An aerial photograph of a lush, dense tropical rainforest. The canopy is a vibrant green, with various shades and textures. In the lower right foreground, a large, gnarled tree trunk with a thick, light-colored bark is visible, extending upwards into the canopy. The overall scene is a vast, undisturbed natural landscape.

**THE LARGE SCALE  
BIOSPHERE-ATMOSPHERE EXPERIMENT  
IN AMAZONIA (LBA)**

**Concise experimental plan**

**The LBA Science Planning Group**



# **THE LARGE SCALE BIOSPHERE-ATMOSPHERE EXPERIMENT IN AMAZONIA (LBA)**

**Concise experimental plan <sup>(1)</sup>**

<sup>(1)</sup> Este documento também encontra-se disponível em Português  
Este documento también se encuentra disponible en Español

This document reflects the status of LBA planning in April 1996. Details of various activities and their timing may change, depending on the availability of funding.

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*This document is intended to provide a concise statement of the goals and objectives of LBA and its expected contribution to Global Change research. Detailed plans of the various scientific elements will be available through the LBA Project Offices (see page 41), or the LBA WWW home page: <http://yabae.cptec.inpe.br/lba>.*



## The LBA concise experimental plan

### SUMMARY OF LBA

The Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an international research initiative lead by Brazil. LBA is 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 centred around two key questions that will be addressed through multi-disciplinary research, integrating studies in the physical, chemical, biological, and human sciences:

- *How does Amazonia currently function as a regional entity?*
- *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?*

In LBA emphasis is given to observations and analysis which will enlarge the knowledge base for Amazonia in six general areas: Physical Climate, Carbon Storage and Exchange, Biogeochemistry, Atmospheric Chemistry, Land Surface Hydrology and Water Chemistry, and Land Use and Land Cover. The program is designed to address major issues raised by the Climate Convention. It will help 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 modelling to provide insight into possible changes in the future.

#### Physical Climate

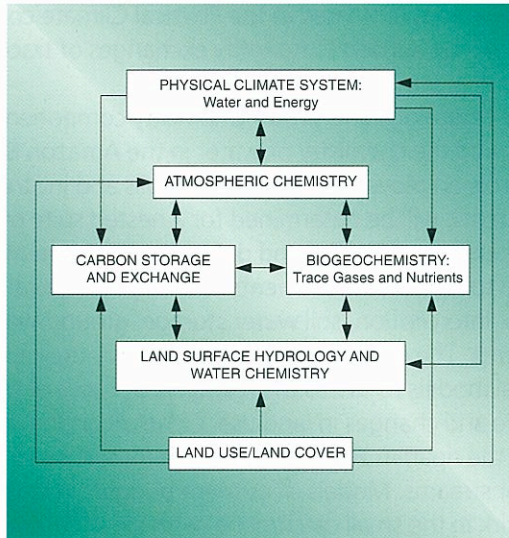
In the Physical Climate component, meteorological and hydrological studies will be conducted for nested spatial scales, from plots to the entire Amazonia, with focus on determining and understanding the spatial and temporal variations of energy and water fluxes. Variations of climate, and the responses of the Amazonian system to these variations, will be determined on daily to seasonal time scales. The data fields generated by a numerical weather prediction model will be stored and used in a four dimensional data assimilation scheme (4DDA) as a primary tool to analyze the observations. The duration of LBA should allow for direct observations of inter-annual climate variations, possibly including the effects of the El Niño-Southern Oscillation (ENSO) cycle. Data collected in the field program will be used to improve representation of key dynamical processes in meteorological models. The results will help to constrain the General Circulation Models used to examine interactions between climate and land cover changes in Amazonia.

#### Carbon Storage and Exchange

The Carbon Storage and Exchange component will address two major issues: (1) are undisturbed ecosystems of Amazonia functioning as a net carbon sink, and (2) how much

## Summary of LBA

Linkages between the components of LBA



carbon is lost as a result of land cover and land use changes such as the clearing of forest for agriculture and selective logging? Multi-year ground-based measurements of carbon stores and fluxes will be made at sites strategically located along gradients of land use intensity, vegetation, and climate, complemented by observations from aircraft campaigns and by modelling. Results from ecological models will be used together with a basin-wide geographic information system (GIS) to estimate Amazonia's carbon budget. Aircraft observations may provide estimates of carbon fluxes integrated over the Basin for short intervals, as a check on models.

### Biogeochemistry

The Biogeochemistry component will focus on nutrient cycling and emissions of greenhouse gases from natural and secondary forests and managed lands. Observations will be made over several years at sites strategically located along gradients of land use intensity and climate, covering a range of soil fertility and land uses. Measurements will quantify fluxes of trace gases (emphasizing methane and nitrous oxide), fluxes of nutrients (including export to rivers), and changing stocks of nutrients. These data will be complemented by periodic airborne observations, multi-scale inventories, and local manipulative experiments. Data will be unified in a GIS and linked to models of ecosystem function. Key deliverables will be the analysis of the effects of land use change on sources of greenhouse gases (a primary emphasis of the Climate Convention); diagnosis of the effects of climatic and land use variations on trace gas and nutrient budgets; and evaluation of the implications for sustainable land use of changes in nutrient dynamics under differing management practices.

### Atmospheric Chemistry

In the Atmospheric Chemistry component, the primary focus will be to understand the present-day influence of Amazonia on tropical and global concentrations of oxidants (ozone, hydroxyl radical), oxidant precursors (nitrogen oxides, hydrocarbons, carbon monoxide), and aerosols, as well as to complement the studies of greenhouse gases (carbon dioxide, nitrous oxide, methane) that are proposed in the Biogeochemistry and Carbon Storage and Exchange components. The experimental design combines long-term ground-based observations and intensive aircraft measurements. The aircraft campaigns will map biosphere-atmosphere exchange of gases and aerosols on the Basin scale, supplementing the ground-based observations, and will investigate transport of gases and aerosols across boundaries of the Basin. Large-scale, three-dimensional atmospheric chemistry models, using assimilated



## The LBA concise experimental plan

### Land Surface Hydrology and Water Chemistry

meteorological observations (obtained in the Physical Climate component), aircraft and ground based data, will be applied to quantify exchanges of trace gases and aerosols between Amazonia and the global atmosphere.

The Land Surface Hydrology and Water Chemistry component will consider issues related to both the quantity and the chemistry of water in the Amazon Basin. The stores and fluxes of water, and the controls on movement of water in soils and in streams, and the associated transport of constituents, will be determined for a nested suite of catchments representing a range of land use intensities. Forested and deforested catchments of several square kilometres will be instrumented to make measurements with high temporal resolution of discharge, rainfall, evaporation, interception, soil water storage, ground water leakage and export of sediment and nutrients. The data will be used to improve the capability of hydrometeorological models to assess the response of flows of the Amazon and its tributaries to changes in climate and changes in land use. Controls on the movement of materials from the upland through the riparian zone and into streams will be studied in small catchments drained by low order streams. Models of nutrient budgets in larger catchments will integrate results from field work in the small catchments with extant models of higher order river biogeochemistry and extant and new models of hydrologic routing.

### Land Use and Land Cover Changes

Land Use and Land Cover changes from natural vegetation to agricultural crops and subsequent regrowth will be quantified and related to both physical and socio-economic causes. Amazonia-wide studies of deforestation and forest alteration will be conducted using satellite remote sensing and survey data. Case studies will be conducted to illustrate how changes in land use affect land cover. Research to define the socioeconomic factors and conditions that cause these changes will focus on the development of predictive models of land cover and land use change.

### Sustainable development

LBA will combine newly developed analytical tools and innovative, multidisciplinary, experimental designs in a powerful synthesis which will create new knowledge to address long-standing issues and controversies. LBA will provide new understanding of environmental controls on flows of energy, water, carbon, nutrients, and trace gases between the atmosphere, hydrosphere, and biosphere of Amazonia to help provide the scientific basis of policies for sustainable use of Amazonian natural resources. The enhancement of research capacities and networks within and between the Amazonian countries associated with LBA will help advance education and applied research into sustainable development, and help in the process of formulating policies for the sustainable development of the region.

### Capacity building

## Introduction

### INTRODUCTION

#### Background

**Despite widespread concern and increased international efforts at conservation, the world's tropical forests continue to disappear at an unprecedented rate. Of vital importance in developing sustainable management and exploitation systems for tropical forests are the questions as to how far human intervention affects the forest's basic capacities to renew themselves and how to safeguard the basic ecological processes such as biological productivity and nutrient and water cycling. Altered cycles of water, energy, carbon and nutrients, resulting from the changes in Amazonian vegetation cover, are expected to have climatic and environmental consequences at local, regional and global scales. To understand these consequences and to mitigate their negative effects, enhanced knowledge is needed of the functioning of both the existing natural forest systems as well as systems which have already been converted to various other forms of land use or secondary regrowth.**

The global population is estimated to reach 6.2 billion by the year 2000. Half of this total, 3.1 billion people, will be living in the less developed countries located predominantly in the tropics between latitudes 23° North and 23° South. The consequences of rapid population growth in these areas are already being experienced in the form of deterioration of the urban environment and conversion and fragmentation of the forest environment.

Recent data from remote sensing show that large areas of Brazilian Amazonia have been changed from forest to pasture and agricultural land (see figure on next page). Data from tropical forests in south-east Asia and equatorial Africa show similar trends. Conversion of primary tropical forests to agriculture and to secondary vegetation represents one of the most profound changes to the global environment in the present era.

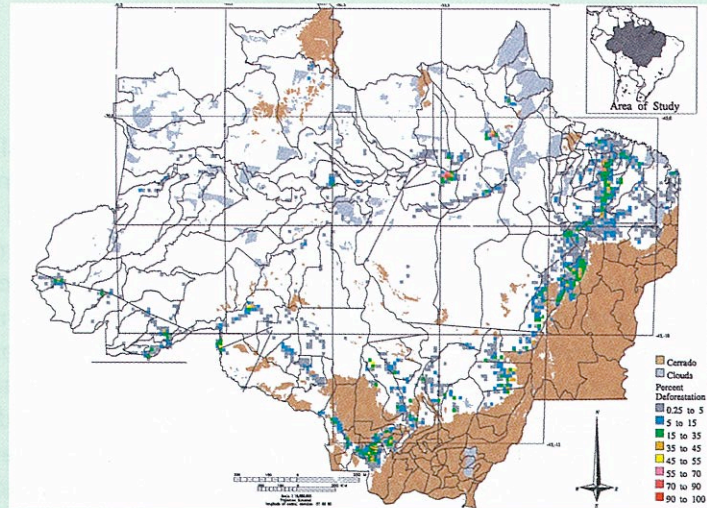
Amazonia has been inhabited by human populations from immemorial times. At the time of the arrival of the European colonizers in the 16th century, it is estimated that several million indigenous people lived in the region. The modern occupation of Amazonia started around 1540, but until the end of World War II human presence in the Amazonian environment brought almost no changes to its natural vegetation cover. The new period of development started with the new policies of many Amazonian countries, primarily Brazil, to develop agriculture and to settle immigrants, mostly landless peasants, coming from densely populated areas such as the poverty-stricken northeast and the southern states of Brazil. A large road-building effort started in the late 1950s and expanded through the 1970s opening up large areas of the forest to agricultural development. Millions of immigrants rushed to

Forest conversion

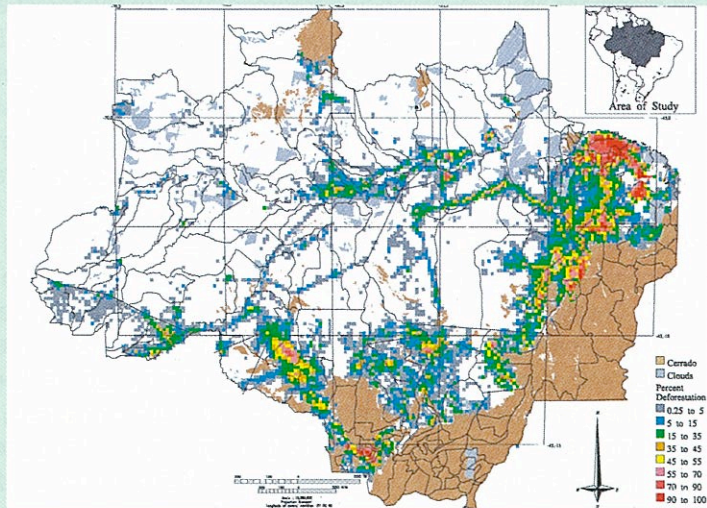
Human pressure on  
Amazonia



## The LBA concise experimental plan



Deforestation (confined to forest strata) in Brazilian Amazonia between 1978 (above) and 1988 (below), estimated using high-resolution LANDSAT satellite imagery, as reported by Skole and Tucker (*Science* 260, 1993). Deforestation increased between 1978 and 1988 from 78 000 km<sup>2</sup> to 230 000 km<sup>2</sup>. In the same study, the total area of a habitat affected by deforestation increased from 208 000 km<sup>2</sup> in 1978 to 588 000 km<sup>2</sup> in 1988. Another estimate using a slightly different stratification of the forest shows a total deforestation of 430 000 km<sup>2</sup>, up to 1991. (Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil, 1992).





