

GLOBAL  
I G B P  
CHANGE

**REPORT No. 32**



International Global Atmospheric  
Chemistry (IGAC) Project

**The Operational Plan**

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)  
of the International Council of Scientific Unions (ICSU)  
Stockholm, 1994

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(IGAC) Project

## The Operational Plan

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## Introduction

The atmosphere is a chemically complex and dynamic system, interacting both internally, mostly within the troposphere and stratosphere, and with the oceans, land and living organisms. Its composition is changing today, and is also known to have changed markedly over the last 160,000 years. Environmentally significant processes occurring in the atmosphere today because of anthropogenic activities include those affecting the ozone layer, the biosphere, and the levels of radiatively active gases and particles. The most important single long-lived greenhouse gas is carbon dioxide, the concentration of which is determined by interactions with the terrestrial biosphere and the oceans, as well as by land clearing and the burning of fossil fuels. Methane, also a very important long-lived greenhouse gas, has major natural and anthropogenic sources; it is destroyed largely by reaction with hydroxyl radicals in the troposphere. Both its sources and sinks are strongly influenced by human activity. Nitrous oxide, with a similar range of sources, and chlorofluorocarbons, purely anthropogenic, are also greenhouse gases; however, their greenhouse potency is offset partially by the stratospheric ozone (O<sub>3</sub>) they destroy. Ozone is a key atmospheric chemical and protective ultraviolet shield. It has a complex chemistry that is influenced by many other trace species. It is also toxic to humans and vegetation, and is an important greenhouse gas. Many other trace gases play key roles through their influence on the concentrations of O<sub>3</sub>, the hydroxyl radical and methane. Gaseous sulphur compounds, both natural and anthropogenic, are oxidised to particulate sulphates which have an important effect on albedo, counteracting the influence of greenhouse gases. Atmospheric chemistry is therefore closely linked to industrial activity, climate and land-use through many complex environmental processes. The *International Global Atmospheric Chemistry (IGAC) Project* is underway and dedicated to understanding this complex system through a combination of observations, theory, and laboratory and modelling studies.

IGAC is jointly sponsored by the International Geosphere-Biosphere Programme (IGBP) and the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Sciences (IAMAS). The goals of IGAC are to:

- Develop a fundamental understanding of the processes that determine atmospheric composition.
- Understand the interactions between atmospheric chemical composition and biospheric and climatic processes.
- Predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere.

The initial science plan for IGAC was developed at a CACGP workshop held at Dookie College, Victoria, Australia, in November 1988, and was documented in a report edited by I. Galbally (CACGP, 1989). The original IGAC plan adopted six major *Foci*, each addressing important problems in global atmospheric chemistry whose solutions require

international cooperation. Early on the need for stronger interdisciplinary approaches in developing a predictive understanding of the Earth system was recognised. The task of addressing biosphere-atmosphere interaction issues was undertaken by the IGBP Coordinating Panel on Terrestrial Biosphere-Atmosphere Interactions, the SCOPE (Scientific Committee on Problems of the Environment) Project on Trace-Gas Exchange and, ultimately, by the participants of a joint *SCOPE-IGBP Workshop on Trace Gas Exchange in a Global Perspective* held in Sigtuna, Sweden, in February 1990. The results of that workshop are detailed in IGBP Report No. 13 (IGBP, 1990). Further information about IGAC can be obtained from the IGAC Core Project Office, Building 24-409, Massachusetts Institute of Technology, Cambridge, MA, 02139-4307, USA, Tel: (+1-617) 253-9887; Fax: (+1-617) 253-9886; E-mail: pszenny@mit.edu.

## Organisation of the Project

The composition and chemistry of the atmosphere are dependent on both climatic, biospheric, geospheric and anthropogenic variables. The organisation of IGAC takes into account the fact that the spatial and temporal distributions of these variables are not uniform and that for some variables (e.g., clouds, phytoplankton, fossil fuel combustion) the distributions are very patchy. As a result of these patchy and sometimes correlated phenomena, it is essential to study a variety of regions over the globe with the full complement of theoretical studies being applied to each region. For this reason, there are five major research areas, called *Regional Foci*, which address the marine, tropical, polar, boreal and mid-latitude regions (Figure1).

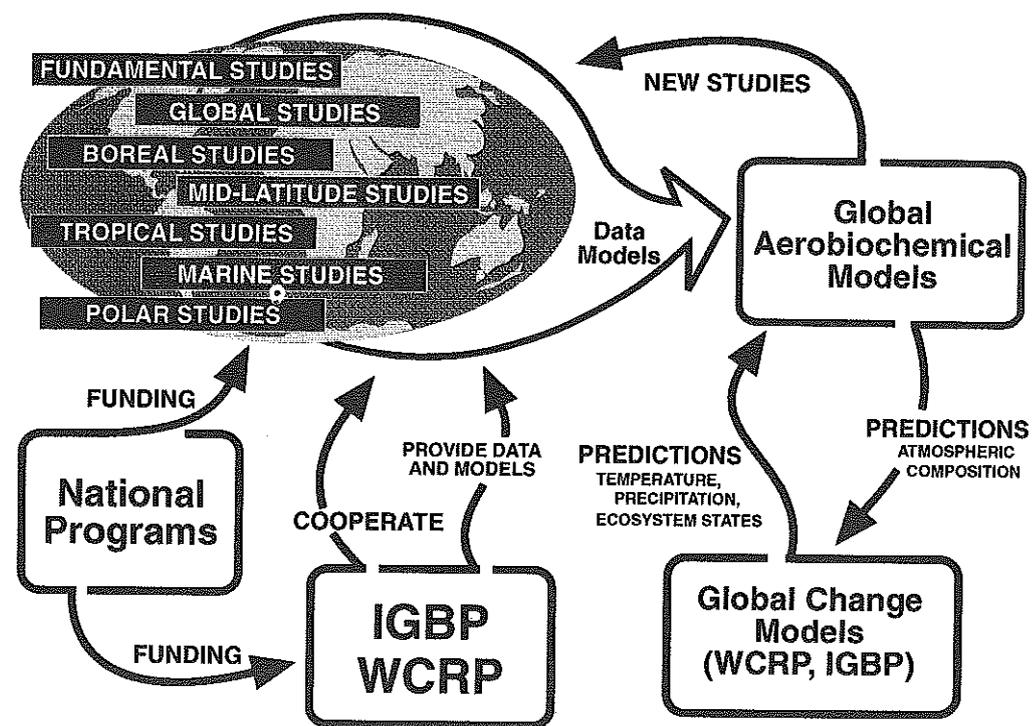


Figure 1. Simplified representation of IGAC operational modes.

These Regional Foci are accompanied by a *Global Focus* addressing global trends, distributions, sources, atmospheric transport, transformations, sinks and modelling of trace gases and aerosols. A seventh *Fundamental Focus* covers experimental and theoretical work essential to all other Foci, namely measurement calibration and intercomparisons, laboratory studies of fundamental molecular properties and new

instrument development. In addition, IGAC is promoting education and training efforts towards further understanding of atmospheric chemistry and associated biological processes in the context of global change.

These seven Foci collectively address areas of greatest current uncertainty and/or perceived importance. The Foci have been developed and will continue to evolve in response to reductions in uncertainties and concomitant changes in perceptions of what areas deserve the most attention.

At the heart of each Focus are so-called *Activities* which comprise achievable endeavours to address the overall IGAC goals (Figure 2).

