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REPORT No. 13

TERRESTRIAL BIOPSHERE EXCHANGE WITH GLOBAL ATMOSPHERIC CHEMISTRY

Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
in collaboration with
the Commission on Atmospheric Chemistry and Global Pollution
of the International Association of Meteorology and Atmospheric Physics

Stockholm, 1990

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Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report

Edited by P. A. Matson and D. S. Ojima

Report of the recommendations from the SCOPE/IGBP Workshop on Trace-Gas Exchange in a Global Perspective, Sigtuna, Sweden, 19-23 February 1990

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Table of Contents

PREFACE

The IGBP is concerned with the significant interactions of biological, chemical, and physical processes that govern changes in the Earth system and that are most susceptible to human perturbation. The primary goal of the IGBP is to develop a predictive understanding of the Earth system, especially in relation to changes that affect the biosphere, over timescales of decades to a few centuries.

The initial emphasis of the IGBP is on developing our understanding of the cycling of key elements between the terrestrial systems, the oceans and the atmosphere and to further understand the interactive effects of climate-induced feedbacks within and between the biosphere and atmosphere.

The fundamental basis of the IGBP is described by four underlying themes (IGBP Report 3, 1988). In brief these are:

- Documenting and predicting global change
- Observing and improving our understanding of dominant forcing functions
- Improving our understanding of transient phenomena
- Assessing the effects of global change that would cause large-scale and important modifications affecting the availability of renewable and non-renewable resources.

In this context, the IGBP has defined a number of priority Core Projects based on several key questions that need to answered (IGBP Report No. 12, 1990). A key question is concerned with the exchange between the terrestrial biosphere and atmospheric chemistry, and is stated as:

> *How is the chemistry of the global atmosphere regulated and what is the role of terrestrial processes in producing and consuming trace gases?*

At issue is the rapid increase in atmospheric concentrations of several trace gases, mainly due to human activities. Increases in production of so-called greenhouse and other trace gases result in changes in the composition of the atmosphere, which also affect physical aspects of the climate system. Many of these gases are produced biologically, or affect biological processes. The sources and sinks of important chemical components of the atmosphere and their interactions with organisms need to be identified and quantified.

Our qualitative understanding regarding basic chemical reactions that transform the many compounds that are brought into the atmosphere, the various processes controlling trace-gas emissions from the biosphere, and the impact of climatic change and changes in land use and industrial activities on the production and consumption of biogenic trace gases have developed rapidly during the past two decades. However, quantitative knowledge of these important atmospheric chemical and biological processes is still very incomplete.

The development of an integrative research project that would alleviate the uncertainty associated with atmospheric chemistry and trace gas exchanges has been undertaken through several initiatives. The Commission on Atmospheric Chemistry and Global Pollution (CACGP) of IAMAP has developed a proposal for an International Global Atmospheric Chemistry (IGAC) Project. This project has been recognized as an IGBP Core Project under the CACGP and SC-IGBP. In November 1988, a CACGP workshop on IGAC proposed an overall framework for a research plan (Galbally 1989).

In addition, a SCOPE project on Trace Gas Exchange held a Dahlem conference on trace-gas exchange in terrestrial ecosystems, and outlined a set of research problems which would interlink the biological processes to the atmosphere (Schimel et al. 1989). To further develop this interaction between the terrestrial biosphere scientists and the atmospheric chemistry community, a second SCOPE workshop was held February 1990 in Sweden jointly with the IGBP to provide details to the general research plan proposed by the participants of the Dahlem conference.

This report provides the terrestrial biosphere components to the research agenda proposed by the IGAC workshop. The IGBP Report No. 12 (IGBP - The Initial Core Projects) sets forth the structure of the research plan for this integrative study of the terrestrial biospheric exchange with the global atmospheric chemistry. This research plan will strengthen and expand the atmospheric chemistry components and incorporate important biosphere studies. It will become an integrated component of IGAC after review by the Scientific Steering Committee for IGAC. Discussions are also underway

between IGAC, JGOFS and IGBP to strengthen the marine biosphere component of IGAC in a similar way.

It is hoped that this effort will strengthen IGAC to become a truly interdisciplinary project to cover a major component of essential global change research. It should provide the necessary insight to achieve a predictive capability of global change on key processes, which interact to generate the unique environment we depend upon.

Thomas Rosswall
Executive Director, IGBP
August 1990

INTRODUCTION

In recent years, we have become increasingly aware of how strongly the physical and chemical properties of the Earth's atmosphere are influenced by emissions from the biosphere and by uptake of trace gases by the biota. Relevant examples are the emission of sulphur gases by marine phytoplankton, the production of methane by methanogenic bacteria, and the exchange of nitrogen oxides and ammonia between the atmosphere, organisms in soils, and plants. Plants also emit numerous trace gases, e.g., hydrocarbons and hydrogen sulphide, and are major sinks for many atmospheric constituents, including pollutants like sulphur dioxide, nitric acid and ozone.

We also appreciate that the interactions between the biosphere and the atmosphere are part of a complex, interconnected system. The emission and uptake of atmospheric constituents by the biota influence chemical and physical climate through interactions with atmospheric photochemistry and the Earth's radiation budget. For example, even the comparatively small amounts of methane and nitrous oxide present in the atmosphere make substantial contributions to the global greenhouse effect (Figure 1). Also, emissions of both

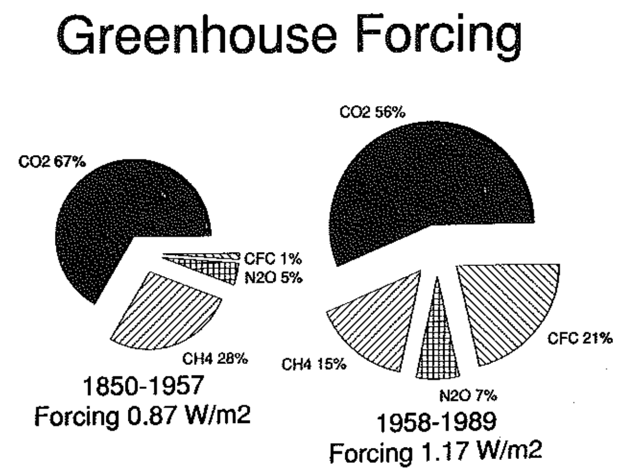

Figure 1. Acummulated greenhouse climate forcings for the periods 1850-1957 and 1958-1989. CO_2 and CH_4 dominate the first period; a marked increase in CFC and N_2O during the last 30y have significantly increased their importance. Biospheric sources are associated with CH_4, N_2O and CO_2 increases; whereas the CFC are mostly anthropogenic as well as a large fraction of the CO_2 increase. (Modified from Hansen et al. 1990)

hydrocarbons and nitrogen oxides from biomass burning in the tropics result in the photochemical production of large amounts of ozone and acidity in the tropical atmosphere. In turn, climate change and atmospheric pollution alter the rates and sometimes even the direction of chemical exchange between the biosphere and the atmosphere through influences both at the level of the individual organism and at the ecosystem level.

In spite of the indisputable importance of atmosphere/biosphere exchange in determining the composition of the atmosphere, the processes which control the flux rates and the magnitudes of the fluxes from many ecosystems remain inadequately known. This is due both to the complexity of the biological and physicochemical systems involved and to the difficulty of measuring exchanges in the field. To improve our understanding of atmosphere/biosphere interactions, a close collaboration between biologists, chemists, and atmospheric scientists is required. This collaboration is necessary in order to develop analytical methods for determining relevant gas fluxes at the concentrations and against the background levels found in the natural atmosphere; to characterize ecosystems in relation to their potential for gas exchange with the atmosphere; to investigate physiological controls and biochemical processes involved in gas production and uptake; to develop and validate the micrometeorological theory and field methods required to measure the exchange fluxes; and to design and develop diagnostic and predictive models at multiple spatial and temporal scales for extrapolation and analyses of environmental change.

The multidisciplinary collaboration required to fulfill these tasks has begun to develop in the last few years. There still remains, however, a need for more intensive interaction between disciplines, including ecology, microbiology and plant physiology, as well as the atmospheric sciences. This appears particularly urgent as a necessary component of the International Geosphere-Biosphere Programme (IGBP), which will be carried out during the 1990s and beyond.

A SCOPE Project on Trace-Gas Exchange was established in 1987. The project goals were to assess our understanding of the controls and interactions in the plant-microbial-soil-water system that regulate trace-gas flux; to assess the status of current techniques for measuring fluxes on multiple scales; to develop a foundation for the design of diagnostic and predictive models of biosphere-atmosphere trace-gas exchange; and to determine how trace-gas exchange interacts with the physical and chemical climate.

In order to review the scientific background in relation to trace-gas exchange and to initiate the planning process, the Project organized the Dahlem Conference on Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere (Andreae and Schimel, 1989), which was held in February of 1989. To provide a sharp focus at the Dahlem conference, the discussion was limited to the trace gases methane (CH_4), nitrous oxide (N_2O), and nitric oxide (NO). These gases were selected because of their rich biogeochemical interactions and their importance for atmospheric chemistry and global climate. The fact that their atmospheric concentrations are increasing, apparently as a result of human activity, provides further complexity and interest to their study.

Following a week of discussions, the participants defined a large number of fundamental gaps which still exist in our understanding of the exchange of trace gases between the biosphere and the atmosphere. The gaps in our knowledge relate not only to the magnitude of the fluxes but also to the mechanisms which control them.

The conferees concluded that, in view of the importance of biogenic trace gases for the chemistry of the atmosphere and for global climate, it is essential that scientific research be designed to improve our understanding of their sources and sinks. This recommendation formed the starting point for a second SCOPE workshop, co-sponsored with the IGBP, on Trace-Gas Exchange in a Global Perspective, held in Sigtuna (Sweden) in February 1990. The objective of the Sigtuna Workshop was to develop a scientific action plan for research on trace-gas exchange between terrestrial ecosystems and the atmosphere. This material was then reviewed and modified by the IGBP Coordinating Panel on Terrestrial Biosphere-Atmospheric Chemistry Interaction, and presented under the title of Terrestrial Ecosystem Gas Exchange Project.

This plan is intended to complement the existing International Global Atmospheric Chemistry (IGAC) Project document (Galbally 1989). IGAC was initiated by the IAMAP Commission on Atmospheric Chemistry and Global Pollution (CACGP) and its science plan was developed by an extensive group of atmospheric scientists at the IGAC workshop held at Dookie College, Victoria, Australia, in November 1988. This IGAC project has been accepted as a Core Project of the International Geosphere-Biosphere Programme (IGBP). While there was a strong perception at the Dookie IGAC workshop that biological

Table 1. Relationship between IGAC Dookie report and IGBP/SCOPE Workshop Recommendations

	IGAC (DOOKIE)		IGBP/SCOPE
	FOCUS 1 Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere		
Activity 1.1	North Atlantic Regional Study		
Activity 1.2	Marine Aerosol and Gas Exchange: Atmospheric Chemistry and Climate		
Activity 1.3	East Asian/North Pacific Regional Study		
	FOCUS 2 Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry		
Activity 2.1	Biosphere-Atmosphere Trace Gas Exchange in the Tropics	2.1	Tropical Land-Use Change and Trace Gas Emissions
Activity 2.2	Deposition of Biogeochemically Important Trace Elements		
Activity 2.3	Impact of Tropical Biomass Burning on the World Atmosphere	2.3	Impact of Tropical Biomass Burning on the Atmosphere and Biosphere
Activity 2.4	Chemical Transformations in Tropical Atmosphere and their Interaction with the Biosphere		
		2.5	Exchanges of Methane and Other Trace Gases in Rice Cultivation
	FOCUS 3 The Role of Polar Regions in Changing Atmospheric Composition		
Activity 3.l	Polar Atmospheric Chemistry		
Activity 3.2	Polar Air-Snow Experiment		
	FOCUS 4 The Role of Boreal Regions in Changing Atmospheric Composition		
Activity 4.1	Northern Wetlands Study	4.1	Estimation of High Latitude Ecosystems in Trace Gas Emissions
		4.2	Ecological and Environmental Controls and Correlates for Trace Gas Source-Sink in High Latitude Ecosystems
		4.3	Sensitivity of High Latitude Trace Gas Sources and Sinks to Environmental Change

(Table 1. Cont.)

	IGAC (DOOKIE)		IGBP/SCOPE
	FOCUS 5 Global Distributions, Transformations, Trends and Modelling		
Activity 5.1	Global Tropospheric Ozone Network		
Activity 5.2	Global Atmospheric Chemistry Survey		
Activity 5.3	The Chemical and Physical Evolution of CCN as Controllers of Cloud Properties (Currently designated as Focus 8)		
Activity 5.4	Development of Global Emission Inventories		
		5.5	Global Integration and Modeling of Fluxes
	FOCUS 6 International Support Activities		
Activity 6.1	Education in Atmospheric Chemistry and Global Change		
Activity 6.2	IGAC Newsletter		
Activity 6.3	Intercalibrations/Intercomparisons		
	FOCUS 7 Trace Gas Fluxes in Mid-Latitude Ecosystems		
		7.1	Exchanges of N2O, CH4 and CO between terrestrial ecosystems and the atmosphere in mid-latitude ecosystems.
		7.2	The importance of mid latitude Ecosystems as net CO2 Sinks
		7.3	Mid-latitude ecosystems as sinks for atmospheric oxidants and sources of oxidant precursors.

interactions with the atmosphere would have to be an essential component of the research activities of the IGBP, the biological and ecological community was not sufficiently well represented to formulate the biological component of the overall research programme. The task of overcoming this deficiency has been undertaken by the IGBP Coordinating Panel on Terrestrial Biosphere-Atmospheric Chemistry Interactions, the SCOPE Project on Trace-Gas Exchange, and the participants of the Sigtuna Workshop held in February of 1990. The proposals made at that workshop form the basis of the recommendations found in the present document.

In order to achieve consistency between the two documents, this document has been written in the same format as the initial IGAC plan, using a hierarchy of foci (i.e., major scientific topics); activities (i.e., research studies within each focus); and tasks within the activities (Table 1). With one exception, the proposed activities and tasks fall within the framework of established IGAC foci. The activities on the effects of land-use change in the tropics, on biomass burning and on rice cultivation expand and complement the IGAC activities in IGAC Focus 2, Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry. The activities on Trace-Gas Fluxes from High Latitude Ecosystems complements the IGAC Focus 4, The Role of Boreal Regions in Changing Atmospheric Composition. The activity on Interpretation and Modeling fits into IGAC Focus 5, Global Distributions, Transformations, Trends and Modeling. Only the Focus dealing with Trace-Gas Exchange in Mid-Latitude Ecosystems has no counterpart in the IGAC plan. This is therefore being proposed as a new Focus 7 in the overall IGAC science plan. A summary of the recommendations from the Dookie and the Sigtuna workshops is included in the IGBP science plan (IGBP Report No. 12).

SUMMARY OF FOCI AND ACTIVITIES

Following the IGAC organization presented in their report (Galbally 1989), the research addressed in this document focuses on issues of specific interest to a number of different geographical regions of Earth. Within each geographical Focus, individual activities address specific issues of importance to that region.

FOCUS 2: Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry and Biosphere-Atmosphere Interactions

ACTIVITY 2.1 Tropical Land-Use and Biosphere-Atmosphere Trace-Gas Exchange in the Tropics (augment to IGAC 2.1)

Status: Active

Committee: I.E. Galbally (Australia-Convenor), C. Johansson (Sweden-Convenor), A.F. Bouwman (Netherlands), R. Conrad (FRG), B. Cros (Congo), R. Delmas (Congo), M. Keller (USA), J. Levine (USA), P.A. Matson (USA), E. Sanhueza (Venezuela), S.C. Wofsy (USA), W.-X. Yang (China).

The tropical regions of the world are subject to major perturbations as a result of human activity and potentially as a consequence of climate change. Recent studies suggest that the tropics are an important source of many trace gases including N_2O, CH_4, non-methane hydrocarbons (NMHC), NO_x and CO. Land-use changes are significant in both the humid tropics, where deforestation is occurring and in savannas, where grazing is intensifying and conversion to agriculture is increasingly important. Initial studies in these systems are essential to understand the biological/physical causes of increased emissions, and to estimate regional fluxes. Development of techniques for spatial extrapolation of fluxes is especially critical in the tropics, where relatively few surface observations have been made.

ACTIVITY 2.3 Impact of Tropical Biomass Burning on the Atmosphere and Biosphere (augment to IGAC 2.3)

Status: Active

Committee: M.O. Andreae (FRG-Convenor), F. Akeredolu (Nigeria), D.H. Ehhalt (FRG), J. Fontan (France), R.C. Harriss (USA), V. Kirchoff (Brazil), P.M. Vitousek (USA). Note requirement for addition of ecologists and biologists.

Recent studies on the chemical composition of the tropical atmosphere show the existence of strongly elevated levels of trace gases, including O_3, CO, and NO_x, that have been attributed to biomass burning. Airborne and satellite measurements have shown that these polluted areas extend over thousands of kilometers. Biomass burning has direct effects on the atmosphere and also influences ecosystem dynamics, both through direct effects on ecosystem processes and through secondary impacts of ozone and other trace-gas compounds on vegetation. We suggest expanded studies of the extent and timing of burning; of the chemical composition of the fire plumes; and of the direct and indirect effects of burning on ecosystems.

ACTIVITY 2.5 Exchanges of Methane and Other Trace Gases in Rice Cultivation (added Activity to IGAC)

Status: Planning

Committee: R. Cicerone (USA-Convenor), H.U. Neue (Philippines), R. Conrad (Germany), K. Minami (Japan), H. Rennenberg (Germany), O.T. Denmead (Australia), R. Sass (USA)

Data available from flooded rice fields indicate that these systems are an important global source of methane. Rice cultivation is increasing in extent and intensity and therefore methane emissions from this source have the potential to increase rapidly. One of the activities proposed for this area is to evaluate methane emissions from current and alternate management systems so that recommendations can be made to reduce methane emissions. Because management strategies designed to reduce methane emissions might inadvertently increase emissions of other trace gases (e.g., nitrous oxide), the effects of management strategies on selected other gases will also be studied.

