JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. D20, 8086, doi:10.1029/2002JD002704, 2002

The Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA): Insights and future research needs

Roni Avissar
Department of Civil and Environmental Engineering, Duke University, Durham, North Carolina, USA

Pedro L. Silva Dias and Maria A. F. Silva Dias
Department of Atmospheric Sciences, University of Sao Paulo, Sao Paulo, Brazil

Carlos Nobre
Instituto Nacional de Pesquisas Espaciais, Brazil

Received 26 June 2002; revised 1 July 2002; accepted 2 July 2002; published 23 October 2002.

[1] This overview summarizes general Large-Scale Atmosphere-Biosphere Experiment in Amazonia (LBA) papers and highlights some of the insights gained from these investigations and needs for future research. It complements the overview of *Silva Dias et al.* [2002a], which summarizes the papers published on the joint major atmospheric mesoscale campaign in the wet season (WetAMC), which was held jointly in Rondonia with the Tropical Rainfall Measuring Mission (TRMM) validation campaign known as TRMM-LBA. It also complements the overview of *Andreae et al.* [2002], which summarizes the papers describing the biogeochemical cycling of carbon, water, energy, aerosols, and trace gases resulting from the European Studies on Trace Gases and Atmospheric Chemistry, known as LBA-EUSTACH Project. The 17 papers summarized under this part of the special issue are regrouped into three main categories: (1) measurements and data sets, (2) remote sensing, and (3) modeling. *INDEX TERMS:* 1640 Global Change: Remote sensing; 1833 Hydrology: Hydroclimatology; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; *KEYWORDS:* hydrometeorology, tropical deforestation, teleconnection from the Amazon, remote sensing for the Amazon, modeling of the Amazon

Citation: Avissar, R., P. L. Silva Dias, M. A. F. Silva Dias, and C. A. Nobre, The Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA): Insights and future research needs, *J. Geophys. Res.*, *107*(D20), 8086, doi:10.1029/2002JD002704, 2002.

1. Introduction

[2] As explained by *Avissar and Nobre* [2002], the Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an ongoing international research initiative led by Brazil, which was initiated in the mid nineties. It was designed to create the new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land-use change on these functions, and the interactions between Amazonia and the Earth system. LBA is centered around two major key questions that are being addressed through multidisciplinary research, integrating studies in the physical, chemical, biological, and human sciences. First, how does Amazonia currently function as a regional entity? Second, how will changes in land use and climate affect the biological, chemical and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate?

[3] In LBA emphasis is given to observations and analysis that improve the knowledge base for Amazonia in six general areas: physical climate, carbon storage and exchange, biogeochemistry, atmospheric chemistry, hydrology, and land use/land cover. The program is designed to address major issues raised by the Climate Convention. It helps provide the basis for sustainable land use in Amazonia, using data and analysis to define the present state of the system and its response to observed perturbations, complemented by modeling to provide insights into possible changes in the future.

[4] This special issue reports on some of the research being undertaken as part of the various components of LBA. In particular, *Silva Dias et al.* [2002a] summarize the papers resulting from the first major atmospheric mesoscale campaign in the wet season (WetAMC), which was held jointly in Rondonia with the Tropical Rainfall Measuring Mission (TRMM) validation campaign known as TRMM-LBA. Preliminary analysis of these results indicate a picture of an intrinsically coupled rain producing system where different surface and atmosphere processes interact at different space and timescales, from local to large scale, and from a few hours to several days, respectively.

0148-0227/02/2002JD002704$09.00

[5] A series of papers describing the biogeochemical cycling of carbon, water, energy, aerosols, and trace gases resulting from the European Studies on Trace gases and Atmospheric Chemistry, known as LBA-EUSTACH project, is also reported in this issue. *Andreae et al.* [2002] synthesize these papers and reflect on what has been learned from this project, and the needs for future research. In general, they emphasize that the LBA-EUSTACH project has shed new light on the way soils, biota, and the atmosphere interact in the Amazon system. Linkages and interactions between the different parts of the system were found at all scales, ranging from processes in the interior of soils and plants through the canopy scale to the effects of the Amazon on the global atmosphere and climate.