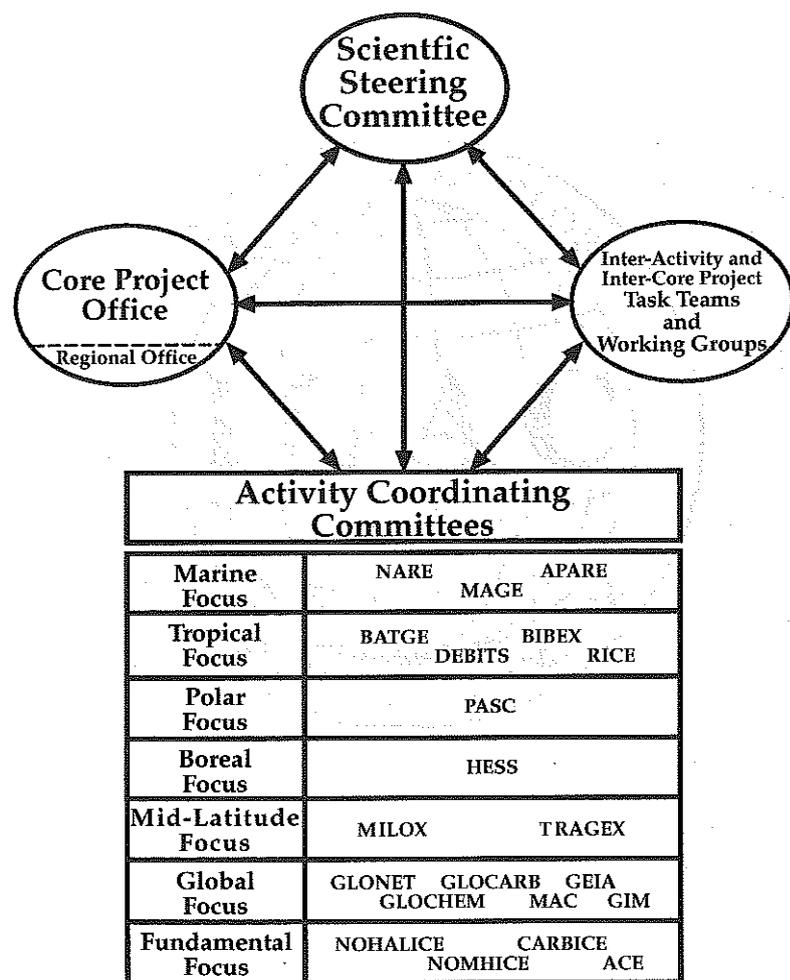


Figure 2. IGAC management structure.

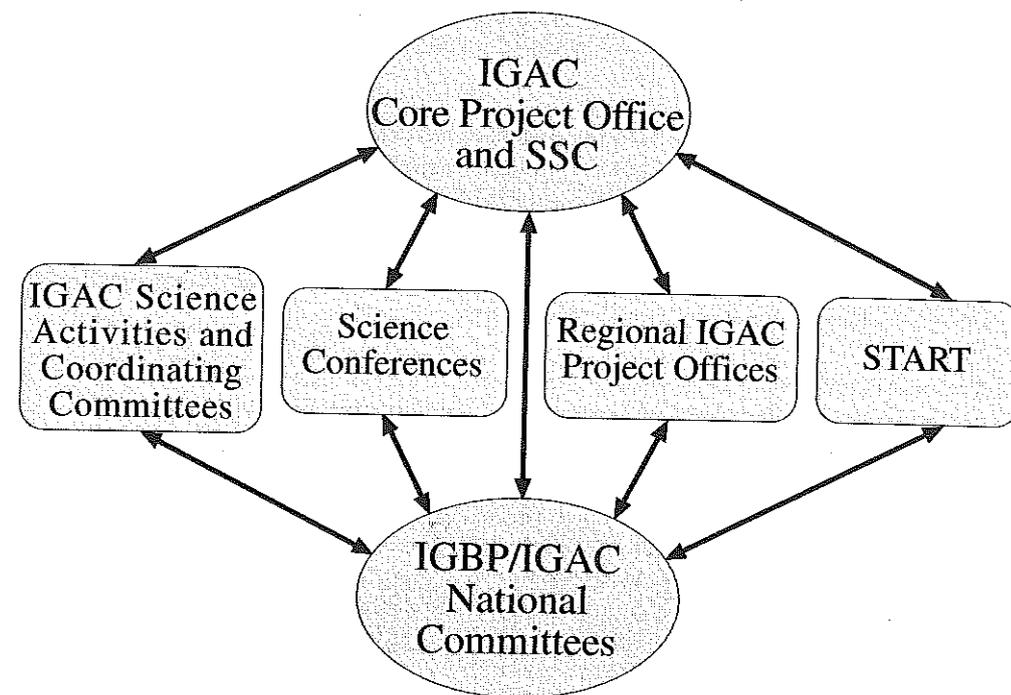


Figure 3. Contact nodes for participation in IGAC, and their linkages.

Where appropriate, IGAC Activities are carried out in cooperation with other IGBP Core Projects and Framework Activities, the World Meteorological Organisation (WMO), the World Climate Research Programme (WCRP) and a large number of other international and national organisations. Specific task teams within IGBP have been convened to develop recommendations for collaborative efforts between the Joint Global Ocean Flux Study (JGOFS) Core Project and IGAC, and among the Biospheric Aspects of the Hydrological Cycle (BAHC) and Global Change and Terrestrial Ecosystems (GCTE) Core Projects and IGAC. Formal liaisons have been established between IGAC and the WMO, and between IGAC and the International Union of Pure and Applied Chemistry (IUPAC). In addition, discussions are underway with an international group of aerosol researchers to augment and improve the aerosol science component of IGAC.

Participation in IGAC is open to all interested scientists because the extent and complexity of the problems under consideration require the participation of scientists with a wide variety of experience and skills. There are several ways in which scientists can become involved in IGAC, as portrayed in Figure 3 above.

## The Research Plan

The components of the IGAC Operational Plan, primarily at the Activity level, are outlined below. The section for each component includes a brief background, the goals, a summary of the research strategy and the planned timetable for its implementation. Most components are described individually in more detail in a series of pamphlets produced by and available from the IGAC Core Project Office.

### Focus 1: Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere

The overall objective of IGAC Focus 1 is to predict the oxidising efficiency of the marine atmosphere, the direct and indirect effects of marine aerosols on climate and the importance of air-sea exchange in biogeochemical cycles. The world's oceans are both a source of biogenic material and a sink for natural and anthropogenic carbon, nitrogen, sulphur and halogen compounds which affect the radiative properties of the atmosphere through scattering, absorption and cloud microphysical processes. Since two-thirds of the Earth's atmosphere lies over the oceans, the transport and chemical processes studied in this Focus impact the entire global environment. Three Activities are currently underway within Focus 1.

#### Activity 1.1: North Atlantic Regional Experiment (NARE) Conveners: F.C. Fehsenfeld, S.A. Penkett

The industrial regions on the continental rim of the North Atlantic are major global sources of gases that influence the oxidising efficiency and the radiative balance of the Earth's atmosphere. In the North Atlantic, the gaseous compounds move from the continental areas where they are emitted into the relatively source-free marine environment where the airborne compounds are processed. This combination of well-defined source areas followed by a vast, relatively source-free region, provides an excellent regime for the study of the mechanisms involved in the chemical processing of the compounds emitted and of the factors affecting the persistence of these compounds and their oxidative products in the marine atmosphere.

NARE was established to study the chemical processes that occur in the remote marine environment of the North Atlantic. NARE planning meetings have been held in July, 1989 in Norwich, England; September, 1990 in Chamrousse, France; April, 1991 in Boulder, Colorado; April, 1992 in Montreal, Canada; and January, 1993 in Norwich, England to articulate scientific objectives and to develop plans for future action. This regional Activity will investigate the processes that determine the fate of continental emissions as well as the processes that deliver these emitted compounds and their

oxidation products to the remote free troposphere. In the course of these studies, NARE will also address intercomparisons, calibrations, shared standards and protocol for data sharing and archiving.

The initial emphasis of NARE is to determine the impact of emissions of pollutants which lead to the production of tropospheric ozone ( $O_3$ ) in the North Atlantic region. The research needed involves measurements of the distribution and trends of  $O_3$  and related parameters in the North Atlantic region, determination of the sources of this  $O_3$  and elucidation of the processes responsible for  $O_3$  formation.

#### Goals

- Assess the long-range transport of photochemically active compounds and/or their products and determine the impact of this transport on North Atlantic regional air quality.
- Ascertain the effect of these compounds on the oxidative properties and radiation balance of the atmosphere.
- Estimate the amounts of these compounds that are deposited in this marine environment and to determine the impact of this deposition on surface sea-water chemistry and marine biological processes.

#### Implementation Strategy

NARE has five distinct Tasks which are described below. Although the Tasks are listed separately, there is considerable overlap among their goals and objectives, and each Task requires significant support from and coordination with the others. A primary role of NARE is to help coordinate extensive international programmes that have been developed to study these complex problems and to stimulate thoughtful discussion of the science that is already understood and help clarify and define that which is yet required. Thus, this regional study is built upon several existing programmes and combines measurements taken at ground-based sites, from ships and from aircraft, with development of detailed models. Three overarching themes serve to describe efforts underway within the NARE Tasks.