FOCUS 4: The Role of Boreal Regions in Changing Atmospheric Composition

ACTIVITY 4.1 Estimation of High-Latitude Ecosystems in Trace-Gas Emissions (augment to IGAC 4.1)

Status: Active

Committee: H.I. Schiff (Canada-Convenor), L. Barrie (Canada), R. Cicerone (USA), W. Glooschenko (Canada), R.C. Harriss (USA), W. Reeburgh (USA), B. Svensson (Sweden).

Northern ecosystems, including northern wetlands, boreal forest, and wetlands associated with the boreal forest are important sources of methane. They may also now or under altered climate be significant sources of other trace gases, such as non-methane hydrocarbons. Essential studies in northern ecosystems include accurate determination of regional budgets based on characteristics of high-latitude ecosystems and of environmental drivers which are both important in controlling trace gas production, consumption, and transport processes.

ACTIVITY 4.2 Ecological and Environmental Controls and Correlates for Trace-Gas Sources in High-latitude Ecosystems

Status: Active

Committee: To be selected in the future.

In selected high-latitude ecosystems, process studies will be necessary to better understand the linkages between biological, soil and environmental factors. In these studies, thermal and soil moisture regimes, biogeochemical characteristics, and soil characteristics, will be examined in conjunction with gas-flux measurements. In addition, the structure of microbial populations, quality of litter, and the plant structure as it affects trace-gas production, consumption, and transport.

ACTIVITY 4.3 Sensitivity of High-latitude Trace-Gas Sources and Sinks to Environmental Change

Status: Planning

Committee: To be selected in the future.

The effect of climatic change or other environmental perturbation on trace-gas emissions will, in the short term, involve changes in abiotic variables, such as temperature and moisture content. However in the longer term, these environmental changes may result in changes within the plant and microbial communities, thus changing the biotic control of trace-gas emissions. Manipulative experiments, process model studies, long-term observations are integral components of this activity. Coordination among these components is critical to assure that evaluation of the potential effects of global change on biogenic trace-gas processes in the high-latitude region.

FOCUS 5: Global Distributions, Transformations, Trends, and Modeling

ACTIVITY 5.5 Development of Global Emission Inventories Including Global Synthesis of N_2O, CH_4 and CO Fluxes (added Activity to IGAC)

Status: Planning

Committee: To be selected in the future.

While many of the flux measurement programmes in the overall project are regional (i.e., tropics or mid-latitudes) many of these studies are of interest chiefly as components of global budgets. This is especially true for the mid- to long-lived species (CO, CH_4, N_2O). We suggest a project to address development of global budgets, and their comparison with atmospheric concentration and inverse model calculations. Global extrapolation requires the ability to generalize flux measurements in space and time. This is a general problem, not limited to any of the specific areas proposed for study. We propose one or a series of studies designed to rigorously test the models and measurement techniques required for extrapolation.

FOCUS 6: International Support Activities

ACTIVITY 6.1 Education in Atmosphere-Biosphere Interactions and Earth System Science (augment to IGAC 6.1)

Status: Planning

Committee: J.W. Winchester (USA-Convenor), H. Rodhe (Sweden), H.I. Schiff (Canada).

While IGAC clearly outlines the need for education of university-level students and their educators, we also emphasize the need to build up the community of scientists required to carry out the studies proposed here and in other global change programmes. This will require both enticing practicing scientists into the general area of global studies, and educating researchers in the multi-disciplinary framework within which disciplinary studies are being carried out.

ACTIVITY 6.4 Activity and Project Coordination. (added Activity to IGAC)

In this document, we propose numerous multi-disciplinary studies that require scarce human and equipment resources. Meanwhile, similar planning is taking place in other IGBP Core Projects as well as in other national and international communities. Collaboration among groups will be the key to carrying out successful regional scale studies. We suggest a planning mechanism for regional-scale studies that encourages the efficient use of resources.

FOCUS 7: Trace-Gas Fluxes in Mid-latitude Terrestrial Ecosystems (added Focus to IGAC)

ACTIVITY 7.1 Terrestrial Mid-latitude Ecosystems as Sources and Sinks for CO, CH_4, and N_2O (added Activity to IGAC)

Status: Planning
Committee: J.M. Melillo (USA-Convenor), K. Smith (UK-Convenor), J. Bogner (USA), J. Freney (Australia), P. Groffman (USA), G. Harris (FRG), K. Heider (FRG), A. Isaejev (USSR), L. Klemedtsson (Sweden), W-H. Su (China), B. Svensson (Sweden)

Mid-latitude ecosystems may be significant sources or sinks for a number of trace gases. In particular, intensive agriculture and forestry may represent a large source for N_2O. Deliberate and inadvertent N fertilization may have reduced the sink strength of these areas for CH_4. Better understanding of the governing processes and regional fluxes is required to complete our picture of the global fluxes of these gas species.

ACTIVITY 7.2 Terrestrial Mid-latitude Sinks for CO_2 (added Activity to IGAC)

Status: Planning
Committee: G.P. Robertson (USA-Convenor), D. Baldocchi (USA), I. Burke (USA), R. Desjardins, I. Fung (USA), P. Jarvis (UK), J.M. Melillo (USA), R. Webster (USA), S. Wofsy (USA)

Terrestrial mid-latitude ecosystems are now suspected to be sinks for CO_2, on the basis of atmospheric concentration gradients and inverse model calculations. Increased uptake of CO_2 may result from a number of causes, including CO_2 fertilization, inadvertent N or S fertilization, or increased biomass burning, resulting in accelerated CO_2 uptake during regrowth.

ACTIVITY 7.3 How Important are Mid-Latitude Ecosystems as Sinks for Atmospheric Oxidants and Sources of Oxidant Precursors and the Role of Volatile Organic Compounds?

Status: Planning
Committee: To be selected in the future

Industrial pollutants are important in controlling atmospheric chemistry and are becoming ubiquitous in the mid-latitudes. These industrial emissions interact strongly with a number of biogenic compounds such as NMHC and NO_x. The biogenic sources and their interactions with the products of industrial activities need to be better understood.

DESCRIPTION OF FOCI AND ACTIVITIES

FOCUS 2: Natural Variability and Anthropogenic Perturbations of Tropical Atmosphere and Biosphere-Atmosphere Interactions

Tropical ecosystems hold more than 60% of Earth's biomass and contain more than 50% of the Earth's plant and animal species. In general tropical, ecosystems are highly productive. Most importantly, tropical ecosystems are undergoing rapid change as a result of human population growth and activities. Land-use changes and their impacts on biogeochemical cycling are being felt locally in reduced productivity of systems; they are also resulting in changes in trace-gas emissions to the atmosphere, with concomitant effects on atmospheric chemistry and atmospheric transport. The projects proposed under this focus in conjunction with the IGAC projects will yield greater understanding of the present state of tropical biosphere-atmosphere interactions and effects of change on trace-gas exchange and atmospheric chemistry.

ACTIVITY 2.1 Tropical Land-Use Change and Trace-Gas Emissions (augment to IGAC 2.1)

Tropical soils and vegetation represent globally significant sources of a broad range of atmospheric gases, including reactive hydrocarbons and CO (Crutzen and Gidel 1983, Logan 1985), N_2O and NO (Keller et al. 1983, 1986, Seiler and Conrad 1987, Kaplan et al. 1988, Matson and Vitousek 1987, Johansson et al. 1988, etc) and CH_4 (Bartlett et al. 1988). Conversion of tropical forests to agriculture and pasture is presently occurring at very rapid rates (6-8 million hectares/year; Melillo et al. 1985), but the impact of these land-use changes on biogeochemical cycling, trace-gas emissions, and atmospheric photochemical and transport processes is not well understood.

Several recent studies of tropical land conversions have suggested the importance of change on trace gases. Luizao et al. (1989) reported that pasture soils near Manaus, Brazil produced 3-fold more N_2O annually than adjacent forests (Figure 2). Available measurements and modelling resullts indicate that tropical deforestation in humid areas could lead to increased regional

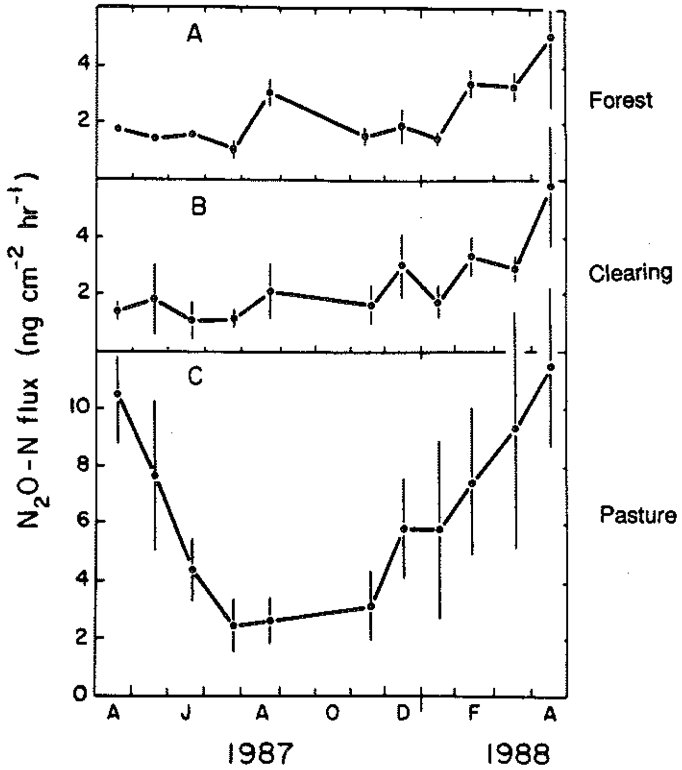

Figure 2. Seasonal pattern of N_2O flux in a) an intact forest, b) a recently cleared and burned site, and c) a pasture near Manaus, Brazil (reproduced from Luizão et al. 1989).

levels of ozone and mineral acidity in rainfall. Observations show that these changes may already be occurring in some areas (Rodhe et al. 1988). However, the extent to which these results can be considered representative of tropical land conversion in general is not known.

Forest conversion to agricultural systems frequently results in rapid loss of soil organic matter and major changes in soil structure and texture. Carbon and nutrient inputs to the soil also change depending on management systems. In addition, soil temperature and moisture regimes may change as a result of reduction in evapotranspiration, altered infiltration, and reduced soil shading. These changes will affect microbial populations and nutrient turnover, which in turn can alter production and consumption of gases by microorganisms. These soil changes may also influence characteristics like diffusivity of soil, with potential effects on emissions. Alterations in soil characteristics, biogeochemical cycling, and trace-gas fluxes may be expected to vary over time, depending on the intensity of management, type of cropping system, intensity of grazing, type of soil, time until fallow period, and other factors.

Removal or alteration of vegetation will influence canopy exchange characteristics as well as soil processes. The conversion of forest to pasture or crop results in changes of plant species as well as in vegetation structure and foliar biomass distribution. Plant species differences alone are expected to change emissions of biogenic NMHC and perhaps NH_3. Ozone and NO_x uptake might also be changed as a function both of vegetation species and leaf area. Furthermore, changes in nutrient availability and microclimate characteristics resulting from forest conversion may affect plant physiological processes, possibly leading indirectly to changes in emissions and uptake of trace gases. Finally, canopy structure may also affect aerodynamic roughness and turbulent transport.

Forest conversions result in spatially heterogeneous surface characteristics, with vegetation canopies of varying heights and patchiness of forested and non-forested areas, resulting in varying surface roughness characteristics. The effects of this variation on the measurement of trace-gas exchange using eddy correlation techniques and the effects on mixing of gases in the convective boundary layer and transport into the free troposphere is not well understood, nor is it certain that present knowledge of reaction kinetics is sufficient for atmospheric chemical modeling in heterogeneous environments. This Activity will address changes in land-atmosphere exchange that result from alterations in soils, canopies, and landscapes in response to land-use change.

Goals:

- Examine the impact of tropical land conversion on trace-gas fluxes and regional atmospheric composition and chemistry.
- Determine the factors that regulate and control trace-gas exchange resulting from tropical land conversion.
- Develop extrapolation approaches and models that estimate and predict effects of current and future land-use changes on trace-gas emissions on local, regional, and global scales.

Implementation:

This Activity will involve short and long-term studies of ecosystem and atmospheric processes to be carried out in areas of active land-use change in both savanna and humid forest regions. Savanna studies and humid forest studies will be considered two distinct Activities. The Activities will run in parallel, but the savanna studies will begin 1-2 years earlier. Long-term studies of ecosystem processes, vegetation and microclimate characteristics, and remote-sensing analyses of the study areas will be initiated first. After two years, short-term (1-3 month) intensive campaigns including aircraft-based measurements will be carried out in the same study regions (see Timetable).

Site Selection. In the savanna, studies will examine the effects of savanna conversion to managed savanna (via burning) and to intensive agriculture; in humid forest, conversions to pasture and agriculture will be emphasized. If possible, study areas will include agricultural research stations or other institutions where background data on soils, vegetation, and climate are available. Site selection will also be carried out to maximize collaborations with on-going terrestrial and atmospheric research groups.

Field Measurements and Process Studies. Research on land-use effects on trace-gas emissions will address process changes on scales ranging from soil/microorganism to canopy and ecosystem to boundary layer and free troposphere. Ultimately, this research will be used to address the global significance of trace-gas exchanges (see also Focus 5). In general, studies of soil emissions, trace-gas exchange within a canopy and transport out of the canopy will be carried out. These studies are described below.

Changes in soil emissions (including NO, N_2O, CH_4, CO, CO_2) and their controlling factors will be studied in replicated managed sites, in control forests, and in fallow systems (Figure 3). In addition to standard soil measurements, in situ ^{15}N isotope dilution studies and closed soil incubations will be used to examine changes in microbial immobilization and mineralization of nitrogen. Enclosure methods will be used to measure soil trace-gas emissions; for the more reactive gases, box measurements will be coupled to tower-based measurements and results interpreted using models of their transformations. Many of the soil process studies must be carried out through one or more annual cycles in order to understand temporal variability.

We expect that they will precede the tower and aircraft based research, and will provide context and constraints for the later phase.

The studies outlined above will be carried out in chronosequences of managed land and forest lands. This will require the use of sites where some history of management is documented (preferably within tropical research stations). This research will be coordinated with other long-term individual investigator studies at a range of sites.

To understand transport of trace gases into and out of a tropical forest canopy, it may be insufficient to only monitor gradients or eddy fluxes. Intermittent large eddies that evacuate deep layers of the canopy may be important, and make it necessary to observe column concentrations within and above the canopy. In situations where vegetation is short (e.g., pasture, crop, savanna), standard micrometeorological techniques such as Bowen-ratio type gradients and eddy correlation approaches will suffice to make flux estimates.

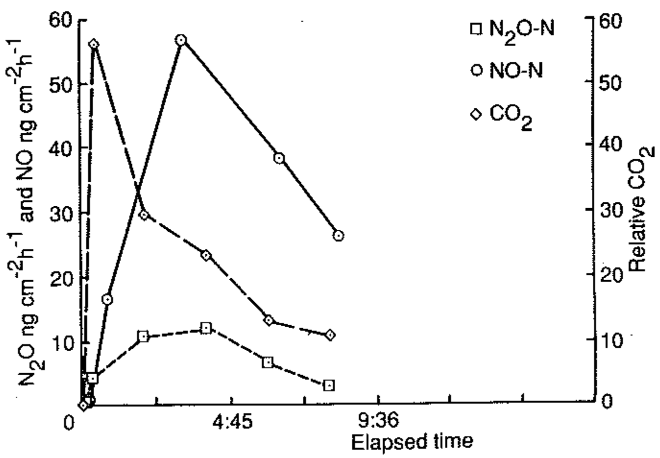

Figure 3. Fluxes of nitrous oxide, nitric oxide, and carbon dioxide from a tropical dry forest immediately following a 2 cm simulated rain. (From Davidson et al. In preparation).

Trace-gas instruments for tower operation are available (or soon will be) for CO_2, total hydrocarbons, O_3, CH_4, NO, NO_x, and NO_2. Such instruments are not widely available, and thus tower-based measurements will be set up for only two 1-3 month periods (in the field campaign phase) of each study. In addition to the tower-based measurements, leaf chamber measurements of NMHC, CO_2, NO_x, water and perhaps CO and O_3 exchange will be carried out, especially in comparisons of cropping and pasture systems. These

measurements, in conjunction with other process studies, will allow mechanistic understanding of species effects on canopy exchange. Additionally, optical methods will be employed to examine canopy leaf area distribution as a function of vegetation type.

In order to examine the effects of patchy, heterogeneous environments on regional-scale atmospheric dynamics, quantitative estimates of the scale and degree of patchiness will be determined using remote-sensing analyses of areal extent of vegetation types, foliar density, and perhaps canopy structure. In addition, intensive micrometeorological data will be acquired through portable tower measurements placed in different sized patches. Other measurements, including gas concentration measurements, will supplement this data. Finally, aircraft- based estimation of eddy fluxes of CO_2, CH_4, and CO, as well as measurements of atmospheric stability and depth of the mixed layer can be used to integrate over patches and test flux models from other scales.

Evaluation and modeling of chemical transformations in tropical environments will require a suite of measurements, including measurements of atmospheric stability and depth of the mixed layer, solar radiation, O_3, CO_2, H_2O, hydrocarbons, NO, and NO_2. The minimum set should be expanded when possible to include mixing ratios of PAN, organic nitrates NO_y, HCHO, H_2O_2 and aerosol composition. Chemical measurements must be supported by micrometeorological measurements. Such aircraft-based operations will be considered only during the intensive campaign phases of the studies.

Models and Extrapolation. Models of soil and ecosystem dynamics, canopy exchange, and atmospheric chemistry and transport will be developed in concert with the process studies described above. Both detailed mechanistic models and more highly parameterized models will be undertaken to allow the use of variables acquired from remote-sensing and ground-based observations.

Models of soil and ecosystem processes and trace-gas flux are in early developmental stages. Mechanistic models of factors controlling microbial processes and diffusion of gases through the soil will be developed. At the same time, we will develop less detailed models that can be driven with inputs from soil and climate data bases, from micrometeorological models, and from remote-sensing data.