## Introduction

Amazonia. That, combined with a policy of fiscal incentives to the establishment of large cattle ranches in Brazil, caused a sharp increase in deforestation rates in Amazonia in the 1980s. Deforestation rates have somewhat stabilized in the early 1990s, but the underlying pressures to continued land use change are still present: a growing population in the developing nations of Amazonia and plans for a road network criss-crossing the region. Furthermore, the lack of sustainable agriculture in Amazonia has driven countless peasants out of their agricultural plots and into mining (gold, cassiterite, diamonds, etc), scattered all over the basin and creating a large number of areas of spontaneous development and deforestation.

## Ecological damage

Biomass burning and alterations in the basin wide carbon balance, resulting from changes in net ecosystem productivity associated with the establishment of new, different vegetation covers following deforestation, may have further significant effects. Amazonia contains almost half of the world's undisturbed tropical evergreen forest and a large area of tropical savanna. The basin is important in the metabolism of the Earth system accounting for approximately 10 percent of the terrestrial net primary production. Equally important, it is a region of high biodiversity. Selective logging has changed the structure and composition of forested areas, particularly in south-eastern Amazonia and along river courses. These practices result in habitat fragmentation which may lead to an irreversible loss in biodiversity. The tropical atmosphere is responsible for 70% of the global oxidizing potential and Amazonia is an important natural source for methane and nitrogen oxides.

All these changes in Amazonia, a vast area of nearly 7 million km<sup>2</sup>, may have climatic, ecological and environmental implications for the region, for the continent and for the globe.





## The LBA concise experimental plan

### Sustainable development of Amazonia and LBA

**Sustainable use of the Amazonian forests must be based on a sound scientific understanding of the environment. New practices will only be successful if their methods and goals do take account of limiting environmental factors and needs. Understanding natural ecosystems will provide the insight needed to design sustainable management systems that may emulate the biological adaptations that have evolved in the special environmental conditions of Amazonia.**

A sound knowledge of how the natural system functions is thus a prerequisite to defining optimal development strategies. The complex interactions between the soil, vegetation, and climate must be measured and analyzed so that the limiting factors to vegetation growth and soil conservation can be established. A first step in the research strategy of the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), in the context of sustainable development, is thus to study the functioning of the natural ecosystem. At the same time important types of land use and secondary regrowth will be studied to identify the factors controlling their function. Understanding how processes and their environmental controls vary among undisturbed forests, agricultural lands, and secondary forests may allow identification of the factors limiting the success of certain land use practices.

New knowledge and improved understanding of the functioning of the Amazonian system as an integrated entity and of its interaction with the Earth system will support development of national and regional policies to prevent the exploitation trends from bringing about irreversible changes in the Amazonian ecosystem. Such knowledge, in combination with enhancement of the research capacities and networks between the Amazonian countries will stimulate land managers and decision makers to devise sustainable alternative land use strategies along with forest preservation strategies.

LBA is designed to create this necessary new knowledge to understand the climatological, ecological, biogeochemical and hydrological functioning of Amazonia. The interactions between land use and the physical climate will be studied over a range of space and time scales. The natural ecosystems will be studied at undisturbed forest and cerrado sites. Conversion of primary tropical forests to agriculture or to secondary vegetation in combination with the inputs from agricultural burning and forest clearing will be studied in relation to altered carbon and biogeochemical cycles in vegetation, soils and atmosphere. The net sources of the key greenhouse gases, oxidants and aerosols, and their transport in the atmosphere will be quantified. Changes in hydrological regimes will be studied in relation to land use change in river catchments. Land use will be studied in both the context of its physical and socioeconomic causes. Models will be parameterized and used to extrapolate experimental results in space and in time, and to predict the future functioning of Amazonia as an entity and its interactions with the Earth system.

Functioning of the natural system

Sustainable land management

Effects of forest conversion

## Introduction

Strengthening  
Amazonian research  
capacity

Research into the Amazonian environment is best carried out when led by Amazonian institutions and the scientists who work there. Foreign involvement in LBA will strengthen the Amazonian research capacity in a variety of ways. The strategy is to involve Amazonian educational and research institutions, scientists and students in the whole process of scientific research from the design and implementation of the experiments, through to the processing and analysis of data and the compilation of reports and formal scientific publications.

### International perspective

**In the early nineties the Brazilian scientific community, in response to the world-wide concern about the fate of the Amazonian environment, called for a new multi-disciplinary research effort. The Earth Science community arrived at the consensus view that an international effort should initially be built around a comprehensive field experiment, to be put in place in Amazonia. Since then, a large number of South American, North American and European research programmes, agencies and individual groups have put LBA as a high priority on their agendas.**

World Climate  
Research Programme

At present LBA is endorsed by the World Climate Research Program (WCRP) as part of the Global Energy and Water Cycle Experiment (GEWEX) and the International Satellite Land Surface Climatology Project (ISLSCP), and by the International Geosphere-Biosphere Programme (IGBP) through its core project Biospheric Aspects of the Hydrological Cycle (BAHC). From the onset LBA has been programmatically supported by IGBP core projects International Global Atmospheric Chemistry Programme (IGAC) and Global Change and Terrestrial Ecosystems (GCTE), by UNESCO's International Hydrological Programme (IHP), and recently by IGBP core project Land Use and Cover Change (LUCC) and the International Human Dimension Programme (IHDP). The Inter-American Institute for Global Change Research (IAI), which supports the inter-Americas dimension of LBA, has been building its long term research programme around the issues which are of utmost relevance to the LBA objectives. LBA is on its way to becoming the first project ever to be supported by all three major research programmes concerned with global, climate and environmental change, notably IGBP, WCRP and IHDP, as one of their main activities.

International  
Geosphere Biosphere  
Programme

Inter-American  
Institute for Global  
Change Research

Rio Climate  
Convention

LBA is a direct response to the Rio Climate Convention which requires each nation to determine its contribution to the global inventory of greenhouse gases and the impacts of its natural and industrial emissions on the oxidizing power of the global atmosphere.

Integrated National  
Policy for Legal  
Amazon

LBA aims to reinforce the Brazilian Integrated National Policy for Legal Amazonia (INPLA) by putting its emphasis on studying activities which degrade soil and water resources, and on studying the ecological balance and on enhancing environmental research skills in the region's institutions.



## The LBA concise experimental plan

### International and national funding

LBA is a research initiative which intends to mobilize a number of joint research contributions to the G7 - Brazil Pilot Programme on Protection of the Tropical Rainforest, mainly through its sub-programme "Science Centres and Directed Research".

LBA requires major commitments from a broad, international research community to provide the necessary human and funding resources. Major national and international research funding programmes in three continents, notably in South- and North America and in Europe, have been presented with this challenge. Some of them have already committed resources to the LBA-start-up activities. Yet, new major commitments at both national and multinational funding levels are still needed to make this interdisciplinary research effort possible.

### LBA rationale and objectives

**We have currently little understanding of how Amazonia behaves as an integrated environmental system and how its many ecosystems respond to human intervention. Although there have been some quantitative studies of the large-scale environmental effects of Amazonian deforestation, these have simply extrapolated the results of single site studies to the whole of Amazonia, with little regard to the different ecological, hydrological and climatic zones which exist within Amazonia. The motivation for LBA is to increase the scientific understanding, through field and modelling studies, of how Amazonia currently functions as a regional environmental entity, and of how this function is affected by land use change and climate and how it will function in the future.**

### Global effects of changes in Amazonia

The vast size of Amazonia and its position in the humid equatorial tropics, give the region a potential for influencing global energy, water, carbon and trace gas budgets which we cannot afford to neglect in the search for understanding of how climate may change in the future. The exchanges of energy, water, carbon, trace gases and nutrients through the atmospheric, terrestrial and riverine systems of Amazonia need to be quantified and understood, at scales from the small plot up to that of the entire basin. We need to understand how conversion of tropical forest will alter those exchanges. We need to be able to predict what impact this deforestation will have on the ecological, climatological and hydrological functioning of Amazonia and how it may affect the region's long-term sustainability. We need to be able to predict what impact these changes will have outside Amazonia.

Only recently has research put us in a position to speculate about the role of Amazonia in the global carbon balance. Some results indicate that Amazonian forests may take up carbon at a low rate, but given the size of Amazonia even small rates of uptake will be significant in terms of the global carbon budget. The rate of uptake may be highly sensitive to temperature,

## Introduction

and the forest may change from being a sink to being a source of carbon for an average temperature rise of a degree or less. Quantifying the carbon balance of Amazonia and finding out how it may respond to future climate and ambient carbon dioxide concentrations is a high priority for the international effort to predict future climate. Moreover, information on carbon stocks and fluxes is required by all countries under the terms of the Climate Convention. LBA will contribute, through measurements and improved models, to make these assessments and to explore scenarios of future change.

The two fundamental scientific questions of LBA are:

- *How does Amazonia currently function as a regional entity?*
- *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?*

Based on these two overarching questions, the objectives of LBA can be summarized as:

- *To quantify, understand and model the physical, chemical and biological processes controlling the energy, water, carbon, trace gas, and nutrient cycles found within Amazonia and to determine how these link to the global atmosphere.*
- *To quantify, understand and model how the energy, water, carbon, trace gas and nutrient cycles respond to deforestation, agricultural practices and other land use changes, and how these responses are influenced by climate.*
- *To predict the impacts of these responses both within and beyond Amazonia under future scenarios of changes in land use and climate.*
- *To determine the exchanges between Amazonia and the atmosphere of key greenhouse gases and species regulating the oxidizing potential of the atmosphere and to understand the processes regulating these exchanges.*
- *To provide quantitative and qualitative information to support sustainable development and ecosystem protection policies in Amazonia, in the context of both its regional and global functioning.*

