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AMAZON BIOGEOCHEMISTRY AND ATMOSPHERIC CHEMISTRY EXPERIMENT (AMBIACE)

The influence of tropical forests (intact, deforested and regrowing) on atmospheric greenhouse gases and on the oxidizing potential of atmosphere: A proposed NASA/INPE cooperative study

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EXECUTIVE SUMMARY

The Amazon Biogeochemistry Experiment (AMBIACE) is proposed as a joint NASA/INPE study in the Amazon Basin to study the consequences of forest conversion, agricultural practice and abandonment, and secondary succession, on regional and global biogeochemistry and atmospheric chemistry. Field experiments, remote sensing observations, and modelling activities will focus on

understanding the ecological processes that regulate biosphere-atmosphere exchange in the tropical moist forest biome;

defining the influence of this biome on global distributions of greenhouse gases (CH_4, N_2O, CO_2);

defining the factors that regulate the oxidizing power of the tropical atmosphere (O_3, CO, non-methane hydrocarbons, NO_x), including biogenic and anthropogenic processes.

The study will integrate measurements of trace gas concentrations with measurements of fluxes at scales ranging from meters to the Amazon Basin. Ecological models of soil nutrient and carbon dynamics, and forest succession will provide the basis for generalizing from intensive studies at roughly a dozen sites, using a "bottom up" approach. Aircraft measurements will provide the basis scaling to the whole Basis using "top down" concepts, and will contribute direct measurements of trace gas concentrations and gradients in the global context. Satellite observations defining land use patterns and trends will be part of the integral design for relating local flux measurements to basin-scale fluxes.

Elements of the experiment will operate over at least a two-year period and the effort will include several missions by low- and high-altitude research aircraft (Electra/P-3/Twin Otter and DC-8 respectively). Intensive studies will be carried out at sites in primary forest, agricultural zones, and regions with extensive secondary succession. Notable features, of the experiment include the long period for ecological and atmospheric studies and the close linkage between cross-cutting observations at spatial scales, from 1 to 10^4 m using four primary techniques: spacecraft, aircraft, eddy-correlation towers, and ground-based ecological studies.

Summary of scientific and experimental design for AMBIACE

The proposed research program focuses on the following scientific issues:

1) Agricultural development in tropical forest areas has been cited as a large net source of CO_2 to the atmosphere. However little is known about the carbon dynamics of tropical soils and almost nothing about carbon accumulation in large areas of secondary vegetation.

2) Atmospheric concentrations of N_2O and CH_4 are increasing rapidly. The tropical forest region represents a globally significant source for both these gases, and is widely believed to dominate current N_2O budgest. Knowledge of the biogeochemistry of these gases is inadequate to define current sources of these gases or to predict how they are affected by forest clearing and associated agricultural development, land abandonment, and ecological succession.

3) The tropical troposphere contains the highest concentrations of OH, making it a dominant region of oxidizing activity of the global atmosphere. Human modification of vegetation and soils can fundamentally modify emission rates for oxides of nitrogen, CO, and hydrocarbons, but the extent of such influence on regional and global scales is not understood.

4) Short-lived reactive chemicals enter the upper troposphere mainly over the tropical continents, due to the localization of deep convection and biogenic emissions in the region. The association of deep convective mixing, intense rainfall, and deep forest canopies

make these regions important sinks for reactive gases such as O_3 and NO_y. The magnitude of these sources and sinks is poorly known, and information is needed to guide development of models for these key processes.

Basic approach

Sites will be selected in two areas of the Amazon Forest with the most agricultural activity, including primary forest, pasture, and abandoned lands in various stages of succession. Within each of these areas a transect will be established to cover a range of amount and seasonality of precipitation. Land use will be defined, monitored, and placed in regional contect using remote-sensing data (primarily LANDSAT via Pathfinder and INPE archives).

Fluxes and distributions of CO_2, CH_4, CO, N_2O, NO_y, non-methane hydrocarbons and reactive sulfur gases will be measured over these areas, at the ground using chamber methods, at landscape scale using tower measurements, and at basin scale using the Electra (or its replacement) or other flux-capable platforms. The DC-8 and INPE aircraft will measure basin-wide and continent-scale concentration distributions, including vertical and continent-ocean gradients. Large-scale atmospheric transport rates will be determined from these data by analysing the measurements the context of a network of radiosonde stations developed by other programs.

Ecological studies will focus on defining the rates for key biological processes and functional relationship with environmental conditions, to elucidate the factors that regulate net rates of exchange of key gases with soils and vegetation. Studies of vegetation and soils should continue for two or more years, and should include studies of areas disturbed by agriculture and timber harvest. Soil studies will be needed to define the nitrogen and carbon cycles for primary vegetation, field succession, degrated (logged) forest, and pasture. The ecological studies can gain leverage from US and Brazilian programs presently underway. Ecological studies on a range of sites will be used to develop and test ecological simulation models, to be combined with satellite-derived and other sources of land use data, to obtain improved estimates for regional fluxes of important gases.

Ground, tower and airborne flux measurements will be combined to test scaling formulas, and to assess large scale gradients (from the sea to the mountains). The recently demonstrated capability for long-term eddy-correlation measurements (Wofsy et al., 1993) will be exploited to resolve key issues in the global cycles of CO_2 and other gases. Airborne flux measurements will play a key role in relating the tower flux data to fluxes on landscapeand basin scales. Flux measurements at all scales will used to test the predictions of ecological models.

MOTIVATION FOR AMBIACE:

INTRODUCTION

Conversion of primary tropical forests to agriculture and/or secondary vegetation represents one of the most profound ecological trends in the present era. Much has been written on the subject, but quantitative, large-scale studies of the effects on the atmosphere are scarce. The proposed study selects landscape suitable to define the influence of disturbance and applies state- of-the-art techniques for making measurements that span relevant spatial and temporal scales (see for example Matson and Vitousek, 1992). The focus on the effects of land and vegetation disturbance and recovery brings in strong component of remotely-sensed observations as well as integrative models for the Amazon region that can be validated or falsified by the proposed process studies and landscape-scale measurements.

In the past decade, several joint US-Brazilian studies improved our understanding of tropical biogeochemistry, tropospheric chemistry, and atmosphere-biosphere exchange. These studies have detected the impacts of human activities on terrestrial vegetation and the influence of vegetation on the composition of the atmosphere. Sophisticated techniques were employed to measure fluxes of H_2O, CO_2, O_3, CH_4, oxides of nitrogen, and heat. A series of NASA-INPE studies (ABLE-2a, b; TRACE-A) developed experimental designs which integrated airborne in situ and LIDAR measurements with carefully coordinated investigations from space and on the ground (including ecological studies and long-term eddy-correlation flux measurements). Here we develop a proposal to extend this experimental paradigm to study the effects of **intact tropical forests, deforestation, logging, agricultural management, and reforestation** on the biogeochemistry of the changing tropical landscape and the effects of the biogeochemical changes on the composition of the atmosphere, including key greenhouse gases (N_2O, CH_4, CO_2) and species regulating the oxidizing potential of the atmosphere (NO_x, CO, hydrocarbons, O_3).