##### A. Free Tropospheric Ozone over the North Atlantic

Observations of  $O_3$  in the free troposphere at an altitude of 3 km over the North Atlantic show a marked seasonal oscillation, with a maximum of about 55 ppbv (parts per billion by volume) in late spring (May-June) and a minimum of about 35 ppbv in winter (December-January). The increase in  $O_3$  between January and May is most intriguing. Its cause may be an increased flux of  $O_3$  from the large reservoir present in the stratosphere in the spring months or, possibly, an increased production from photochemical processes within the troposphere. Evidence for this second explanation comes from measurements of many hydrocarbons in the free troposphere over the Atlantic made simultaneously with the  $O_3$  measurements. They indicate a distinct seasonal variation of total carbon in the form of reactive hydrocarbons, such as  $C_2H_2$ ,  $C_2H_6$ ,  $C_3H_8$ ,  $C_4H_{10}$ ,  $C_5H_{12}$ ,  $C_6H_6$ ,  $C_7H_8$ , etc., in free tropospheric air with a maritime polar origin reaching the west coast of Scotland. Sea-level measurements made in November, 1982 suggest that the latitudinal

extent of this reservoir of about 20 ppbv of reactive carbon in the Atlantic region is from about 20°N to at least 40°N and that a large reduction to levels typical of the Southern Hemisphere occurs between 20°N and the equator. This large reservoir of reactive carbon is capable of generating an equivalent amount of O<sub>3</sub> on a mixing ratio basis, when it is oxidised in the atmosphere between the months of February and May, provided sufficient nitric oxide (NO) is also present. Unfortunately, there are very few published data on NO concentrations in the Atlantic region for comparison. A further feature of interest, which comes from close examination of the Atlantic free tropospheric hydrocarbon data, is that the distribution of hydrocarbons, particularly with respect to the ratios of the normal to the iso-isomers of pentane, hexane, heptane and octane, can be interpreted in terms of an efficient nitrate radical (NO<sub>3</sub>) chemistry preferentially removing the iso-isomer during winter months. Other possible explanations include a seasonally varying source other than motor vehicle exhaust, which is dominant in the winter months. Resolving the many uncertainties concerning the source of the O<sub>3</sub> observed in *clean* air over the North Atlantic and, by inference, the surrounding continents and the nature of hydrocarbon oxidation processes in addition to hydroxyl radical (OH) chemistry are two of the major objectives of NARE.

The link between NARE goals and those of IGAC's Activity 1.3, *East Asian/North Pacific Regional Experiment (APARE)*, is obvious. Given the nature of atmospheric circulation and the long lifetimes, particularly for O<sub>3</sub> and its precursor molecules in winter, the same type and degree of chemical processing probably will be observed in the North Pacific region that are observed in the North Atlantic region.

#### *B. Ozone Export from North America over the North Atlantic*

Ozone has both natural and anthropogenic sources in the troposphere. The primary natural source is injection from the stratosphere. The anthropogenic source is photochemical production from precursors emitted by industrial and transportation combustion sources. To understand the budget and, hence, the effects of O<sub>3</sub>, it is important to quantify and compare the magnitudes of these two sources. The heavily polluted eastern coast of North America is a particularly large source of O<sub>3</sub> and its precursors that can be transported to the temperate North Atlantic Ocean. During summer the atmospheric circulation in the temperate North Atlantic region is dominated by the Bermuda High, with flow to the northeast along the Atlantic Seaboard. To evaluate the significance of this transport, O<sub>3</sub> and carbon monoxide (CO) levels were measured during 1991 and 1992 at sites on the Atlantic coast of Canada. The sites (Cape Sable, Nova Scotia; Sable Island; and Cape Race, Newfoundland) were spaced at approximately 500 km intervals downwind from the northeastern urban corridor of the United States.

CO is an anthropogenic pollutant that is relatively non-reactive (lifetime about 1 month in the summer) and has been used as an effective tracer of anthropogenic pollution. The measured relations between the concentrations of O<sub>3</sub> and CO in the air advected over the North Atlantic, coupled with the emissions inventory of CO in eastern North America, provide the basis of estimating the amount of O<sub>3</sub> exported from North America.

Measurements were made at the three sites from mid-July to mid-September, 1991. Five minute averages of O<sub>3</sub> and CO concentrations were calculated. At each of the three sites the data showed generally constant, low levels of O<sub>3</sub> and CO, frequently interrupted by

episodes of correlated, elevated levels of both species. Linear regression analyses of the data yielded relatively large correlation coefficients, which indicate that approximately one-half to three-quarters of the variance in the O<sub>3</sub> levels at each site can be captured by a simple linear relation between O<sub>3</sub> and CO levels.

A strong, positive correlation between O<sub>3</sub> and CO was observed at Sable Island in August, 1991. The linear correlation coefficient indicates that more than three-quarters of the variance in the measured O<sub>3</sub> during this single summer month can be captured by a linear relationship between O<sub>3</sub> and CO. This suggests summertime photochemical production of O<sub>3</sub> from anthropogenic O<sub>3</sub> precursors emitted from source regions on the North American continent. By contrast, in the winter at Sable Island, the data were characterised by high CO levels and even lower O<sub>3</sub> levels, which result in significant negative correlation between O<sub>3</sub> and CO. In December more than half of the variance in the measured O<sub>3</sub> can be captured by a linear relationship. This indicates the chemical titration of O<sub>3</sub> by anthropogenically emitted nitric oxide and volatile organic carbon compounds (VOCs) in the absence of photochemical production.

Monthly linear correlations for the full data sets from the three sites were found to be strongly positive at all three sites for the summer months. At Sable Island the correlation disappeared as autumn progressed, and a negative correlation developed in the winter. This negative correlation in turn disappeared as spring progressed, followed by the reappearance of the positive correlation.

The slopes of the linear regressions provide an indication of the amount of O<sub>3</sub> photochemically produced from the precursors that were emitted into the air masses with the CO. That is, the amounts of O<sub>3</sub> and CO in these transported air masses were at a molar ratio of about 30%. Because the amount of CO emitted over North America is approximately known from emissions inventories, and because the fraction of this CO that is transported to the North Atlantic can be estimated, it is possible to estimate the quantity of O<sub>3</sub> photochemically produced from the precursors and transported to the North Atlantic: It is approximately 100 billion moles of O<sub>3</sub> per summer. This amount is greater than that reaching the lower troposphere in this region from the stratosphere, the primary natural source of O<sub>3</sub>. This conclusion supports the contention that O<sub>3</sub> derived from anthropogenic pollution has a hemisphere-wide effect at northern temperate latitudes.

#### *C. Combined Ozone and Particulate Measurements in the North Atlantic Region*

The analysis of the AEROCE (Atmospheric/Ocean Chemistry Experiment) data has provided unique insights on the cycle of sulphur, nitrogen, trace elements and O<sub>3</sub> in the North Atlantic atmosphere. The aerosol, precipitation and O<sub>3</sub> data sets demonstrate the importance of transport of sulphur and nitrogen pollutants from North America to the North Atlantic atmosphere. These same data clearly document the widespread transport of sulphur, nitrogen, metals and mineral aerosols from Africa. Indeed, these data unequivocally support the hypothesis that the atmospheric chemistry of most of the North Atlantic is highly impacted by continental sources a large fraction of the time.

Also, despite the dominance of continental processes in all data sets, the importance of marine processes, especially for sulphur, can clearly be seen. Observations of the seasonal

cycles of methanesulphonate (MSA) in aerosol and precipitation characterise for the first time the main features of dimethylsulphide (DMS) production in an ocean region of this size.

With regard to the atmospheric dynamics of long-range transport, the combination of the O<sub>3</sub> and aerosol data sets, along with the various tracers, yields insights into the processes controlling oxidant concentrations in the atmosphere and their association with specific sources. In addition, the combination of the aerosol and precipitation data sets allows an assessment of scavenging mechanisms and the relative importance of dry deposition as a removal mechanism.