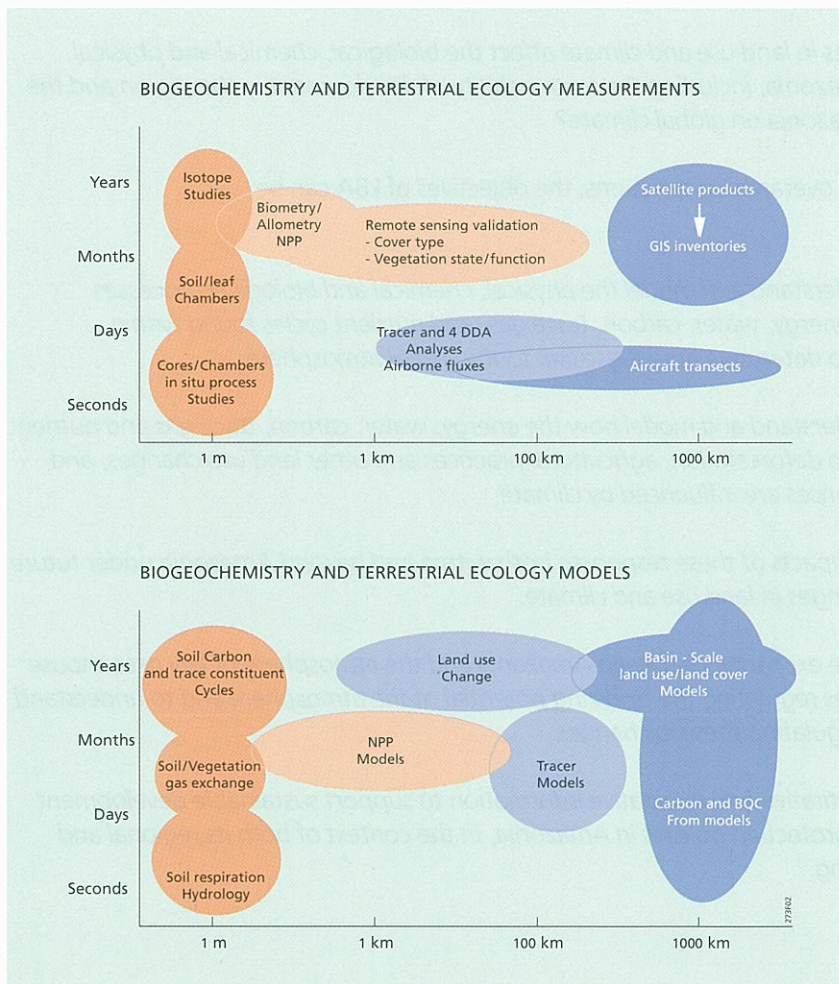


## The LBA concise experimental plan

The range of measurements and models addressing the LBA objectives on biochemistry and terrestrial ecology

### RESEARCH STRATEGY

The experimental design is based on a multi-disciplinary approach, integrating across the spectrum of earth, life and human sciences. The individual LBA-component studies will serve their specific disciplinary objectives, while at the same time contributing to the common LBA objectives. Combining efforts on well- focused sets of subjects with a series of disciplinary-oriented studies will ensure the transfer of experience, ideas and data across disciplinary boundaries.



To provide a coherent framework for the many studies to be conducted in LBA - studies that differ widely in subject, location, scale and approach - two concepts will be used to structure the research: one based on gradients of land use intensity and climatic seasonality, the other based on a hierarchy of spatial and temporal scales.

To address the eco-physiological and biogeochemical aspects of different stages of forest conversion, the proposed measurement sites will be positioned along two major transects spanning gradients of land use intensity and seasonality of rainfall (see map on page 17). One transect will run from the perennially wet, evergreen rainforest in western Amazonia to the east through the region of Manaus and into the region of seasonally dry forests in Pará and then south into the cerrado region around Brasília. This transect focuses on infertile soils and includes areas that have been subject to forest conversion and agricultural use for comparatively long periods of time. A second transect will run from northern Rondônia to the south-east into the central part of Mato Grosso. This transect will focus on the more fertile soils of Amazonia and areas subject to relatively recent forest conversion. Both



## Research strategy

*The range of measurements and models addressing the LBA objectives on physical climate and hydrology*

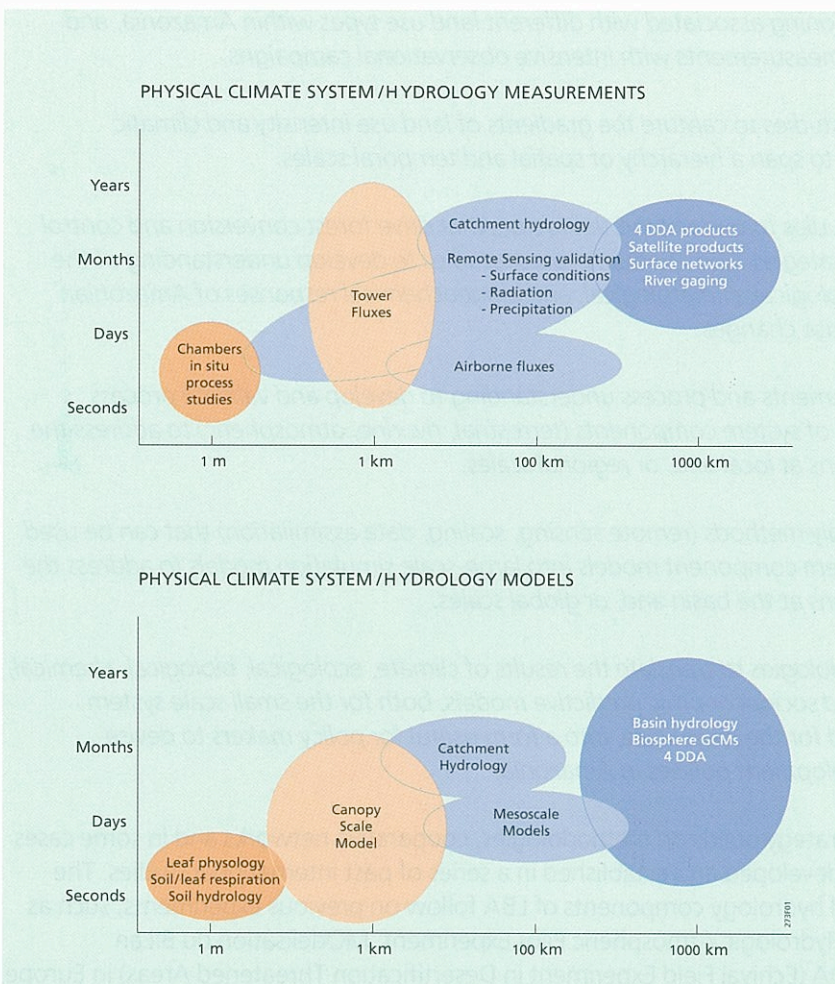
transects span rainfall gradients ranging from about 2.5 to 1.2 metres per year, and include regions subject to little or no development pressure to regions of intensive land use. Three or four intensive study areas will be arranged along each of these transects and in these areas ecological and biogeochemical process studies and monitoring will be conducted. Clusters of flux towers will be deployed in the major land use types, including primary forests. Other towers and monitoring studies will be deployed outside these transects for more extensive characterization of Amazonia.

Local process studies will be used to investigate biological, chemical, physical and socio-economic phenomena by direct observation. These studies will be used to describe the

functioning of the individual components of the total system. The results of the component studies will be integrated across the two eco-climatic transects through the use of ecological models and remotely sensed data. The local process studies will also support the large-scale component. This will consist of synoptic measurements and models which should integrate the experience of the process studies into a basin-scale framework to describe the functioning of the whole region, together with the budgets of energy, water, carbon, trace gases and nutrients (see diagrams).

The observational component of these process studies is confined to a time span of a few years. As such it will include diurnal and full seasonal cycles. It may also include inter-annual variations that relate to longer term variability like the El Niño - Southern Oscillation. Increased understanding of processes at these time scales will allow exploration of regional and global change scenarios into future decades by improved models.

To integrate the large-scale objectives of the project with the smaller-scale in situ process studies, LBA must include a multi-scale perspective that focuses on using the knowledge gained from the process studies





## The LBA concise experimental plan

to develop and validate small-, medium- and large-scale models. These models will in turn be used to explore the consequences of a range of future land use and climatic scenarios to provide policy-makers and the public with assessments of the sustainability of different development strategies.

We can therefore summarize the experimental strategy of LBA as:

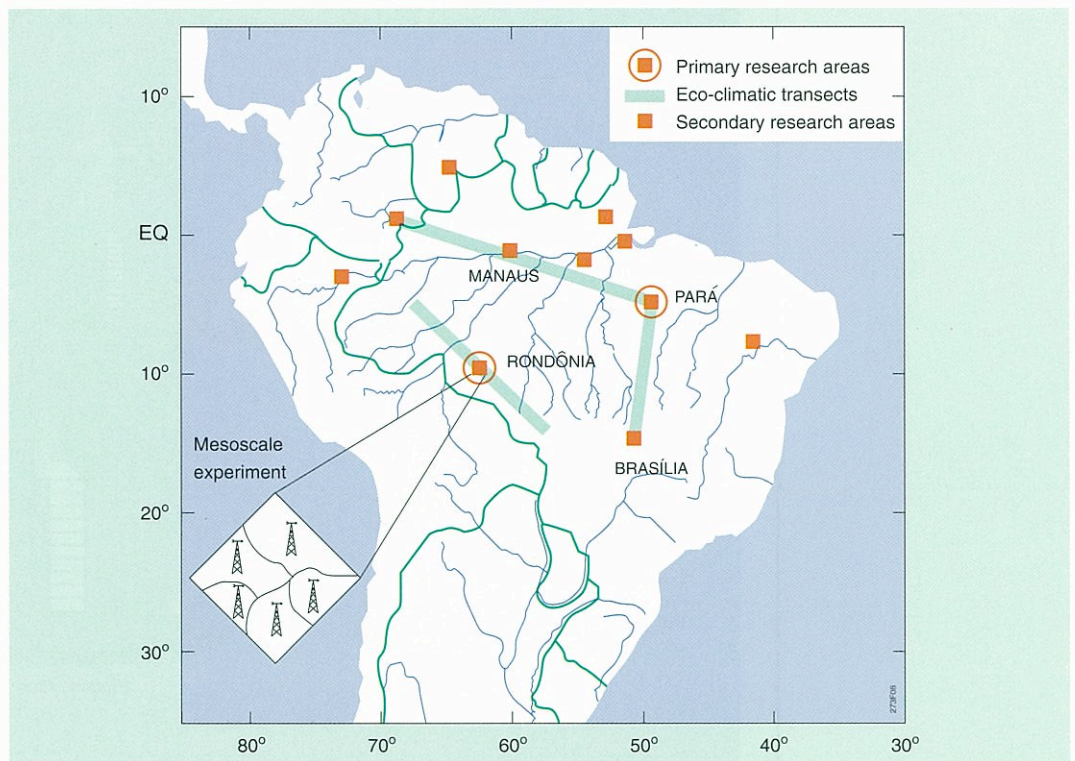
- *Measure over the long term (3-5 years) the important fluxes (energy, water, carbon, trace constituents) and states (vegetation type and condition, soil chemistry, agricultural practices, etc.) that govern the near-surface physical climate, the carbon cycle and the ecological functioning associated with different land use types within Amazonia, and augment these measurements with intensive observational campaigns.*
- *Structure these studies to capture the gradients of land use intensity and climatic seasonality, and to span a hierarchy of spatial and temporal scales.*
- *Conduct case studies to understand the factors that drive forest conversion and control local land use strategies, and conduct process studies to develop understanding of the ecological, hydrological, climatological, and biogeochemical responses of Amazonian systems to land use changes.*
- *Use the measurements and process understanding to develop and validate process oriented models of system components (terrestrial, riverine, atmospheric) to address the research questions at local and, or regional scales.*
- *Develop and apply methods (remote sensing, scaling, data assimilation) that can be used to integrate system component models into large-scale simulation models to address the research questions at the basin and, or global scales.*
- *Develop methodologies to translate the results of climate, ecological, biological, chemical, hydrological, and socioeconomic predictive models, both for the small scale system components and for the large scale, into a form useful for policy makers to devise sustainable development policies in Amazonia.*

The LBA research strategy builds on methodologies, cooperative networks and in some cases field infrastructure developed and established in a series of past international studies. The physical climate and hydrology components of LBA follow on previous experiments, such as HAPEX-MOBILHY (Hydrologic Atmospheric Pilot Experiment, MOdelisation du BILan HYdrique) and EFEDA (Echival Field Experiment in Desertification Threatened Areas) in Europe,

## Research strategy

### A new generation of Land surface - Biosphere - Atmosphere experiments

FIFE (First ISLSCP Field Experiment) and BOREAS (Boreal Ecosystem-Atmosphere Study) in North America, and HAPEX-Sahel (Hydrologic Atmospheric Pilot Experiment in the Sahel) in Africa. Projects in Amazonia, like CAMREX (Carbon in the Amazon River Experiment), ABRACOS (Anglo-Brazilian Amazonian Climate Observation Study) and RBLE (Rondônia Boundary Layer Experiment) have demonstrated the feasibility of undertaking this kind of research in the region. Similarly, the ecology, biogeochemistry and atmospheric chemistry components of LBA build on ABLE 2A and 2B (Amazon Boundary Layer Experiments), AGE (Amazon Ground Emissions), TRACE-A (Tropical Atmospheric Chemistry Experiment-Atlantic) and also BOREAS. They are a direct response to the concept of the 'land use intensity transects' recommended for the humid tropics by the IGBP Terrestrial Transects Science Plan. Unlike the previous experiments, LBA is concerned with the fate of the entire ecosystem under conditions of changing land use and climate. This is reflected in the research strategy regarding the time-scale of LBA-field activities: monitoring of basic environmental characteristics will extend over several years with the intention of capturing the inter-annual dynamics of ecosystem behaviour.