The degree of integration among models at various scales (ecosystem, canopy, atmospheric chemistry, etc.) will depend on the gas of interest. For example, soil process models that estimate N_2O and CH_4 emissions may not require integration with canopy transport models to permit extrapolation to regional and global scales. Model estimates can be tested by comparison with flux estimates from tower and aircraft-based measurements as technological developments permit. For reactive gases such as NO, models of soil emissions can provide inputs for canopy models; canopy models (which include chemistry and biological exchange) then estimate ecosystem-atmosphere exchange, which interact directly with boundary layer models of chemistry.

Sensitivity analyses on models at all levels must be conducted to provide an assessment of which variables need to be measured. There is a need for extensive interactions between the modelling community concerned with trace-gas exchange and those concerned with global chemical transport models to ensure that models developed interface with global models (see Focus 5 Activity 4).

Remote Sensing. Estimation of the distribution and regional emissions of trace gases in response to tropical land conversions may be done through direct extrapolation approaches (multiplying average fluxes in each land use by land-use areal extent) and modeling approaches. Either approach requires remote-sensing and ground-based data bases. Remote-sensing data are also critical for the description of land surface heterogeneity for use in boundary layer mixing studies described earlier. Several remote-sensing approaches which may be useful to this study are currently available or are under development. Land-use classification based on thematic mapper or SPOT sensor data are crucial to selection of specific field sites, description of the heterogeneity or "patchiness" of regions, and for measurements of areal extent as a bases of extrapolation. While these sensors will easily differentiate broad land-use classes, it will be difficult to detect differences between certain agricultural systems, degree of degradation or condition of these systems, and stage of succession in forest regeneration in many instances. Remote-sensing studies must be initiated to examine these detection capabilities.

Experimental radar sensors are being applied for measurements of canopy structure, foliar distribution, and vegetation classification. Likewise, high spectral resolution sensors are being tested, and may be used for spectral characterization of such variables as canopy chemical characteristics and trace-

gas concentrations. Finally, satellite systems planned for the late 1990s will include a range of sensors designed for study of both vegetation and atmospheric characteristics, and may be useful for later studies in this project.

Use of these and other sensors may require ground data in addition to those described above. We propose to collaborate with investigators involved in on-going remote-sensing projects in the tropics whenever possible, and will encourage remote-sensing researchers to consider use of study sites developed for this project.

Timetable:

1990 Meeting of Project Coordinating Panel to finalize site selections for both long-term studies and instrument intercomparison.

1991 Instrument intercomparison at savanna site.

1991 Begin long-term ecosystem process studies in savanna sites. Carry out remote-sensing studies.

1992-94 Carry out 2 intensive campaigns in savanna area 1-3 months each)

1992 Begin long-term ecosystem research in humid forest sites.

1994-96 Carry out 2 intensive campaigns in humid forest study area.

ACTIVITY 2.3 Impact of Tropical Biomass Burning on the Atmosphere and Biosphere.

Biomass burning has only recently been recognized as a major source of important trace gases and aerosol particles. Current estimates are that 5 Pg of biomass carbon are burned each year, an amount comparable to that resulting from fossil-fuel combustion. The perturbations to global atmospheric chemistry which are caused by this largely anthropogenic activity are especially important in the tropics. Satellite observations have revealed elevated levels of O_3 and CO over vast areas of Central Africa and South America, over the tropical Atlantic, and the Indian Ocean. It is now thought that biomass burning provides a major global source of a number of atmospheric gases besides CO_2, including CH_4, CO, and NO. Through photochemical reactions, these emissions cause substantial production of tropospheric ozone which enhances photochemical activity of the atmosphere. On the other hand, enhanced CO emissions lead to a lowering of the hydroxyl radical concentrations, thus lowering oxidation efficiency of the atmosphere. Biomass burning also causes considerable emissions of smoke aerosol particles which may partly serve as cloud condensation nuclei. In this way, biomass burning could affect not only regional and global atmospheric chemistry, but also weather and climate.

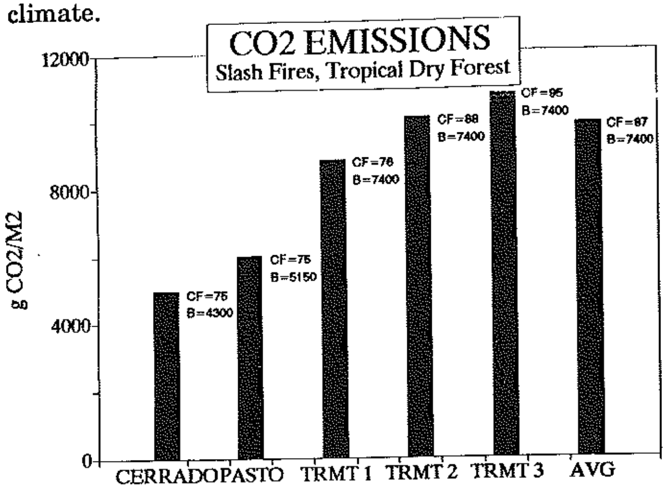

Figure 4. The variation of CO_2 emissions resulting from slash fires in tropical dry forest. Mass of C emitted from tropical dry forest fires may be an overlooked source of CO, CO_2 and NMHC into the atmosphere. CF is the combustion factor for each burn. B is the dry aboveground biomass present. Conversion of biomass to CO_2 emission was computed as biomass combusted (g/m2) x 1.536 CO_2 volatilized (g/g) based on Sandberg et al. 1989). (Figure reproduced from B. Kauffman and R. L. Sanford, Jr. in prep.)

Our understanding of trace-gas emissions resulting from biomass burning is not commensurate with their environmental importance. Too little is known at this time of the geographical distribution of biomass fires, of fire intensities and the relative amounts of flaming and smoldering fires in various ecosystems, of trace-gas emission factors, of the chemistry within biomass burning plumes, and of the impacts of biomass burning on ecosystems (Figure 4). We propose a research plan which addresses the major gaps in our knowledge. This plan is intended to complement the studies currently planned under the auspices of IGAC. The following four tasks are proposed for this area of research:

- Spatial and temporal characterization of biomass burning
- Chemical characterization of biomass burning emissions and plume chemistry.
- Short and long-term effects of fires in terrestrial ecosystems
- Ecological effects of the deposition of biomass burning products.

Task 2.3.1 Spatial and temporal characterization of biomass burning

Insufficient information is available on the spatial and temporal distribution of biomass burning in the tropics. Although the Food and Agriculture Organization (FAO) has published statistics on land-use changes for the late 1970s, from which biomass burning estimates may be derived, these statistics are incomplete and for some countries not reliable. Most importantly, under the pressures of population growth, changes in land use have accelerated over the past decade, particularly in the tropical forest and savanna regions. There is thus an urgent need to obtain reliable and up-to-date global inventories of fire locations and of biomass quantities burned for permanent cultivation, for shifting cultivation and of fires in the humid savannas. Satellite observations during the next decade will afford considerable improvements in our ability to map the geographical distribution and frequency of fires, and will also provide information on their temperatures and spatial extent.
Emissions to the atmosphere from biomass burning are directly related to the amounts and characteristics of above-ground biomass. The above-ground carbon loading determines the amount of CO_2 and other carbon compounds emitted to the atmosphere; emission factors for the release of other trace-gases relative to CO_2 are available from aircraft or test-fire observations. Distinction must be made between flaming and smoldering phases of burning, as the emissions of combustion products are quite different for both phases. Current estimates of above-ground biomass loadings in forests and savannas are uncertain by 30-50%, which precludes the compilation of sufficiently accurate global emission inventories. The influences on biomass loading in savannas caused by grazing, insects, and agricultural activity also need to be studied.

Goals:

- To construct global inventories of biomass burning, with particular emphasis on establishing spatial and temporal statistics.

- To forecast future trends in biomass burning.

- To quantify the above-ground biomass loadings of diverse ecosystems subjected to biomass burning and their relationship to weather, nutrient status of the soils and land-use patterns (agricultural practices, grazing activities).

Implementation:

Remote-sensing methods provide important means for compiling geographical statistics of fire frequencies. Among existing systems, the Advanced Very High Resolution Radiometer (AVHRR) sensor carried on board the NOAA series of satellites possesses several characteristics which make it suitable for studying both fires and vegetation characteristics. The most pertinent characteristics are visible and near-infrared bands, which can be combined in vegetation indices and used to monitor the photosynthetic activity of green biomass; thermal sensors which record changes associated with physical changes in the vegetation canopy; and high temporal frequency of coverage, which offers monitoring capabilities for studying the spatial and temporal changes in vegetation canopies.

In the framework of developing a global fire-monitoring system, these sensor qualities provide data from which it should be possible to derive parameters such as size, fire spread rates, fire temperature, smoke characteristics of active fires, geographic location, densities, frequencies of fires, and vegetation characteristics before and after fires (Figure 5).

Limitations of the AVHRR data are its spatial resolution (1-4 km), which is coarser than the dimensions of most fires, and its low temperature saturation in the thermal channel. These limitations will be significantly reduced in future sensors such as EOS/MODIS which will have a 500 m resolution, a temperature saturation of 700 °K at 3.75 microns (compared with 320 °K for AVHRR-channel-3) and of 1100 °K at 11 microns. Other EOS sensors such as HIRIS and MISR will also offer increased spatial resolution in an increased number of spectral bands, plus the capability of monitoring simultaneously land-surface characteristics and atmospheric conditions.

Ground-based data compilations are essential complements to remote-sensing efforts, and they can be undertaken immediately. Collaborations with the FAO should be initiated to compile improved country-by-country inventories of

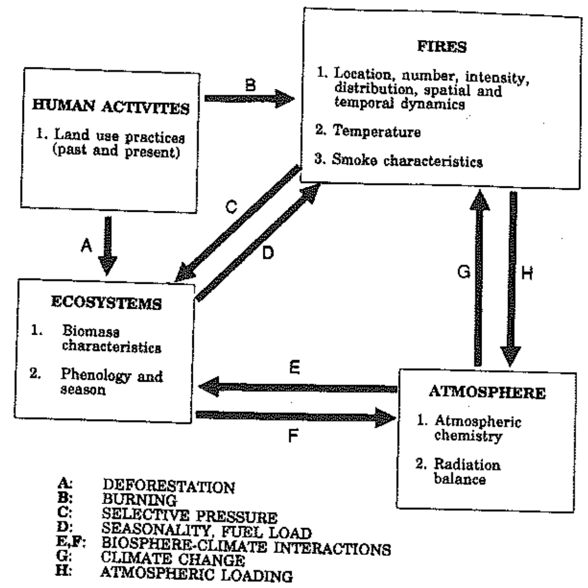

Figure 5. Diagram illustrating system linkages and parameters which may be derived from remote sensing: tropical ecosystem (modified from Malingreau 1990).

biomass burning practices. Selected areas (e.g., the savannas of Africa and South America) should be targeted for on-site investigations. The focus of these investigations should be to provide corroboration of the satellite measurements and the FAO data, as well as to understand the socioeconomic factors regulating biomass burning.

Biomass burning emissions are intimately tied to the biomass loadings of ecosystems. There is a particular need to document the biomass loadings of wet savannas, which are currently thought to provide the major global source of biomass burning emissions. Estimates for savannas could be made on the basis of statistical correlations between rainfall, productivity, and standing biomass. However, grazing introduces a major complication to calculating fuel loads from biomass consumption. Grazing by herbivores is generally high in savannas, perhaps averaging 50% or so of above-ground plant production. It has been shown in the Serengeti grasslands that grazing intensity is inversely correlated with fire frequency; other studies have shown that grazing directly reduces combustion losses of C and N. Thus, human use, livestock populations, and fire management interact to control emissions of C and N from savanna burning. Combined geographic data on above-ground plant production and grazing will be required to estimate fuel availability in savannas. In cultivated areas, burning of agricultural waste in the field or for energy must be accounted for as well.

Field studies in diverse ecosystems provide at this time the most promising means for gleaning information on combustible biomass C loadings. Remote sensing can be a useful tool for estimating end-of-season biomass (using an integrated vegetation index approach). Possibilities of using microwave data to distinguish between green biomass and combustible material should be investigated.

Biomass loadings in specific locations may change drastically from year to year. It is therefore essential that the data obtained in field studies be used to construct models relating above-ground biomass loadings to land-use and meteorological variables. These models should be designed to enable extrapolation of observations to successive years, and to forecast future trends.

Timetable:

1990 Meeting of the IGAC Coordinating Committee on Tropical Biomass Burning in Williamsburg, VA, following the AGU Chapman Conference on Global Biomass Burning.

1991 Dahlem conference on biomass burning, organized by P.J. Crutzen and J. Goldammer.

1990- Compilation of a global biomass burning data base from field observations.

1990- Field studies of above-ground biomass loadings in diverse ecosystems. Development of models to relate biomass loadings to land-use types and meteorological variables.

1990-92 Construction of a global land cover map using existing data from remote sensors such as NDVI, SPOT, SIMMR, and TM.

1998- Beginning of the EOS programme; use of data from MODIS, HIRIS, etc. to construct global land cover maps with 0.5-1 km resolution.

Task 2.3.2 Chemical characterization of biomass burning emissions and plume chemistry

Biomass burning releases large quantities of reactive compounds to the atmosphere, in particular the gases NO_x, hydrocarbons, and CO. Large quantities of soot and organic carbon aerosol are also emitted. Chemical reactions involving NO_x and hydrocarbons produce large amounts of O_3, consuming the precursors in the process. Aircraft observations of relatively aged plumes from biomass burning have documented an almost total conversion of NO_x to less reactive NO_y species, and elevated levels of O_3 (50-100 ppb). Chemical transformations in fresh plumes appear to regulate the ultimate chemical input from biomass burning into the global atmosphere.

Aircraft measurements of the chemical composition of plumes from biomass burning have been made by several groups in diverse environments. However, these research efforts must be viewed as preliminary. Typically, chemical characterizations have been limited to a few species, and data are lacking for some potentially important species including aerosols. Process models must be developed to describe the chemical transformations occurring in the burns and in the fresh biomass burning plumes.

Goals:

- To quantify the gas and aerosol emissions resulting from biomass burning in diverse ecosystems, under conditions of flaming and smoldering combustion.
- To develop process models describing the composition of emissions as a function of biomass type and environmental variables which integrate models of fire dynamics and combustion chemistry, especially for savanna systems.
- To document and model the reactivity of the chemical species in biomass burning plumes.

Implementation:

A major research effort is needed to document in detail the chemical composition of plumes from biomass in various environments. This programme should take advantage of recent advances in aircraft instrumentation technology, that have considerably improved the detection limits and measurement accuracies for many trace gases. The availability of sampling platforms (aircraft, helicopters, towers) needs to be expanded.

The availability in the late 1990s of remote-sensing data on tropospheric composition will add a new dimension to our ability to document the composition of biomass burning plumes, and their dispersal in the global atmosphere. Global mapping of CO and O_3 columns will be achieved by the GOME (SCIAMACHY) sensor, scheduled for inclusion on the ESA ERS-2 satellite in 1993-1994 and later launches. Global mapping of CO will also be available on the EOS-A platform in the late 1990s, using the MOPPITT or TRACER sensors. The sensor TES, planned for launching on the EOS-B platform, will provide horizontal and vertical mapping of a number of trace species including CO, O_3, NO_x, and HNO_3.

Programmes to measure the products of biomass burning in combustion-chambers are currently under way in several laboratories. More studies, conducted over a range of biomass types and combustion conditions, are urgently needed to document the nature and concentrations of direct combustion products. Combustion chamber experiments provide a unique opportunity for measuring emissions of N_2 from biomass burning. Preliminary experiments at the Max-Planck Institute for Chemistry in Mainz, FRG suggest that N_2 emissions could account for approximately 50% of the total nitrogen of volatilized in biomass burning (Crutzen, pers. comm.). If confirmed, this result would point to a major sink of fixed nitrogen from biomass burning in the humid savannas. Chemical models will be needed to interpret the observations from combustion chambers and relate them to easily measurable variables such as biomass composition, biomass flammability, oxygen availability, and flame temperatures found in the field.

Biomass burning plumes are rapidly cooled as they mix with the local atmosphere, and are then transported with the prevailing winds. Chemical transformations producing O_3, and oxidizing NO_x, take place as the plumes are advected over hundreds of kilometers and slowly disperse into the surrounding atmosphere. The chemical evolution of a plume can be documented by small aircraft through cross-sections of the plume at successive distances from the burn site. Such studies would provide key information for evaluating the rates of chemical transformations within the plumes. Requirements for

photochemical modeling include measurements of O_3, H_2O, CO, hydrocarbons, carbonyls, NO, and NO_2. Additional measurements of H_2O_2, a number of oxygenated hydrocarbons (dicarbonyls, ketones, peroxides, alcohols, organic acids), NO_y species (in particular PAN, HNO_2, HNO_3, and organic nitrates), aerosol characteristics (size distribution, composition, cloud condensation nuclei densities), and photolysis rate constants for NO_2 and O_3 are highly desirable. The chemical measurements should be supported by ancillary meteorological measurements and photographs allowing documentation of the spread of the plume over time.

Photochemical tracer models simulating the chemical evolution of biomass burning plumes will be needed to interpret the aircraft observations. It is not clear at this time whether the photochemical mechanisms currently used for air pollution modeling can be successfully applied to biomass burning plumes, since the hydrocarbon mix and the hydrocarbon/NO_x ratios may differ considerably from those in urban or rural atmospheres. The plume chemistry could be further complicated by heterogeneous reactions involving aerosols. Comparison of model results with observations would allow us to determine current gaps in our understanding of photochemical processes in biomass burning plumes. A programme of laboratory kinetic studies should accompany this activity.

Timetable:

1990	Meeting of the IGAC Coordinating Committee on Tropical Biomass Burning, Williamsburg, VA, following the AGU Chapman Conference on Global Biomass Burning.
1991	Dahlem conference on biomass burning, proposed by P.J. Crutzen and J. Goldammer.
1990-92	Field studies of biomass burning plumes, focusing on detailed characterizations of the plume composition.
1991-93	Development of photochemical models to interpret the chemical evolution of the plumes observed from aircraft.
1990-95	Combustion chamber experiments to characterize biomass burning products under different combustion conditions, and for different biomass types.