#### Task 1.1.1: Chemical Transformation and Meteorological Processes

The Earth's atmosphere is an oxidising medium. As a result of atmospheric chemistry, compounds containing carbon, hydrogen, nitrogen, sulphur in reduced forms, and other elements emitted by a variety of natural and anthropogenic sources are oxidised, yielding either non-reactive long-lived species (e.g., carbon dioxide (CO<sub>2</sub>)) or short-lived species that are removed by wet and dry deposition (e.g., nitric acid (HNO<sub>3</sub>), sulphuric acid (H<sub>2</sub>SO<sub>4</sub>)). Therefore, in order to assess the environmental consequences associated with the release of various compounds into the atmosphere, it is important to understand the oxidation mechanisms.

The tropospheric oxidation of a particular compound is accompanied by a sequence of gas-phase and aqueous-phase processes. A majority of the oxidants responsible for these transformations are produced photochemically. Throughout most of the atmosphere the process that initiates the formation of these oxidants is the photolysis of O<sub>3</sub>. Therefore, understanding the tropospheric distribution of O<sub>3</sub> and the processes that control its production and removal is essential to understanding the oxidising efficiency of the troposphere. These processes also influence the atmospheric lifetimes of greenhouse gases and substances that deplete the stratospheric O<sub>3</sub> layer. Tropospheric O<sub>3</sub> itself is a powerful greenhouse gas. The initial emphasis of NARE is to understand these processes in detail and to develop a predictive capability for oxidation of trace gases in the North Atlantic region.

In order to understand inter-regional and intra-hemispheric production and dissemination of O<sub>3</sub> and its precursors, it is necessary to identify the mechanisms responsible for the escape of O<sub>3</sub> and its precursors (nitrogen oxides (NO<sub>x</sub>), VOCs and CO) from sources within the planetary boundary layer to the free troposphere, to characterise the intra-hemispheric transport processes for these compounds, to understand the chemical processing that occurs during long distance transport, and to develop and validate predictive models of chemistry and transport.

#### Task 1.1.2: Ozone Climatology of the North Atlantic

It is now well established that elevated and potentially harmful levels of O<sub>3</sub> are being produced during summer in many areas of North America and Europe. Most of this O<sub>3</sub> is being produced photochemically from NO<sub>x</sub> and VOCs, which have both human-influenced and natural sources. Ozone has a relatively long lifetime, varying from days or weeks in the summer to months in the winter, which implies that it can be transported on hemispheric scales. Its concentration over the Atlantic can be influenced strongly by

emissions from North America, Europe and, possibly, Asia. Hence, for an understanding of the oxidising and radiative properties of the troposphere, it is critical to determine the distribution of O<sub>3</sub> and its precursors as a function of season throughout the North Atlantic region.

#### Task 1.1.3: Transport and Deposition

Aside from their involvement in O<sub>3</sub> production, the substances advected from continental to marine atmospheres can also influence biogeochemical processes occurring in the underlying ocean. To determine the impact of continental material on these processes, it is first necessary to determine the magnitude of the transport processes.

The North Atlantic contains the major physical, chemical and biological attributes of the world oceans. It has regions of high and low biological productivity which provide contrasting marine source regions for atmospheric species. It is bordered by continents which serve as major sources of natural and anthropogenic species. Recent studies show that transport from North America to the western Atlantic and transport from Africa to the tropical North Atlantic are the most important sources and that a combination of atmospheric processes is important for such transport to occur, including vertical-exchange processes, pollutant interactions with clouds, coastal-zone effects and recirculation.

#### Task 1.1.4: Model Development

In order to define better the strategy for field measurements, a strong component of modelling will be needed to assist in planning as well as interpreting the results of the field studies. The models will be used to help establish the numbers, types, and timing of the measurements and to define the important atmospheric conditions and meteorology needed to gather the critical data. The models to be developed are concerned with chemistry, transport and deposition. The domain of the models will be the North Atlantic and substantial portions of the surrounding continents.

#### Task 1.1.5: Ancillary Science: Instrument Development, Intercomparison and Laboratory Kinetics

A variety of sensitive and accurate instruments is required to measure O<sub>3</sub> and its chemical precursors along with the meteorology that is responsible for the dissemination of these compounds. Examples of requirements include the development of vertical sounding techniques such as O<sub>3</sub> lidar, development of new sonde sensors (e.g., for H<sub>2</sub>O<sub>2</sub>) and development of reliable, portable measurement techniques for critical oxidising free radicals such as hydroxyl (OH) and NO<sub>3</sub>. Intercomparison exercises are necessary for many species, but particularly for hydroperoxyl (HO<sub>2</sub>) and organic peroxy (RO<sub>2</sub>) radicals, HNO<sub>3</sub> and VOCs.

Laboratory kinetics studies are needed to supply specific reaction rate constants and spectroscopic data for model simulation of specific processes. Of particular interest for future NARE studies are the reactions of NO<sub>3</sub> which may be important for initiating oxidation in the dark. Also, more laboratory investigations are needed to define the

secondary products produced in the oxidation of VOCs. Finally, it should be noted that the future technology that will be used to measure trace chemicals in the atmosphere will be developed initially to detect these compounds in the laboratory.

#### Timetable

1992-	Ozone distribution and trends field measurements
1993	Summer field sampling intensive
1995-1997	Winter-spring field sampling intensives

#### Activity 1.2: Marine Aerosol and Gas Exchange (MAGE)

Convener: B.J. Huebert

The oceans cover about 70% of the Earth's surface and are major sources and major sinks of many trace species that affect the radiative balance of the Earth either directly (e.g., CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O)) or indirectly (CO, hydrocarbons, halogen and sulphur compounds) by altering the photochemistry of the marine atmosphere. It is essential that these source, sink and transformation processes be studied in detail.

Understanding the exchange between the atmosphere and oceans requires studies of both emissions from the ocean surface and deposition to it from the atmosphere. Since these studies are limited by the lack of direct measurements of the most important fluxes, MAGE has made the development and testing of new flux-measuring strategies and technologies one of its principal objectives. Furthermore, it is necessary to improve the current understanding and predictive capabilities of the physical and biogeochemical processes controlling the oceanic and atmospheric concentrations of these climatically important trace species. Studies of these processes (e.g., the physical parameters influencing air-sea exchange, the biological production and consumption of climatically important gases and their precursors, marine photochemistry and its effect on chemical concentrations) will require not only measurements of the trace species but also of many ancillary physical, chemical, biological and meteorological parameters. The complexity of these studies requires an integrated, interdisciplinary approach which often includes simultaneous measurements from several research platforms.

Sulphur chemistry is a subject of particular interest to MAGE. Improving the current understanding of the impact of DMS emissions on clouds is fundamental to improving climate models, since some models suggest that a 4% increase in the areal extent of marine stratocumulus clouds could have a cooling effect equivalent to (offsetting) a 30% increase in CO<sub>2</sub>. Cloud condensation nuclei (CCN) formed from DMS might be one of the significant controllers of cloud radiative properties. Again, such studies are limited by the difficulty in measuring both the emissions of DMS and the deposition of sulphur dioxide (SO<sub>2</sub>), MSA and sulphate aerosol.

Continental outflow can affect the chemistry of the marine boundary layer (MBL) through the addition of anthropogenic pollutants. To determine the effect of reducing air pollution on global change, it is essential, for instance, to find out in what regions of the ocean sulphate aerosol formation is dominated by man-made SO<sub>2</sub>, and where DMS is the

major source. The continents can also have a major impact on biota, since the atmospheric transport of nutrients derived from continental sources is thought to limit productivity in some marine regions. How might changes in land-use practices alter the productivity of the oceans? Such uncertainties and questions cannot be answered without much better estimates of fixed-nitrogen and trace metal deposition.

Finally, marine aerosols are important factors in the global radiation budget, independent of their role as CCN. Existing models of aerosol deposition are very sensitive to such factors as size, which, unfortunately, changes dramatically over the normal humidity gradients in the MBL. Improved deposition measurements are needed to estimate the lifetimes of these radiatively important particles, so that the impact of changes in source terms can be modelled.

#### Goals

- Understand the chemical, biological and physical mechanisms that control the exchange of trace gases and particulate material between the atmosphere and the ocean surface.
- Develop formulations of ocean exchange processes for inclusion in global-scale climate and air chemistry models.
- Extend the experimental knowledge of air-sea interchange to conditions with strong winds, rough seas and spray.