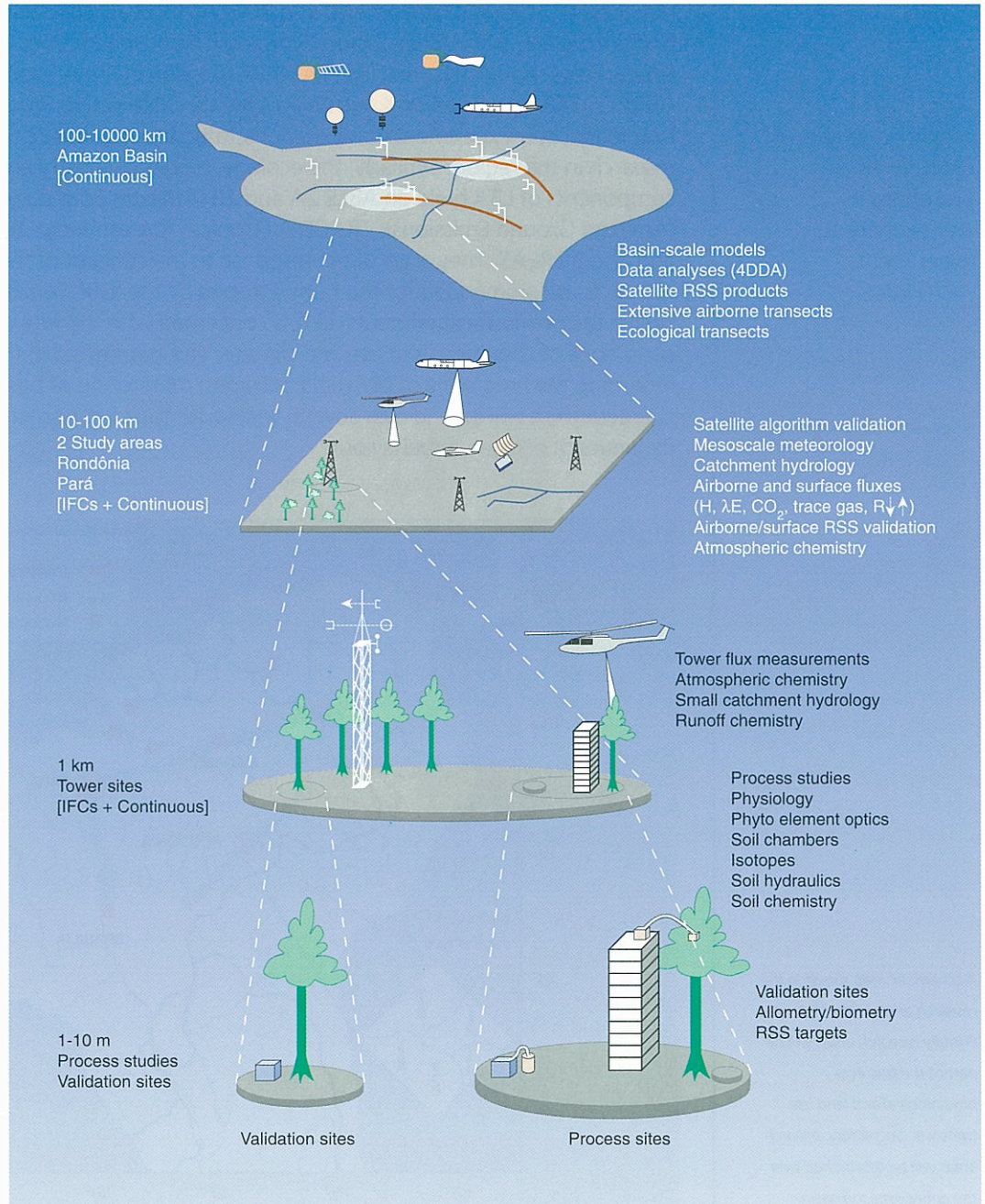


A schematic map showing the research areas in the LBA. Primary research areas will be part of the two eco-physiological and land use transects. Secondary research areas will be established over the entire Amazon basin.



## The LBA concise experimental plan

Although the LBA scaling strategy builds partly on the methodology developed in previous land surface experiments, unlike these, LBA is concerned with the fate of the entire ecosystem. This is reflected in the time-scale of LBA field activities which includes multi year monitoring of environmental characteristics.





## Science themes

### SCIENCE THEMES

LBA research will be scientifically organized into six themes: Physical Climate, Carbon Storage and Exchange, Biogeochemistry, Atmospheric Chemistry, Land Surface Hydrology and Water Chemistry, and Land Use and Land Cover. Many of the component studies are observationally and methodologically strongly linked, necessitating and at the same time guaranteeing cross-component integration.

#### Physical Climate

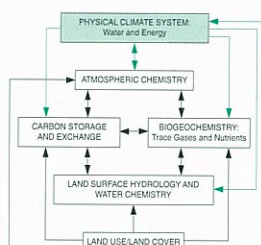
**This LBA component will study the transport of energy and water through the atmospheric part of the energy and water cycles, and how the interactions between the vegetation and the atmosphere influence these cycles.**

The tropical land and atmosphere form a highly coupled system. The surface fluxes not only control the inputs of water and energy to the atmosphere, but depend themselves on the dynamical and thermodynamical properties of the planetary boundary layer through a chain of processes involving cloudiness, soil water content, evaporation, sub-surface hydrology and vegetative cover. Observing and modelling these coupled land surface/atmosphere processes is the first task of the Physical Climate component of LBA:

- *What are the surface and meteorological controls on the fluxes of energy and water, and how do they vary both in space, over Amazonia, and in time, between seasons and from year to year, to affect the regional budgets of energy and water?*

To answer this question, the field measurement programme will be implemented as a transect of tower sites, well separated along the ecoclimatological gradients within Amazonia (map on page 17). Measurements will be made of standard weather variables and the surface exchanges of energy, water vapour and carbon dioxide. Some of the sites may also be instrumented for trace gas flux measurements as discussed in the Biogeochemistry section. There will be measurements of plant physiological and soil properties which control the fluxes. The sites will be used to determine the main surface and meteorological controls on the magnitude and cycle of the fluxes of energy, water vapour, CO<sub>2</sub> and momentum and will provide calibration and validation data for one-dimensional flux models.

In addition to these well instrumented sites there will be a network of continuous climate and soil monitoring sites, many of which will be sited along the otherwise sparsely instrumented margins of Amazonia. At these sites, measurements of climate and soil moisture will be made, along with a characterization of vegetation structure that is part of the Carbon



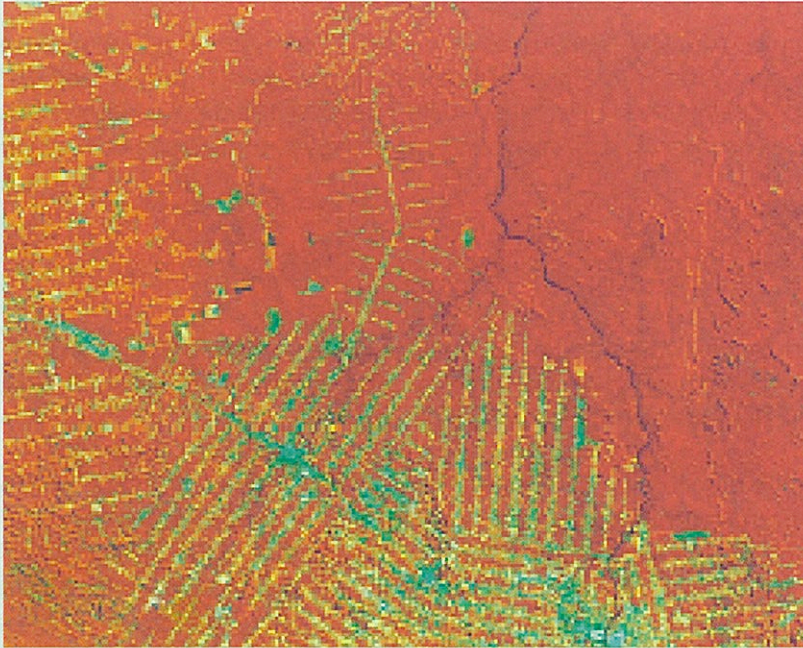
Interactions between land surface and Planetary Boundary Layer



Continuous climate and soil monitoring



## The LBA concise experimental plan



*"Fish-bone" pattern of deforestation typical of small farm holdings in Rondônia, up to 1988. This typical structure of the land-surface cover leads to the so called aggregation problem in linking the land-surface and atmospheric processes. On smaller scales, represented by a sequence of forest strips (in red) and agriculture land (in green), the question is how these could be "averaged" in terms of their interaction with the atmospheric boundary layer. Over the entire mesoscale domain, threshold (minimum) sizes of the forest-clearing, which can still alter the mesoscale circulations and therefore influence regional climate, need to be investigated. Compare this pattern to the one on page 34 (source: NASA LANDSAT Pathfinder project).*

### Model sensitivity analysis

### Primary research areas: Rondônia and Pará

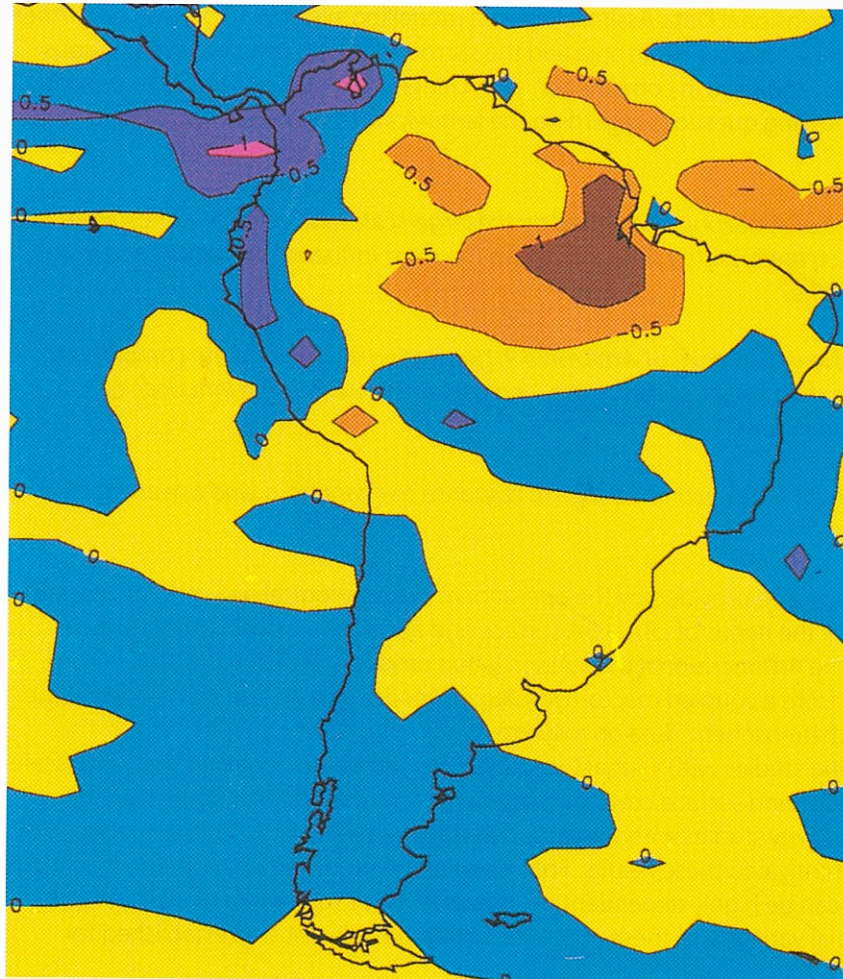
and Biogeochemistry components of LBA. The data from these sites will be used for testing rather than calibrating models.