[6] Here we summarize the other articles included in this special issue on LBA and we highlight some of the insights gained from these investigations and needs for future research. These papers result mostly from the studies carried out under the hydrometeorological, ecological, and land-use components of the LBA project.

2. Summary of Results

[7] The papers summarized under this part of the special issue can be regrouped into three main categories: (1) measurements and data sets, (2) remote sensing, and (3) modeling. Clearly, some of the papers include components of these three categories. We included them in the category that we felt they fit best.

2.1. Measurements and Data Sets

[8] *Costa et al.* [2002] present a data set of large-scale hydrological river flow routing parameters for the Amazon and Tocantins basins. This data set contains data on river network at 5 min resolution, time series of monthly means of river discharge and river stage throughout the basins, sinuosity of each of the main rivers, and depth of the water table and transmissivity of the aquifer. This type of data set is particularly useful for macrohydrological routing models such as HYDRA, which is used in other studies presented in this special issue.

[9] *Bustamante et al.* [2002] used closed chamber techniques to measure soil fluxes of NO, N_2O and CO_2 in savanna areas of the Cerrado subjected to prescribed fires. They find that soil moisture and vegetation type are more important in controlling NO and CO_2 fluxes than fire regime, and that the N_2O fluxes were below detection limit in any of the vegetation-fire treatments. In a companion study, *Kisselle et al.* [2002] used transparent and opaque static chambers to measure the flux of CO at the same sites. They find that fire increased soil surface CO emissions significantly. Measurements made 30 days after the fire showed daytime CO production over 10 times higher than that of the unburned savanna. They also find a higher emission in the transparent chambers, emphasizing that the fire created both photochemically and thermally reactive precursors.

[10] To investigate the potential impact of drought on the ecosystem of the Amazon, *Nepstad et al.* [2002] established an exclusion experiment in the Tapajos National Forest. As a result of the soil-water reduction during the first two years of the experiment, they found that aboveground net primary productivity decreased and both soil emission of N_2O and consumption of CH_4 increased.

[11] *Townsend et al.* [2002] investigated how conversion of forest to cattle pasture affects soil phosphorus (P) fractions along pasture chronosequences in central Brazilian Amazon and southwestern Costa Rica. In the Brazilian sites, significant losses in total soil P and soil organic carbon (SOC) were seen with pasture age on already P-deficient Oxisol and Entisol soils. However, P losses were from inorganic soil P fractions, while organic forms of soil P remained constant or increased with pasture age, despite the decline in SOC. In Costa Rica, SOC remained constant across the Oxisol sites and increased from forest to pasture on the Mollisols, while soil organic P increased with pasture age in both sequences.

2.2. Remote Sensing Studies

[12] The spatial and temporal extent of inundation in the Amazon basin is a key information for many of the hydrometeorological, biogeochemical and ecological studies conducted in the Amazon. Among others, this information can be used to estimate the emission of methane (an important greenhouse gas) from wetland. Using the 37-GHz polarization difference observed by the Scanning Multichannel Microwave Radiometer on board the Nimbus-7 satellite, *Hamilton et al.* [2002] derived the inundation patterns in the large floodplains of South America. Using predictive relationships between flooded area and water levels in the nearby rivers, they were able to extend the inundation record for periods varying between decades and up to a century depending on the floodplain.

[13] Using radar altimetry from the TOPEX/POSEIDON satellite, *Birkett et al.* [2002] monitored the variations in surface height (stage) for large wetlands, rivers, and associated floodplains. This method is particularly useful in regions where traditional gauges are absent. They find that water levels in the Solimoes and Amazon are particularly well defined with this method.