Deforestation in Brazilian Amazon: Rates and Dynamics

Deforestation in the Amazon Basin has occurred primarily in a crescent-shaped area along the eastern and southern edge of the closed canopy forest, particularly in Para (eastern Amazon) and Rondonia (western Amazon). Para has extensive areas of very old secondary growth, including large areas of palm forest resulting from a long history of land use in the area. By contrast, forest regrowth in Rondonia is dominated by stands of successional vegetation on abandoned pastures and cropland; the vegetation is frequently dominated by Cecropia an early pioneer species in the tropics. Unlike the degraded second growth vegetation of the eastern Amazon, these areas are accumulating carbon and turning nitrogen over rapidly.

The total area of deforested land in the Brazilian Amazon has increased from 67 x $10^3 km^2$ to 251 x $10^3 km^2$ in 1988 (Skole and Tucker, 1993). This increase in the total deforested area is the result of an average rate of clearing of 18 x $10^3 km^2 yr^{-1}$. Tropical forest clearing and burning in Brazil has been estimated to result in a net input to the atmosphere of between 0.3 and 0.5 GtC/yr, or approximately 30% of the global biotic net flux.

Most studies of net carbon flux from tropical deforestation have computed carbon release from the net increase in total area deforested over time, effectively assuming no regrowth of forest vegetation. However satellite observations show a highly dynamic pattern of land transformation involving a cycle of deforestation, regrowth, and re-clearing (Skole and Tucker, 1993). Figure 1 shows an example, indicating areas of deforestation in active use, probably as pasture, and areas of once-deforested land in secondary succession. Few studies of CO_2, N_2O, CH_4, NO_x, or other trace gases consider fluxes from secondary vegetation, reflecting the absence of data defining the reforestation rates and associated trace gas biogeochemistry.

Sequential acquisition of satellite data over time makes it possible to determine the land cover history of a site or region. Figure 2 shows the deforested area in 1988 for the entire closed-canopy forest of the Legal Amazon. This map was produced at 1:500,000 scale; here values been summed into a 16 km x 16 km grid mesh for simplicity of display (see insert on Figure).

Data acquired from the French SPOT satellite for a test area in the Brazilian Amazon from 1986 to 1989 documents the amount of secondary growth and the transition rates between forest, agriculture, and successional cover types. In this test area, between 1986 and 1988, new agricultural land came from clearing 4.12 x 10^3 ha/yr of primary forest and 1.97 x 10^3 ha/yr of secondary vegetation. Between 1988 and 1989, 8.63 x 10^3 ha/yr of primary forest and 6.21 x 10^3 ha/yr of secondary vegetation was cleared for

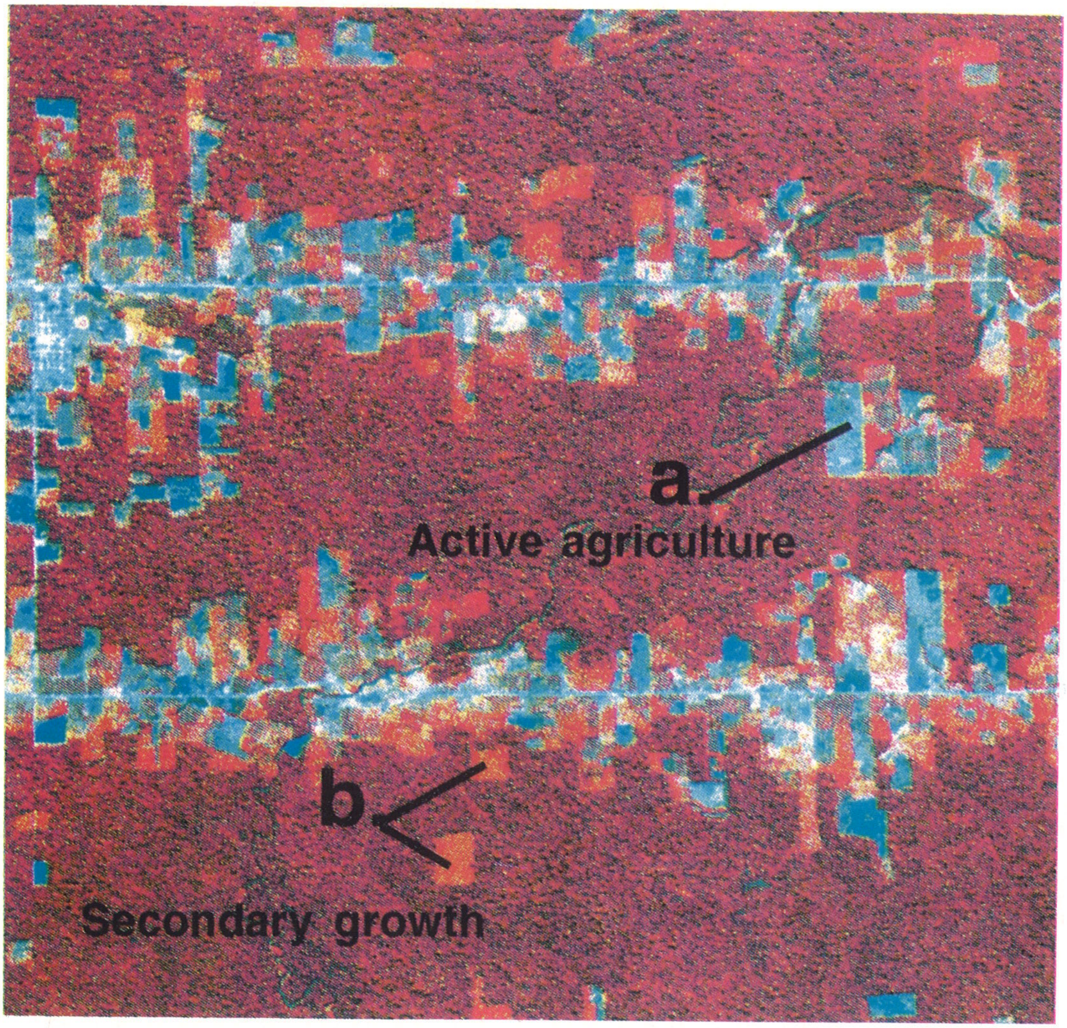

Figure 1. A section from a Spot multispectral image from the test area showing land in active agriculture and secondary growth.

Uma secção de uma imagem multiespectral SPOT de área de teste mostrando terra sob agricultura ativa e crescimento secundário (rebrota).