#### Implementation Strategy

The MAGE Coordinating Committee met in Anaheim, California in February, 1990 and subsequently in Chamrousse, France in September, 1990 to discuss the action plans for this Activity. The Committee identified two areas in which MAGE could contribute to studies of air-sea exchange. The first is to promote the development of new measurement technologies, while the second is to organise field projects both to test the new technologies and to facilitate large interdisciplinary research studies. Opportunities have been identified in both areas. The MAGE Coordinating Committee also met in Hobart, Tasmania, in February, 1993. The Committee decided then to encourage the addition of a biological experiment to the ACE-1 programme (Southern Hemisphere Marine Aerosol Characterisation Experiment; see Task 1.2.2.C and Activity 6.4), and to investigate European interest in a MAGE experiment in the Atlantic or Mediterranean after ACE-1.

#### Task 1.2.1: Development of Novel Measurement Techniques

At present, air/sea exchange research is seriously limited by technology. Most of the important fluxes have never been measured directly in the field. Improvements in the understanding of marine aerosol properties and gas exchange processes can only be achieved through the development of new measurement technologies.

MAGE is very interested in supporting the efforts of principal investigators who wish to develop and deploy novel methods for estimating marine surface fluxes. For instance, MAGE has encouraged the development of fast sensors for DMS, SO<sub>2</sub>, CO<sub>2</sub> and other species, in the hope of making eddy-correlation measurements of fluxes from ships or

towers together with traditional techniques. MAGE is also encouraging the improvement of ship-borne eddy-correlation methodology. One of the ASTEX/MAGE ships (see Task 1.2.2, section B below) carried an extensive micrometeorological system, which was primarily used for estimating momentum and moisture fluxes.

#### Task 1.2.2: Field Measurements (Methodology Intercomparison Tests)

MAGE investigators completed two significant field programmes in 1992 and additional ones are planned for 1995 and beyond.

##### A. MAGE/JGOFS Equatorial Pacific Experiment:

This was the first field programme of the MAGE Activity. It was planned to coordinate with the Joint Global Ocean Flux Study (JGOFS) and to complement the JGOFS oceanographic programme with non-CO<sub>2</sub> trace gas and atmospheric chemistry measurements.

Two MAGE ships participated alongside the research vessel *Tommy Thompson* in the Equatorial Pacific JGOFS experiment during the spring of 1992. Since the primary JGOFS interest is in the carbon cycle and biological productivity, the MAGE observations of atmospheric nutrients and biogenic gases were designed with collaborative interpretations of the phenomena in both phases in mind. NOAA's (National Oceanic and Atmospheric Administration) research vessel, *Vickers*, carrying investigators from ten U.S. institutions and Russia, conducted a study which emphasised biogenic trace gas fluxes and sulphur chemistry. U.S., U.K. and Egyptian scientists on the research vessel *Wecoma* studied fluxes of atmospheric carbon, nitrogen and sulphur, and the impact of atmospheric iron on productivity.

##### B. ASTEX/FIRE Experiment in the Tropical Atlantic:

FIRE (First ISCCP Regional Experiment) is an on-going multi-agency programme designed to promote the development of improved cloud and radiation parameterisations for use in climate models, and to provide assessment and improvement of ISCCP (International Satellite Cloud Climatology Project) products. It is primarily a national project of the United States, with important contributions by scientists from the United Kingdom and France. The strategy of FIRE has been to combine modelling activities with satellite, airborne and surface measurements to study two types of cloud systems – cirrus and marine stratocumulus – that have important roles in climate system by virtue of their extensive areal coverage, persistence and radiative effects. FIRE has been designed to be conducted in two phases. FIRE Phase I (1984-1989) was designed to address fundamental questions concerning the maintenance of cirrus and marine stratocumulus cloud systems. FIRE research over those years has led to major improvements in the current understanding of the role of these clouds in the global climate system. FIRE Phase II (1989-1994) is focusing on more detailed questions concerning the formation, maintenance and dissipation of these cloud systems.

The Atlantic Stratocumulus Transition Experiment (ASTEX) is a part of the second series of FIRE international cloud climatology experiments. The ASTEX/MAGE experiment was a multinational effort to improve our capability for studying cloud/chemistry

interactions and the air/sea fluxes that affect them. Improved analytical techniques and new observational strategies were tested, with the goal of incorporating more realistic chemistry and physics into climate models.

MAGE contributed two ships, two aircraft, and surface measurements on two islands to the ASTEX/MAGE experiment in the eastern subtropical North Atlantic in June of 1992. The aim of ASTEX/MAGE was to understand the factors – including air/sea fluxes and the formation and loss of aerosols – which control the life cycles and radiative properties of marine stratocumulus clouds. Extensive sulphur, hydrocarbon and photochemical experiments were conducted in both Eulerian and Lagrangian reference frames. Constant-density balloons and an inert tracer were twice released from the research vessel *Oceanus* to tag airmasses, track their Lagrangian evolution and evaluate surface sources and sinks. The NCAR (National Center for Atmospheric Research) *Electra* flew three or four flights into each of these airmasses, while the University of Washington C-131 made one flight. NOAA's research vessel *Malcolm Baldrige* positioned itself downwind to characterise the tagged air as it passed out of the study area. This effort to develop new experimental strategies for studying air/sea fluxes depended on the combined efforts of scientists from the U.S., France, Germany, U.K., Spain and Portugal.

A tremendous amount of experience was obtained from the ASTEX/MAGE experiment about how to conduct Lagrangian studies in the marine atmosphere. One Lagrangian experiment was conducted in extremely clean air, while the other was in polluted air from Europe. Data analyses are underway; it is becoming clear that the budget studies have produced excellent pictures of the evolution of marine sulphur over time. At the conclusion of the ASTEX/MAGE experiment, the science teams met in Santa Maria, Azores in June, 1992 to debrief and discuss plans for data analysis. A data workshop was conducted in February, 1993, in Hilo, Hawaii.

##### C. First Aerosol Characterisation Experiment:

The *Southern Hemisphere Marine Aerosol Characterisation Experiment* (ACE-1) is being planned in collaboration with IGAC Activity 6.4 (MAC, *Multiphase Atmospheric Chemistry*). ACE-1 is to take place in late 1995 in the vicinity of Cape Grim, Tasmania, and will involve scientists from New Zealand, Australia, the U.S., Europe and southeast Asia. The intent is to study the DMS flux and its conversion to aerosols in a region where anthropogenic influences are minimal.

This experiment will also be coordinated with the IGBP/JGOFS Southern Ocean experiment, which was originally planned for the same area and time period. Although the U.S. JGOFS Southern Ocean field work has been delayed until 1996, MAGE will coordinate its measurements with Australian JGOFS. IGAC scientists hope to have one research vessel (NOAA's *Discoverer*) on which atmospheric sampling and studies of sulphur and nutrient chemistry and biology in the water column can be conducted. Italian tracer technology will be used to confirm the Lagrangian trajectories identified by both constant-density and constant-altitude balloons released from the ship. NCAR's new C-130 will be the primary airborne sampling platform. There are opportunities for investigators to make related measurements at surface sites at Cape Grim in New Zealand and on Macquarie Island, Australia (where IGAC scientists will be erecting a sampling tower for the experiment), as well as from Antarctic supply ships which will be transiting the study area. ACE-1 offers an excellent chance for investigators to observe the

relationship between gradients in water column and atmospheric properties in the Southern Ocean in the context of a very comprehensive atmospheric chemistry experiment.

#### D. Second Aerosol Characterisation Experiment:

The second in this series of experiments, Radiative Forcing due to Aerosols over the Polluted North Atlantic Region (ACE-2), is planned for boreal summer, 1997. A multinational effort built around a core of European scientists will conduct studies similar to those planned for ACE-1 (see Activity 6.4).

#### E. Flux Measurement Methods Development and Testing Experiments

Reliable methods for measuring fluxes of trace species directly are still lacking, so significant work is needed on technique development. Although it is likely that so-called "two-layer" models will be used for parameterising exchange in models, confirming techniques based on different physical principles are needed for each important species. Micrometeorological techniques are particularly important, since they measure fluxes directly on relatively short time scales. Accordingly, two future experiments have been proposed.