[14] *Roberts et al.* [2002] used Landsat scenes and a multistage process to map primary forest, pasture, second growth, urban, rock/savanna, and water in central Rondonia. This technique helps provide a status of land use which is useful for various ecological and hydrometeorological studies.

[15] *Hagen et al.* [2002] try to reconstruct time series of nonforested area in Rondonia by combining coarse and fine spatial resolution remote sensing data obtained from the Landsat Thematic Mapper and AVHRR GAC reflectance data. This technique allows them to detect interannual changes in more details than would be possible otherwise. They find considerable interannual change in the variability and trends of fractional cover within individual pixels during the period 1989/1998.

2.3. Modeling

[16] *Coe et al.* [2002] used ecosystem and hydrological models in conjunction with long time series climate data to simulate the river discharge and flooded area of the Amazon/Tocantins River Basin over the last 60 years. They find that short (3–4 years) and long (28 years) modes of precipitation variability drive spatial and temporal variability in river discharge and flooded area throughout the basin.

[17] *Misra et al.* [2002a] evaluated the performance of the Regional Spectral Model (RSM) developed at the U.S. National Center for Environmental Prediction in simulating the interannual variability of precipitation over the Amazon River Basin, the Intertropical Convergence Zone, the Pacific and Atlantic ocean basins, and extratropical South America and find that the model compare reasonably well with observations. As part of this study, they find that the moisture flux convergence determines most of the interannual variability of precipitation over the Amazon Basin, the Atlantic InterTropical Convergence Zone, and the Nordeste region of Brazil. They also find that both surface evaporation and surface moisture flux convergence are critical in determining the interannual variability of precipitation over the southern Pampas, Gran Chaco area and the South Atlantic Convergence Zone.

[18] In another study, *Misra et al.* [2002b] evaluated the impact of two different land surface schemes in the RSM on the Amazonian hydroclimate. One of the schemes is considered to be simple (it consists of two soil layers and a uniform vegetation fraction) and the other is the "Simplified Simple Biosphere" (SSiB) scheme, which in spite of its name simulates explicitly more processes and is considered to be more complicated than the above mentioned simple model. Interestingly, the performance of the RSM coupled with the more sophisticated scheme does not result in superior predictions. In a comparable study, *Chou et al.* [2002] evaluated the performance of the Eta model coupled with the SSiB scheme over South America. They also make a comparison of their results with those obtained with the Eta model coupled with a simpler scheme, namely the "bucket" model. They concluded that the SSiB scheme improves the performance of the Eta model in simulating the continental precipitation and surface temperature during the wet season.

[19] *Franchito et al.* [2002] used various data sets collected during LBA to evaluate the infrared and solar radiation scheme developed by *Chou and Suarez* [1994]. This scheme includes the combined effects of absorption and scattering due to the major gases (water vapor, CO_2 and O_3), most of the minor trace gases (NO_2, CH_4 and CFCs) and clouds and aerosols. It proved to perform well over both forest and grassland.

[20] *Baidya Roy and Avissar* [2002] investigated the impact of deforestation at the microscale and the mesoscale on the formation of convective clouds during the dry season. Using simulations produced with the Regional Atmospheric Modeling System (RAMS) supported with satellite images, they find that deforested areas (pasture) trigger cloud formation. They also emphasize that synoptic flow advects the clouds away from their original location but does not eliminate them. In a follow-up study, *Weaver et al.* [2002] investigated the various parameters, in addition to land-surface characteristics, that affect the development of mesoscale circulation generating clouds as a result of landscape heterogeneity. They find that model configuration (e.g., grid size, nudging strength, among others) can have an impact as important as that of the landscape heterogeneity.

[21] Finally, using a set of simulations produced with the NASA Goddard Institute for Space Studies (GISS) general circulation model (GCM), *Werth and Avissar* [2002] find that the deforestation of the Amazon basin affects very significantly the hydroclimatology of the basin. Moreover, they find that this deforestation also affects the hydroclimatology of other locations on earth, including a significant reduction of precipitation in North America. In general, the further away from the tropics, the weaker the teleconnected signals.