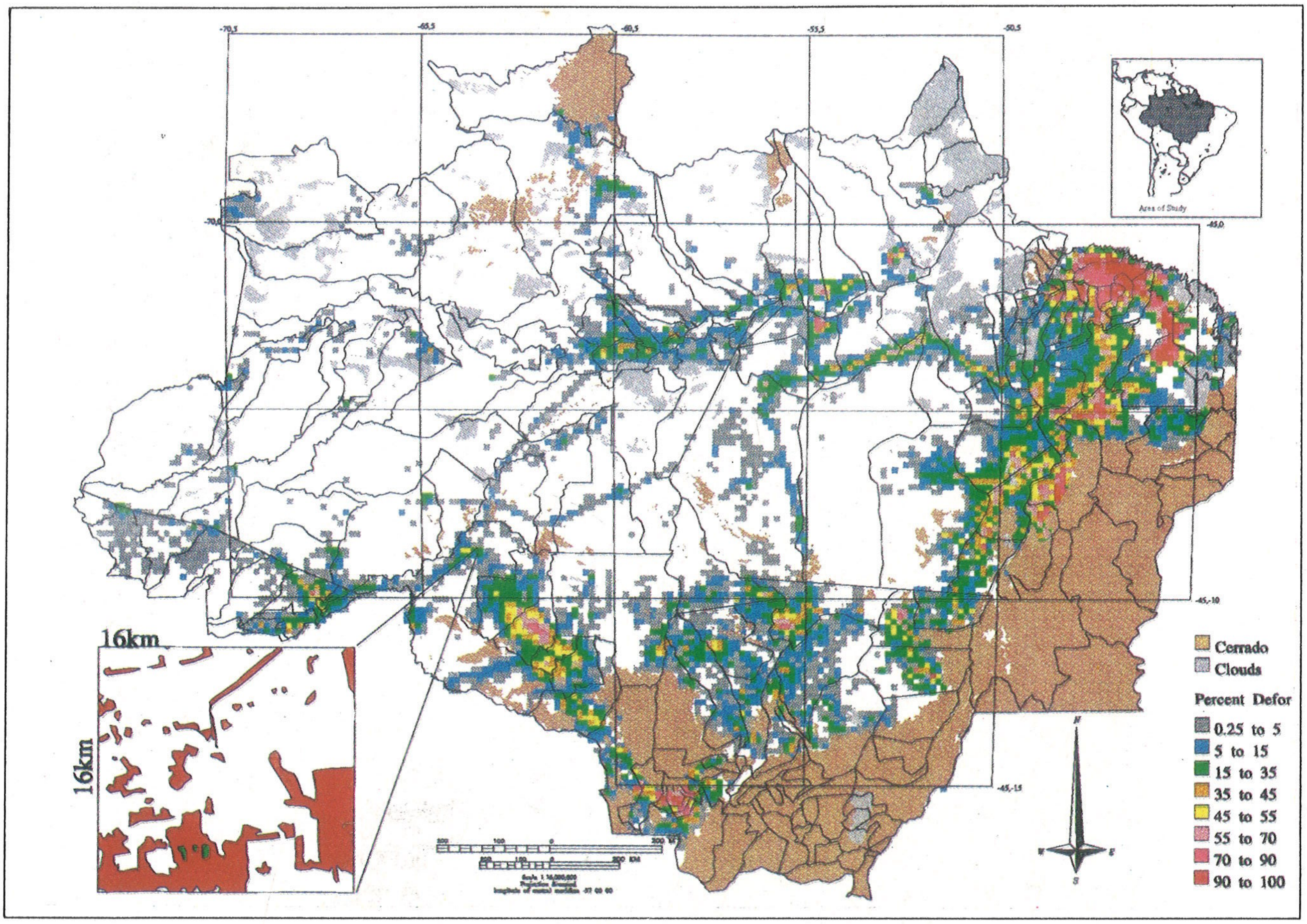

Figure 2. Deforestation in the Brazilian Amazon in 1988 mapped from Landsat TM data. The vector dataset has been gridded for simplicity of display. As shown on the legend, each color represents a deforestation density, expressed as a percentage of the grid cell. The inset shows detail from the vector dataset.

Desflorestamentos na Amazônia Brasileira em 1988 obtidos de imagens Landsat TM. O banco de dados, na forma vetorial, foi dividido em grade por simplicidade visual. Como se mostra na legenda, cada densidade de sombra representa uma densidade de desflorestamento, expressa como uma porcentagem da célula de grade. O segmento inserido mostra o detalhe do banco de dados.

agriculture. The results are consistent with the presence of large areas of secondary vegetation (Skole et al., 1994). A large amount of natural forest was partially cleared or degreded, 1.54 x 10^3 ha/yr between 1986 and 1988 and 5.29 x 10^3 ha/yr between 1988 and 1989. This degradation, or thinning, is different from complete clearing for agriculture. It can be seen in the satellite imagery and has been verified in the field. Degradation (e.g. by logging) represents a transformation to second growth, since the forest will subsequently aggrade. Degradation of primary forest represented 27% of all primary forest conversions each year between 1986 and 1988, increasing to 38% between 1988 and 1989.

Abandonment of agricultural land is an important land cover transition. About 11% of agricultural land was abandoned each year between 1986 and 1988, but between 1988 and 1989 (a period with a two-fold increase in forest clearing), 22% (!) of the cleared land was abandoned annually. Abandonment rates were 70% of clearing rates from primary forests in 1986-1988, and 83% in 1988-1989 (Figure 3). The average turnover time was only about 5 years. Of the 5.804 x 10^3 total ha, abandoned to secondary growth between 1986 and 1988, 2.596 x 10^3 ha, or 45% was quickly re-cleared during the next two years. The clearing of secondary vegetation is an important source of "new" agricultural land; for instance, between 1988 and 1989 42% of the new agricultural land created was from clearing of secondary growth.

Observations from this preliminary study suggest that the conventional perception of deforestation as a one-way process, replacement of primary forest vegetation with permanent agriculture and pasture, is inaccurate. Secondary vegetation in the Brazilian Amazon represents a potentially large fraction of the total "deforested" area, and forest clearing often affects secondary, rather than primary, vegetation. Consequently current estimates of the net flux of trace gases and carbon associated with deforestation could be significantly in error. Recent studies of pastures in active use indicate that losses of soil carbon may be quite different from the near-100% assumed in models, and this issue also emerges as a major focus for carbon studies.

Effects of land change on biogeochemistry and atmospheric chemistry

The conversion of forest to pastures and other agricultural uses leads not only to the loss of aboveground biomass but to major changes in belowground biology and chemistry. Recent studies using in a tropical forest area outside of the Amazon Basin (the Atlantic Lowlands of Costa Rica) show that belowground carbon derived from forest vegetation is rapidly lost during the first decade after clearing (Veldkamp, in press). The rate at which pasture-derived carbon accumulates depends upon the productivity of the pasture grass species and management issues such as stocking rate.