The data and calibrated models from these sites will be used to determine how the natural ecosystem controls its use of water and survives dry season drought. Model sensitivity analysis will investigate how the sustainability of the ecosystems will be affected in a changed climate.

Two of the tower sites (Rondônia and Pará, see map on page 17) will be classified as intensive field measurement sites (i.e. primary research areas) where there will be a concentration of process studies aimed at understanding the effects of land use change on climate, carbon storage and exchange, biogeochemistry and the sustainability of these natural and perturbed land use systems under changed climatic conditions. While studies in Pará will be more focused around such ecological questions, at the Rondônia site a mesoscale field study will also be carried out to investigate the mechanisms linking changes in land use and climate, by addressing the following questions:

- *What are the mesoscale mechanisms by which differences in surface characteristics translate into large-scale weather and climate anomalies?*





The annual change in rainfall (mm per day) predicted by the Hadley Centre Global Circulation Model, if the entire Amazon forest was replaced by pasture. LBA will provide data to improve such models (source: Hadley Centre, 1994).

- *What is the role of dry and moist convection in transferring energy and how will it change with different land use patterns?*

To address the question of interactions of the heterogeneous land cover with the lower atmosphere and the climate at mesoscale ( $10^2$ - $10^4$  km<sup>2</sup>), measurements of the fluxes from areas of forest, regrowth and pasture will be made at the Rondônia site and scaled up to the whole mesoscale domain. During two short campaigns this basic surface network will be augmented by an array of radiosonde stations, aircraft observations (including dropsondes and measurements of radiative transfer), and ground-based boundary layer sounding, including tethered balloons. Aircraft will be used to measure the area-aggregate fluxes, and to assess the representativeness of the flux measuring sites. Remote sensing will be used to provide information on surface radiative fluxes, precipitation, and surface characteristics within the mesoscale domain. Mesoscale meteorological models, with grid sizes down to a kilometre or less, will then be used to investigate the behaviour of the atmospheric boundary layer, atmospheric circulations and cloud formation, and how these may

combine to produce different climates over the undisturbed and cleared forest areas.

Moist convection is the main route by which water, energy and trace constituents move from the surface layer of the atmosphere into the troposphere. Much of the impact of changes in land use on rainfall and climate is expected to occur through changes in the intensity and frequency of convective storms. There is at present no data set of tropical moist convection over land. Thus the measurements, particularly from the wet season campaign, will be of great value for validating the cloud and convection schemes of all Global Circulation Models. A site will be established in Rondônia where a rain gauge network and radar will be used to validate estimates of rainfall made with the TRMM satellite.



## The LBA concise experimental plan

### 4-Dimensional Data Assimilation

An operational, 4-Dimensional Data Assimilation and modelling system (4DDA) will be further developed, and implemented for Amazonia and the surrounding regions over a continuous period of several years and used in combination with General Circulation Models to provide an answer to the following questions regarding the large-scale (continental and global) climate processes:

- *How is the rainfall of Amazonia controlled by the large-scale land-surface-atmosphere interaction? Which areas within Amazonia have the most influence on rainfall and how does this vary in time?*
- *What is the relative importance of Amazonia in generating its own climate compared to the role of external planetary-scale forcing, and conversely what is the influence of Amazonia on global climate?*
- *How will the climate of Amazonia change in response to changes in land use and global climate forcing?*

The basic input data will be provided by the operational meteorological network, which will be enhanced to meet the needs of LBA. LBA surface and aircraft data observations will be used for validating the 4-Dimensional Data Assimilation products, which will also include modelled river flow from a coupled macro-hydrological model. The system will produce time series of surface and atmospheric data on a 40 km grid.

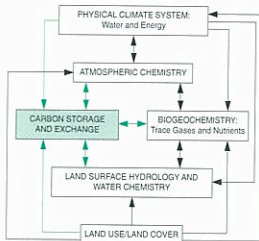
Previous modelling studies with Global Circulation Models have suggested that large scale changes in Amazonian land surface cover may affect the regional climate (figure on the previous page). Sensitivity studies with these models have shown that realistic descriptions of the land surface are critical to these results. For example, the predicted climatic effects of large scale deforestation can be highly dependent on albedo, surface roughness or soil hydraulic properties. The spatial variation of these and other properties are not well established for Amazonia.

The information and insight derived from the diagnostic studies and from model simulations will be applied to evaluate the impact on Amazonia of climate variability and change, both natural and anthropogenic, particularly as it affects the water resources and their critical role in maintaining the ecological balance at regional and global levels. Also the improved understanding of the physical climate processes, as well as the better surface and atmospheric datasets, will serve to improve the predictive capability of current weather forecast models for Amazonia.

### Global Circulation Models: sensitive to land surface cover

### Climate change impacts

## Science themes



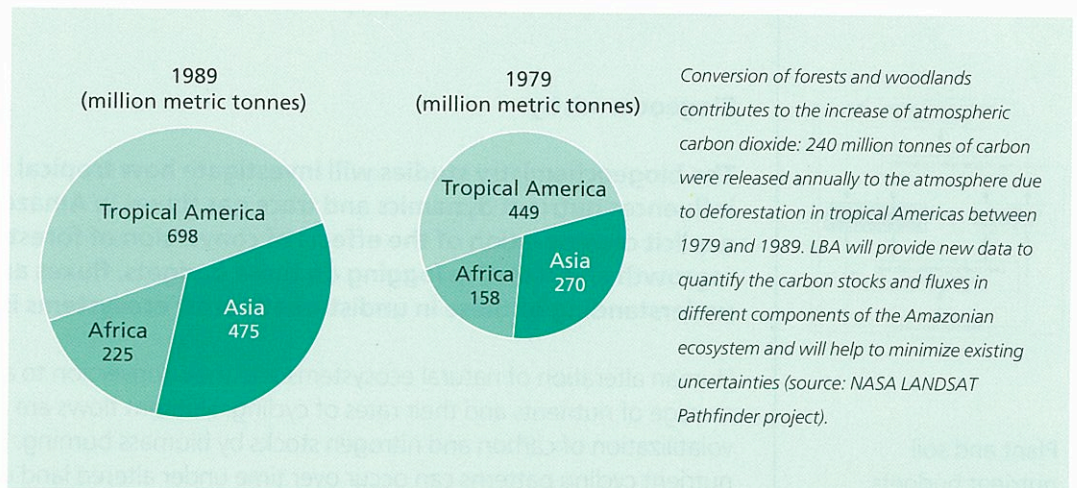
## Carbon cycling

### Carbon Storage and Exchange

**Amazonia constitutes a large global store of carbon. Forest conversion in Amazonia is a net source of carbon to the atmosphere, while recent measurements indicate that undisturbed forest systems may be a net carbon sink. The importance of sequestration of carbon in regrowing forest on abandoned lands is unclear. These issues represent uncertainties in the global carbon balance and may influence the carbon dioxide concentration of the atmosphere and thus interact with the climate system.**

Changes in carbon stocks occur when there is change in land use or land cover (e.g. fire, clearing, logging, planting and regrowth) but also result from changes in the balance between photosynthesis and respiration occurring as a result of variations in physical and chemical conditions. Studies are required to determine both the areal extent of different land uses and the associated changes in carbon fluxes and stocks. These issues lead to the following questions:

- *How will changes in land use affect the net carbon balance between terrestrial ecosystems and the atmosphere, and do undisturbed forest ecosystems function as net carbon sinks?*
- *What are the sizes of the carbon pools in the vegetation and soils of intact, secondary and selectively-logged forests, savannas, and agricultural lands? What are the net rates of carbon exchange between the atmosphere, vegetation and soil, and how are the size of the pools and the rates of exchange altered by natural and human disturbances?*





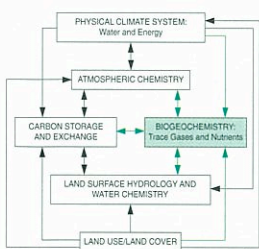
## The LBA concise experimental plan

### Measurements of carbon stocks and of carbon exchanges

These will be addressed with two approaches: an inventory approach that tracks the areal extent of different land covers and the associated carbon pools in vegetation and soil, and direct determination of the balance between photosynthesis and respiration using CO<sub>2</sub> measurements under a range of conditions at key sites. The carbon stocks in vegetation and soils per area of various land use types are still major uncertainties. Within major vegetation type, carbon stocks should be measured along regional gradients of land use intensity and climate from humid tropical forest to cerrado. To elucidate seasonal and inter-annual variability, and sensitivity of carbon exchange to climatological variables, eddy-covariance systems will be operated (near-) continuously for several years in coordination with the experiments serving the Physical Climate component of LBA. Supporting measurements of canopy structure, in-canopy concentrations and fluxes, and soil respiration will be required. Flux data will be related to climate and vegetational structure through the use of models incorporating biochemical, physiological and micrometeorological components.

### Scaling up through models and GIS

Information generated through these activities will be used to scale up to regional and basin levels. Use will be made of process models and geographic information systems (GIS). Short time scale calculations of carbon fluxes, consistent with the calculated water and energy exchanges, will be made by calibrated biosphere-atmosphere models. The Centro de Previsão de Tempo e Estudos Climáticos (CPTEC) mesoscale meteorological forecast model will be upgraded with simulation routines for horizontal and vertical transport of CO<sub>2</sub> and other atmospheric species. The 4-Dimensional Data Assimilation products of this model, validated by aircraft and in situ measurements, will be used to quantify the atmospheric carbon budget over most of South America. Sensitivity experiments with Global Circulation Models will be used to investigate how the large scale carbon balance will change in response to different land use and global warming scenarios, and how feedback will amplify or reduce the expected rate of increase in atmospheric CO<sub>2</sub>.



### Plant and soil nutrient budgets

## Biogeochemistry

**The biogeochemistry studies will investigate how tropical forest conversion influences nutrient dynamics and trace gas fluxes in Amazonia. This calls for an explicit consideration of the effects of conversion of forest to agricultural uses, regrowth and selective logging on these budgets, fluxes and exchanges. Implicitly, understanding of these in undisturbed forest ecosystems is also required.**

Human alteration of natural ecosystems and their conversion to agriculture changes the storage of nutrients and their rates of cycling. Nutrient flows are also altered by direct volatilization of carbon and nitrogen stocks by biomass burning. Further modifications to nutrient cycling patterns can occur over time under altered land use, such as when pastures



## Science themes



age or degrade. These changes have implications for carbon balances, trace gas fluxes and surface water chemistry and are likely to be the main factors limiting the sustainability of the altered ecosystem. The central question thus is:

- *How do the stocks, cycling rates and budgets of nitrogen, phosphorus, potassium, calcium, magnesium and aluminium change under the different land covers and land uses and how does this affect the sustainability of agricultural productivity and the rates of regrowth and carbon accumulation in abandoned pastures and regrowing, secondary forests?*

### Agricultural productivity

Studies of the effects of land use change on plant and soil nutrient dynamics will examine nutrient pools and cycling rates in the same suite of land use types as in the Carbon Storage and Exchange component. The ways in which nitrogen and phosphorus cycles are altered by human disturbance are of major interest. Total stocks of nitrogen, phosphorus, potassium, calcium, magnesium and aluminium in soils, vegetation and harvested materials will be measured. The cycling of these nutrients between soils and vegetation, and the losses of these nutrients through aquatic and gaseous export will be determined. The role of phosphorus and other nutrients in controlling pasture productivity and forest regrowth will be assessed across the transects mentioned before.