3. Discussion and Conclusions

[22] The results of *Misra et al.* [2002b] and *Chou et al.* [2002] indicate that very similar numerical experiments using almost the same land-surface schemes in different hosting atmospheric models result in different conclusions. Indeed, *Misra et al.* [2002b] do not see a clear advantage of using a more sophisticated land-surface scheme for simulations of the Amazon while *Chou et al.* [2002] claim an improvement by using the same sophisticated scheme as compared to simulations produced with simple schemes. Together with the study of *Weaver et al.* [2002], who point out the importance of setting up correctly initial and forcing conditions in regional models, these results emphasize that regional models such as the RAMS, the RSM, and the Eta model cannot be used as "black boxes" and need to be set up very carefully to produce realistic simulations. Furthermore, many of the parameters needed to feed the land-surface schemes at the scale used in the atmospheric models are not well known. Therefore modelers still introduce some subjectivity in their numerical experiments, and the more accurate parameters (at the proper scale) can be estimated, the more realistic will be their simulations. As part of LBA, it is therefore important to keep on developing advanced databases of the Amazon land-surface parameters needed in the hydrometeorological and ecological models.

[23] The remote sensing studies of *Hamilton et al.* [2002], *Birkett et al.* [2002], *Roberts et al.* [2002] and *Hagen et al.* [2002] as well as the ground-based observations made by *Costa et al.* [2002], *Bustamante et al.* [2002], *Kisselle et al.* [2002], *Nepstad et al.* [2002] and *Townsend et al.* [2002], all provide interesting insights and information that are used for the specific analyses described in their respective papers. But all these data sets have also the potential of advancing various modeling studies.

[24] One of the two major key scientific issues that LBA is committed to address is the investigation of the role of changes in land use and land cover on the biological, chemical and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate. Results from the WetAMC/TRMM campaign summarized in *Silva Dias et al.* [2002b] as well as the modeling work of *Baidya Roy and Avissar* [2002] and *Werth and Avissar* [2002] suggest the potential impact of deforestation on precipitation described in Figure 1. Simulations with various GCMs over the past decade, including those of *Werth and Avissar* [2002] presented in this issue, indicate that the total deforestation of the Amazon is likely to reduce the precipitation in that region by about 20–30%. Unfortunately, GCMs are not well equipped to simulate partial deforestation as is in fact taking place in the Amazon and it is not obvious how to estimate the effects of partial deforestation on precipitation. In Figure 1, three different patterns are proposed among many possible speculated options. Maybe the simplest one

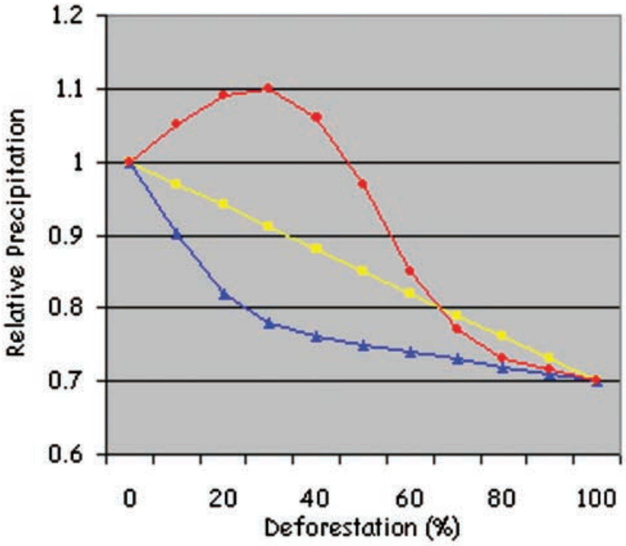

Figure 1. Conceptual impact of deforestation on relative precipitation. The three curves indicate different models, among many other possible ones.