1990-95 Aircraft measurements of the composition of biomass burning plumes, with focus on documenting the chemical evolution of individual plumes.

1991-98 Development of models of combustion chemistry to interpret the combustion chamber measurements. Development of integrated biomass combustion models that simulate fire spreading and plume composition on the basis of observable variables such as biomass composition, biomass structure, flame temperature, meteorological parameters, and topography.

Task 2.3.3 Short- and long-term effects of fires on terrestrial ecosystems

Fire has both short- and long-term effects on trace-gas exchanges between the biosphere and the atmosphere. Short-term changes in fluxes of biogenic trace gases following fire have been reported from many systems. These are driven by changes in nutrient availability (caused by the release of nutrients during combustion), microclimate (caused by the removal of canopy, soil blackening, reduced evapotranspiration, altered infiltration), and microbial populations. Together, these changes can result in higher fluxes of specific N and C containing trace gases after fire; increases can persist for days to years following fire. In contrast, biogenic emissions of non-methane hydrocarbons may be drastically reduced for periods of a few months or until vegetation is reestablished.

Fire removes large quantities of C, N, and S from burned areas; it leaves most of the other essential elements behind. Fire also affects ecosystem structure and function for long periods of time, especially in forest environments. In consequence, biological productivity in burned sites eventually may become limited by low nitrogen availability, and the fixation of carbon and fluxes of N and C containing gases can be reduced in the long term (other than during fires). Some of the nitrogen removed appears to be N_2; most of the rest is deposited back to the surface, but this deposition may occur far from burned areas. In particular, some of the nitrogen may be transferred from frequently-burned savanna to infrequently burned forest. This loss of nitrogen in combustion may be partly replaced by biological nitrogen fixation, but replacement is often incomplete, particularly where fire is frequent.

Goals:

- To determine the short- and long-term effects of fire on post-fire exchanges of trace gases between terrestrial ecosystems and the atmosphere;
- To determine the long-term effects of fire on carbon and nitrogen storage and turnover.

Implementation:

Key areas for assessing the effects of biomass burning on terrestrial ecosystems are tropical forests and pastures, savannas, and boreal forests. The research programme should include the following menu of field and model studies:

Sampling of well-characterized sites that differ in fire history. Sampling should be based on an understanding of the pattern of nutrient dynamics at particular times during recovery from fire.

Manipulative experiments designed to understand the factors that control fluxes at different stages of recovery.

Analysis of the immediate, short- and long-term consequences of fire intensity and fuel loads on biogeochemical cycles and trace gas fluxes.

Models of ecosystem changes due to fires.

For the longer-term perspective, a replicated set of experimentally burned plots should be established in savanna and cleared forest regions, and the effects of different fire regimes on C, N, and other element dynamics should be observed over a period of years. It would be most appropriate to establish such a set in a savanna area that does not now experience frequent burning (perhaps in the South American tropics), another set in an area that has had frequent burning for many years (in Africa; in this case, treatment would consist of partial fire suppression), and a set in active or degraded pasture. Research at the Konza Prairie Long-Term Ecological Research Site (USA) can provide a model for this programme. Sites with controlled experimental burning regimes do exist in the tropics; their suitability for such a study should be assessed.

Measurements in such sites should be long-term and not intensive; their design should make use of field and modeling experience developed in temperate grasslands.

While this programme should emphasize the suite of C- and N-containing gases, the long-term effects of fire on budgets of P and other elements should not be neglected. While losses from any individual fire are small, the lack of any mechanism for replacing P can make cumulative losses from several fires biologically significant. Also of interest is the existence of a positive feedback between the occurrence of fire and the flammability of biomass. Frequent fire selects for species (mostly grasses) with highly combustible above-ground parts and the capacity to regenerate rapidly from below-ground tissues; such species tend to be rich in terpene and other volatile compounds. In this sense, fire can beget larger and more intense fire. In the American tropics, the introduction of fire-enhancing African grasses is believed to have prevented (via fire enhancement) succession back to forest on degraded pasture lands, and may have increased the extent and intensity of savanna fires. Laboratory studies of combustibility and combustion products focusing on this grass-fire cycle and the significance of African grasses in the New World would be a useful complement to long-term studies of C and N biogeochemistry.

Task 2.3.4. Ecological effects of deposition of biomass burning products

While the impact of atmospheric ozone on vegetation processes has received attention in the temperate zone, the potential for similar effects has not been studied in the tropics. Levels of ozone comparable to those which reduce photosynthesis in temperate zones occur over much of the tropics during the dry season as a consequence of biomass burning; it is likely that similar or greater effects on photosynthesis, growth, and yields in the tropics could be observed. These effects are probably differential among species and therefore may have significant effects on population and community processes in natural areas far from burned sites. However, the research programme should emphasize effects on crops because many tropical areas do not have excess agricultural production, and because the effects of oxidants on crops are rapid and local - and hence perhaps of direct interest in tropical countries. In the longer term, deposition of anthropogenically fixed nitrogen and other products of biomass burning could alter biogeochemical dynamics in tropical regions.

Goal:

- To understand the biogeochemical consequences of atmospheric deposition resulting from biomass burning.

Implementation:

Field and growth-room studies of the effects of oxidants on crop photosynthesis and yield should be instituted, preferably at major agricultural research stations in tropical countries that currently experience high ozone levels. The effects of deposition of other burning-derived species (e.g., HNO_3) should be explored in a preliminary way. Necessary background information can be derived from regional studies of atmospheric deposition currently contemplated under IGAC. Establishment of further sampling networks across forest-savanna boundaries in continental regions will enable us to address the magnitude of burning-induced transport across biome boundaries. Once these patterns are identified and the magnitudes of deposition fluxes better identified, experiments to determine the consequences of deposition should be initiated.

Timetable:

1990 First meeting of the coordinating committee.

1991 Dahlem conference on biomass burning, proposed by P.J. Crutzen and J. Goldammer.

1990-91 Compilation of existing information on patterns of oxidant distribution in the tropical troposphere and the deposition of other species derived from biomass burning.

1991-94 Measurements of short- and long-term exchanges of trace gases following fire and their regulation in a range of ecosystems.

1991-94 Development of mechanistic models for the interpretation of field experiments

1991-98 Select and establish long-term experimental sites; initiate and maintain burning treatments.

1992-93 Initiation of measurements of oxidant effects on productivity and yields of tropical crops.

1992-94 Development of an experimental programme to study the effects of N and acidic deposition on the functioning of tropical ecosystems.

1994-96 Design and execution of coordinated studies to evaluate models

ACTIVITY 2.5 Exchanges of Methane and Other Trace Gases in Rice Cultivation (added Activity to IGAC)

Wetland rice cultivation is considered to be one of the most important sources of atmospheric methane, on a par with natural wetlands. Although the atmospheric methane concentration is increasing at about 1% per year, it is not known how much of the increase is due to increased emissions from rice paddies. It is certain though, that to meet the needs of increased populations, there will be increases in rice production in the years ahead. Table 2 shows that a doubling of rice production is needed in the next ten years. The increased production will be achieved mainly by intensifying cropping, two crops per year, rather than by expanding the area of rice cultivation. With present agronomic practices, this will lead to increased CH_4 emissions.

Table 2. Actual and projected rice area and rice production by rice environments in South and Southeast Asia.

Environment	Area 1000 ha	%	Production mt	%
1980				
Irrigation	28,867	33	94.2	52
Shallow rainfed	30,375	35	54.7	30
Medium/deep water	11,587	13	16.2	9
Tidal coast land	5,290	6	5.3	3
Upland	11,593	13	11.6	6
Total	87,712	100	182.0	100
2000				
Irrigation	52,741	42	232.1	59
Shallow rainfed	39,905	32	104.6	27
Medium/deep water	13,114	11	30.8	8
Tidal coast land	6,046	5	9.1	2
Upland	12,793	10	18.0	5
Total	124,599	100	394.5	100

For other trace gases, there is insufficient evidence to determine whether rice paddies constitute a greater source than other land-use systems, but increased rice production can be expected to increase these emissions also. Moreover, it might well be that a consequence of changing rice management practices to reduce methane emissions would be to increase emissions of other gases, like N_2O.

Goals:

- To determine if rice cultivation is an important cause for the increase in atmospheric concentration of methane and other trace gases.
- To understand the causes of the variability in methane emission from rice cultivation from region to region and over time.
- To identify management practices for rice cultivation in the future that will stabilize or reduce the emission of methane as grain production is increased to meet the demands of an expanding world population.

To achieve these goals, we will pursue a series of tasks at several sites in different, representative rice-cultural systems where core investigations would be conducted. These will be designed to determine the magnitude of the CH_4 emission and the operation of CH_4 production, consumption, and transport processes in the field. We also will establish a number of ancillary field and laboratory investigations to improve measurement techniques and to determine the effects of soil, plant, and management factors. Since more than 90% of rice is cultivated in Asia (Table 3), the core sites should represent the different Asian rice ecosystems. Table 5 lists several locations selected according to climatic region and harvested rice area (Table 4). The research will be organized around three major tasks.

Table 3. Regional distribution of worked rice production and relative size of trade and stocks (milled rice) 1987.

Region	Percent
East Asia	45.4
Southeast Asia	22.2
South Asia	23.5
Latin America	3.9
Africa	2.2
Others	2.8

Total production of milled rice	298 million t
Stocks	51 million t
Trade	12 million t

Table 4. Harvested rice area by region, 1985.

Region	Rice Ecosystem (1000 ha)			
	Irrigated	Rainfed	Deep water	Upland
South Asia	19.206	24,356	8,812	7,877
S. E. Asia	11,975	12,494	3,604	3,274
East Asia	32,196	1,910	0	779
Africa	1,007	1,293	2,084	154
Latin America	2,279	415	0	4,460

Table 5. Possible sites for core investigations

Ecosystem	Region	Country	Site
Irrigated Rice	S. E. Asia	Philippines	Maligaya
Rice Res.St.	South Asia	India	
Rainfed Rice	S.E. Asia	Thailand	Ubou Rice
Res. St.	South Asia	India	
Deep Water Rice	S. E. Asia	Thailand	
	South Asia	India	
		Bangladesh	
Tidal wetlands	S. E. Asia	Thailand	

Task 2.5.1 Survey of methane exchange in different agricultural management regimes within the major rice growing regions of the world

Goals:

- Establish uniform methods of measurement for field determination of the emission of methane and other trace gases and develop new and improved measurement technologies.

- Assess and compare the daily, weekly, seasonal, and annual methane exchange from rice cultivation at representative tropical sites.

Implementation:

Almost all our knowledge of emissions from rice paddies comes from a handful of investigations employing chamber measurements (Mosier 1989, Schutz and Seiler 1989, Wesely et al. 1988), backed up by some isotopic evidence involving ^{13}C and ^{2}H (Wahlen et al. 1988, 1989). While chambers will continue to be the main measurement tool for study of many of the questions raised here (i.e., fertilizer practices, management practices, comparisons between cultivars), there is a need for corroborative measurements which integrate over larger space and time scales and which do not disturb the natural environment. Micrometeorological measurements represent such an alternative, but it is only now that sufficiently sensitive sensors employing tunable-diode lasers are becoming available. The first such sensors are now being used for tower- and aircraft-based eddy-correlation measurements of CH_4 fluxes in high latitudes; they should be in more general service in another year.

Development of an eddy-correlation system suitable for measurement of methane and other gas emissions from rice paddies is needed. This system should be deployed in at least two of the contemplated core field sites where the requirement for large flat areas can be met. Field-wide emission values obtained with this instrument will provide a comparison with chamber measurements and provide additional data on water-vapour loss and CO_2 uptake. Profile techniques employing infra-red gas analysis to measure vertical gradients of methane in the air above the rice plants are also being developed, and these could be employed alongside the eddy-correlation equipment in the field investigations.

The development and operation of these micrometeorological techniques require specialized equipment and operational expertise. The use of these techniques should be vested in one or two appropriate research groups. Likewise, chamber development is an art and, as far as possible, one proven type of chamber should be used for all the investigations so that intercomparisons are possible.

Measurements of methane emission must be carried out so as to include variations in flux that can occur on daily, weekly, seasonal, and annual cycles; they must include fallow periods or other times when rice plants are not in the field. Daily variation of methane emission has been related to diel soil temperature changes measured at the 5 cm depth. While diel methane flux variations have been observed in some studies, it has not appeared universally, perhaps because of other factors such as weather, plant activity and field management. Variation in methane emission over the growing season has been correlated with soil temperature in some studies, particularly those in the temperate zone, but not in others.

Methane emission studies at the different locations will be accompanied by measurements of air, water and soil temperatures; water depth and additions; soil pore-water gas concentrations; fertilization schedule; soil chemical; physical and biological parameters; above and below-ground biomass; and rates of methane production.

Task 2.5.2 Process studies on the regulation of methane emission from rice fields

Goals:

- To assess the effects of present and projected agricultural practices and various soil types on trace-gas emissions.

- To determine the effects of oxidation processes on the emission of methane and other trace gases.

- To determine the role of plant anatomy in the emission of methane and other trace gases.

- To assess the influences of rice cultivars and various sources of organic matter on trace-gas production and emission.

Implementation:

The effects of agricultural practices and soil properties on trace-gas emissions from paddy soils. Differences in agricultural practices have a major effect on annual methane emissions. Application of rice straw significantly increases methane emission rates (Minami 1990), while the effects of compost application on methane emission are small (Yagi and Minami 1989). Tillage operations vary according to water availability, soil texture, topography, rice culture, and resources available. Hand and animal powered tillage are still common in most Asian countries and wet tillage is the preferred land preparation, resulting in earlier seasonal anoxic conditions than those found in soils that have better drainage characteristics. Remarkable variations of methane emission have been observed under different water-management treatments (Minami 1989). Because fertilization practices and water-management regimes differ from region to region, emission measurements must be obtained in areas representative of these practices.

The role of soil differences in methane emission from rice fields is open to question. Koyama (1963) found no significant difference among nine Japanese rice soils, but a study in Texas (Sass et al. 1990) reported a three-fold emission difference between two rice fields on different soil types, even though they were treated the same and were in close proximity. If sense is to be made of variation in methane emission, comparative emission measurements must be made in soils representative of the major rice growing regions of the world, particularly in China and India.

It is proposed to examine trace-gas production and emission from sites (Table 5) that are representative of the rice growing regions where management practices differ. In some cases, the practices are linked to soil type, but this is not universal.

Methane oxidation processes and transfers of trace gases. Pathways for CH_4 emissions generated in paddy soils are diffusion into the floodwater, loss through ebullition, and transport through the aerenchyma tissue of rice. Oxidation at the root-soil interface is also possible. Transport through the

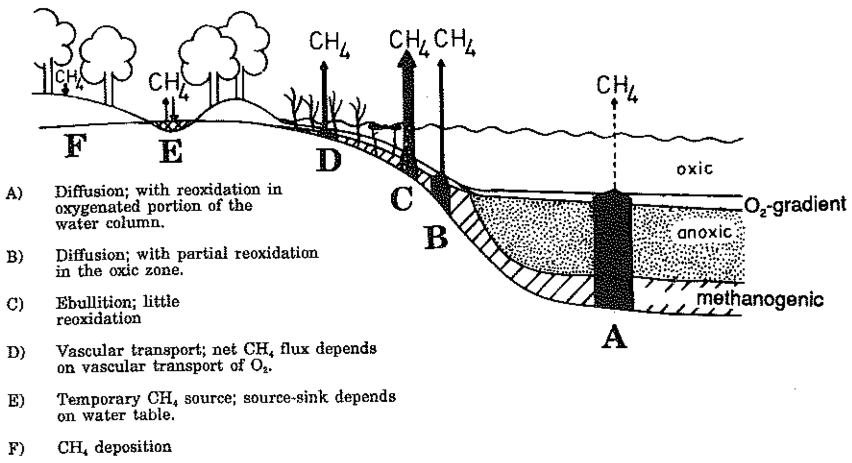

Figure 6. Transport and oxidation processes involved in CH_4 cycling between terrestrial ecosystems and the atmosphere (modified from Conrad 1989).

plant is currently thought to be the major pathway (Figure 6). The amount of methane emitted to the atmosphere is however controlled by the amount of oxidation at the root surface and the resistance to diffusion created by the internal anatomy of the rice plant at various stages of growth and development. The amount of oxidation at the root surface is controlled by the amount of O_2 reaching the root surface, which in turn is controlled by O_2 diffusion into the leaf, photosynthetically produced O_2, and the resistance to diffusion of O_2 created by leaf and root internal structure. The significance of differences in internal anatomy and development of aerenchyma between various varieties of rice and rice cultivation systems is poorly known.

From the few data available it appears that up to 90% of the CH_4 emitted from rice paddies is transported via the plant into the atmosphere. This transport is facilitated by the presence of aerenchyma. Oxygen is transported in the aerenchyma of the rice plant from the leaves to the roots. Part of the oxygen diffuses into the soil, thereby providing the aerobic environment for methane oxidation. Consequently, transport processes in the rice plant may provide means of positive and negative control for methane emission from rice paddies. However, information on methane and oxygen transport on a diel or seasonal scale for important culture varieties is lacking. For other trace gases like N_2O or NH_3, the path of efflux (e.g., rice plants, diffusion, ebullition) is unknown.

To establish the contribution of transport processes in rice plants in the exchange of methane and other trace gases, and to investigate the use of these processes to reduce trace-gas emissions from rice paddies, a series of experiments are proposed. The rates of methane and other trace-gas emissions from paddies planted with different varieties in different soils will be determined. These experiments will be aimed at finding those rice varieties that reduce efflux of methane and other trace gases into the atmosphere and/or enhance the transport of O_2 into the soil.