Mineralization of roots and soil organic matter following clearing leads to large releases of inorganic nitrogen and to significant increases in nitrogen oxide emissions. The period of increased nitrogen availability also depends upon management. Pastures quickly lose nitrogen through gaseous export, leaching, and grazing. Unless this nitrogen is replaced by artificial fertilization or by nitrogen fixing species, pastures become nitrogen poor and nitrogen oxide emissions fall below forest levels (Keller, et al. 1993).

Tropical forests in the global carbon balance

Carbon dioxide is the most intensively studied greenhouse gas. Combustion of fossil fuel releases 5.5 GtC/yr (1 GtC=10^{15} g (Rotty, 1987) to the atmosphere. About half is taken up by the ocean (2.1-2.5 GtC/yr) (Keeling and Schertz, 1992; Quay et al, 1992) and the remainder accumulates in the atmosphere (2.8 GtC/yr; Keeling et al., 1989). Several influential studies have indicated that an addi-

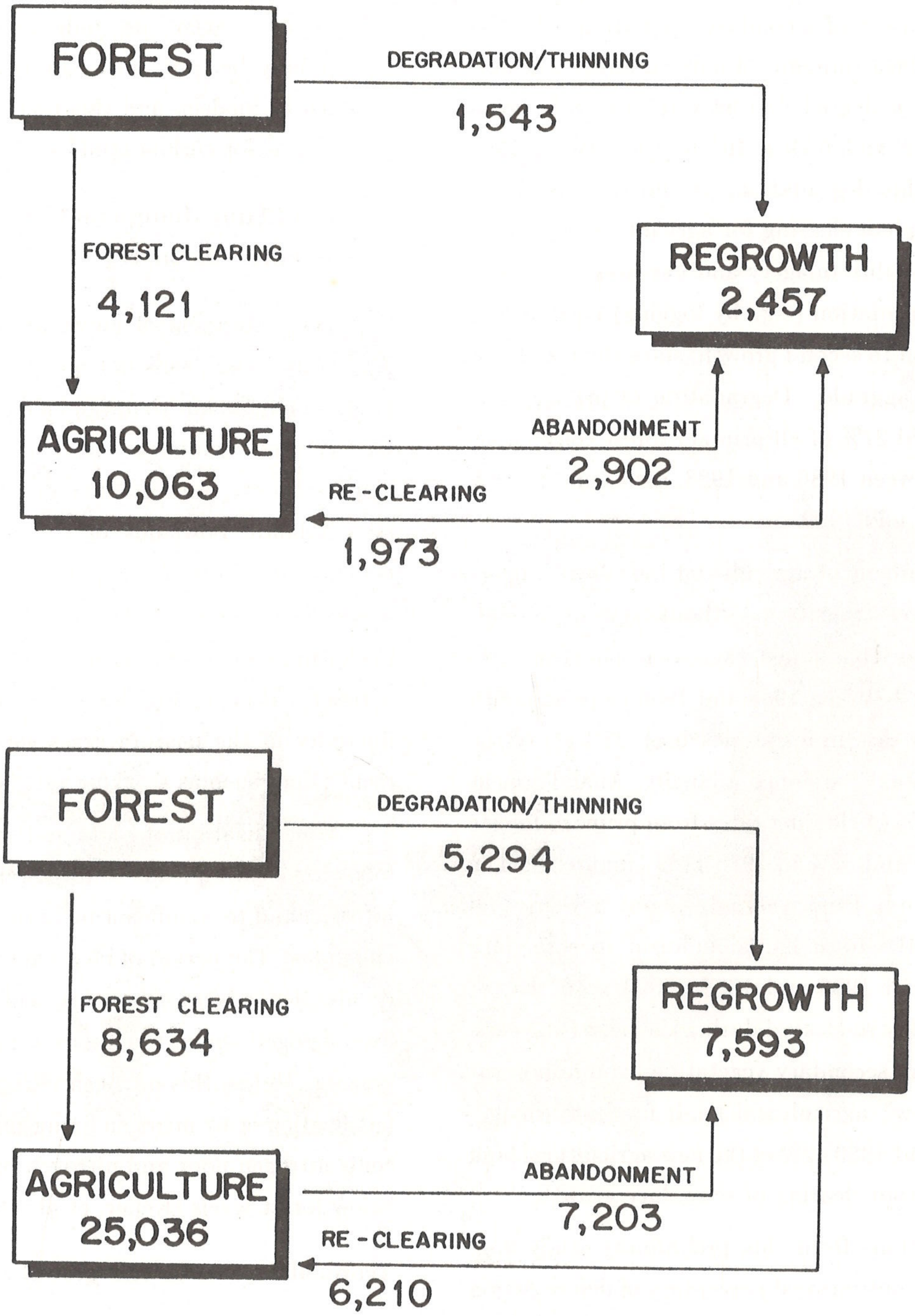

Figure 3. Rates of Transition between Land-Cover Types from a Test Site in the Brazilian Amazon, 1986-1988 (top) and 1988-1989 (bottom). Values with arrows are annual transition rates in ha. Values within the regrowth and agricultural boxes are retention rates in ha.

Taxas de transição entre tipos de terrenos de um local de testes na Amazônia Brasileira, 1986-1988 (em cima) e 1988-1989 (em baixo). Valores com setas são taxas de transição anual em ha. Valores nas áreas de rebrota e de agricultura (nos retângulos) são taxas de retenção em ha.

tional 1-2 GtC is released by tropical deforestation (Houghton et al., 1983; Watson et al., 1990), giving rise to the celebrated "missing carbon" (missing from global budgets for CO_2). The balance could be provided by temperate forests, if they are growing faster than currently believed, or by tropical forests if deforestation is releasing less carbon or reforestation is taking up more carbon than assumed in global models.

In AMBIACE we propose a concerted effort to define the role of tropical deforestation and reforestation in the global carbon cycle. Three or more tower eddy-correlation measurements will be carried out continuously for 1-2 years, one in primary forest, one in secondary vegetation (possibly with two different ages), and one in pasture (possibly with different treatments, or with one sector in early succession). Logged areas may also be selected for study.

Recent experiments (Fan et al., 1992; Wofsy et al., 1993) show that rates of trace gas emission or uptake (CO_2, O_3, CH_4, etc) can be determined for at least two different vegetation types from a single tower, if the tower is situated so that the two vegetation types are in different sectors, both of which are frequently (but not simultaneously) in the footprint. The experiments will determine annual net carbon fluxes for these environments (along with fluxes for eactive species, see below), and will define the relationship between incident solar radiation, temperature, etc, and the net flux for CO_2 and oather gases. It might be possible to combine activities with ABRACOS or other existing research activities, although the focus of AMBIACE requires that high priorty be given to selection of sites suitable vegetation and soils.

The study will provide large-scale and ecosystem-scale, observations, cross-cutting in time. In combination with remote-sensing observations and ecological studies, the airborne and tower data will provide the basis for improved estimates of the carbon flux to the atmosphere from representative tropical areas including primary forest, agricultural use, and regrowth. Improved models should allow reconstruction of past trends in flux associated with variation of clearing and abandonment rates.