consists of a linear decrease of precipitation with the increase of the deforested areas (yellow curve). It is also conceivable that a relatively small deforestation could cause a major decrease of precipitation, with a progressing deforestation not having further significant impact (blue curve). An alternative pattern could represent first an increase of precipitation as a result of partial deforestation, maybe due to the mesoscale circulations as described by *Baidya Roy and Avissar* [2002] and observed by *Sa et al.* [2002], followed by a catastrophic decrease passing some threshold value (red line). Note also that in their case study, *Silva Dias et al.* [2002b] found that the process of organization of convection into precipitating convective lines in Southwest Amazon was increased as a result of changing the landscape from forest to a mixture of forested and pasture patches.

[25] The effect of above average temperatures in the eastern and central Pacific Ocean, referred to as "El Niño," has been shown to have a major impact on weather very far away from this region [*Shabbar et al.*, 1997]. The warm ocean surface provides appropriate conditions needed for the development of thunderstorms, which export large amounts of heat, moisture and kinetic energy to the middle and higher latitudes. This transfer, which is illustrated in Figure 2a by the yellow arrows originating in the warm Pacific Ocean and which alters the ridge and trough pattern associated with the polar jet stream [*Hou*, 1998], is referred to as "teleconnections" [*Glantz et al.*, 1991; *Namias*, 1978; *Wallace and Gutzler*, 1981]. *Wu and Newell* [1998] concluded that sea-surface temperature variations in the tropical eastern Pacific Ocean have three unique properties that allow this region to influence the atmosphere effectively: large magnitude, long persistence, and spatial coherence.

[26] Almost two-thirds of the global precipitation is associated with mesoscale cumulonimbus and stratiform cloud systems located equatorward of 30° [*Keenan et al.*, 1994]. In addition, much of the world's lightning occurs over tropical continents, with maxima also over midlatitude continents in the warm seasons [*Lyons*, 1999; *Rosenfeld*, 2000]. As shown in the pioneering study by *Riehl and Malkus* [1958] and *Riehl and Simpson* [1979], 1500–5000 thunderstorms (which they refer to as "hot towers") are the conduit to transport this heat, moisture, and wind energy to higher latitudes. Since thunderstorms only occur in a relatively small percentage of the area of the tropics, a change in their spatial patterns would be expected to have global consequences. Furthermore, land-use change has the same three attributes indicated by *Wu and Newell* [1998]. Thus a similar teleconnection is expected to occur as a result

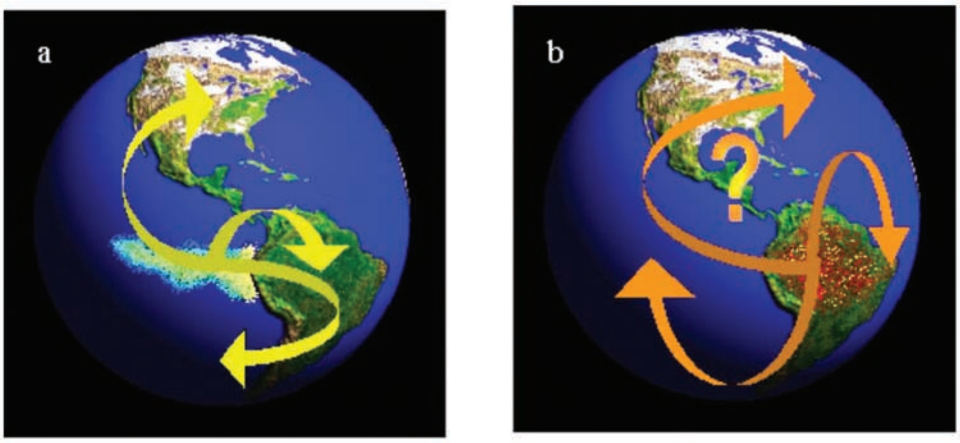

Figure 2. Illustration of hydrometeorological teleconnection resulting from (a) an El Niño event, schematically represented with the warming of the eastern Pacific Ocean west of the coast of South America; and (b) a major deforestation of the Amazon basin, schematically represented with the warming of the basin. While sea-surface temperature increases by a few degrees during an El Niño event, the surface temperature can increase by about 20 K as a result of deforestation. Note that the spatial extent of the temperature increase is similar to that of the sea-surface temperature in the El Niño event.