The first would be a tower-based field campaign in which the two-layer method (TLM) and micrometeorological approaches would be intercompared. The Dutch research platform *Meetpost Nordwijk* is an ideal site for such an experiment, since its flow distortion has already been well characterised. Ideally the experiment would include eddy-correlation of all species which could be measured rapidly, such as O<sub>3</sub>, DMS, NO<sub>y</sub>, N<sub>2</sub>O, total sulphur, CO<sub>2</sub> and, perhaps, CH<sub>4</sub>. Eddy-accumulation and conditional-sampling methods would be used for a variety of species such as hydrocarbons, alkyl halides, DMS and, perhaps, NH<sub>3</sub>. Several fluxes (DMS, some hydrocarbons) could also be measured by gradient methods. Finally, a ship would be used to make the surface measurements for the TLM comparison, and a dual-tracer experiment might also be included. A small aircraft might profitably be added to the experiment to confirm the tower and shipboard measurements. An October, 1994 workshop is planned.

Once this experiment has characterised the most promising techniques, they could then be used in a second experiment designed to assess fluxes over a wide range of forcing factors. It has been suggested that a transect across the Atlantic at about 20°S in approximately 1998 would work well for this. This area is relatively convenient logistically, with airfields on both ends and near the middle of the region. It would allow studies of productivity and fluxes in rich upwelling Argentinean waters, then yellow river water, then blue, non-productive waters and finally in rich, upwelling waters near Africa. The contrast would provide the kinds of data needed to create expert systems which will convert satellite measurements of chlorophyll into reliable biogenic trace gas flux estimates. The possibility of joint work with the JGOFS North Atlantic Process Study in 1998 or 1999 is being explored as well.

#### Timetable

- 1992 MAGE Equatorial Pacific Experiment in the spring.  
ASTEX/MAGE experiment in June.
- 1993 IGAC MAGE/MAC Planning Meeting for Southern Hemisphere Marine Aerosol Characterisation Experiment, in Hobart, Australia in February.  
ASTEX/MAGE data workshop in Hilo, Hawaii in February.
- 1994 Meeting of the MAGE Coordinating Committee in September in Japan (in conjunction with the CACGP Meeting). Articulation of other MAGE objectives, such as studying the impact of severe storms on fluxes; discussion of novel approaches for understanding air/sea fluxes.  
Planning workshop in October in the Netherlands for *Meetpost Nordwijk* flux measurement intercomparison experiment.
- 1995 Field experiment (ACE-1) in Southern Ocean in October-December.
- 1996 *Meetpost Nordwijk* flux measurement intercomparison experiment.
- 1997 Field experiment (ACE-2) in North Atlantic in June-August.
- 1998 South Atlantic flux measurements transect cruise.

#### Activity 1.3: East Asian/North Pacific Regional Experiment (APARE)

Convener: H. Akimoto

The East Asian Continental Rim Region is characterised by high and rapidly growing anthropogenic emissions of NO<sub>x</sub>, SO<sub>2</sub>, hydrocarbons and other air pollutants due to its high and growing population density and, in some regions, intensive industrial development. The emissions affect chemical processes in the continental outflow resulting in different features in oxidative products, aerosol content, etc., from those in marine airmasses of Pacific origin. Evidence has already been accumulated that concentrations of O<sub>3</sub> in air masses passing across the East Asian continent and northwestern Pacific islands are substantially elevated compared to those characteristic of the central Pacific. Long-range transport of continental aerosols from the northwestern Pacific regions to mid-Pacific islands has also been reported.

Despite the obvious urgent need for an intensive study of the anthropogenic impact on atmospheric chemistry in this region, none was conducted before the implementation of the APARE Activity. Quantifying the emissions and the fate of atmospheric constituents in the East Asian troposphere necessitates international cooperation among scientists from this part of the world, as well as from other interested nations.

The scientific goals of APARE are to quantify the oxidising efficiency and atmospheric acidification by studying the emission, transport, chemical transformation and deposition

of primary and secondary chemical species over the East Asian Continental Rim Region and northwestern Pacific Ocean. To accomplish these objectives, well-coordinated experiments including ground-based measurements and aircraft campaigns will be essential, along with emissions inventory efforts and modelling studies. Although the scientific objectives are similar to those of IGAC Activity 1.1 (NARE), the composition of pollutants in this region is expected to be quite different from that over the Atlantic because of different meteorological conditions and emission patterns.

The first planning meeting for APARE was organised and held at the National Institute for Environmental Studies (NIES) in Tsukuba, Japan in March, 1990. The meeting was attended by scientists from Australia, China, Japan, Korea, Taiwan and the United States. Coordination and organisation of sub-programmes were discussed, and the initial members of the Coordinating Committee were elected. The second APARE planning meeting was held in March, 1991 in Tsukuba and the two activities, PEM-WEST and PEACAMPOT (see below), were adopted as sub-programmes of APARE, along with the East Asian Monitoring Programme. The third APARE workshop was held in November, 1992, in San Francisco, USA to review ongoing APARE activities: PEM-WEST, PEACAMPOT and CATS. In November-December 1993, an International APARE Conference on Air Pollution and Climate Change in East Asia was organised at National Taiwan University in Taipei, Taiwan. It was attended by about 100 scientists from 23 Asian and Pacific countries

#### Goals

- Assess transport and chemical transformations of air pollutants over the East-Asian continent and the northwestern Pacific Ocean. Particular emphasis is on the distribution and photochemistry of reactive species, to understand the oxidising efficiency and O<sub>3</sub> budget of the region.
- Determine the deposition of primary and secondary pollutants in the East Asian region. Understanding the present status and future prospect of acidification of the atmosphere and deposition of acidic species in the region is a major emphasis.

#### Implementation Strategy

The following four tasks have been planned and developed under APARE:

##### Task 1.3.1: Emissions inventory and Atmospheric Chemistry Data Base

This Task will develop the emissions inventory and atmospheric chemistry data base for the study region. Of special importance are emissions of SO<sub>2</sub>, NO<sub>x</sub>, CO, VOC and NH<sub>3</sub>. Furthermore, a compilation of existing measurements of these compounds and O<sub>3</sub>, as well as deposition data for acidic species should be developed.

##### Task 1.3.2: Surface Measurements of Important Trace Gases

Surface-based measurements of O<sub>3</sub>, SO<sub>2</sub>, NO<sub>x</sub>, VOC and peroxyacetylnitrate (PAN), as well as of the chemical composition of aerosol and precipitation at various sites in the study area, are an important component of the activity. They are complementary to the campaign-type intensive field programmes.

##### Task 1.3.3: Intensive Field Programmes

Intensive field programmes employing aircraft and ships are important components of the activity, which should be supplemented by modelling efforts. Output of the emissions inventory and other atmospheric data bases supports the modelling activity.

##### Task 1.3.4: Ground Surface Monitoring Network

The importance of a long term monitoring programme in East Asia is realised and networking of several representative monitoring stations in the study region is proposed. Establishment of a regional data centre would encourage networking of monitoring stations.

#### On-going APARE Subprogrammes

The tasks outlined above are being implemented and coordinated by three international programmes under the umbrella of APARE:

##### 1. Pacific Exploratory Mission-West (PEM-WEST):

PEM-WEST is one of the PEM-series of campaigns executed by the U.S. National Aeronautics and Space Administration (NASA) as a part of its Global Tropospheric Experiment (GTE), which utilises large, extensively instrumented aircraft (e.g., DC-8) as a primary research tool.

The scientific objectives of the PEM-WEST campaign are to:

- Estimate the natural budgets of and the anthropogenic impacts on O<sub>3</sub> and its precursors, i.e., NO<sub>x</sub>, CO, CH<sub>4</sub> and non-methane hydrocarbons (NMHCs), over the Western Pacific;
- Estimate the major sources of sulphur species over the Western Pacific.

Two aircraft campaigns with the NASA DC-8 aircraft covered the latitudinal extremes of 60°N to 5°S. Major landing sites, from which one or more intensive flights were conducted, include Tokyo, Hong Kong and Guam for Phase A, and Guam, Singapore, Hong Kong and Tokyo for Phase B. The Phase-A campaign was completed in September-October, 1991, and the Phase-B campaign was implemented in February-March, 1994. Ground-based measurements were also executed at several selected sites in a continuous mode during the campaign period to measure O<sub>3</sub>, NO<sub>x</sub>, SO<sub>2</sub>, PAN, CO, etc. Several automated stations at remote islands were operated for the measurement of aerosols.

##### 2. Perturbation by East Asia Continental Air Mass to Pacific Oceanic Troposphere (PEACAMPOT):

PEACAMPOT is an aircraft campaign coupled with ground-based observations, which is sponsored by the Global Environmental Research Programme of the Japan Environmental Agency (JEA).