Additional experiments will be designed to develop field methods for quantifying methane oxidation, and to determine the effects of a number of variables (including nitrogen, organic carbon, etc.) on methane oxidation. The transport of oxygen into the rhizosphere enables oxidation processes that may vary on diel and seasonal time scales. Important parameters for CH_4 oxidation include efficiency of O_2 transport by the plant; diel and seasonal variability of plant photosynthetic and root respiration activities; reduced compounds in the soil that compete for soil O_2; microbial O_2 demand, pH and redox potential; soil physical parameters; faunal activity; and O_2 production by organisms in floodwater and soil-water interface.

Measurements of methane oxidation in rice fields will be based on a variety of techniques, including mass balance of produced versus emitted gases, process-level measurements using radioisotopes, integrating measurements with stable isotopes, and methane oxidation potentials based upon laboratory measurements.

The influence of different cultivars and sources of organic matter on trace-gas production and emission. The production of trace gases in rice paddies is driven by organic matter generated by the living plant (e.g., exudates, roots), senescent rice plants, primary and secondary production in the flood water, and/or human inputs of organic matter. The amount of living plant organic matter in the form of mucigels, shredded root surfaces, etc. is to a certain extent controlled by:

- varietal differences (above-ground/below-ground allocation);
- soil properties which will affect rooting depths; and
- period during vegetative growth.

Inputs of senescent plant material will depend on the amount, timing and turnover rate of incorporated material. Contributions of varying amounts of carbon supplied from the overlying water community will depend on the biota in the overlying water column and the degree to which the community is turned over in the water column vs settling out on the soil surfaces.

Experiments to determine the importance of each of these sources of organic matter will be conducted in glass-houses or in microplots in the field. A combination of labelling studies and manipulative field experiments that alter cultivars, floodwater inputs, or litter inputs will be employed.

Task 2.5.3 Empirical, process, and predictive models of methane and other trace-gas emissions from rice fields

Goals:

- To provide a retrospective analysis on the role of rice production on increasing atmospheric concentrations of methane and other trace gases.
- To assist in understanding complex processes of production, oxidation and transport which control trace-gas exchange from rice fields.
- To provide direction, integration and coordination of field research activities.
- To predict the influence of environmental, physiological, and agronomic changes that may occur in rice production on trace-gas exchange.

Implementation:

Three different sets of models concerning the estimation of methane and other trace-gas exchange within rice production systems will be developed. These will include:

Model 1: An empirical model to demonstrate the past and present roles of rice production in the increase of trace-gas concentrations in the atmosphere. An

initial attempt will be made to improve current global extrapolations of the few gas emission measurements that are available to current and past global conditions. The existing measurements will be stratified by regions and by cropping systems, and records of the past and present extent of each type of system will be employed to develop regional and global estimates.

Model 2: Development of process models coupling production, oxidation, reduction, and transport of trace gases. These models will be based on the plant physiological, microbial, and chemical mechanisms that regulate trace-gas production and transport in wetland rice fields; they will include the effects of plant varieties, soil type, climate, and agricultural management. Variations in plant and microbial properties that occur on diel and developmental time scales will be included in these models, as will dynamics during non-cropped periods.

Model 3: A global predictive model. This model will incorporate the above process model with a geographic information system (GIS) to provide predictions of the effects of changes in rice cultivation systems on trace-gas production, and to extrapolate emission measurements from the core sites to much coarser spatial and temporal scales. The model would link remotely sensed data on simple variables such as biomass, leaf area index, temperature, and water depth to emission rates.

Timetable:

1990 Next meeting of the coordinating panel, Tsukuba, Japan.

1990-91 Continue development of the research plan: choose sites, select participating researchers, prepare proposals.

1992-94 Carry out flux measurements, process studies, and model development in the intensive sites.

1994-96 Evaluate new cropping systems and cultivars designed to reduce trace-gas fluxes.

1994-96 Extrapolate results beyond the intensive sites.

FOCUS 4: The Role of Boreal Regions in the Changing Atmosphere

High-latitude ecosystems (including tundra, wetlands, and boreal forest) have large stores of organic matter bound in soils, sediments, and vegetation. These ecosystems are quite extensive in the Northern Hemisphere (Figure 7). For example, boreal wetlands are estimated to account for half of the total global wetland contribution of methane to the atmosphere (Cicerone and Ormeland 1988). Boreal soils are generally poorly drained and anoxic, and thus act as sources of reduced gases to the atmosphere. Because the high latitudes are expected to have a significantly greater amplitude of climate change than the temperate and tropical regions, boreal regions are of special interest in terms of response to global warming. Possible responses may include increased CO_2 release from soils and sediments as decomposition rates increase with temperature, and increased methane emissions. However, the degree to which these responses may occur is unknown. Detailed field surveys and experimental manipulations will be required to develop an understanding of current atmosphere-biosphere exchanges as well as predictions of future responses.

Goals:

- Estimation of the strength of the biogenic trace-gas sources and sinks in high-latitude ecosystems in a global context. Availability of data on land type (e.g., Aselmann 1989) and flux measurements (e.g., Harriss 1989), and tests of extrapolation models (e.g., Matson et al. 1989) need to be addressed.

- Determination of the principal ecological and environmental characteristics that control ecosystem trace-gas production, consumption and transport (cf. Rosswall et al. 1989) in high-latitude ecosystems.

- Estimation of the sensitivity of the high-latitude source - sink of trace gases to environmental change (e.g., Robertson et al. 1989).

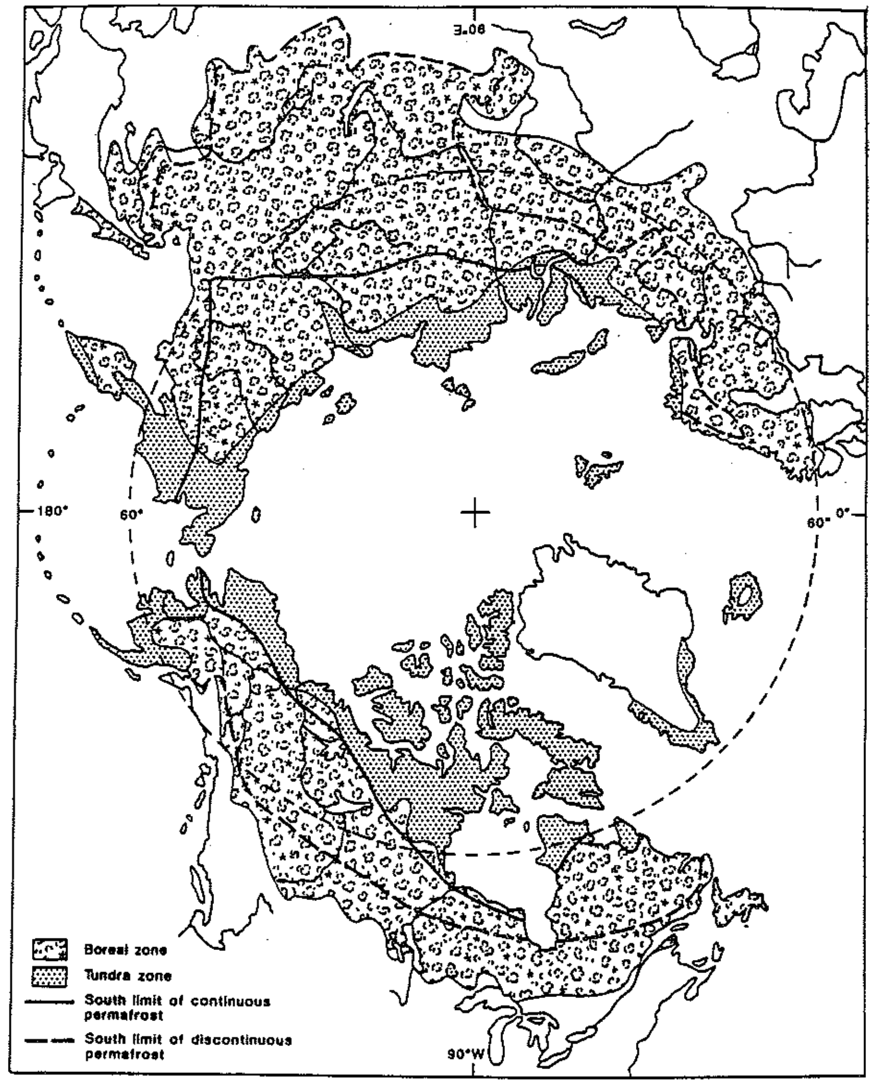

Figure 7. Regional distribution of the boreal forest, tundra, and arctic regions of the northern hemisphere and the southern extent of continuous and discontinuous permafrost (reproduced from Roulet et al. submitted).

ACTIVITY 4.1. Estimation of High-Latitude Ecosystems in Trace-Gas Emissions (augment to IGAC 4.1)

The modeling efforts of Aselmann and Crutzen (1989) and Matthews and Fung (1987) showed a large difference in the estimation of the northern wetlands as a source of atmospheric CH_4. This difference is attributable to differences in (i) data bases on ecosystem type and areal extent of each ecosystem; (ii) flux estimates used for each ecosystem type; and (iii) annual duration of flux period. The following three tasks are designed to alleviate the uncertainties in the estimates of these three key factors.

Task 4.1.1 Standardized high-latitude ecosystem data base

There is a need for a standardized classification of high-latitude ecosystems. The classification should be based on a combination of vegetation, soils, hydrology, and biogeochemistry. The resolution needs to be broad enough to allow global and regional extrapolation, but fine enough to allow recognition of small-scale variations in vegetation and environmental factors.

Goal:

- To develop a standardized classification and ecosystem characterization data base for high-latitude ecosystems.

Implementation:

Several classification systems have been developed for wetlands that could be used to delineate various classes of wetlands relative to vegetation, soil, hydrological, and biogeochemical characteristics. In Canada, an ecologically based classification system for wetlands has been developed (National Wetland Working Group, 1988). Through the activity within the IBP Tundra Study (Sweden) two decades ago a classification was developed based on work by Sonesson (1970). Classifications have also been developed for forestry purposes, and more recently these have been used to characterize and evaluate areal extent of different peatlands and forests in Sweden (Hånell, 1989).

Similar programmes of wetlands and non-wetlands classification should be initiated for boreal regions where none exists. A workshop should be held to

compare land classification and land data-base systems for boreal regions to determine how best to maximize the use of existing data-base resources and to determine the areas requiring primary analysis. This workshop should be focused on differentiating the key controlling factors of trace-gas emissions related to land surface characteristics (both abiotic and biotic) associated with the wetland class.

An institution to house the data base, and a data-base coordinator to oversee the organization and development of the classification is needed. The data base should be accessible to all interested.

Timetable:

1991 Convene the workshop by Fall 1990 to utilize and direct the Northern Wetland Study data-base development.

1992 Completion of a northern wetland data base.

1993 Completion of a boreal forest and the tundra/polar data base.

Task 4.1.2 Ecosystem/Geographical trace-gas flux data

Estimates of the role of northern ecosystems in trace-gas emissions requires a large set of flux measurements using chambers, towers and aircraft covering the temporal and spatial variability in each ecosystem unit. Although reliable flux measurements of CH_4 are available for several ecosystems and regions, data for many northern ecosystems and regions are lacking. There is a lack of flux measurements of NMHC, N_2O, NO_y, DMS, COS, and H_2S from almost all northern ecosystems and regions.

Goal:

- Develop measurement protocol for inventorying trace-gas fluxes in high-latitude ecosystems.

Implementation:

Annual measurements of CH_4 flux should be obtained from ecosystems such as: upland boreal forests, beaver ponds, coastal marshes, shallow lakes and reservoirs and in all wetlands in the regions of Western Siberia and Pechora of the USSR, in Scandinavia and Finland, and in Alaska and Canada. Measurement of NMHC, N_2O, NO_y, DMS, COS, and H_2S are required for almost all major ecosystems and regions of the high latitudes. A priority list has been suggested for these gases (Roulet 1990).

Development of flux-measurement groups in the Soviet Union, Finland and Scandinavia should be initiated. There is a great need for the development of reliable and practical field techniques for measurements of the concentrations and fluxes of NMHC, VOC, N_2O, NO_y, DMS, COS, and H_2S that can be used in remote, generally inaccessible, and often hostile environments. For gases where fast response sensors are not adequate (Anderson et al. 1989) eddy accumulation, which is a variant of eddy correlation techniques, needs to be further developed (Buckley et al. 1988, Wesely et al. 1989). Such technology should also be incorporated in aircraft-based flux systems.

Timetable:

1991 Initiate measurement programmes. Development of field techniques for measuring biogenic trace gases other than CH_4.

1996 Completion of CH_4 flux measurements from identified ecosystems and regions, and initiate measurements of NMHC (VOC) fluxes.

2000 Completion of measurement of non-CH_4 biogenic trace gases from high-latitude ecosystems.

Task 4.1.3 Extrapolation models and test of extrapolations

Methods of extrapolation of gas flux have been delineated by Matson et al. (1989) and Stewart (1989). Two approaches can be taken: (i) linear extrapolation based on areal extent of ecosystem types, and (ii) extrapolation based on some environmental and/or ecosystem factor(s) which correlates with the trace gas flux (e.g., temperature, moisture).

Several intercomparisons between modeled fluxes (extrapolation) from an ecosystem and measured fluxes by flux towers and aircraft have been undertaken or are being presently undertaken. Examples of these are the

FIFE (Sellers et al. 1990), ABLE-3A (Harriss and Wofsy 1989), ABLE-3B (Hoell et al. 1990) and the NWS (NWS Newsletter 1989, 1990).

Investigations into the isotopic comparison of CH_4 sources and atmospheric composition of CH_4 are being performed (Stevens and Engelkemeir 1988, Wahlen et al. 1989, 1990). The validity of this approach has been demonstrated and especially the multi-isotope approach is most promising (Figure 8). However, only few data have been obtained from high-latitude ecosystems.

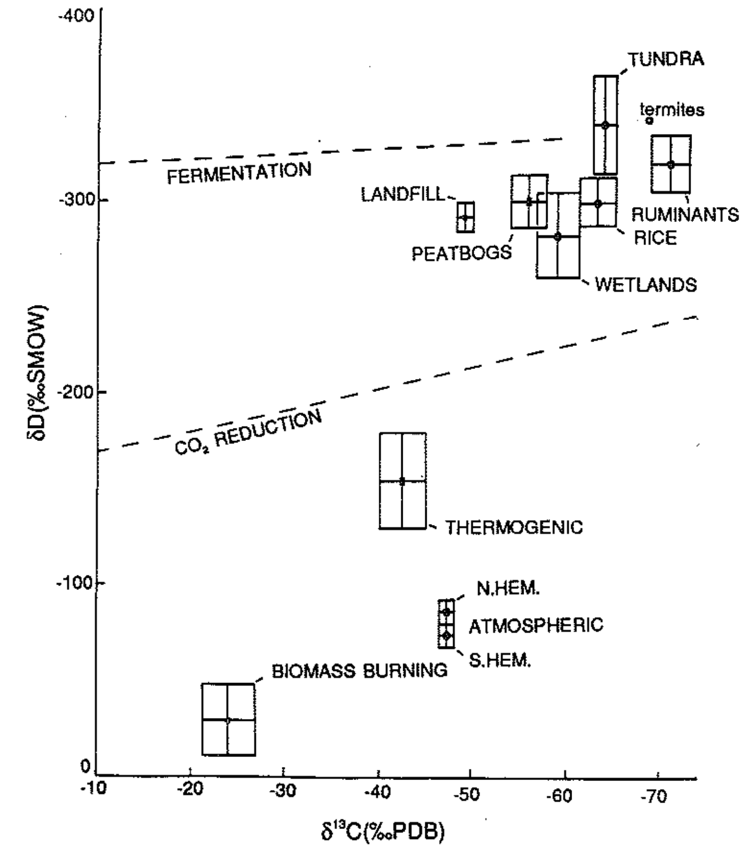

Figure 8. Source of methane can be related to the range of delta D versus delta ^{13}C for various methane sources and for atmospheric methane (from Wahlen et al. 1990). The dashed lines indicate the boundaries inferred for biogenic methane from acetate fermentation and from CO_2 reduction as proposed by Schell (1980). The relative contribution from the two processes in different wet ecosystems are very similar, about 70% from acetate fermation and about 30% from CO_2 reduction. (reproduced from Roulet et al. submitted).

Goal:

- To develop extrapolation techniques for quantifying CH_4 fluxes from high-latitude ecosystems.

Implementation:

There are three principal research requirements for this task. First, areal flux estimates of trace gases should be obtained using boundary layer aircraft flights in a particular area. Areal estimates of heat and water vapour have been obtained from 15 x 15 km site in FIFE (Desjardins et al. 1988, Betts et al. 1990) and these results are useful in developing scaling-up techniques for other trace gases. For more detailed intercomparison between models, chamber, tower, and aircraft measurements a relatively homogeneous area of at least 4 x 4 km is desirable. It is recognized this constraint may be difficult to fulfill in many high-latitude ecosystems.

Second, a comparison between flux extrapolated estimates of emissions from high-latitude ecosystems and isotopic reconstructions of trace-gas sources and sinks must be carried out. These investigations may refine source strength estimates, and reveal how much "fossil" or aged carbon is released to the atmosphere. Isotopic analysis and time series measurements of atmospheric CH_4 from these source regions would reveal temporal trends in the CH_4 emissions from high-latitude ecosystems.

Finally, an intercomparison of chamber techniques is needed. Static and dynamic chambers are widely used in estimating fluxes from a variety of ecosystems. Chambers have the advantage of yielding inexpensive rapid and generally intercomparable results (Mosier 1989) but they remain an operationally defined compromise. Results of studies conducted through the EUROTRAC subproject BIATEX should be utilized in assessing the relationship of chambers relative to micro-meteorological techniques. Dörr and Munnich (1987) have detailed a technique based on soil ^{222}Rn distributions and fluxes, that could be employed as a means of better intercalibration with other flux-chamber measurements. This method clearly works in dry soils and requires testing in wetland and waterlogged soils. It also has the advantage of producing non-destructive measurements. In addition, concern regarding gas standards used in these analyses needs to be addressed (IGAC 1989).