of man-made landscape changes in the tropics. In fact, this is supported by the influence function analysis of *Grimm and Silva Dias* [1995], which indicates the potential role of anomalous precipitation in the tropical sector of South America in forcing such teleconnection patterns in the northern and southern hemisphere. This is illustrated in Figure 2b by the orange arrows originating in the deforested amazon, which according to the results of *Baidya Roy and Avissar* [2002] and some of the preliminary data analyses resulting from the WetAMC/TRMM campaign [*Silva Dias et al.*, 2002b; *Sa et al.*, 2002], tends to indicate an increase of cumulus activity.

[27] These preliminary results need to be confirmed with more in-depth analyses and more accurate simulations. Additional data sets of ground observations and remotely sensed pictures are currently being collected as part of LBA. This information will be useful for more complete analyses and modeling studies. Further modeling developments are needed to better understand the various processes involved in the complex Amazonian system. The studies of *Coe et al.* [2002], *Misra et al.* [2002a, 2002b], *Chou et al.* [2002], *Franchito et al.* [2002], *Baidya Roy and Avissar* [2002], *Werth and Avissar* [2002], and *Weaver et al.* [2002] that appear in this part of the special issue, together with the studies summarized by *Silva Dias et al.* [2002a] and *Andreae et al.* [2002] will help design more accurate and more efficient models of this system. Among other issues, to better understand the teleconnections between the Amazon and other locations on earth, it will be essential to develop a global-scale model capable of accounting for the clouds and precipitation triggered by landscape heterogeneity resulting from deforestation. This could be achieved by either parameterizing these processes or explicitly representing them at a high resolution.

[28] In conclusion, the various articles presented in this special issue have described some of the preliminary, important findings gained during this unique experiment in the Amazon. However, many new questions have been raised as a result of these findings, which remain to be investigated to provide a better understanding of the Amazon and its interactions with the rest of the earth. Follow-up studies, including data collection and modeling, will undoubtedly provide further insights needed to accomplish this essential task.

[29] **Acknowledgments.** This paper was written with the support of the U.S. National Aeronautics and Space Administration under grant NAG5-9746. The views expressed herein are those of the authors and do not necessarily reflect the views of this agency.

References

Andreae, M. O., et al., Biogeochemical cycling of carbon, water, energy, trace gases and aerosols in Amazonia: The LBA-EUSTACH experiments, *J. Geophys. Res.*, *107*, 8066, doi:10.1029/2001JD000524, 2002.

Avissar, R., and C. A. Nobre, Preface to special issue on the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), *J. Geophys. Res.*, *107*, 8034, doi:10.1029/2002JD002507, 2002.

Baidya Roy, S., and R. Avissar, Impact of land use/land cover change on regional hydrometeorology in Amazonia, *J. Geophys. Res.*, *107*, 8037, doi:10.1029/2000JD000266, 2002.

Birkett, C. M., L. Mertes, T. Dunne, M. H. Costa, and M. J. Jasinski, Surface water dynamics in the Amazon Basin: Application of satellite radar altimetry, *J. Geophys. Res.*, *107*, 8059, doi:10.1029/2001JD000609, 2002.

Bustamante, M. M. C., A. S. Pinto, L. T. Viana, R. F. Varella, K. Kissele, R. A. Burke, M. Molina, and R. Zepp, Soil emissions of N_2O, NO_x, and CO_2 in soils of Brazilian savannas to prescribed fires, *J. Geophys. Res.*, *107*(D20), doi:10.1029/2001JD000342, in press, 2002.