The role of the Amazon in the global methane cycle

Methane is a key species for greenhouse forcing and for atmospheric chemistry. According to ice-core studies, its concentration has more than doubled since pre-industrial times, of the most dramatic demonstrations of global environmental change.

Much has been learned about sources and sinks of CH_4 during recent studies, which included a special NASA program to analyse natural and anthropogenic emission rates. Results from ABLE-2 showed that the Amazon is a major natural source of CH_4 (Bartlett et al., 1988; Devol et al., 1988). However, estimates of the total source rely on extrapolations of small-scale measurements on the Amazon floodplain, and remain highly uncertain. In general, upland forest soils have proven to be sinks for methane (Keller, et al., 1986; Goreau and de Mello, 1987). However, there is evidence that widespread small wetlands in the forest biome may also be important sources; these sites are supplied with abundant detrital carbon. Determining the overall lanscape balance is a significant challenge.

Following clearing of swamps or alluvial forests, secondary vegetation or agricultura lands might be expected to release less CH_4 than natural wetlands, making deforestation responsible for reduced emissions. However, this expectation could be incorrect. For example, Harriss and coworkers (1988) found that conversion to agriculture of swampland actually increased CH_4 releases in Florida, due to modification of the hydrologic cycle and accumulation of organic residues in a wet environment. Replacement of upland forests by pastures can convert the small soil methane sink into a source (Keller, et al. 1993).

AMBIACE will focus on better definition of large-scale sources of CH_4 from the a Amazon Basin, by combining large-area flux measurements using the DACOM instrument as demonstrated in ABLE-3 (Ritter et al., 1992), and potentially other aircraft (e.g. the INPE aircraft). Long-term tower flux measurements will provide data on sources in the forest and agricultural environments, using direct eddy-correlation.

Impacts of Land Conversion on Nitrogen Oxides

Nitrous oxide (N_2O) is a long-lived greenhouse gas (> 150 years) whose atmospheric concentration is increasing at 0.25-0.31% per year (Prinn et al., 1990). Nitrous oxide is one of the most important greenhouse gases along with CO_2, CH_4, chlorofluorocarbons and O_3. On a molar basis, it is 300 times more effective at trapping infrared radiation than CO_2 (Rodhe, 1990). Nitrous oxide is also the chief source of NO in the stratosphere, an important catalyst for stratospheric ozone recombination (Crutzen, 1970; McElroy and McConnel, 1971; Jackman et al., 1980).

Neither combustion nor any major industrial process can account for the observed global N_2O increase (Muzio and Kramlich, 1988; Prinn et al., 1990). The rapid onset of artificial fertilizer application in temperature zone agriculture during the 1940's has been suggested as part of the explanation for this increase but these emissions can explain only part of the increase (McElroy, 1978; Watson et al. 1990).

Soils of the humid tropics are the single largest known source of N_2O (Keller et al. 1983, 1988; Matson and Vitousek, 1990). Conversion of tropical forests to agriculture since the 1940's has been implicated as a major contributor to the post-World War II increases in atmospheric N_2O concentrations (Prinn et al., 1990; Matson and Vitousek, 1990). Applications of nitrogen fertilization to humid tropical agroecosystems projected in the order of 50 Tg/yr (Vitousek and Matson, 1992), could be particularly important in this regard.

Nitrous oxide emission from soils of moist tropical forestsin Hawaii, Costa Rica, and Brazil correlated strongly with soil nitrogen mineralization potentials (Matson and Vitousek, 1987). Fertilizer NO_3^- additions (and to a lesser extent NH_4^+ additions) greatly increased N_2O emissions from a tropical forest soil (Keller et al., 1988). Fertilized soils in the temperate zone emit far more N_2O than do unfertilized soils (Eichner, 1990; Mosier et al., 1991).

While it is clear that the conversion of tropical to intensive agriculture could significantly enhance N_2O emissions to the atmosphere, quantitative understanding is lacking. AMBIACE will be designed to carrefully elucidate the links between land conversion-agricultural practice-climate variability-N_2O emissions. Ground studies across the climatic transects will cover a variety of management practices common in those zones today and practices expected to grow as social and economic conditions change.

The soil processes, underlying the global cycle of N_2O also play potentially central roles in regulating tropical concentrations of NO, which in turn regulates concentratonsof O_3, OH, and other oxidants. Understanding soil and combustion emissions of NO is essential to the problem of photochemical productions/destruction of tropospheric ozone. Systematic studies of relationship between land use and NO emissions to the atmosphere in the United States indicate that fertilized corn crops are significant source, but undisturbed grasslands, forests, and wetlands in the US are not (Williams et al., 1992). However, NO emissions from tropical forest soils are vastly larger than from midlatitude forest soils, and other sources (e.g. fossil fule combustion are much smaller. Therefore forest soils could be important factors in the regional and global NO_x cycle, and we propose that AMBIACE should study rates of NO emission from diverse ecosystems, the processes leading to NO emissions from tropical soils, relationships between land conversion and changes in NO flux, atmospheric transformations of soil-derived NO_x, and the photochemical effects of the emitted NO on atmospheric chemistry.

The emission of NO from soils, and deposition of NO_y to ecosystems, are very important considerations in evaluating the impact of human activities in the tropics on the global nitrogen cycle. Kaplan et al. (1988) discovered the enormous potential for emission of NO by tropical forest soils during ABLE-2A. The underlying mechanisms are unclear, and it is possible that the soil emission rate depends on influx of NO_3^- or on disturbance and regrowth in important ways as yet unknown. Other studies in Brazil, the United States, and Canada have developed high quality measurement capabilities, and demonstrated the potential importance of biosphere-atmosphere interactions to understanding nitrogen budgets at various spatial scales (e.g. Bakwin et al., 1990, 1992; Jacob et al., 1992; Jacob and Bakwin, 1991; Williams et al., 1992).

Recent experiments at Harvard Forest (Munger et al., unpublished data) demonstrate the feasibility of long-term measurements of NO_y flux, using versions of the catalyst deployed atop the ABLE-2B tower (Bakwin et al., 1992) and the eddy-correlation method (see Figure 4). The seasonal pattern of wet and dry deposition at this site suggested that NO_y is deposited efficiently once oxidized to HNO_3, and that the oxidation rate basically balanced the emission rate in a region. There was no observable deposition of NO_x radicals. Concentrations of the key NO_x radicals are regulated by a balance between emission and oxidation. AMBIACE studies are intended to elucidate the analogous processes in the tropics.

Carbon monoxide and hydrocarbons

Carbon monoxide, methane, and volatile organic carbon (VOC) are te reduced species in atmospheric redox chemistry. Concentrations of these species regulate the rate of photochemical production or destruction of O_3 and the rate of conversion of OH to HO_2. When they are oxidized, methane and VOC contribute important sources of HO_x, enhancing photochemical destruction of O_3 if NO_x levels are low, but pontentially increasing O_3 concentrations if NO_x levels are high.