Generally the resources are in place to carry out most of this activity. Plans are well underway to carry out an extrapolation experiment as part of the upcoming Boreal Forest Experiment in 1994 in Canada. Preliminary plans have been prepared, but will require refinement once the results of FIFE and the NWS are analyzed.

Timetable:

1990 NWS Scale-up experiment and ABLE-3B Scale-up experiment

1991 Chamber intercomparison studies and isotopic reconstruction

1994 Boreal Forest Experiment

ACTIVITY 4.2 Ecological and Environmental Controls and Correlates for Trace-Gas Sources in High-latitude Ecosystems (Augment to IGAC 4.1)

Numerous studies have indicated variables that correlate with CH_4 flux, including temperature (Harriss 1989, Crill et al. 1988, Whalen and Reeburgh 1988, Moore and Knowles 1987), moisture regime (Whalen and Reeburgh 1990, Sabacher et al. 1986, Svensson 1976, 1986), and net primary production (Aselmann and Crutzen 1989). There are many other factors in high-latitude ecosystems that are probably important in controlling trace-gas fluxes such as structure of microbial populations, quality of litter, soil chemistry, soil physical properties, water flow, and the plant structure as it affects transport. The little information on the factors that correlate with the exchange of NMHC, NO_y, DMS, COS, and H_2S suggest that many of the same factors will be important.

Modelling efforts on both ecosystem and regional scales require understanding of factors that control trace-gas fluxes. This activity is designed to elucidate broad environmental and edaphic controls, and to understand the key biological processes controlling trace-gas emissions and exchange.

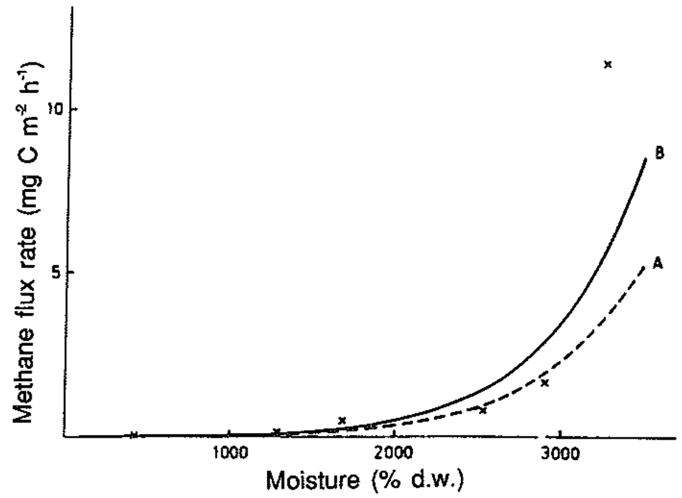

Figure 9. Influence of moisture on methane flux in a tundra mire. Curve A represents the ombrototropic plant communities only, while B is the relationship for all the plant communities. The mean rates are also indicated (x). (Modified from Svensson 1986).

Task 4.2.1 Survey and environmental correlation studies

This task is designed to measure gas fluxes along environmental and edaphic gradients, and to relate fluxes to other ecosystem and climatic characteristics. This information will be used to identify controlling mechanisms (to be addressed in Task 4.2.2) and will provide information useful for development of regional models of trace-gas exchange.

Goal:

- To examine the relationship between trace-gas production, consumption, and transport to environmental and ecosystem characteristics in high-latitude ecosystems.

Implementation:

In these studies, thermal and soil moisture regimes, biogeochemical characteristics (oxygen, C:N, P, Ca, pH), and soil characteristics (available carbon, decomposition rates), will be examined in conjunction with gas-flux measurements. In addition, the storage of trace gas in the soils should be measured through time, as well as isotope signatures of stored and emitted CH_4. These relationships are currently being tested on a wide range of

CH_4. These relationships are currently being tested on a wide range of northern wetlands through the NWS/ABLE-3B and other studies.

Task 4.2.2 Mechanistic process studies

It is widely recognized that trace-gas fluxes in any given environment are controlled by three processes: (a) production, (b) consumption, and (c) transport. Understanding each process at a mechanistic level is necessary to interpret temporal and spatial variability in the trace-gas flux.

Goal:

- To resolve the influence of the environmental controls on production, consumption and transport rates.

Implementation:

Detailed studies will be conducted in a limited number of key high-latitude environments, especially fens, bogs, and forests. Analytical and experimental methods are currently available for CH_4 but similar experiments should be conducted for other trace gases as techniques are developed.

This programme should tie in wherever possible with proposed and ongoing programmes such as the Long-Term Ecological Research, the NWS, and former IBP sites. In addition, there are a number of research centres where this work could be promoted such as the Experimental Lakes Area, Churchill Centre for Northern Studies, and the McGill Subarctic Research Station, Petawawa and Turkey Lakes Forest Research Centres, and Chalk River, Canada; Abisko, Sweden; and Kevo, Finland.

Timetable:

1990 Continue and initiate further studies in areas where work is required.

1993 Intercomparison and assessment workshop.

1995 Synthesis of process studies.

ACTIVITY 4.3 Sensitivity of High-latitude Trace-Gas Sources and Sinks to Environmental Change (Augment to IGAC 4.1)

Production and consumption of trace gases in high-latitude ecosystems are dependent on several biotic and abiotic variables including organic substrate availability, composition of the microbial community, soil temperature, and soil moisture status (Svensson and Rosswall 1984, Whalen and Reeburgh 1988, Harriss 1989, Conrad 1989). The effect of climatic change or other environmental perturbation on trace-gas emissions will, in the short term, involve changes in abiotic variables, such as temperature and moisture content. However in the longer term, these environmental changes may result in changes within the plant and microbial communities, thus changing the biotic control of trace-gas emissions.

Goals:

- Evaluate year-to-year variations and directional changes in trace-gas emissions.

- Evaluate the impact of environment and ecosystem changes on trace-gas emissions.

Task 4.3.1 Long-term measurement programme

There are only a few CH_4-flux measurement programmes in high-latitude ecosystems that have been continued for more than one growing season. Short records are insufficient to determine any relation between climate and trace-gas flux. Establishment of atmospheric chemistry observatories near source areas would be one approach to identify long-term changes. Such programmes exist to examine other problems (e.g., GMCC, ALE/GAGE), but these sites are not situated in locations suitable for trace-gas emissions from high-latitude ecosystems.

Goal:

- To develop an inter-annual and seasonal time series of the concentration and flux of trace gases from the major ecosystems of the high latitudes.

Implementation:

The NWS has established an atmospheric chemistry observatory in Fraserdale, Ontario, Canada, to measure several trace gases at the junction of the Hudson Bay lowlands wetlands and boreal forest zone. This facility is schedule to operate for 1990 to 1992. The continuation of the Fraserdale observatory could serve as an observatory for both the extensive northern wetlands region of Canada (northwest sector from observatory), and the boreal forest (northeastern to southeastern sector). Similar observatories should be established in the tundra region (e.g., Churchill, Manitoba; Schefferville, Quebec; Kevo, Finland; Abisko, Sweden. Wherever possible, these sites should tie in with the IGBP Regional Research Centres. A suite of biogenic trace gases should be measured throughout the year: CH_4, NMHC, VOC, N_2O, NO_y, DMS, COS, CO_2, H_2S as well as CO and O_3. In addition, a subset of samples should be analyzed for isotopes.

A second component to long-term analysis is the establishment of long-term chamber programme in key ecosystems at existing research facilities that are part of Long-Term Ecological Research sites or have been in existence for more than 10 years. Candidate arctic and subarctic sites include Bonanza Creek LTER, Toolik Lake LTER, and Barrow, Alaska; Churchill, Manitoba; Schefferville, Quebec; Abisko, Sweden; and Kevo, Finland. Possible boreal forest sites are the Marcell Forest, Minnesota and the Experimental Lakes Area, Ontario. The US/Canada Boreal Forest Experiment will be reviewing potential sites. In the USSR, there are several Biosphere Reservations, but no developed facilities for trace gases monitoring currently exist.

Finally, low altitude north-south aircraft measurements of CO_2, H2O and other radiatively important trace gases as sensors become available will be used to obtain flux measurements in correspondence with spectral reflectance data from aircraft and satellite. This information will be helpful to optimize the use of remotely sensed spectral data to parameterize gaseous exchange of radiatively important gases.

Timetable:

1990 Establishment of the Northern Wetland and Boreal Forest Atmospheric observatory site at Fraserdale, Ontario.

1992 Establishment of long-term chamber programmes at representative ecosystem sites.

1993 Establishment of long-term Atmospheric Chemistry observatories in the arctic/subarctic zones.

Task 4.3.2 Experimental analogs of sensitivity of trace-gas flux

The sensitivity of trace-gas flux to environmental change can be studied using the natural environmental variability along a transect or manipulative experiment within a given ecosystem. Several studies have used transects over different ecosystems and change in latitude to derive estimates of regional fluxes (Sebacher et al., 1986; Whalen and Reeburgh, 1990b). This approach can be used as an analog for the influence of ecosystem change on trace-gas flux. Alternatively, existing ecosystems can be manipulated to simulate changes that might occur. Initially, the observed changes will occur in response to physical factors, but if manipulations are run for decades, changes in the biological community that are important to trace-gas flux emissions, may be identified. Because of the expense and difficulty of field ecosystem manipulations, laboratory manipulations at microcosm scales should be undertaken. These experiments may give valuable information for planning field studies and allow a clearer identification of the relationships between manipulation factors and gas fluxes.

Goals:

- Examine fluxes along environmental and successional gradients as natural analogs to potential climate change.

- Develop manipulation experiments to examine sensitivity of gas exchange to environmental change.

Implementation:

The NWS transect from the Hudson Bay coast inland provides an example of successional change in ecosystems, associated with the emergence of the Lowlands from Hudson Bay over 5000 years. Major recent disturbances, such as associated with the Alaskan pipeline, also provide opportunities to address changes in trace-gas flux along succession gradients. Similar transects should be established in the boreal forest and the arctic and subarctic tundra biomes.

The impact of acidic precipitation on bog ecosystems is being addressed at the Experimental Lakes Area, Ontario (S. Bayley, University of Alberta). Simulated acid rain is being added to a bog and peat water chemistry and plant response are being monitored. The acid nature of the bog limits the production and emission of CH_4, so the response of CH_4 flux to acidification has not been pronounced. Additional experiments should take place in the major gas producing ecosystems in each of the boreal, subarctic and arctic regions.

Laboratory studies addressing the degradation of different parts of peat-forming organic matter and the influence of temperature, fertilization, and N- and S-deposition on peat decomposition and methane production and consumption will be initiated in a variety of comparative sites. In addition, microbial and substrate controls on methane production and consumption will be investigated and isotopic analyses on atmospheric CH_4 and CH_4 emitted from various boreal systems will be continued. Given the high costs of field manipulations, it is probable that trace-gas exchange studies can only be made if good contacts are established with other projects in which manipulations form a major focus.

Timetable:

1991 Establish field programme and determine control emissions as soon as possible.

Task 4.3.3 Process-based trace-gas exchange models

Ecological models provide a tool for making spatial and temporal extrapolations of trace-gas emissions. Models which use remote-sensing information as inputs have been or are being developed. These models simulate the biogeochemistry of carbon and nitrogen and fluxes of several important trace species, and will allow improved understanding of atmosphere-ecosystem exchanges and their role in tropospheric chemistry.

Goal:

- Develop a mechanistic framework linking environmental factors to processes related to trace-gas production, consumption, and exchange.

Implementation:

Trace-gas models coupled to ecosystem models will be developed to investigate the environmental and biotic controls on trace production and consumption. The ecosystem model will simulate decomposition and provide carbon substrate for input into short-term physiological models. Methane production and oxidation will be simulated separately and then used to calculate the net CH_4 flux. The partitioning of carbon gas fluxes from the soil into CO_2 and CH_4 will depend on temperature, soil moisture, oxygen concentrations, and pH. Temperature will regulate overall microbial activity including decomposition, methanogenesis and methanotrophy. The temperature optima for each of these processes may be different (Svensson 1984). As a result of these interactions, changes in temperature may have unforeseen impact on CH_4 emissions. Soil moisture will regulate both overall rates of decomposition and soil redox. The soil redox will in turn regulate decomposition, and the balance between methanogenesis and methanotrophy. The length of the diffusion pathway and the oxygen content within it will also be an important determinate of how much of the CH_4 produced is oxidized.

FOCUS 5: Global Distributions, Transformations, Trends, and Modelling

Our understanding of how the biotic contributions to greenhouse-gas fluxes are reflected in the global atmospheric signal will require extrapolation of process studies from various regions. These extrapolations will need to be coupled with other information relative to key controlling biological and environmental parameters. Development of a geographic information system that can spatially and temporally link the data sets globally must occur. Such a system will then provide the basis for interaction with process and transport models.

ACTIVITY 5.5 Global Integration and Modeling of Fluxes (added Activity to IGAC Focus 5)

While many of the flux measurement studies in the overall Core Project are regional (i.e., tropics or mid-latitudes) many of these studies are of interest chiefly as components of the global budgets. This is especially true for the mid- to long-lived species (CO, CH_4, N_2O). We suggest a set of tasks to address development of global budgets, and their comparison with atmospheric concentration and inverse model calculations. Global extrapolation requires the ability to generalize flux measurements in space and time. This is a general problem, not limited to any of the specific areas proposed for study. We propose one or a series of studies designed to rigorously test the models and measurement techniques required for extrapolation.

Goals:

- To quantify fluxes of gases significant to global atmospheric chemistry
- Develop and test extrapolation approaches using combined ground-based process studies and mesoscale modelling and measurements.

Task 5.5.1. Global synthesis of N_2O, CH_4 and CO fluxes.

Integration, interpretation, and global extrapolation of process studies and regional flux estimates are necessary, yet difficult studies to implement due to the large uncertainties involved. The coordination of research efforts to attain global estimates of trace gas fluxes into the atmosphere and of global atmospheric chemistry must be undertaken. The following is proposed to achieve this goal.

Goal:

- The development of global models and source/sink budget for N_2O, CH_4, and CO.

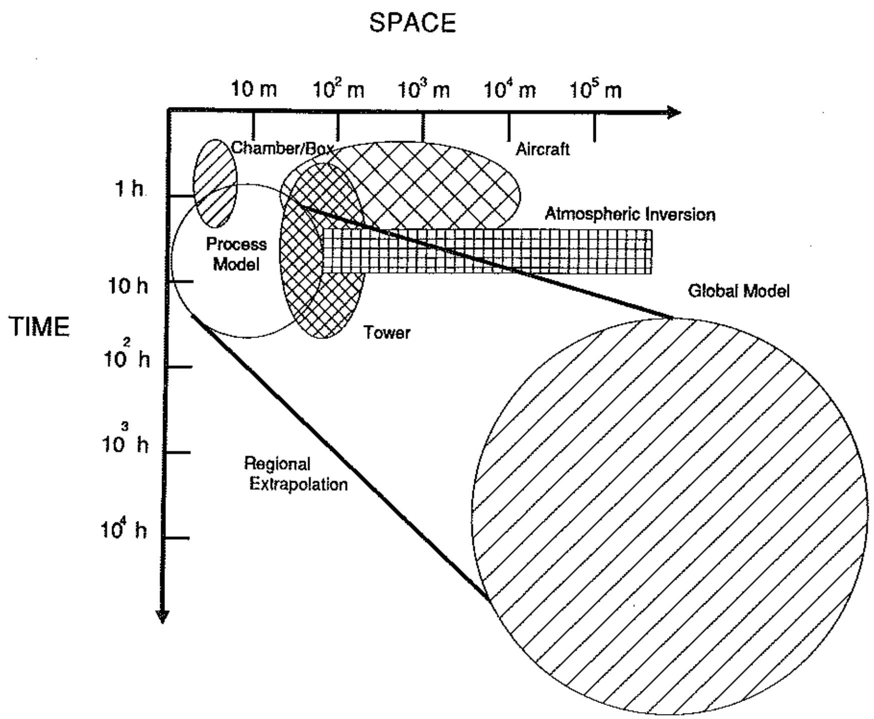

Figure 10. Time and space aspects of estimation of biogenic gas fluxes. (Modified from Stewart et al. 1989).

Implementation:

This integration task will require a number of Activities, similar to those proposed within regional studies, but at a larger scale. These are, first, the development of a global geographic data base including a suitable classification of area by flux potential (i.e., soil, vegetation class) and distribution of driving variables (e.g., climate, N deposition). Second, measured flux rates or models of rates will be used to estimate fluxes from the various combinations of areas and driving variables in the GIS system to obtain global flux rates with the areal stratification and driving variables. Third, global fluxes must be compared to atmospheric sinks and to the predicted distribution of sources and sinks using inverse modelling. This final step constitutes the validation of the regional estimates and techniques used in global extrapolation. When these source-based extrapolations fail to match inverse predictions, both calculations must be examined. This study should build upon the expertise and resources developed by current on-going efforts on global extrapolation and inverse-modelling (i.e., Matthews and Fung 1987, Aselmann and Crutzen 1989).

Timetable:

1991 Meeting of modelling and measurement teams from the various activities to discuss status of data, data systems, models, and validation approaches.

Task 5.5.2 Flux extrapolation pilot study

The extrapolation of small scale field measurements to regional estimates is a crucial methodological problem due to heterogeneity in the land surface. Development of the methodology will require a strong interaction and coordination between those investigators performing detailed process studies, mesoscale modelling, and/or meteorological measurements working at various scales. This coordination is crucial since these prototype studies will have to be developed in such a way that validation at a later stage is possible. In order to develop the programme in a logical fashion, one gas will be used throughout the whole programme. CO_2, followed by methane are the most promising gases for scaling up studies since the technology is or will soon be available for chamber, tower and aircraft measurements.

Goal:

- Develop and test extrapolation approaches using combined ground-based process studies and mesoscale modelling and measurements.

Implementation:

During the first stage of this task, the identification of an appropriate study site (or set of sites) must be made. Preferably, it will consist of a limited number of ecosystems, (e.g., a study are consisting of a forest-agricultural land-use mix would be ideal).

The size of the study area should accommodate various observational and measurement scales including satellite observations (c. 30-1000 m), airborne and eddy-correlation flux measurements (c. 10-1000 m), and plot studies (c. 1-10 m). An ideal size for the study area is approximately 10x10 km.