### Trace gas fluxes

Upland soils, wetland soils and sediments, and the vegetation of Amazonia all exchange significant quantities of trace gases with the atmosphere. These three sources have different controls that may be altered by land use change. LBA will focus on quantification of the fluxes between the land and the atmosphere and on determination of how various factors control these fluxes. First priority will be given to nitrogen oxides and methane for which natural and managed systems in Amazonia constitute a significant global source. Second priority will be given to carbon monoxide, volatile organic carbon compounds, and reduced sulphur gases.

Trace gases of interest are those that are important to the radiative properties of the troposphere (e.g. nitrous oxide and the reduced sulphur gases), those which regulate the oxidant balance (e.g. carbon monoxide, nitric oxide, nitrogen dioxide, and volatile organic carbon gases), and methane which has both functions. The research questions are:



## The LBA concise experimental plan

### Measurements through enclosure and micrometeorological methods

- *What are the fluxes of trace gases between the atmosphere and ecosystems (both uplands and wetlands) for Amazonia? How are these fluxes, with special emphasis on nitrogen oxides and methane, affected by land use change? How does land use change affect the oxidant balance in Amazonia?*

Trace gas fluxes will be measured at various points along the gradients in land use intensity and ecoclimatic conditions. Enclosures and micrometeorological methods are the two major categories of approaches for the study of biosphere-atmosphere trace gas exchange. Enclosures allow for rapid measurements of long-lived and reactive trace gases in small areas which make experimental manipulations technically and economically feasible. Micrometeorological methods will be applied from a variety of platforms such as towers, tethered balloons, and aircraft. On a larger scale, budget studies may be possible using atmospheric transport models and ground- or aircraft-based measurements. Studies should be made of the underlying gradients of natural controls, including total precipitation and drought intensity, vegetation associations, soil type and fertility, drainage and topography. Ecosystem models will be used to predict trace gas production and emission.

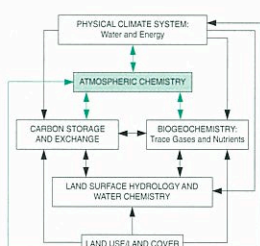
## Atmospheric Chemistry

**The atmospheric chemistry component will provide a foundation of knowledge to determine the exchange of greenhouse gases, oxidants, and aerosols between Amazonia and the global atmosphere, to understand the relevant processes, and to assess the related implications of rapid development in the region.**

The Climate Convention requires each nation to determine the contributions of its natural and industrial emissions to the global atmospheric inventories of greenhouse gases, aerosols, and oxidants. Amazonia is thought to contribute a major source (and in some cases a sink) of many important species including  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ,  $\text{O}_3$ , nitrogen oxides,  $\text{CO}$ , non-methane hydrocarbons,  $\text{NH}_3$ , and organic particles. This contribution is expected to be greatly affected by human activity over the next decades as a result of deforestation, land-use change, biomass burning, and colonization. We need to understand how unperturbed Amazonian ecosystems interact with the atmosphere and how anthropogenic perturbations may modify these interactions now and in the future.

The experimental plan for the atmospheric chemistry component of LBA is designed to achieve this understanding. It involves a combination of long-term ground-based measurements and intensive two-month aircraft campaigns, as illustrated in the figure on the next page. The observations will be used to address the following key questions:

### Emission assessments



## Science themes

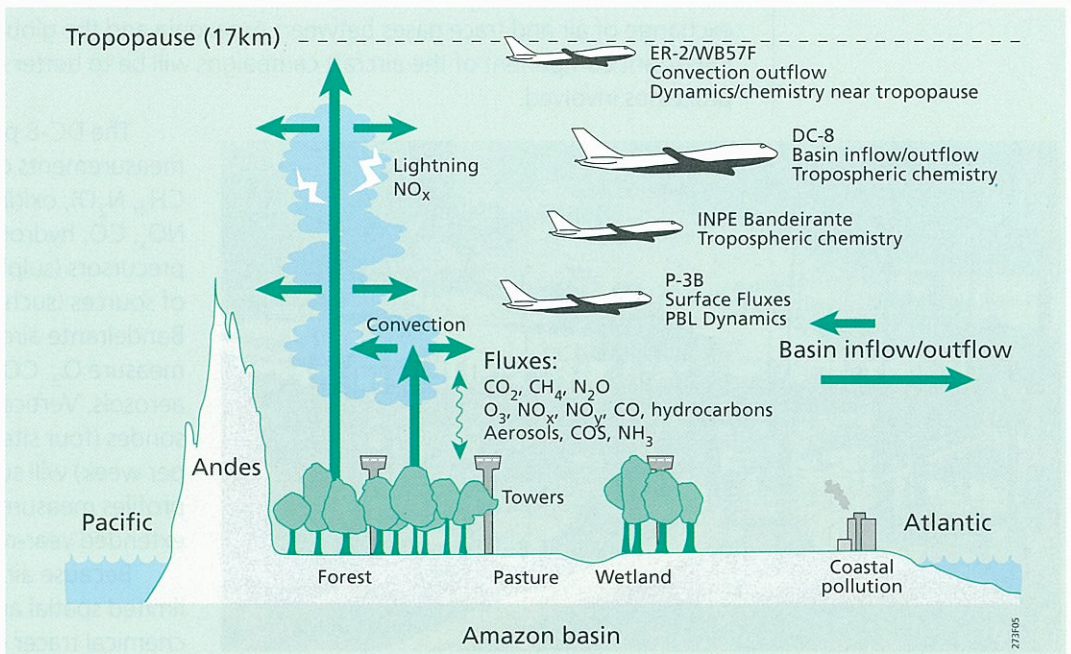
- *What are the biosphere-atmosphere fluxes of greenhouse gases, oxidants, and aerosols (including their precursors) over the range of ecosystems in Amazonia?*

### Ground based observation network

A network of 2-6 ground-based sites will be established for long-term observations of atmospheric chemistry and biosphere-atmosphere exchange. Concentrations and fluxes of  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ,  $\text{O}_3$ ,  $\text{CO}$ ,  $\text{NO}_x$ , non-methane hydrocarbons, reactive sulphur gases, and aerosol particles will be measured at the smallest scales using chamber methods and at landscape-scale using towers. Flux measurements will emphasize direct (e.g. eddy correlation or eddy accumulation) observations of accessible species ( $\text{CO}_2$ ,  $\text{O}_3$ ,  $\text{NO}_x$ ,  $\text{NO}_y$ ) with similarity approaches for other gases (e.g.  $\text{N}_2\text{O}$ ,  $\text{CO}$ , non-methane hydrocarbons, sulphur gases) designed to gain leverage from, and be calibrated by, the direct flux measurements. Measurements will continue for several years to define episodic, seasonal, and inter-annual variations of trace species. The sites will be strategically located along ecological and climatological gradients, and will coincide with flux towers installed for the Carbon and Biogeochemistry components of LBA.

### Airborne flux observations

The long-term tower measurements will be supplemented during the aircraft campaigns by Basin-scale surveys of biosphere-atmosphere fluxes using the NASA P-3B aircraft. The P-3B will be equipped with micrometeorological instrumentation for eddy correlation or accumulation flux measurements of  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{H}_2\text{O}$ ,  $\text{O}_3$ ,  $\text{CO}$ , along with possibly  $\text{N}_2\text{O}$ ,  $\text{NO}_x$ ,



Range of measurements which will be set up for LBA - Atmospheric Chemistry experiment (source: TRACE-B).



## The LBA concise experimental plan

### Vertical profiles

hydrocarbons, and aerosols. Momentum and sensible heat fluxes will also be measured. These aircraft observations are complemented by flux measurements from the tower measurement network of the Physical Climate and Biogeochemistry components. The aircraft payload will further include aerosol and ozone lidar monitors to document the vertical structure of the planetary boundary layer. A number of additional chemical species will be measured aboard the aircraft including hydrocarbons, halocarbons (tracers of industrial influence), aerosol size distribution and composition, and  $^{222}\text{Rn}$  (tracer of land- surface air). The flight tracks will be designed to cover a range of natural and disturbed environments, and will be closely coordinated with the tower observations.

- *What are the net export fluxes of greenhouse gases, oxidants, and aerosols from Amazonia to the global atmosphere?*

### Airborne concentration measurements

Measurements from the NASA DC-8, NASA P-3B, and INPE Bandeirante aircraft will be used to determine the concentrations of trace species over Amazonia and, in combination with the CPTec 4DDA model, the flux of these species across the Basin boundaries. Participation of a fourth, higher-flying aircraft (the NASA ER-2 or the NSF WB57F) will be sought to explore the tropopause region. CPTec will support the day-to-day aircraft operations through weather forecasts. These forecasts will be of great importance in identifying regions of inflow/outflow across the boundaries of Amazonia. Deep convection plays a critical role in determining the exchange of air and trace gases between Amazonia and the global atmosphere, and an important component of the aircraft campaigns will be to better understand the dynamical processes involved.

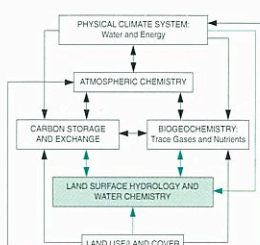


The DC-8 payload will include measurements of greenhouse gases ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ), oxidants and precursors ( $\text{O}_3$ ,  $\text{OH}$ ,  $\text{NO}_x$ ,  $\text{CO}$ , hydrocarbons), aerosols and precursors (sulphur species,  $\text{NH}_3$ ), and tracers of sources (such as halocarbons,  $^{222}\text{Rn}$ ). The Bandeirante aircraft will be equipped to measure  $\text{O}_3$ ,  $\text{CO}$ ,  $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{N}_2\text{O}$ , and aerosols. Vertical  $\text{O}_3$  profiles from ozone sondes (four sites in Amazonia, three sondes per week) will supplement the vertical profiles measured from aircraft and can be extended year-round.

Because aircraft campaigns offer only limited spatial and temporal coverage, 3-D chemical tracer models will be essential to



## Atmospheric chemistry modelling



## Science themes

quantify trace species fluxes across the boundaries of Amazonia. These models will use assimilated meteorological observations (e.g., from CPTC) and include a chemical simulation capability. Observed biosphere-atmosphere fluxes will provide surface boundary conditions. Simulation of species concentrations measured aboard the aircraft will serve to test and refine the models. In addition to their importance for post-campaign data interpretation, the models will play a key role in pre-campaign planning by identifying prominent transport patterns and chemical gradients that will require investigation by the aircraft.