Biomass burning represents a major source of CO in the Amazon region during the dry season (Andreae et al., 1988; Crutzen et al., 1979). However, studies during ABLE-2 demonstrated that substancial sources arise either from oxidation of biogenic hydrocarbons, or from metabolic processes in the forest (Kirchhoff et al., 1990; Harriss et al., 1990; Ritter et al., 1990). These non-combustion sources are not well-understood quantitatively; they operate in all seasons of the year, and may play a major role in determining the concentrations of CO in the Amazon region, and in the tropical region globally. How do the source strengths change in response to modification of the vegetation? Fluxes of reactive hydrocarbons in the Amazon forest exert an overwhelming impact on photochemistry in the lowest scale height of the atmosphere (Jacob and Wofsy, 1988). Most of these hydrocarbons are biogenic, and fluxes may be altered in unknown ways where the vegetation has been modified.

Fluxes of reactive hydrocarbons or CO from the forest can be measured with high time resolution, using continuos, accurate measurements of gradients above the forest canopy. A dual channel gas chromatograph has been demonstrated at Harvard Forest capable of continuous unattended determination of concentrations and gradients for isoprene (Figure 5) and other hydrocarbons (Goldstein et al., 1992). Gradients are measured also for CO_2, heat, H_2O, and

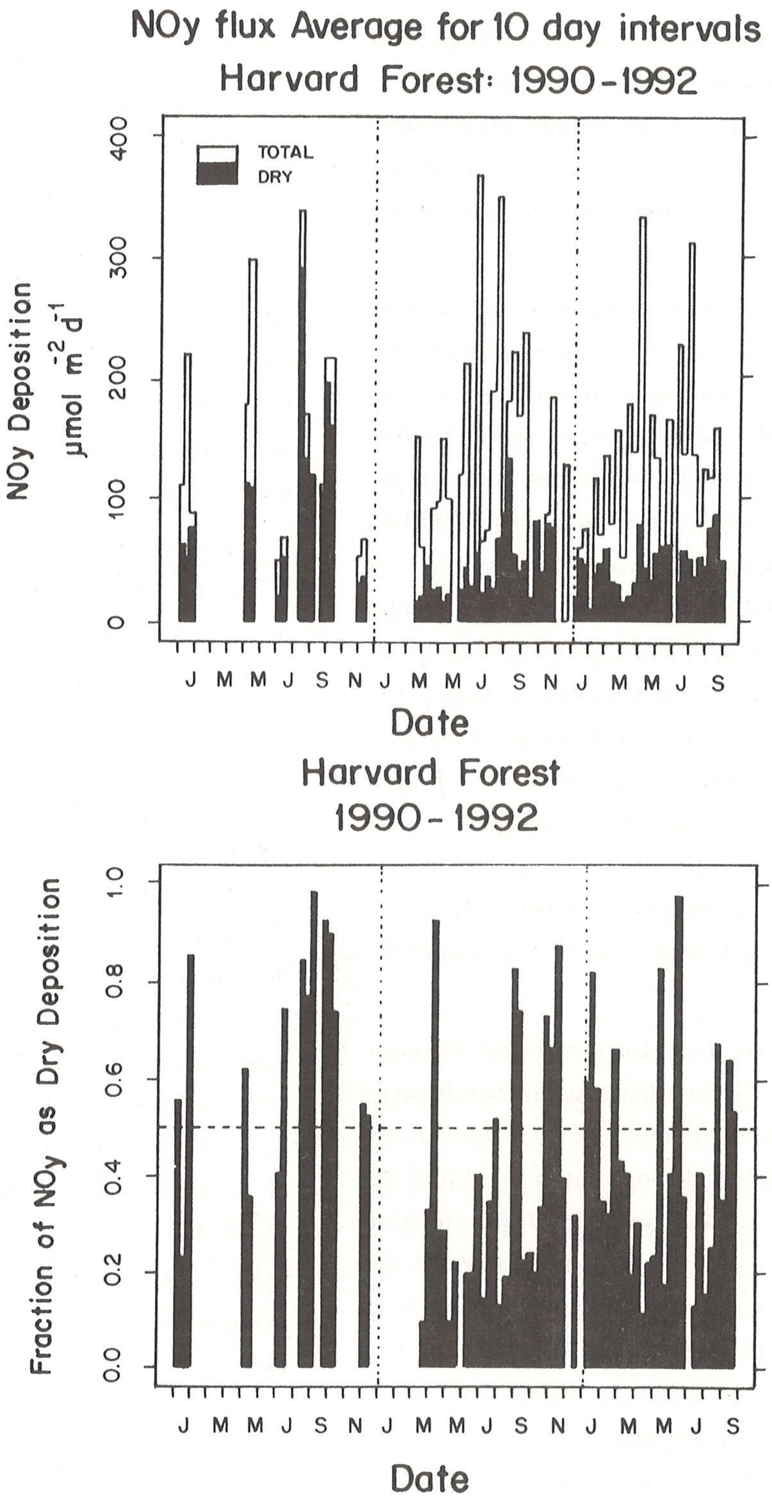

Figure 4. NO_y flux Average for 10 day intervals Harvard Forest: 1990-1992

Médias de fluxo de NO_y para intervalos de 10 dias na floresta de Havard: 1990-1992.

O_3, simultaneously sampled from the same dual inlets, and nulled every two hours by simultaneously measuring from a single inlet. This apparatus allows rigorous testing of similarity between VOC or CH_4 (CO with a different chromatograph) and the tracers for which fluxes are measured by eddy correlation. New results from NCAR indicate that conditional sampling provides an excellent method for measuring fluxes of VOC and CO at a site where eddy-correlation measurements are being made (Dabbert et al., 1993). These measurements provide flux data for isoprene or CO with high temporal resolution. Also "fingerprints" of sources of hydrocarbons can be defined by analysis of variations in hydrocarbon concentrations, and seasonal variations can be determined.

According to model studies, convection pumps significant quantities of CO, hydrocarbons, and other short-lived species into the upper troposphere. If correct, this would imply that tropical forests may play a disproportionately large role in the chemistry of the global upper troposphere. However, these model predictions have not yet been tested by observations; we propose to do this as a key part of the AMBIACE program, using aircraft measurements of a wide range of species that allow us to "fingerprint" trace gases originating from biomass burning, industrial sources, and biogenic processes (e.g. Wofsy et al., 1993).

Ozone

Ozone photolysis drives atmospheric photochemical oxidation (OH concentrations), and hence determines the oxidizing power of the atmosphere. Concentrations of O_3 are regulated by complex interactions between transport into the region, photochemical production/removal, and uptake by vegetation (Gregory et al., 1988, 1990; Browell et al., 1988, 1990; Kirchhoff et al., 1990). Studies of O_3 include LIDAR and in situ measurements of large-scale distributions, airborne fluxes, and tower fluxes, combined with data on NO_x, and reactive hydrocarbon concentrations. Changes in the NO_x, CO or hydrocarbon concentrations may occur in response to deforestation or conversion to secondary vegetation.