Within the study area, a stratified measurement network will be established to determine the environmental variables controlling fluxes from the various ecosystems and the role of landscape characteristics contributing to variability in the emissions.

After one year of process level measurements, a large boundary layer experiment will be performed. In this experiment, aircraft will be used in order to get estimates of fluxes over the region. These flux estimates will be compared with estimates derived from models capable of depicting fluxes over the same spatial and temporal scales. The results of these comparisons will be used to evaluate both the modelling and aircraft approaches to large area flux estimates. This evaluation is crucial for the development of flux models and better understanding of the spatial and temporal variability of fluxes, and thus leading to methodology for global evaluation of source/sink relationships in the terrestrial ecosystems.

Timetable:

1991 The site for the trace-gas extrapolation pilot study will be chosen at this meeting outlined in Activity 5.5.1.

FOCUS 6: International Support Activities

The accomplishment of the goals set forth in this document and the IGAC Project requires the participation of many scientific disciplines, research organizations, and funding organizations. These activities will require scarce resources, including scarce equipment (e.g., research aircraft) and even scarcer personnel (interdisciplinary scientists). We concur with the need for broadened education in Earth Sciences (IGAC Activity 6.1). We also recognize the need for careful planning and collaboration among the Activities outlined in this report, in the IGAC Project, and in other IGBP and international groups; given the limited equipment, funding, and personnel available.

ACTIVITY 6.1 Education in Biosphere-Atmosphere Interactions and Earth System Science. (augment to IGAC Activity)

The IGAC Project emphasizes the need for education of educators and university students on the biospheric and atmospheric aspects of global change. The principal effort in accomplishing that goal is through the conference, workshop and short-course opportunities (IGAC p.36). We strongly concur with that approach. In addition, we recognize the immediate need for education of researchers (modellers, chemists, ecologists, etc) who can work in multi-disciplinary modes. That requirement is especially crucial in developing countries.

Goal:

- To encourage practicing scientists to participate and contribute to studies of global issues

- To train students in multi-disciplinary aspects of global change, so that they may contribute their own areas of expertise to the accomplishment of IGAC goals.

Implementation:

Each IGAC coordinating committee must be responsible for establishing liaisons with universities in host countries, and for contacting local universities as soon as sites are chosen.

ACTIVITY 6.4 Activity and Project Coordination (augment to IGAC Activity)

Planning for regional-scale studies is now proceeding within the IGAC activities and in other IGBP Core Projects, as well as national, and international programmes. It is clear that extensive planning on scales beyond that of individual activities or projects will be required to ensure access to limited equipment and funding. We suggest that IGBP coordinate international planning meetings for regional-scale studies involving aircraft measurements, and that each Core Project monitors instrument and aircraft needs of that project.

FOCUS 7: Trace-Gas Fluxes in Mid-Latitude Ecosystems

The temperate region is densely populated and most of its ecosystems are subject to human influence. For example, large areas of forests and grasslands have been converted to agriculture. In addition, as a result of industrial activity, many systems experience altered chemical climates. Strong interactions occur between industrial and biogenic chemical species, with consequences for tropospheric chemistry and biological function.

There have been many studies of trace-gas fluxes in the temperate regions. In only a few instances, however, have these estimates been based on frequent measurements made over an entire year. Also, most studies have focused on small areas (e.g. individual fields) and on primarily mechanistic questions. As a result, many trace-gas fluxes in the temperate zone are not well defined at the regional scale. The consequences for trace-gas fluxes of converting "natural" to agricultural lands and the effects of loading ecosystems with nutrients (N and S) and toxins on fluxes are just beginning to be understood. We propose a research programme for the next decade that addresses the major gaps in our knowledge about trace-gas fluxes in mid-latitude ecosystem; many of these questions arise as inconsistencies have become apparent during data synthesis (Andreae and Schimel 1989). This programme is intended to augment the studies for other regions currently planned under the auspices of IGAC.

Three projects are proposed:

1) Exchanges of N_2O, CH_4 and CO between terrestrial ecosystems and the atmosphere.

2) The role of mid-latitude ecosystems in the global carbon budget - sources or sinks?

3) Biogenic emissions and the oxidant cycle in mid-latitudes.

ACTIVITY 7.1 Exchanges of N_2O, CH_4 and CO Between Terrestrial Ecosystems and the Atmosphere (added Activity)

The global budgets of N_2O, CH_4 and CO are not well known. Both N_2O and CH_4 are greenhouse gases. Carbon monoxide exerts strong control over the chemistry of the troposphere and lower stratosphere through its influence on hydroxyl radical and ozone concentrations. Terrestrial systems of the mid-latitude region may play important roles but are poorly quantified in the budgets of these three gases.

Heavy fertilization of agricultural plots and high inputs of nitrogen in precipitation to forests may have increased their capacity to produce N_2O. The regional magnitude of these increases is not well documented although, at least for agricultural systems, they are thought to be substantial (Bouwman 1990).

Drainage of wetlands and increased nitrogen inputs to both agricultural and "natural" ecosystems may have decreased their capacity to consume methane (Melillo et al. 1989, Steudler et al 1989). The importance of these decreases for the global CH_4 budget has yet to be determined.

The addition of nitrogen to soils may also reduce their capacity to consume CO (Melillo et al. 1989). All aspects of the CO budget in the mid-latitude regions are poorly understood (Cicerone 1988). Clearly, this is an area that requires further study.

Goals:

- To quantify the role of mid-latitude ecosystems as sources for N_2O.
- To quantify the role of mid-latitude ecosystems as sinks for CH_4.
- To define the processes and land management practices that control N_2O and CH_4 exchange in mid-latitude systems.
- To understand the biological sources and sinks of CO.

Implementation:

N_2O - Regional extrapolations need to be based on precise and representative measurements of N_2O (and NO_x) fluxes from agricultural ecosystems on the scale of the individual farm field (i.e., on the order of 1 to 100 ha, depending on region). This is necessary because management systems, including N-fertilization, vary widely between adjacent fields. Scaling from the individual field to the regional level is possible for many countries because of the existence of good data bases including information on N-inputs, N losses, etc.

It is proposed, therefore, to establish a network of measurement stations across four continents, each with sites covering a range of crops, soil types, and management systems typical of the region.
At each site, N_2O (and NO_x) time series of fluxes should be determined and related to the controlling factors, some of which (N input, irrigation, inhibitors, etc.) may be manipulated. N_2O fluxes from these sites will be monitored over 24-hour periods at least monthly for two years. After that the sampling frequency may be reduced and focused on conditions of particular significance.

N_2O sources will also be determined in a set of forest sites that represent a range of N inputs. Here again, N_2O fluxes will be related to controlling factors, some of which may be manipulated in experimental plots.

At present, N_2O flux data are wholly dependent on the use of small (<1 m^2) chambers and gas chromatographic analysis. In this study, this technique will be used, but will be supplemented by (and cross calibrated against) a new system engineered to apply to the scale required. This will be based on tunable diode lasers (TDLAS). The TDLAS will also be used, where necessary, in conjunction with extended chambers ("tunnels"), and radon techniques to take advantage of the sensitivity gain achieved by containment within a chamber, while at the same time overcoming much of the spatial variability problem associated with the traditional chamber design by enclosing a strip of land > 10 m long. FTIR may be an alternative to the TDLAS.

Cross-calibration of chambers against the TDLAS technique will make it possible to use data already gathered by chambers, and to continue their use where logistical/financial constraints preclude the use of TDLAS or similar systems.

Along with these measurements, process-based models will be developed and after completion of the measurement phase of the project, regional models will be developed and tested.

CH_4 - Studies of the role of mid-latitude ecosystems as sinks for CH_4 will be carried out in much the same way as for N_2O. Networks of sites will be established in forest, grassland and agricultural ecosystems. Each network will contain a subset of sites arrayed along a nitrogen deposition gradient to test the hypothesis that high levels of nitrogen deposition depress CH_4 uptake. In addition, at some sites manipulations of factors that control CH_4 uptake, such as temperature and moisture, will be experimentally manipulated. Finally, process-based models will be developed and after completion of the measurement phase of the project, mesoscale extrapolations of the process model will be carried out. Experimental manipulation will also be carried out to evaluate the consequences of draining of wetlands for the CH_4 flux.

CO - Fluxes of CO above soils and plant canopies are very poorly understood. It is therefore necessary in the implementation to investigate the biology and chemistry of CO production and destruction in plants and soils. The necessary measurements include CO and N_2O fluxes at the core sites for process study, and laboratory investigation of the dependence of CO emission from plants on the underlying processes of photosynthesis, carbon metabolism and their responses to physiological stress. While early work shows soil generally to be a sink for CO, more recent work shows that it may also be a source. Laboratory studies are therefore required to identify the processes operating and their dependence on soil physical and biological properties.

Timetable:

1990-93 Establish 10 grassland and 10 forest sites that are well characterized in terms of climate, vegetation, soils and N-cycling rates.

1992-95 Establish fertilization plots at each site and examine the dependence of methane and carbon monoxide emission/deposition on major nutrient cycling (N). Long-term measurements of CH_4 flux will be made to understand seasonal dependence.

1990-96 Measure N_2O production at each site to identify the source strength of each major ecosystem, concentrating efforts on process studies on agricultural systems. Long-term measurements of N_2O fluxes and the major controlling physical and climatic variables will be made.

1991-94 Develop techniques for integrating N_2O fluxes over longer spatial scales than the 0.1 to 1.0 m^2 soil plots currently used (TDLAS)

1992-96 Model CH_4 and N_2O exchange processes over soils and vegetation canopies. Validate net-exchange estimates from models using new techniques for N_2O (long path TDLAS and micrometeorological methods.)

ACTIVITY 7.2 How Important are Mid-Latitude Ecosystems as a Net CO_2 Sink? (added Activity)

Atmospheric CO_2 concentrations continue to rise as a result of human activity. The airborne content of CO_2 reflects only a fraction (45%) of the CO_2 that is released via anthropogenic sources. Tracer and modeling studies (linked to the global CO_2 monitoring network) indicate that the oceans cannot account for the imbalance in the global carbon budget. Some estimates suggest that terrestrial ecosystems are a source of CO_2, yet new data and analyses suggest that increased mid-latitude carbon storage may account for the "lost" carbon.

Interactions of the C cycle with chemical climate , and with land use, may contribute to the sink strength of the mid-latitudes for CO_2. Large portions of the mid-latitudes have undergone substantive land-use changes since 1900, including extensive reforestation with increased storage in woody biomass and soil organic matter. With much of the present forest area in the region now in a mid-successional, aggrading stage, there is now a potential for mid-latitude forest to become a significant net C-sink. Moreover, because increasing levels of nitrogen in precipitation (inadvertent fertilization) and atmospheric CO_2 may boost net primary production, changes in chemical climate may amplify the potential sink strength for CO_2. On the other hand, this potential may be reduced or reversed if acid deposition and accumulation of toxic ozone levels result in significant forest decline and production losses in agricultural ecosystems. Because of the multiple controls over CO_2 exchange and C storage, manipulative experiments are required to understand causation.

There is therefore major uncertainty in the rates of change of carbon storage in mid-latitude ecosystems.

Goals:

- To determine the consequences of changing land use (reforestation, succession, deforestation, urbanization) on CO_2 exchange in mid-latitude ecosystems.
- To evaluate the effect of changing physical climate (temperature, moisture) on CO_2 exchange.
- To evaluate the effects of chemical deposition (N, S, and acid) on CO_2 exchange.
- To determine the effects of elevated CO_2 on the gross and net CO_2 exchange of representative mid-latitude biomes.

Implementation:

Site networks will be established in temperate forests around the world. These networks will include sites of varying successional age and management practices and measurements of NPP, soil respiration, decomposition, C-fixation, ecosystem CO_2 exchange, and the climatic and biotic variables that drive these processes will be made. These will be measured intensively over at least one year to determine the seasonal patterns and key environmental controls. After this intensive sampling period is over, measurements will be continued at a lower pace to determine interannual variation and long-term changes in site C-dynamics.

Manipulations:

Plots in each core site of the networks will be treated in several ways to improve our understanding of the long-term effects of various climatic drivers (physical and chemical) on ecosystem function and trace-gas exchange. These manipulations will include: elevated CO_2, increased soil temperature, altered moisture, N, S, and fertilizer additions. To the extent possible, field and laboratory studies must examine the interactive effects of the various perturbations.

Manipulative studies will evaluate whole-tree physiological response, as well as below ground and microbial responses (e.g., root respiration, decomposition and mineralization rates).

The most difficult manipulation is enhanced CO_2, as the large structure makes whole-tree manipulations difficult. Most CO_2 exposure studies have been conducted on seedlings and saplings. The physiological response of immature plants to physiological stimuli differ significantly from their mature counterparts. Long-term CO_2 exposure studies are needed on mature trees and whole ecosystems. Two types of facilities are needed to perform long-term CO_2 enrichment studies. One is a facility to enclose mature trees to study their physiological responses to CO_2. Manipulative studies can be performed indoors in large tree-size cuvettes (as are available at the Forest Research Inst. Rotorua, NZ). They can also be performed in open-top chambers to see how trees exposed to their natural environment respond to increased CO_2. This technique has been favorably demonstrated in short-term studies on eucalyptus in Australia.

Whole ecosystem CO_2 exposure studies require further upward scaling in the size of the facility. It is desirable to enclose a fully functional ecosystem unit. This size is undefined, but may range up to one hectare. It should encompass the variability of the soils and vegetation that occur naturally and should represent the whole ecosystem. Such an exposure system is needed to assess the role of CO_2 enrichment on all of the components of the ecosystem, leaf photosynthesis, respiration, allocation, leaf nitrogen content and their consequent effects on decomposition and mineralization. The exposure facility must operate continuously for several years (at least 3 and preferably 5 to 10) to study the several annual growth cycles which will affect the cumulative N availability and carbon storage of the system.

Resources:

The number of research groups capable of measuring ecosystem CO_2 fluxes worldwide is limited. These teams are outlined below.

North America: Several groups including University of Nebraska; NOAA/Oak Ridge; University of California-Davis; Argonne National Lab; Harvard

University; Agriculture Canada; Guelph University; and University of British Columbia.

Europe: University of Edinburgh; University of Paris.
Asia: Pacific Forest Research Institute, Christchurch, NZ; CSIRO, Canberra, Australia.

Timetable:

1990-92 Measure CO_2 fluxes over mid-latitude forests and rangeland, using a range of techniques, cuvettes to aircraft, of largely existing programmes.

1992-96 Extend the CO_2 flux programme to other sites, especially natural ecosystems.

1992-95 Measure and assess carbon budgets of mid-latitude natural and managed ecosystems.

1991-93 Develop experimental facilities for conducting elevated CO_2 exposure experiments and initiate measurements.

1993-98 Make long-term physiological and carbon/water economy studies of vegetation canopies in the elevated CO_2 and temperature facilities.

1990-95 Develop and validate models of canopy carbon exchange and storage.

ACTIVITY 7.3 How Important are Mid-Latitude Ecosystems as Sinks for Atmospheric Oxidants and Sources of Oxidant Precursors and the Role of Volatile Organic Compounds?

The mid-latitudes contain a substantial fraction of the terrestrial surface of the globe, and have been assumed to provide a substantial fraction of the natural NO_x emissions to the atmosphere. The magnitude of the fluxes, and the processes determining them are poorly understood yet the supply of NO_x to the atmosphere constitutes a primary control of oxidant production (O_3, H_2O_2). Volatile organic compounds (VOC) emitted by plant canopies provide a control on production of photochemical oxidants.

Mid-latitude ecosystems are thought to be important source areas of isoprene, terpene, and possibly alkenes, yet the magnitude of the fluxes and the controlling physical, chemical and biological processes remain poorly understood.

Terrestrial ecosystems also represent a major sink for O_3 by dry deposition, a process that while better understood than regional natural NO_x emissions, is still subject to important uncertainties. Fluxes have been measured in very few mid-latitude ecosystems, and the presence of large areas of enhanced O_3 concentrations within and downwind of the industrial regions presents a phytotoxic stress to many plant communities. Effects of this stress on physiological processes and on the exchange of heat, water vapour, CO_2 and a range of trace gases have been observed but cannot be quantified on regional scales with current understanding.

Lastly mid-latitude ecosystems contain large areas (notably but not exclusively in Europe and North America) in which regional modification of the "chemical climate", has altered the cycling of major plant nutrients (e.g., nitrogen and sulphur). The effects of the deposition of N, S and acidity on nutrient cycling and on the exchange of a range of trace gases (including N_2O, NO_x, O_3, and CH_4) remain uncertain.

Goals:

- To quantify the source and sink strength of NO_x in mid-latitude ecosystems
- To quantify the source strength of VOC from mid-latitude ecosystems
- To quantify the response of mid-latitude sources of NO_x and VOC to changes in the physical and chemical climate.

Implementation:

Three scientific tasks are required to achieve the goals of this activity . These are:

Task 7.3.1 Long-term field measurements in representative mid-latitude ecosystems to measure fluxes and associated controlling variables for the range of soil, vegetation, and atmospheric conditions in the region.

These studies are required to show the response of VOC and NO_x exchange to different chemical and physical climates, from the pristine areas of Asia, Southern Africa and South America to polluted areas of Western Europe and North America. The response of VOC and NO emissions in relation to major nutrient cycling (N, P, K, S) in these ecosystems are therefore key activities. As those regions traverse a range of climatic zones, the response of the trace-gas fluxes to physical variables, notably temperature, water (both soil and plant retention are essential here), and radiation represent the other focus for measurements.

Task 7.3.2 Process directed field and laboratory studies addressing the fundamental mechanisms and controls on the production, transport and dispersion of oxidants and their precursors and the major variables regulating fluxes.