Chou, M. D., and M. J. Suarez, An efficient thermal infrared radiation parameterization for use in general circulation models, in *Technical Report Series on Global Modeling and Data Assimilation*, vol. 3, *Tech. Memo. 104606,* 102 pp., Goddard Space Flight Cent., Greenbelt, Md., 1994.

Chou, S. C., C. A. S. Tanajura, Y. Xue, and C. A. Nobre, Validation of the coupled Eta/SSiB model over South America, *J. Geophys. Res.*, *107*, doi:10.1029/2000JD000270, in press, 2002.

Coe, M. T., M. H. Costa, A. Botta, and C. M. Birkett, Long-term simulations of discharge and floods in the Amazon basin, *J. Geophys. Res.*, *107*, 8044, doi:10.1029/2001JD000740, 2002.

Costa, M. H., C. H. C. Oliveira, R. G. Andrade, T. R. Bustamante, F. A. Silva, and M. T. Coe, A macroscale hydrological dataset of river flow routing parameters for the Amazon Basin, *J. Geophys. Res.*, *107*, 8260, doi:10.1029/2000JD000309, 2002.

Franchito, S. H., E. C. Moraes, and V. B. Rao, Simulations with a radiation model and comparisons with LBA data sets, *J. Geophys. Res.*, *107*, doi:10.1029/2001JD001356, in press, 2002.

Glantz, M. H., R. W. Katz, and N. Nicholls (Eds.), *Teleconnections Linking Worldwide Climate Anomalies*, Cambridge Univ. Press, New York, 1991.

Grimm, A. M., and P. L. Silva Dias, Analysis of tropical-extratropical interactions with influence functions of a barotropic model, *J. Atmos. Sci.*, *52*, 3538–3555, 1995.

Hagen, S., B. H. Braswell, S. Frolking, W. A. Salas, and X. Xiao, Determination of subpixel fractions of nonforested area in the Amazon using multiresolution satellite data, *J. Geophys. Res.*, *107*, 8049, doi:10.1029/2000JD000255, 2002.

Hamilton, S. K., S. J. Sippel, and J. M. Melack, Comparison of inundation patterns among major South American floodplains, *J. Geophys. Res.*, *107*, 8038, doi:10.1029/2000JD000306, 2002.

Hou, A. Y., Hadley circulation as a modulator of the extratropical climate, *J. Atmos. Sci.*, *55*, 2437–2457, 1998.

Keenan, T. D., B. Ferrier, and J. Simpson, Development and structure of a maritime continent thunderstorm, *Meteorol. Atmos. Phys.*, *53*, 185–222, 1994.

Kisselle, K. W., R. G. Zepp, R. A. Burke, A. Siqueira Pinto, M. M. C. Bustamante, S. Opsahl, R. F. Varella, and L. T. Viana, Seasonal soil fluxes of carbon monoxide in burned and unburned Brazilian savannas, *J. Geophys. Res.*, *107*, 8051, doi:10.1029/2001JD000638, 2002.

Lyons, W. A., Lightning, in *Storms, Hazard and Disaster Ser.*, edited by R. A. Pielke Sr. and R. A. Pielke, Jr., pp. 60–79, Routledge, New York, 1999.

Misra, V., P. A. Dirmeyer, B. P. Kirtman, H.-M. H. Juang, and M. Kanamitsu, Regional simulation of interannual variability over South America, *J. Geophys. Res.*, *107*, 8036, doi:10.1029/2001JD900216, 2002a.

Misra, V., P. A. Dirmeyer, and B. P. Kirtman, A comparative study of two land surface schemes in regional climate integrations over South America, *J. Geophys. Res.*, *107*, 8080, doi:10.1029/2001JD001284, 2002b.