AMBIACE will investigate the sources and sinks of these gases using the integrated experimental design to improve the understanding of large scale fluxes and to elucidate the underlying mechanisms that regulate these fluxes at scales from enclosures, to ecosystem scale (towers) and basin scale (aircraft and remote sensing). AMBIACE will also examine the basic mechanisms that regulate O_3 concentrations by detailed photochemical and flux measurements of O_3 and related species. The low-altitude and high-altitude airborne platforms will play a central role in these experiments, providing the photochemical measurements and helping to define the global-scale uptake rate the surface. As in previous missions, the unique capablity of the LIDAR for remote observations represents an essential capablity.The novel features of AMBIACE are the focus on uptake rates for different types of disturbed vegetation and the emphasis on seasons with relatively little influence of biomass burning.

Impact of South American Trace Gas Emissions on Global Tropospheric Chemistry: AMBIACE and tropical convection experiments (e.g. LAMBADA)

The NCAR/Max-Planck, ABLE, and TRACE missions to the South American tropics have all been, in part at least, motivated by the concept that the region is unique as a source of gases, as a zone with rapid photochemical rates, and as a region of enhanced vertical transport (i.e., 'a cylinder of the Earth's heat engine"). All of the measurements made to date support the concept that this region may be uniquely important for trace gas connections between the biosphere and the free troposphere, but the magnitudes and mechanisms of convective transport from the atmospheric boundary layer to the up-

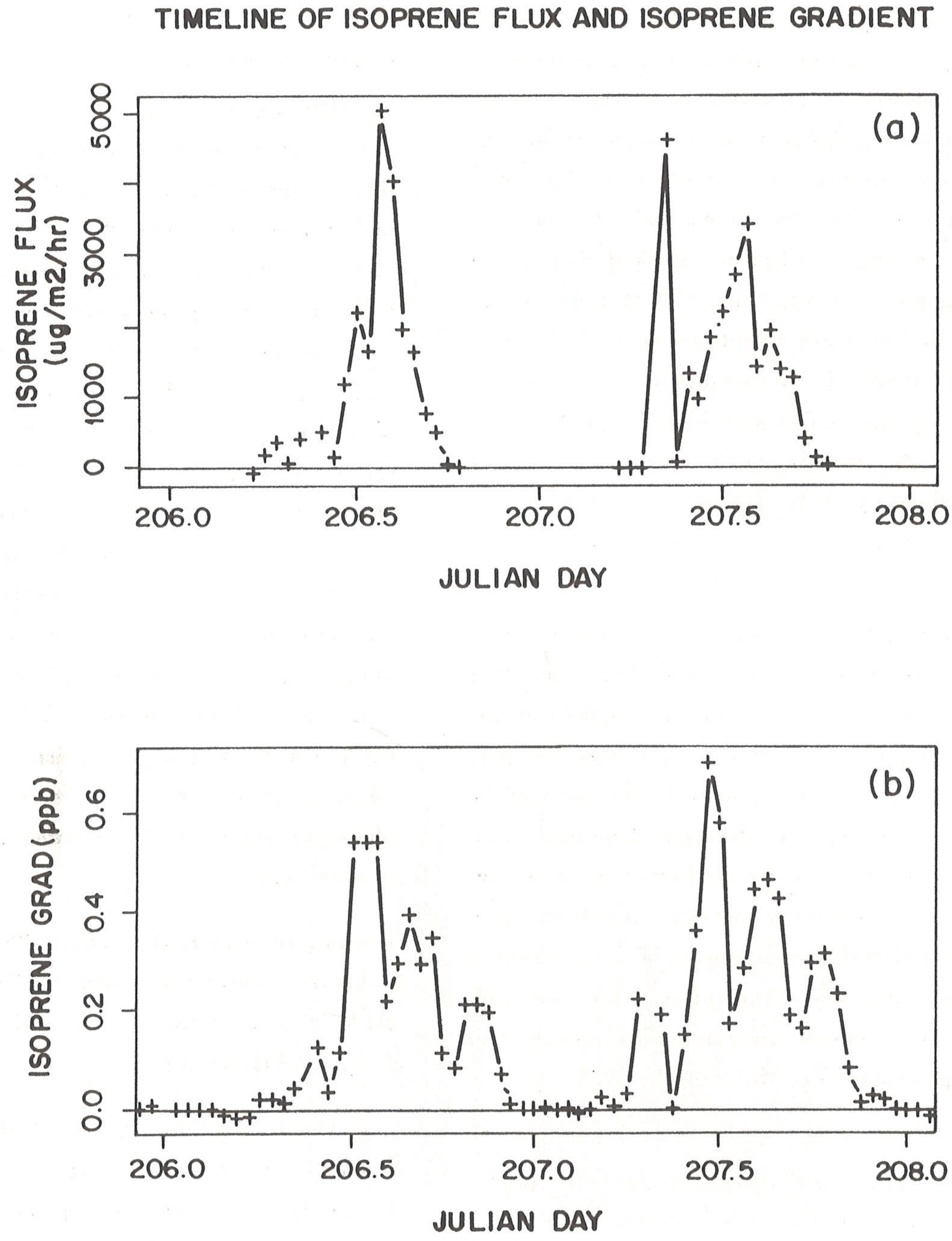

Figure 5. Timeline of Isoprene Flux and Isoprene Gradient.

Variação temporal do fluxo de isopreno e de seu gradiente.

per troposphere over Amazonia remain to be quantified. An intensive effort to quantify convective transports, and associated atmospheric chemical processes in the tropical free troposphere during AMBIACE, could make significant new progress.

Measurements using the DC-8, with its high-altitude capability, would be the key for examing this issue. A comprehensive experimental design for an intensive experiment on convective transports in Amazonia is beyond the scope of this concept paper. Clearly, strong connections could be established to the conceptual framework currently under discussion for LAMBADA.

One of the AMBIACE intensives should focus on the September-October period when the transition from dry to wet seasons takes place in the Amazon Basin. Other seasonal transitions will also likely be considered for aircraft studies.

Outline of the experimental design for AMBIACE

Scientific question:

What are the consequences of forest conversion, agricultural practice and abandonment, and secondary succession, on regional and global biogeochemistry.

Hypotheses to be tested:

1. Secondary vegetation takes up globally significant quantities of carbon, and soil carbon reservoirs are important.

2. Deforestation and subsequent land management practices have major effects on atmosphere-biosphere exchange rates for greenhouse gases, N_2O an CH_4, and for gases important to atmospheric chemistry (NO, O_3, CO, non-methane hydrocarbons).

3. Exchange of gases with tropical vegetation represents an important factor in regulating the oxidizing power of the tropical troposphere, and concentrations of O_3 and HO_x can be modified on the basin scale by deforestation, forest regrowth, and agricultural practice.