## Land Surface Hydrology and Water Chemistry

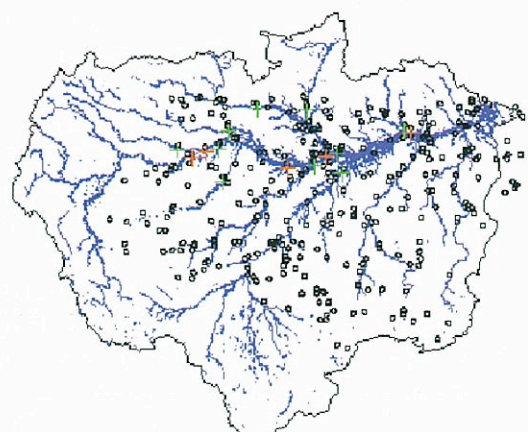
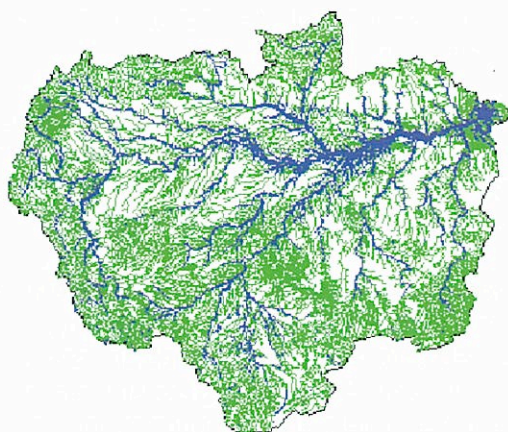
**Amazonia is a region with an abundance of water and the world's largest river system with its associated areas of periodically inundated land. Land-use changes will result in significant alterations in the flow of water, the sediment transport and the chemistry of the region's river systems.**

The hydrology component will study the quantity and quality of water as it moves through the land phase of the hydrological cycle. The hydrological response of the Amazon basin to changes in land use and climate will be established. Four science questions will be addressed:

- *What would be the response in the volume and timing of flow in the River Amazon to the changes in climate, particularly rainfall and evaporation, as predicted by Global Circulation Models, or which may occur as a result of large scale change in land use?*

River routing schemes will be developed to reproduce the flow at all places along the Amazon

*River and gauging network within the Brazilian Amazon catchment (operated by DNAEE: Departamento Nacional de Águas e Energia Elétrica).*





## The LBA concise experimental plan

### Basin-wide river routing

and its tributaries. This will require improvements of existing digital elevation maps of Amazonia. The schemes will be used to route the runoff predicted by Global Circulation Models through the basin. The routing schemes (map on previous page) will also be used in combination with a basin wide hydrological model to estimate evaporation as the difference between precipitation and runoff plus changes in soil water storage. These estimates will be used to validate the large scale meteorological models and the sub-models within them. The consequences of large scale land use change and climate change on the hydrology of the Amazon will be explored by coupling a basin wide hydrological model to a Global Circulation Model.

- *What are the water stores and fluxes, and the controls on water movement and transport of constituents on and below the surface of small uniform basins? How does change of land use affect the sustainability of the ecosystem for different soil types and topographies, and how can the larger scale models be improved to represent these small scale processes?*

### Paired catchment studies

Forested and deforested catchments of several square kilometres will be instrumented to make measurements with high temporal resolution of discharge, rainfall, evaporation, interception, changes in soil-water storage, groundwater leakages, and sediment yield and transport. Runoff and evaporation will be modelled using high resolution distributed process-based hydrological and hydrochemical models, which take account of the topographic influence on the export of nutrients and sediment. The models will be driven with data from stations, located within the basins, which form part of the large-scale network of surface weather and flux stations. Because the headwaters of the Amazon play an important role in defining its sediment load and biogeochemistry, two of these small basins will be located in the Andes: one forested, the other deforested. Another two will be located within larger scale catchments ( $10^2$ - $10^5$  km<sup>2</sup>), one forested, the other deforested, which are part of the Rondônia mesoscale field study.

- *What are the spatial and temporal patterns of surface and sub-surface water storage and flux in the soils and river corridors of the Amazon Basin, and how are they influenced by variations in climate and land use? What are the characteristics of soil moisture and river flow for mesoscale basins and how can they be predicted?*

### Nested drainage basin approach

A nested drainage basin approach will be used as an interpretative framework for distributed land surface hydrological models with different "overlapping" spatial resolutions, applied to small, uniform basins ( $\sim 10$  km<sup>2</sup>), a large mixed landscape basin ( $10^3$ - $10^5$  km<sup>2</sup>) and the entire Amazon river system ( $\sim 10^7$  km<sup>2</sup>). Mountain and lowland mesoscale drainage basins ( $10^2$ - $10^5$  km<sup>2</sup>) will also be studied. These will be large enough to contain a variety of soil types and land

## Science themes

### Soil hydrology

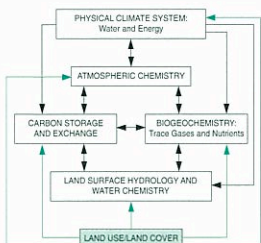
uses, but small enough to be strongly impacted by land use change. Although the soils of much of Amazonia are relatively well surveyed at a coarse scale, soil mapping needs to be improved for much of Amazonia. Important hydraulic properties for the various soil classes are not well known. Field measurements will be made to determine these parameters for the major classes across Amazonia. To predict flow processes in basins of this size requires parameterization of the spatial heterogeneity in the soil, topography, land cover, and rainfall. A distributed modelling approach will be used to reproduce the soils, topography, or rainstorm distribution so that the land use effect can be isolated. The models will be validated against runoff measurements and then be used for investigating other scenarios of land use or climate.

### Nutrient transport to wetlands and streams

Studies of the dynamics of surface water chemistry will focus on the ways in which surface water chemistry is altered by changes in land cover and land use. Changes in the dynamics of carbon, nitrogen, and phosphorus in riparian zones and streams are of particular interest. Because the river corridors of a region express the integrated interaction of hydrological processes and the land surface, understanding how the organic matter and nutrient composition of river corridors respond to forest conversion is an essential precursor to assessing the impact of land use change on the ecological functioning and sustainability of the region.

- *How do the pathways and fluxes of organic matter, nutrients and associated elements through river corridors (riparian, floodplain, channels and wetlands) change as a function of land cover?*

Two major approaches will be used to study how changes in land cover affect surface water chemistry. The first is the study of lower order streams which examines controls on the movement of material from uplands through the riparian zone and into streams. These low order streams will drain catchments with different land uses. The second approach is modelling element budgets at the larger scale. This modelling activity will combine process models developed from the low order stream studies with extant models of higher order river biogeochemistry and the models of hydrological routing mentioned before.



## Land Use and Land Cover Change

**The predictions of future changes in the functioning of Amazonia rely on quantitative forecasts of the rates of change and spatial patterns of future land-cover, and our predictive understanding of the land-use practices that drive these changes.**



## The LBA concise experimental plan

### Remote sensing of land cover

The conversion of closed-canopy forests to agricultural fields can be (and is routinely) estimated using existing techniques, but statistics on other land-cover changes such as selective logging, the conversion of cerrado vegetation to agriculture, and the abandonment and regrowth of forests are not available, although with some additional research investment satellite imagery might be used to distinguish between these categories.

The Land Use and Land Cover component will address the following questions:

- *What are the rates and mechanisms of forest conversion to agricultural land uses, and what is the relative importance of these land uses?*
- *At what rate are converted lands abandoned, what is the fate of these abandoned lands, and what are the overall dynamic patterns of land conversion and abandonment?*
- *What area of forest is affected by selective logging each year?*
- *What are plausible scenarios of future land cover change in Amazonia?*

### Multi-scale investigations of land use dynamics

Three scales of investigation will be used. Firstly, Amazonia-wide studies of the rate, location and spatial pattern of deforestation and forest alteration will be conducted using satellite remote sensing, government statistics, and survey data. At a second level, case studies and field investigations will be carried out in conjunction with multi-temporal, high-resolution satellite data to determine the local-scale dynamics of deforestation, abandonment, and second-growth turnover. These case-study analyses will use data from census documents and



from new surveys to define the parameters that control local land use strategies, which will in turn illustrate how changes in land use affect changes in land cover. Because the causes of deforestation are also related to external institutional and economic factors, an explanation of driving forces cannot be made with satellite data, surveys, and field studies alone. To develop a predictive model of land cover and land use changes, a third level of analysis will be necessary to define the socioeconomic factors and conditions that are creating these changes.

## THE ROLE OF REMOTE SENSING

**The themes described in this plan pose questions that require mesoscale and basin-wide georeferenced fields and maps of land cover, biophysical, meteorological and atmospheric quantities. Most of these can only be obtained through the use of concurrent and retrospective satellite and aircraft remote sensing data.**

Many of the same types of data are required by different investigations, albeit in different locations and at different scales. Thus the remote sensing activities in LBA will be driven by the science issues but coordinated within LBA to ensure acquisition, archiving and timely distribution of data to investigators.

Remote sensing permits integration of information and processes pertinent to ecosystem-atmosphere exchanges of carbon, trace gases, water and energy, across a broad range of geographic scales. Links between remote sensing data and key variables and parameters of atmosphere and land surface will be established and validated at local scales, where extensive ground observations are practical. A combination of remote sensing, mesoscale modelling and other spatial integration techniques will permit an extension of this knowledge to other geographic scales. Furthermore satellite data have the stability needed for long-term monitoring of these variables at a wide range of temporal frequencies.

The temporal and spatial scope of satellite data provides a unique tool that can be used to study the dynamics of vegetation communities (disturbance, succession, fire, etc.) over a wide range of scales.

Remote sensing will help to place the intensive study sites in their correct ecoclimatological and geographic context. This is important to enable optimization of the field sampling design at basin-wide and more local scales and will be necessary for correct interpretation of research results.

Finally, because biomass burning is an extremely important issue in Amazonia, remote sensing will be used to monitor the frequency of occurrence and extent of fires and subsequent distribution of atmospheric aerosols.

Over the past few years great strides have been made in remote sensing algorithms, however extensive testing and development is needed to validate these for conditions specific to Amazonia. This applies to radiative transfer modelling. It applies to algorithms to identify certain types of land cover unique to Amazonia, including forest regrowth stages. Further development is also needed for algorithms to process active and passive microwave sensor images that will be required to deal with the ubiquitous cloud cover and seasonal smoke from biomass burning, and to algorithms to retrieve atmospheric profiles of temperature and water vapour, cloud properties and precipitation.

A broad constellation of satellites will add to existing archives during LBA, including

Spatial and temporal integration

Monitoring of land use dynamics

Optimization of field sampling design

Fire monitoring

Algorithm development and refinement



## The LBA concise experimental plan

### Multiple air- and space borne platforms and sensors

Landsat 7, SPOT, ERS, JERS, RADARSAT, ADEOS, ENVISAT and CBERS, as well as the EOS platform and TRMM. Remote sensing technique development can contribute to the scientific aims of LBA to allow LBA to benefit from the enhanced capabilities of new sensors and algorithms while, at the same time, validating the new sensor products and algorithms. Aircraft will provide an additional platform from which higher spatial resolution data will be acquired.

LBA will maintain close contacts with national and state agencies concerned with planning to benefit from their local knowledge, existing remotely sensed and GIS data sets and to engage them in the interpretation of relevant LBA results to support sustainable management of the resources of Amazonia.



*Deforestation and land use patterns typical of cattle ranches around Pará. This structure of the land-surface cover leads to an aggregation problem in linking the land-surface and atmospheric processes that is qualitatively different from the one depicted on page 20 (source: NASA LANDSAT Pathfinder project).*



## Organization and management

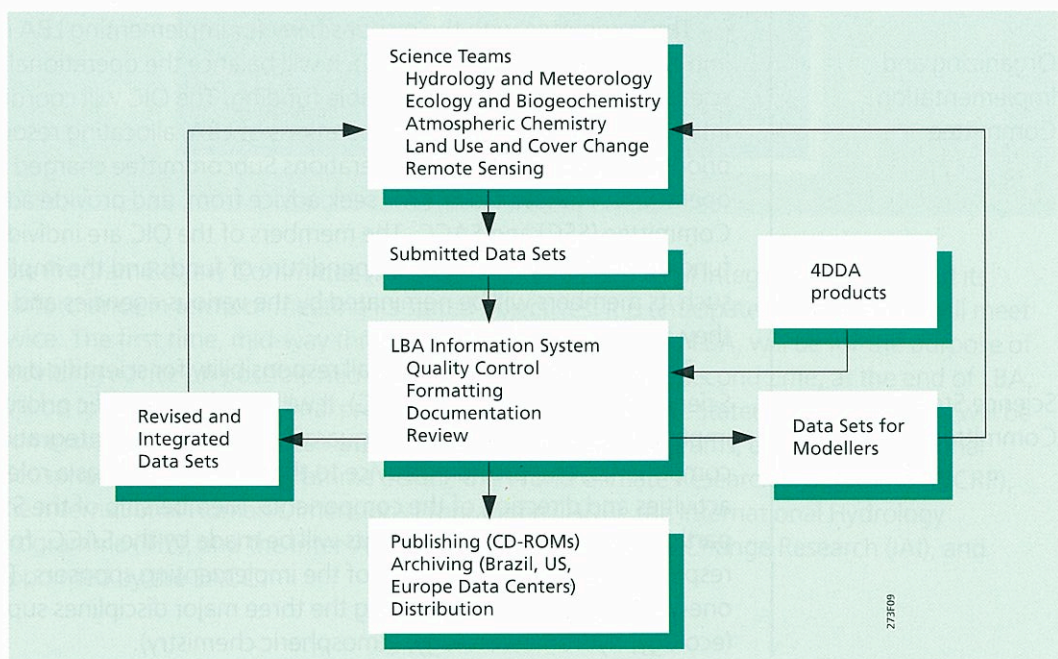
### ORGANIZATION AND MANAGEMENT

#### Data management

**A data management system will be created to act as a repository for all the LBA data. It will include already existing data and all the new satellite, aircraft, and ground-based data from the individual science teams.**

All data gathered under contributing initiatives to LBA will be made available to all other contributors to LBA as soon as possible but at least within no more than two years of the date of their original collection. By the end of the project all data will be in the public domain. LBA will produce a large and complex data set. A data management system will therefore be created based on templates successfully deployed in some of the past land surface - biosphere - atmosphere experiments. This will ensure a timely compilation with a minimum investment in time and effort. The database will act as a repository for all the LBA data, including satellite data, 4DDA data and data from the individual science teams. The data will be quality checked, rendered to a common format, and made available to the LBA community as rapidly as possible and eventually transferred to a permanent archive. To facilitate use by non-LBA

Data sharing,  
exchange and quality  
assessment



LBA Integrated Data System



## The LBA concise experimental plan

investigators, each data set will be carefully documented and linked in the orderly framework, so that it remains useful after the project has been completed.