Namias, J., Multiple causes of the North American abnormal winter 1976–77, *Mon. Weather Rev.*, *106*, 279–295, 1978.

Nepstad, D., et al., Effects of partial throughfall exclusion on canopy processes, aboveground production, and biogeochemistry of an Amazon forest, *J. Geophys. Res.*, *107*, 8100, doi:10.1029/2001JD000360, 2002.

Riehl, H., and J. S. Malkus, On the heat balance in the equatorial trough zone, *Geophysica*, *6*, 504–537, 1958.

Riehl, H., and J. M. Simpson, The heat balance of the equatorial trough zone, revisited, *Contrib. Atmos. Phys.*, *52*, 287–297, 1979.

Roberts, D. A., I. Numata, K. Holmes, O. Chadwick, G. Batista, and T. Krug, Large area mapping of land-cover change in Rondonia using multitemporal spectral mixture analysis and decision tree classifiers, *J. Geophys. Res.*, *107*, 8054, doi:10.1029/2001JD000374, 2002.

Rosenfeld, J., Sentinels in the sky, *Weatherwise*, *53*, 24–29, 2000.

Sa, L. D. A., M. J. A. Bolzan, F. M. Ramos, R. Rosa, and C. R. Neto, Analysis of fully developed turbulence above and below Amazon forest canopy using Tsallis' generalized thermostatistics, *J. Geophys. Res.*, *107*(D20), doi:10.1029/2001JD000378, in press, 2002.

Shabbar, A., B. Bonsal, and M. Khandekar, Canadian precipitation patterns associated with the Southern Oscillation, *J. Clim.*, *10*, 3016–3027, 1997.

Silva Dias, M. A. F., et al., Clouds and rain processes in a biosphere atmosphere interaction context in the Amazon Region, *J. Geophys. Res.*, *107*, 8072, doi:10.1029/2001JD000335, 2002a.

Silva Dias, M. A. F., et al., A case study of convective organization into precipitating lines in the southwest Amazon during the WETAMC and

TRMM-LBA, *J. Geophys. Res.*, *107*, 8078, doi:10.1029/2001JD000375, 2002b.

Townsend, A. R., G. P. Asner, C. C. Cleveland, M. E. Lefer, and M. M. C. Bustamante, Unexpected changes in soil phosphorus dynamics along pasture chronosequences in the humid tropics, *J. Geophys. Res.*, *107*, 8067, doi:10.1029/2001JD000650, 2002.

Wallace, J. M., and D. S. Gutzler, Teleconnections in the geopotential height field during the Northern Hemisphere winter, *Mon. Weather Rev.*, *109*, 784–812, 1981.

Weaver, C. P., S. Baidya Roy, and R. Avissar, Sensitivity of simulated mesoscale atmospheric circulations resulting from landscape heterogeneity of model configurations, *J. Geophys. Res.*, *107*, 8041, doi:10.1029/2001JD000376, 2002.

Werth, D., and R. Avissar, The local and global effects of Amazon deforestation, *J. Geophys. Res.*, *107*, doi:10.1029/2001JD000717, 2002.

Wu, Z.-X., and R. E. Newell, Influence of sea surface temperature on air temperature in the tropic, *Clim. Dyn.*, *14*, 275–290, 1998.

R. Avissar, Department of Civil and Environmental Engineering, 123 Hudson Hall, Box 90287, Duke University, Durham, NC 27708, USA. (avissar@duke.edu)

M. A. F. Silva Dias and P. L. Silva Dias, University of Sao Paulo, Rua do Matao, 1226, Sao Paulo-SP 05508-9000, Brazil. (mafdsdia@model.iag.usp.br; pldsdias@model.iag.usp.br)

C. A. Nobre, Center for Weather Forecasting & Climate Research National (CPTEC), Space Research Institute, Cachoeira Paulista SP 12630-000, Brazil. (nobre@cptec.inpe.br)