4. The Brazilian Amazon provides globally significant inputs of short-lived trace gases into the free troposphere, especially CO, biogenic hydrocarbons, short-lived sulfur gases, and emissions from biomass burning.

Measurements:

1. Satellite observations

Satellite data will be help to select the sites for ground-based ecological investigations and tower studies, and to monitor changes in vegetation cover during the course of the experiment.

Platforms: LANDSAT, AVHRR, SPOT; possible new platforms.

2. DC-8 measurements

The DC-8 should make at least two missions into the region to survey concentrations of a wide range of species, especially NO_y and its constiutens (NO, NO_2, PAN, HNO_3), CO, non-methane hydrocarbons, sulfur gases (SO_2, DMS) and greenhouse gases (CO_2, CH_4, N2, and O_3). The purpose is to define the large-scale horizontal gradients, to confirm source-sink relationship, to validate or falsify model preditions of upwelling into the upper troposphere, and to define sources of trace gases by determining the chemical signatures for trace gas assemblages originating in the region. The DC-8 would also undertake carefully timed, limited soundings down to the boundary layer, to provide first-order estimates of sources and budgets for gas exchange with the ecosystem (Gregory et al., 1990; Wofsy et al., 1988). The O_3 LIDAR would privide an important capablity for improving understanding of the regional O_3 budget.

3. Electra (or replacement) INPE aircraft measurements

These aircraft provide a much more detailed look at the lowest scale height of the atmosphere, providing a link between the very large scales sampled by the DC-8 and the vegetation/boundary-layer scale. They also should measure eddy-correlation fluxes, providing the connection to tower eddy-correlation fluxes. A wide range of species concentrations should be determined, similar to the DC-8. The flux measurement capabilities already demonstrated (CH_4, CO, CO_2, O_3) provide powerfull analytical tools. The possibility of airborne NO_y eddy-correlation fluxes, demonstrated at towers, should be explored. Significant participation by INPE scientists in the airborne campaign is important.

The importance of airborne flux measurements should be apparent. These data provide first-order scaling-up for ecosystem-scale (tower, enclosure) measurements, as well as connecting the basin scale to the global scale. We note in this context that many key problems in global change and atmospheric chemistry are conceptually defined as flux problems (global budgets, turnover times for upper or middle troposphere, etc). The airborne and ecosystem-scale flux measurements together represent a powerful reality-ckeck on model predictions, in many cases the only reality check (fluxes cannot be determined from satellite data nor from conventional measurements of concentrations for reactive trace gases).

4. Tower measurements

Tower measurements should be made at three or more sites at least one in primary vegetation, others in successional or managed vegetation. The measurements should be continuous for two years, able to run unattended for 3 - 7 days, and if possible solar-powered. Tower data should include eddy-correlation fluxes for heat, H_2O, CO_2, and O_3, NO_y if possible, and concentrations and vertical gradients for these species and for CO (if possible, for hydrocarbons including isoprene; all of these would be feasible with continuos line or generator power). Careful selection of sites should allow sampling of two different vegetation types on a single soil type, by a single tower installation.

5. Ground-based measurements

We plan a program that will allow analysis of how the cycle of conversion of forest to pasture and agriculture and reversion to forest in the Amazon basin affects trace gas fluxes (both greenhouse and reactive species, e.g. CO_2, CH_4, N_2O, NO_x, O_3, CO, hydrocarbons) between the land and the atmosphere. We will study the controls on trace gas fluxes at the square meter level and develop models for predicting the fluxes at the ecosystem level, which will be tested and refined using the tower data. The ecosystem models will be coupled with regional information on rates of forest clearing and pasture abandonment as determined by remote sensing to provide estimates of trace gas fluxes at the regional scale, to be tested and refined using the aircraft measurements. Hence the experiment is intended to provide major advances in scaling up ecosystem-level models to regional and global scales.

Field measurements to be made in addition to the gas flux measurements include: plant biomass and tissue chemistry: soil texture, pH, CEC, exchangeable cations, total C and 13/12-C isotopic ratios, total N and 15/14-N isotopic ratios, inorganic N pools, N mineralization and nitrification rates, total P and P fractions, wet and try deposition of fixed N. Measurements of dynamic plant and soil characteristcs will be made several times over the course of the year. In addition to providing information to address the primary objectives of AMBIACE, the field studies will give us an understanding off how land-use change affects site fertility. Biogeochemical studies and models developed through this work will help judge which land management alternatives are sustainable. This issue is of great importance to Brazilian economic planners and resource managers.

Ground-based measurements of fluxes of trace gases from soils and vegetation are planned to cover at least 2 full calendar years, possibly with a series of intensive study periods; the experimental design must be carefully chosen to elucidate the underlying mechanisms for gas emission (e.g. nitrogen mineralization rates) in order to provide a basis for scaling up. For example, it may be desirable to implement new techniques, recently demonstrated, for quasi-continuous measurement of soil fluxes, providing greatly enchanced information on the factors influencing trace gas emissions.

Interpretation of the aircraft measurements require a framework of meteorological observations. The concept discussed for LAMBADA, which would install a network of radiosonde sites with frequent soundings, would provide an excellent foundation for analysis of airborne tracer data. A strong participation by INPE scientists should be readily established in this framework.

6. Modelling

A range of modelling activities should be incorporated into the experiment design, to provide a framework for hypothesis-testing and a tool for scaling up and for assessing the role of vegetation modification on basin-scale cycles of trace gases. It is anticipated that model development will include *prediction* of key observations *before* the data are acquired, and refinement (or replacement) of models in response to experimental data. Modelling activity is anticipated to include ecosystem models of carbon and nitrogen dynamics in soils and vegetation as well as atmospheric chemistry models defining oxidation potential, reactive trace gas distributions over the atmospheric upwelling zone, etc.

A note on availability of satellite data for AMBIACE

We intend to use satellite data as an integrative tool in AMBIACE. We believe that AMBIACE can obtain leverage by interfacing with NASA's Humid Tropical Forest Inventory Project of the Landsat Pathfinder, which is focused on acquiring and analyzing Landsat MSS and TM data in the Legal Amazon. The project, which is now underway, will acquire complete coverage of the Amazon for three periods of time: mid late 1970s, mid 1980s, and early 1990. Digital images of the entire basin, presently being analyzed and mapped to show the total area deforested and the area in secondary growth for each time period, will be available. The difference between two successive time periods reflects the rate of deforestation. Thus, considerable digital data will available for AMBIACE from ongoing programs, along with most of the labor-intensive analysis.

It will also be important to have access to contemporary data. The ground receiving station in Brazil, operated by INPE, routinely collects all the data acquired within a line-of-sight radius of the receiving antenna. In the past INPE has collected every satellite pass for the entire Amazon. Thus, for many locations, frequent images should be available, and active participation by INPE scientists should be expected.

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