The scientific objectives of PEACAMPOT are to:

- Characterise the transport of acidic aerosols and their precursors in marine air around Japan;
- Analyse the distribution and long-range transport of oxidative species such as O<sub>3</sub>, PAN and their precursors in the East Asian Continental Rim Region.

PEACAMPOT campaigns were completed in coordination with PEM-WEST Phases A and B in Fall 1991, and Spring 1994, respectively.

### 3. East Asian Regional Data Center

A regional data centre for atmospheric chemistry has been established at the Global Change Research Center, National Taiwan University. Assimilation of atmospheric chemistry data from the surface observation stations in the study region has been proposed.

#### Future Direction of APARE

The field of interest of APARE is expected to expand to cover the upwind background continental air over Russia and China. Cooperation with atmospheric scientists in South-East Asia and South Asia is also envisioned.

#### Timetable

- 1992 Third APARE Workshop in San Francisco, USA in November:  
(1) to review APARE activities: PEM-WEST, PEACAMPOT and other activities related to APARE; (2) to review inventories of major air pollutants in East Asia and measurement of ground-based observations; (3) to discuss future APARE activities: Phase-B campaigns of PEM-WEST and PEACAMPOT, networking of IGAC/APARE ground stations and membership of IGAC/APARE Coordinating Committee.
- 1993 Fourth APARE Workshop in Taipei, Taiwan
- 1994 Implementation of Phase-B campaign (PEM-WEST, PEACAMPOT) in the spring.
- 1995 Fifth APARE Workshop and Coordinating Committee meeting, Tokyo, Japan

## Focus 2: Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry

The overall objectives of IGAC Focus 2 are to understand the chemical processing and transport of gases in the tropical atmosphere, and the role of terrestrial biosphere-atmosphere trace gas exchanges in regulating atmospheric composition. Much of the research in this Focus is directed toward understanding the effects of human activities,

especially land-use change and land-use intensification on trace gas fluxes and atmospheric chemistry. Several interrelated Activities are addressing these major objectives.

### Activity 2.1: Biosphere-Atmosphere Trace Gas Exchange in the Tropics: Influence of Land-Use Change (BATGE)

Conveners: R.A. Delmas, M. Keller

Tropical soils and vegetation represent globally significant sources of a broad range of atmospheric gases, including VOCs, CO, N<sub>2</sub>O, NO and CH<sub>4</sub>. Conversion of tropical forests and savannas to agriculture and pasture is presently occurring at very rapid rates, but the impacts of these land-use changes on biogeochemical cycling, trace gas emissions and atmospheric photochemical and transport processes are not well understood.

Several recent studies of tropical land conversions have suggested the importance of land-use change on trace gas fluxes. Available measurements and modelling results indicate that tropical deforestation in humid areas could lead to increased regional levels of O<sub>3</sub> and of mineral acidity in rainfall. Observations show that these changes may already be occurring in some areas. However, the extent to which these results can be considered representative of tropical land conversion in general is not known.

Forest and savanna conversion to agricultural systems may result in major changes in soil organic matter and soil structure. Soil temperature and moisture regimes may change as a result of reduction in evapotranspiration, altered infiltration and reduced shading. Management by fertilisation and irrigation greatly influence nutrient and water budgets. These changes will affect microbial populations and nutrient turnover which, in turn, can alter production and consumption of trace gases by microorganisms. 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 and 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 VOCs and perhaps NH<sub>3</sub>. Ozone and NO<sub>x</sub> 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.

Forest conversions result in spatially heterogeneous surface characteristics with vegetation canopies of varying heights and with patchiness of forested and non-forested areas which, in turn, result in varying surface roughness characteristics. The effects of this variation on the measurement of trace gas exchange in the convective boundary layer and transport into the free troposphere are not well understood, nor is it certain that present knowledge of reaction kinetics is sufficient for atmospheric chemical modelling in heterogeneous environments.

BATGE has been established to address changes in tropical land-atmosphere exchange that result from alterations in soils, canopies and landscapes in response to land-use change.

#### Goals

- Determine the fluxes of trace gases between tropical biomes and the atmosphere.
- Determine the factors that control these fluxes.
- Assess the effects of land-use change, including agricultural expansion and forest harvesting, on the exchange of trace gases.
- Develop the ability to predict the impact on these fluxes of both climatic and land-use change by formulating the exchange of trace gases in terms of ecosystem properties.

#### Implementation Strategy

BATGE involves short- and long term studies of ecosystem and atmospheric processes, carried out in areas of active land-use change in both savanna and humid tropical forest regions. Two Tasks have been initiated and are coordinated by Task coordinators; a third Task is in the planning stage.

##### Task 2.1.1: Measurement Intercomparison

The objectives of the intercomparison are: 1) to provide an intercomparison of trace gas flux measurement techniques and 2) to identify factors that control the ability to scale from chamber measurements to micrometeorological techniques.

A planning workshop for this Task was organised by R.A. Delmas and J.P. Lacaux and was held at the Lamto Research Station, Ivory Coast in February, 1992. Discussion at the workshop focused on measurement techniques and site selection. A final site decision was made in late 1992 and the intercomparison is planned to take place in October-November, 1994, at the Nylsvley Nature Reserve in South Africa.

##### Task 2.1.2: Comparative Studies Network

The objectives of this trace gas network are: 1) to identify sites with long term research on trace gas fluxes in response to land-use change and agricultural intensification in the tropics, thereby identifying gaps in knowledge, 2) to facilitate data comparisons and syntheses and 3) to facilitate interactions among measurement and modelling activities.

This Task seeks to coordinate long term studies within the tropics in order to identify research gaps and improve synthesis and modelling of trace gas fluxes. The emphasis in this task is on sites that are undergoing land-use change or agricultural intensification, such as fertilisation, irrigation or grazing. It is expected that the network synthesis will provide geographic and ecological perspectives on trace gas emissions and the factors that control them, will foster development of global models of trace gas flux and will provide a regional and global context for results from intensive, multidisciplinary field campaigns

outlined under Task 2.1.3. Currently, 10 sites are included in the network. A workshop is being planned for 1995 to synthesise field data and to compare with simulation outputs from several trace gas models. Task 2.1.2 was initiated in late 1991 and research sites in tropical America, Africa, Australia and Hawaii have been established. Efforts to identify additional sites and groups are on-going. Preliminary results appear in the book and special issue of *The Journal of Geophysical Research - Atmospheres* devoted to the First IGAC Scientific Conference (see Bibliography). Interested groups should contact BATGE conveners for inclusion in the network.

##### Task 2.1.3: Multidisciplinary Field Studies

Research on land-use effects on trace gas emissions must address process changes on scales ranging from soil and microorganism, to canopy and ecosystem, to boundary layer and free troposphere. Task 3.1.3 proposes coordinated field studies of trace gas exchange, involving measurements of soil gas fluxes, whole ecosystem trace gas exchange and atmospheric transport and processing. Such studies will be used to test models of trace gas emissions at ecosystem to regional scales, and will allow evaluation of the extent to which landscape heterogeneity controls gas exchange between ecosystems and the troposphere. The field campaigns will include ground, aircraft and satellite components, and will address questions related to the sources, sinks and atmospheric transport of a range of trace gases. One of these campaigns, Experiment for Regional Sources and Sinks of Oxidants (EXPRESSO), is being planned jointly with Activity 2.3. Other campaigns are in early planning stages and will be developed in participation with GCTE and other IGBP or national projects.

##### A. Field Campaigns:

Field campaigns will be carried out in areas subject to rapid land use change. Sites will be selected where some history of management is documented. Ideally, chronosequences of natural environments, managed land, and secondary successive environments will be located on similar substrates. Soil and vegetation emissions will be studied along with canopy exchange, reaction and transport. This will require techniques that operate on a variety of scales. The research will be coordinated with other long term individual investigator studies in the site network.

Changes in soil emissions (including nitric oxide (NO), N<sub>2</sub>O, CH<sub>4</sub>, CO, CO<sub>2</sub>) and their controlling factors will be studied in replicated managed sites, in control forests and in fallow systems. 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. In addition to standard soil measurements, *in situ* isotope studies and closed soil incubations will be used to examine changes in microbial immobilisation and mineralisation of nitrogen. Many of the soil process studies must be carried out through one or more annual cycles in order to understand temporal variability. These studies are expected to precede the tower- and aircraft-based research, and will provide context and constraints for the later phase.