A data base of LBA-relevant data collected during numerous previous research experiments in the Amazon is being created. This will facilitate further analysis of LBA results and their extrapolation beyond the LBA time framework.

### Project organization

Initial scientific planning for LBA has been undertaken by a loosely organized, large group of scientists from many disciplines (see box page 40). Starting in 1996, a new organizational structure of LBA will be formalized, encompassing four main committees.

The committee with the lead responsibility for LBA is the South American Coordinating Committee (SACC). It will oversee the conduct of the LBA program and approve plans and implementation actions. It will ensure that any proposed activities under LBA are appropriate to the stated goals, and that they meet the requirements, both programmatic and legal, of working in the LBA campaigns. The SACC provides the highest level of interface with the cooperating governments in South America, and it will solicit the required approvals from these governments. It will consist of individuals from the host countries in South America, and it has the responsibility of appointing all other committees of LBA.

The committee with the responsibility for implementing LBA is the Organizing and Implementation Committee (OIC). It will balance the operational needs, requirements, and scientific priorities with the available funding. The OIC will coordinate the major infrastructural needs and field operations of LBA, allocating resources to meet the overall priorities. It will direct a Field Operations Subcommittee charged with the day-to-day operations. In these tasks it will seek advice from, and provide advice to the Scientific Steering Committee (SSC) and SACC. The members of the OIC are individually responsible to the funding bodies of LBA for the expenditure of funds and the implementation of priorities. As such its members will be nominated by the various agencies and countries funding LBA, and they are appointed by the SACC.

The committee with the overall responsibility for scientific direction and strategies is the Science Steering Committee (SSC). It will develop scientific priorities and experiment plans for implementation in LBA, thereby guaranteeing scientific integration of the various components, and providing advice to the SACC. It also has a role in coordinating the scientific activities and direction of the components. Membership of the SSC will come from selected participants of LBA. Appointments will be made by the SACC, following nominations by responsible officials within each of the implementing sponsors. The chair of the SSC will be a one-year rotating position among the three major disciplines supporting the experiment (ecology, hydrometeorology, atmospheric chemistry).

Pre LBA data archive

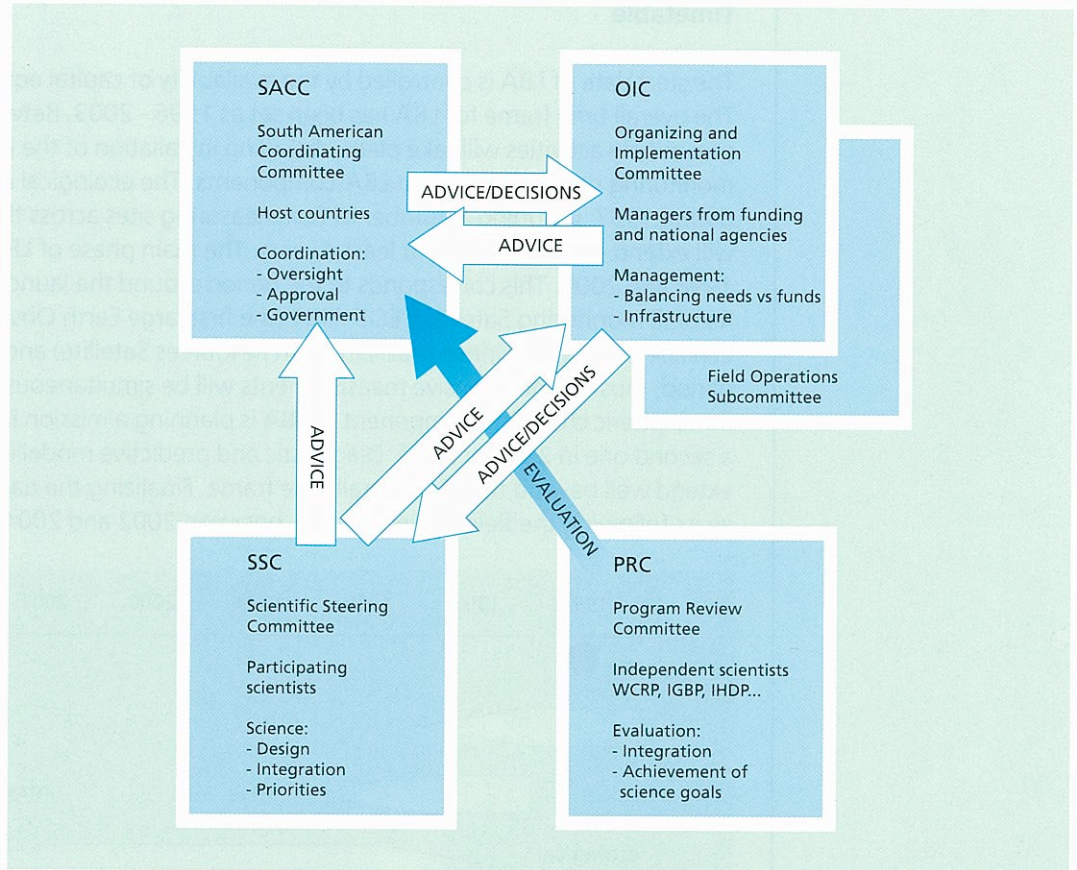
South American  
Coordinating  
Committee

Organizing and  
Implementation  
Committee

Science Steering  
Committee

## Organization and management

LBA management structure



### Program Review Committee

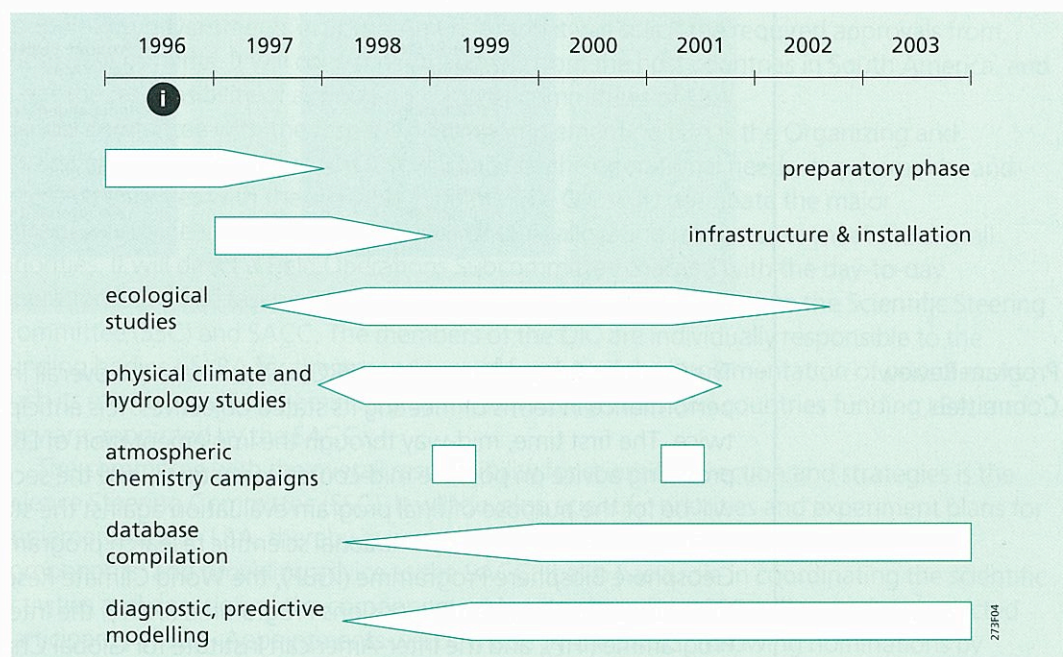
The Program Review Committee (PRC) will evaluate the overall integration of LBA and its performance in terms of meeting its stated objectives. It is anticipated that the PRC will meet twice. The first time, mid-way through the implementation of LBA, will be for the purpose of providing advice on possible mid-course corrections, and the second time, at the end of LBA, will be for the purpose of final program evaluation against the stated goals. Members will be nominated by the major international scientific research programs, e.g. the International Geosphere Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the International Hydrology Programme (IHP), and the Inter-American Institute for Global Change Research (IAI), and appointed by the SACC.



## The LBA concise experimental plan

### Timetable

The start date of LBA is controlled by the availability of capital equipment, people and funds. The overall time frame for LBA has been set as 1996 - 2003. Between 1996 and 1997, several preliminary activities will take place, including installation of the measurement and monitoring networks for most LBA-components. The ecological monitoring is planned to start during 1997, including a number of flux measuring sites across the Amazonian basin, and it will extend over a period of at least 4 years. The main phase of LBA will take place between 1998 and 2000. This corresponds to the period around the launching of the TRMM (Tropical Rainfall Monitoring Satellite), EOS-AM1 (the first large Earth Observing System platform), ENVISAT, CBERS (Chinese-Brazilian Earth Resources Satellite) and Landsat 7. During this period, most of the intensive measurements will be simultaneously deployed in the field. The atmospheric chemistry component of LBA is planning a mission in 1999, possibly followed by a second one in 2001 or 2002. Diagnostic and predictive modelling will start in 1997 and will extend well beyond the LBA-overall time frame. Finalizing the data base is planned for the years following the field campaigns, i.e. between 2002 and 2004.



## Organization and management

### LBA Science Planning Group

Between 1992 and 1995, LBA scientific planning has been undertaken by the *ad hoc* LBA Science Planning Group through a series of meetings and workshops. These have been supported and sponsored by a number of Brazilian institutions, notably the Instituto Nacional de Pesquisas Espaciais (INPE), Instituto Nacional de Pesquisas da Amazônia (INPA) and Universidade de São Paulo (USP), by the International Geosphere Biosphere Programme, Core Project Biospheric Aspects of the Hydrological Cycle (BAHC), by the World Climate Research Programme (WCRP), components Global Energy and Water Cycle Experiment (GEWEX) and International Satellite Land Surface Climatology Project (ISLSCP), by the National Aeronautics and Space Administration (NASA), by the European Union, by the Inter-American Institute for Global Change Research (IAI) and by the United Nations Educational, Scientific and Cultural Organization (UNESCO).



## The LBA concise experimental plan

*During the preparatory phase of LBA the following people have contributed to the LBA scientific planning under the leadership of C.A. Nobre (Centro de Previsão de Tempo e Estudos Climáticos, Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, Brazil)*

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## Notes