The process studies require identification of the major sources and sinks within vegetation canopies and the soil, and the physiological processes generating and controlling fluxes. This necessarily includes laboratory investigation of both plant and soil systems using controlled environment facilities as well as intensive campaigns of field measurements. The latter require the collaborative efforts of soil microbiologists, plant physiologists and where possible micrometeorologists to obtain the fluxes and the associated physical chemical and biological measurements to identify and quantify the controlling processes under field conditions. The laboratory studies in contrast allow the different disciplines to explore their respective components of trace-gas production and transfer. Where possible the intensive, process-related studies will be applied at sites where these longer term data are available.

Task 7.3.3 Modelling of trace-gas exchange processes, extrapolation to regional scales and field validation.

The trace-gas flux modelling activities include process level simulation of production in soil and vegetation, canopy and soil-exchange models and the regional-scale simulation of gas exchange based on land use, atmospheric

dispersion, and air chemistry process. Validation experiments include the comparisons between field measurements and model estimates at the soil surface and plant canopy scale and where possible between plant canopy measurements and models and aircraft flux measurement.We will establish networks of sites in areas subject to intensive ozone deposition (E. North America and W. Europe) and in control regions. Stations will be established within these regions to measure concentrations of ozone, NO_x, and VOCs. Sets of measurements will be carried out diurnally throughout the year to determine seasonal patterns of exchange and to evaluate the primary environmental controlling factors. Specific experimental work will be carried out to determine the specific process controls necessary to model gas exchanges. These mechanistic models will be used to develop regional and temporal extrapolations.

There are several established national projects (outlined under resources) currently evaluating biota interactions with the oxidant cycle. This project will therefore build on these programmes, filling in needs where appropriate.

Resources:

N. America:
Harvard forest LTER. (This also includes manipulative experiments on nutrient inputs and physical conditions.) Atmospheric deposition gradient study sites (Melillo) Lindberg's sites. The SURON study.

W. Europe:
EUROTRAC subproject BIATEX (Biosphere-atmosphere exchange of trace gases). The current programmes are directed towards NO, NO_2, O_3, and VOC exchange over forest and short (agricultural and moorland) vegetation.

Soviet Union:
An extensive study of VOC is in progress in the Soviet Union, directed at both process study and regional-scale estimates of fluxes.

Peoples Republic of China:
10 core sites which existing measurements of VOC fluxes and plans to extend the measurements to NO_x.

Timetable:

1990 Field experiments to measure fluxes of NO, NO_2, O_3 and VOC over grass and coniferous vegetation. These studies are primarily directed towards process studies of trace-gas exchange and the controls.

1991 Develop surface-atmosphere exchange models.

1992 Measurements of NO, NO_2, O_3, VOC at sites with small inputs of N, S and with infrequent large O_3 episodes.

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APPENDICES

A. ACRONYMS

ABLE	Atmospheric Boundary Layer Experiment
AGU	American Geophysical Union
ALE	Atmospheric Lifetime Experiment
AVHRR	Advanced Very High Resolution Radiometer
BIATEX	Biosphere-Atmosphere Exchange of Trace Gases
CSIRO	Commonwealth Scientific and Industrial Research Organization
DMS	Dimethylsulphide
EOS	Earth Observing System (USA)
ERS	ESA Remote Sensing Satellite
ESA	European Space Agency
EUROTRAC	European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
FAO	Food and Agriculture Organization
FIFE	First ISLSCP Field Experiment
GAGE	Global Atmospheric Gases Experiment
GEDD	Global Environmental Data Directory
GMCC	Global Monitoring for Climate Change
GIS	Geographic Information System
HAPEX	Hydrological Atmosphere Pilot Experiment
HIRIS	High Resolution Image Spectrometer (NASA/GSFC)
IBP	International Biological Programme (ICSU)
IAMAP	International Association of Meteorology and Atmospheric Physics
ICSU	International Council of Scientifc Unions
IGAC	International Global Atmospheric Chemistry Project
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change (ICSU)
LTER	Long-Term Ecological Research Project
MLE	Mid-Latitude Ecosystem
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectrometer (NASA/GSFC)
MOPITT	Measurement of Pollution in The Troposphere
NDVI	Normalized Difference Vegetation Index
NMHC	Non-Methane Hydrocarbons
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Production
NWS	Northern Wetland Study
PAN	Peroxyacetylnitrate
SCIAMACHY	The Scanning Imaging Absorption Spectrometer for Atmospheric Chartography/Chemistry
SC-IGBP	Special Committee for the IGBP
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SIFE	Second ISLSCP Field Experiment
SPOT	Système pour l'Observation de la Terre (France)
TDLAS	Tunable Diode Laser
TES	Tropospheric Emission Spectrometer
TM	Thematic Mapper
TRACER	Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research
VOC	Volatile Organic Compounds

B. IGAC Steering Committee

Chairperson: R.G. Prinn
Department of Earth, Atmospheric and Planetary Sciences, M.I.T., 54-1824, Cambridge, MA 02139, USA

Secretary: D.H. Ehhalt
Institute for Chemistry, 3 Kernforschungsanlage Julich, Postfach 1913, Julich, D-5170, FRG

Members: D.L. Albritton (USA), P. Buat-Menard (France), P.J. Crutzen (FRG), R.A. Duce (USA), R.C. Harriss (USA), P.A. Matson (USA), G.I. Pearman (Australia), H. Rodhe (Sweden), E. Sanhueza (Venezuela), H.I. Schiff (Canada).

Conveners and Members of IGAC Activity Coordinating Committees

FOCUS 1: *Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere*

Activity 1: North Atlantic Reginal Study (NARE)
Status: Active
Convenor: F. Fehsenfeld
Aeronomy Laboratory, NOAA/ERL
325 Broadway
Mail Code R/E/AL7, Boulder, CO 80303
USA

Members: P. Buat-Menard (France), R. Duce (USA), J. Galloway (USA), G. Harris (FRG), I. Isaksen (Norway), D. Kley (FRG), H. Levy (USA), D. Martin (France), V. Medinetz (USSR), S. Penkett (UK), J. Prospero (USA), W. Seiler (FRG), D. Whelpdale (Canada).

Activity 2: Marine Gas Emissions, Atmospheric Chemistry and Climate (MAGE)
Status: Planning
Convenor: B. Huebert
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882
USA

Members: G. Ayers (Australia), A. Bandy (USA), T. Bates (USA), B. Bonsang (France), H. Bingemer (FRG), R. Dickerson (USA), B. Hicks (USA), P. Holligan (USA), P. Liss (UK), S.E. Larsen (Denmark), C. Leck (Sweden), B.C. Nguyen (France), W. Oost (Netherlands), R. Prinn (USA), E. Saltzman (USA).

Activity 3: East Asian - North Pacific Regional Study (APARE)
Status: Planning
Convenor: H. Akimoto
National Institute for Environmental Studies
16-2 Onogawa
Tsukuba, Ibariki 305
Japan

Members: S.C. Liu (USA), T. Ogawa (Japan), W.-X. Yang (China), Y. Zhuang (China).

FOCUS 2: *Natural Variations and Anthropogenic Perturbations of Tropical Atmospheric Chemistry*

Activity 1: Biosphere-Atmosphere Trace Gas Exchange in the Tropics (BATGE)
Status: Active
Convenors: I.E. Galbally
CSIRO Division of Atmospheric Research
Private Bag 1
Mordiallic, Vic 3195
Australia
and
C. Johansson
Arrhenius Laboratory
Department of Meteorology
University of Stockholm
Stockholm S-106 91
Sweden

Members: A.F. Bouwman (Netherlands), R. Conrad (FRG), B. Cros (Congo), R. Delmas (Congo), M. Keller (USA), *J. Levine (USA), *P.A. Matson (USA), E. Sanheuza (Venezuela), S.C. Wofsy (USA), W.-X. Yang (China).

Activity 2: Deposition of Biogeochemically Important Trace Elements (DEBITE)
Status: Planning
Convenor: G. Ayers
CSIRO Division of Atmospheric Research
Private Bag 1, Mordialloc, Vic 3195
Australia

Members: P. Artaxo (Brazil), J. Galloway (USA), J.-P. Lacaux (France), H. Rodhe (Sweden).
Further members from the SE Asian region will be identified. The membership will be revised as further activities are developed.

Activity 3: Impact of Tropical Biomass Burning on the World Atmosphere
Status: Active
Convenor: M.O. Andreae
Max Planck Institute for Chemistry
Postfach 3060, Mainz D-6500
FRG

Members: F. Akeredolu (Nigeria), D.H. Ehhalt (FRG), J. Fontan (France), R.C. Harriss (USA), V. Kirchoff (Brazil), P.M. Vitousek (USA). Note requirement for addition of ecologists and biologists.

Activity 4: Chemical Tranformations in Tropical Atmospheres and Their Interactions with the Biosphere
Status: Conceptual
Convenor: P.J. Crutzen
Max-Planck Institute for Chemistry
Postfach 3060, Mainz D-6500
FRG

Members: F. Akeredolu (Nigeria), D. H. Ehhalt (FRG), J. Fontan (France), R.C. Harriss (USA), V. Kirchoff (Brazil)

Activity 5* Exchanges of Methane and Other Trace Gases in Rice Cultivation
Status: Planning
Convener: Ralph Cicerone
Department of Geoscience
Schol of Physical Sciences
University of California, 92717
Irvine, California
USA

Members: H.U. Neue (Philippines), R. Conrad (Germany), K. Minami (Japan), H. Rennenberg (Germany), O.T. Denmead (Australia), R. Sass (USA)

FOCUS 3: *The Role of Polar Regions in Changing Atmospheric Composition*

Activity 1: Polar Atmospheric Chemistry (PAC)
Status: Planning
Convenor: R. Schnell
GMCC, NOAA/ARL
Boulder, CO 80303
USA

Members: L. Barrie (Canada), P. Buat-Menard (France), R.J. Delmas (France), H. Dovland (Norway), R. Jaenicke (FRG), J. Heintzenberg (Sweden), T. Ito (Japan), K. Rahn (USA).

Activity 2: Antarctic Air-Snow Experiment (ASE)
Status: Planning
Convenor: R.J. Delmas
Laboratoire de Glaciologie
C.N.R.S.
BP 96, 38042 St Martin d'Heres, Cedex
France

Members: L. Barrie (Canada), R. Charlson (USA), C. Davidson (USA), J. Heinztenberg (Sweden), M. LeGrand (France), D. Wagenbach (FRG).

FOCUS 4: *The Role of Boreal Regions in Changing Atmospheric Composition*

Activity 1: Northern Wetlands Study (NOWES)
Status: Active
Convenor: H.I. Schiff
Department of Chemistry
York University
Downsview, Ontario MJ3 1P3
Canada

Members: L. Barrie (Canada), R. Cicerone (USA), W. Glooschenko (Canada), R.C. harriss (USA), W. Reeburg (USA), B. Svensson (Sweden).

Activity 2:* Ecological and Environmental Controls and Correlates for Trace-Gas Sources in High-latitude Ecosystems (Augment to IGAC 4.1)
Status: Active

Activity 3:* Sensitivity of High-latitude Trace-Gas Sources and Sinks to Environmental Change (Augment to IGAC 4.1)
Status: Planning

FOCUS 5: *Global Distributions, Transformations, Trends and Modelling*

Activity 1: Global Tropospheric Ozone Network (GLONET)
Status: Active
Convenor: R.C. Prinn
Dept. of Earth, Atmospheric and Planetary Sciences
M.I.T., 54-1824
Cambridge, MA 02139
USA

Members: D. Albritton (USA), R. Atkinson (Australia), R. Bojkov (Switzerland), J. Burrows (FRG), B. Cros (Congo), I. Galbally (Australia), R. Hartmannsgruber (FRG), M. Ilyas (Malaysia), V. Kirchoff (Brazil), D. Kley (FRG), J. Logan (USA), G. Megie (France), T. Ogawa (Japan).

Activity 2: Global Atmospheric Chemical Survey (GLOCHEM)
Status: Planning
Convenor: D.H. Ehhalt
Institute for Chemistry
3 Kernforschungsanlage Julich
Postfach 1913, Julich D-5170
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Members: P. Crutzen (FRG), H. Fischer (FRG), J. Fushman (USA), G. Harris (FRG), I. Isaksen (Norway), B. Ridley (USA), H. Schiff (Canada).

Activity 3: The Chemical and Physical Evolution of CCN as Controllers of Cloud Properties (In the IGBP framework, this Activity has been proposed as FOCUS 8 due to the relative importance of the research)
Status: Planning
Convenor: R.J. Charlson
Department of Atmospheric Science
University of Washington
Seattle, Washington 98195
USA

Members: T. Choularton (UK), J. Gras (Australia), B. Huebert (USA), G.G. Lala (USA), G. Lambert (France), P. McMurry (USA), J. Ogren (Sweden), L. Radke (USA), P. Zimmerman (USA).

Activity 4: Development of Global Emission Inventories
Status: Planning
Convenor: T. Graedel
AT&T Bell Laboratories
Rm 1D-349
Murray Hill, NJ 07974
USA

Members: A.F. Bouwman (Netherlands), D. Cunnold (USA), P. Midgeley (USA), R. Swart (Netherlands).

Activity 5*: Global Integration and Modeling of Fluxes (added Activity to IGAC Focus 5)
Status: Planning

FOCUS 6: *International Support Activities*

Activity 1: Education in Atmospheric Chemistry and Global Change
Status: Planning
Convenor: J.W. Winchester
Department of Oceanography
Florida State University
Tallahasse, FL 32306-3048
USA

Members: H. Rodhe (Sweden), H.I. Schiff (Canada).

Activity 2: The IGAC Newsletter
Status: Active
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H.I. Schiff (Canada), R. Duce (USA), E. Sanhueza (Venezuela), N. Bhandari (India), H. Akimoto (Japan), P. Warneck (FRG), D. Lowe (New Zealand), P. Fraser (Australia), R. Delmas (Congo), A. Ryabshapko (USSR)

Activity 3: Intercalibrations/Intercomparisons
Status: Active
Task 1: Gas Standards for CO, CH_4 and Chlorinated Hydrocarbons
Convenor: P.J. Fraser
CSIRO, Division of Atmospheric Research
Private Bag 1, Mordialloc, Vic 3195
Australia

Members: L. Heidt (USA), Y. Makide (Japan), R. Prinn (USA), G. Sachse (USA), P. Steele (USA), R.F. Weiss (USA).

Task 2: Non-Methane Hydrocarbon Intercomparison Experiment
Convenor: F. Fehsenfeld
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Members: B. Bonsang (France), H. Niki (Canada), J. Rudolf (FRG), W. Seiler (FRG), H.B. Singh (USA).

FOCUS 7:* **Trace-Gas Fluxes in Mid-Latitude Ecosystems** (Added Focus to IGAC)

Activity 1: Exchanges of N_2O, CH_4 and CO Between Terrestrial Ecosystems and the Atmosphere (added Activity)
Status: Planning
Convenor: J.M. Melillo
USA
and
K. Smith
UK
Members: J. Bogner (USA), J. Freney (Australia), P. Groffman (USA), G. Harris (FRG), K. Heider (FRG), A. Isaejev (USSR), L. Klemedtsson (Sweden), W-H. Su (China), B. Svennson (Sweden)

Activity 2: How Important are Mid-Latitude Ecosystems as a Net CO_2 Sink? (added Activity)
Status: Planning
Convenor: G.P. Robertson
USA

Members: D. Baldocchi (USA), I. Burke (USA), R. Desjardin, I. Fung (USA), P. Jarvis (UK), J.M. Melillo (USA), R. Webster (USA), S. Wofsy (USA)

Activity 3: How Important are Mid-Latitude Ecosystems as Sinks for Atmospheric Oxidants and Sources of Oxidant Precursors? (added Activity)

Status: Planning
Convenor:
Members:

(NOTE: '*' - indicates augmented or additional Foci or Activity to the IGAC Dookie report)

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No. 2. A Document Prepared by the First Meeting of the Special Committee, ICSU Secretariat, Paris 16-19 July, 1987 (1987)

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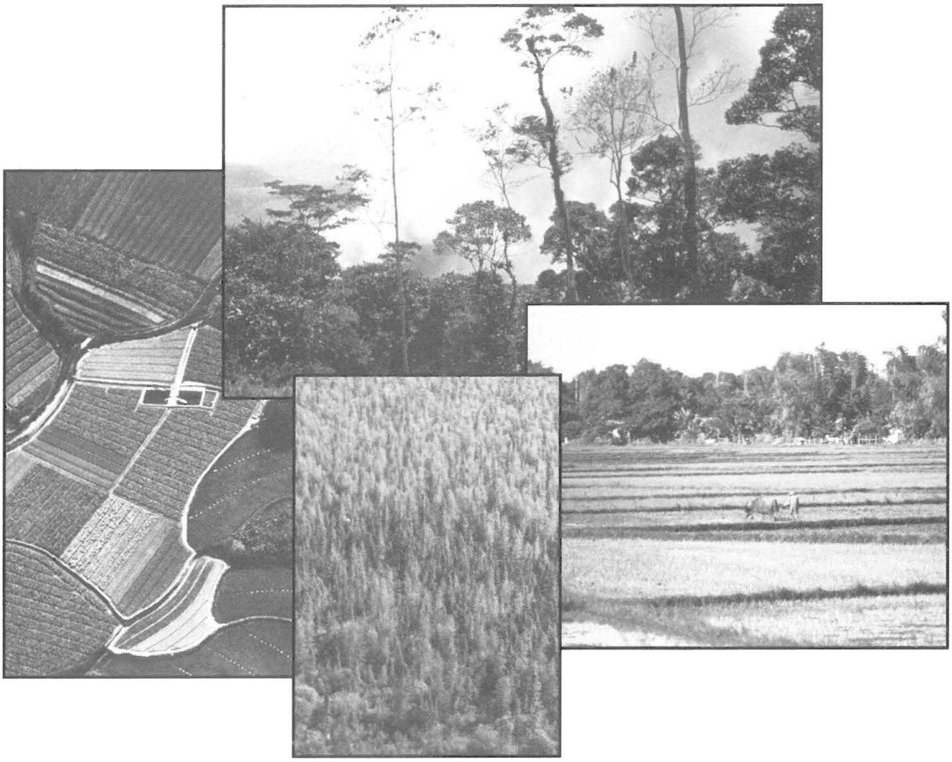

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