual sites can be as high as 30% for Tapajós site. There is a conjecture that the Tapajós site has experienced recent major disturbance, leading to significantly higher values of NPP. This is not taken into account in the model. Simulated values of LAI are much greater than observed ones; this overestimation is probably due to incorrect allocation of carbon in the ecosystem carbon pools. The AGLB simulated has large differences in comparison with the AGLB map of Saatchi et al. (2007). The correlation of errors shows that errors in simulated biomass are not climate driven, so we must improve the allocation coefficients and the resident times of each carbon pool. Obtain correct values of allocation coefficients and resident times is quite a challenge as these values may vary spatially. The model considers the same value for the entire biome. Future research testing different values of these parameters are needed.