To understand transport of trace gases into and out of a tropical forest canopy, it may be insufficient to monitor only gradients or eddy fluxes. Intermittent large eddies that evacuate deep layers of the canopy may be important and, therefore, 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.

Trace gas instruments for tower operation exist, or soon will, for CO<sub>2</sub>, total hydrocarbons, O<sub>3</sub>, CH<sub>4</sub>, NO, NO<sub>x</sub> and nitrogen dioxide (NO<sub>2</sub>), but are not widely available. Thus, tower-based measurements will be set up for intensive periods during each multi-year study. In addition to the tower-based measurements, leaf chamber measurements of NMHCs, CO<sub>2</sub>, NO<sub>x</sub>, water and CO exchange will be carried out, especially in comparisons of cropping and pasture systems. The minimum set should be expanded when possible to include mixing ratios of PAN, organic nitrates, total reactive nitrogen (NO<sub>y</sub>), formaldehyde (HCHO), hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and aerosol composition. 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 using portable towers placed in different sized patches. Other measurements, including gas concentrations, will supplement these data. Finally, aircraft-based estimation of eddy fluxes of CO<sub>2</sub>, CH<sub>4</sub> and CO, as well as measurements of atmospheric stability and depth of the mixed layer, will be used to integrate over patches and test flux models from other scales.

As noted above, a major field campaign being planned jointly with Activity 2.3 (BIBEX) is the Experiment for Regional Sources and Sinks of Oxidants (EXPRESSO). This investigation of tropical biogeochemistry will take place in the Central African Republic and the Congo with some aircraft missions extending over South Africa. Further information on EXPRESSO is given in the BIBEX section of this Operational Plan. In addition, BATGE scientists are currently involved in planning efforts for biogeochemical studies focused on land-use change in tropical ecosystems in Amazonia in the late 1990s.

### *B. 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 parameterised models will be employed to allow the use of variables acquired from remote sensing and ground-based observations.

Models of soil and ecosystems processes and trace gas fluxes are at an early stage of development. Mechanistic models of factors controlling microbial processes and diffusion of gases through the soil will be developed. At the same time, less detailed models will be developed 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<sub>2</sub>O and CH<sub>4</sub> 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, which include chemistry and biological exchange, then estimate ecosystem-atmosphere exchange, which interact directly with boundary layer chemistry models.

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 that concerned with global chemical transport models, to ensure that models developed interface with global models.

### *C. 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 type by land-use areal extent) and modelling approaches. Either approach requires remote sensing and ground-based data. Remote sensing data are also critical for the description of land surface heterogeneity for use in the boundary layer mixing studies, described earlier. Several remote sensing approaches which may be useful in this study are currently available or are under development. Land-use classifications based on thematic mapper or Système pour l'Observation de la Terre (SPOT) sensor data are crucial for selection of specific field sites, for description of the heterogeneity or patchiness of regions and for measurements of areal extent as bases for extrapolation. While these sensors will easily differentiate broad land-use classes, it will be difficult in many instances to detect differences between certain agricultural systems, degree of degradation or condition of these systems, and stage of succession in forest regeneration. Remote sensing studies must be initiated to examine these detection capabilities.

Experimental radar sensors are being applied to measurements of canopy structure, foliar distribution and vegetation classification. Likewise, high spectral resolution sensors are being tested, and may be used for spectral characterisation 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. Collaboration with investigators involved in on-going remote sensing projects in the tropics will be sought, whenever possible. Remote sensing researchers will be encouraged to consider use of study sites developed for this project.

### *Timetable*

1992	Site selection for intercomparison campaign (Task 2.1.1).
1992-	Network trace gas studies.
1994-1995	Planning activities for coordinated field studies (Task 2.1.3).
1994	Instrument/methods intercomparison campaign at Nylsvley Nature Reserve.
1996-2000	Coordinated field studies (two intensive campaigns) in humid tropics.

## Activity 2.2: Deposition of Biogeochemically Important Trace Species (DEBITS)

Convener: G. Ayers

The deposition of chemical species to the Earth's surface provides a natural sink for atmospheric trace species that influence atmospheric chemistry, while also acting as a source of nutrients for biological systems. However, in regions where the biogeochemical cycles of many species are grossly perturbed by anthropogenic activities, atmospheric deposition can become an equally important source of toxic substances to the biosphere. Both dry and wet deposition pathways must be determined if the biogeochemical cycles are to be understood quantitatively. This is especially so in tropical regions, where current knowledge is very limited and must be expanded if the impacts of regional environmental change on both the regional ecosystems and on global climate are to be assessed properly. This is the rationale behind the creation of DEBITS. The main role of DEBITS is to serve as a coordinating/instigating body, aimed at encouraging existing and new national atmospheric science resources to take on DEBITS-related work.

DEBITS commenced with an experiment based on a network of precipitation chemistry stations covering the South-East Asian region, for which the first planning workshop was held in Singapore in August, 1990. The scope of this Activity has since been expanded to other tropical regions, and sub-committees have been established in South America and in Africa. The long term goal of assessing the importance of dry as well as wet deposition for atmospheric chemistry in all the tropical regions will require on-going development of several additional experiments in these and other regions.

### Goals

- Determine the atmospheric removal rates by dry and wet deposition of biogeochemically important trace species.
- Identify factors that regulate these deposition fluxes.

### Implementation Strategy

DEBITS involves experiments, or Tasks, covering various tropical regions, aimed at producing data on both wet and dry deposition of a range of chemical species containing N, S, P and C, major sea-salt components, as well as species of special interest such as organic acids, organic nitrogen compounds,  $O_3$  and  $H_2O_2$ .

#### Task 2.2.1: Composition and Acidity of Asian Precipitation (CAAP)

Asia is a region of rapid population growth and accelerated industrialisation. The increasing requirement for energy is likely to be produced primarily by combustion of fossil fuels. This results in vastly increased emissions of anthropogenic chemical species into the regional atmosphere. The experience of industrialised Europe and North America demonstrates the consequences of high volumes of the combustion products  $SO_2$  and  $NO_x$ : Increased atmospheric acidity (sulphuric and nitric acids) which can profoundly degrade sensitive soil and groundwater systems, high levels of photochemical

oxidants such as  $O_3$ , which can damage crops and contribute significantly to the greenhouse effect, sulphate aerosols that may modify climate, and marked increases in the deposition of toxic organics and trace metals to continental and near-coastal ecosystems. Given this knowledge and the added fact that little is known currently about the atmospheric chemistry of the Asian region and the sensitivity of the regional environment to changes in atmospheric chemistry, now is the time to gather the data needed for a proper assessment of future prospects. The CAAP Experiment is the initial Task of DEBITS aimed at filling these quite evident and compelling gaps in knowledge.

The initial scientific objective of the CAAP Experiment was to quantify for Asia/Southeast Asia the wet deposition part of the biogeochemical cycles of important nutrient species, emphasising especially the elements sulphur and nitrogen, but including also a range of other compounds. The explicit emphasis on the S and N cycles is a recognition of the importance of these cycles globally. S and N are key elements in the nutrient status of many ecosystems. They are at the heart of the acidic deposition problems currently experienced in certain regions, and there are strong connections between their atmospheric oxidation products, photochemical air pollution and global climate. This rationale is of particular relevance to the Asia/SE Asia region, which currently lacks a significant database on regional S and N cycles, but is the part of the globe with the highest rate of increase in anthropogenic S and N emissions. This lack of data currently precludes any quantitative assessment of potentially adverse environmental consequences of these rapidly increasing emissions.

The CAAP Experiment started in August, 1990 at the First CAAP Workshop held in Singapore. Twenty-three scientists from seventeen countries participated in this planning workshop, which had three main objectives: (1) to stimulate in Asian scientists an awareness of contemporary questions concerning the global atmospheric environment emphasising the likely relevance of these to Asia, (2) to serve as a forum seeking out any unpublished Asian information on atmospheric chemistry and composition, with which to begin addressing these questions, and (3) to formulate a work plan for establishment of a regional experiment aimed at quantifying the flux of important pollutants and trace nutrients from the atmosphere to the Earth's surface in Asia.

The Second CAAP Workshop was held in September, 1992 in Bombay, India, two years after the First CAAP Workshop, to assess the extent to which the plans developed in Singapore had been implemented. It provided a forum for presentation and scientific discussion of several new datasets accrued in the first two years of CAAP and it provided an opportunity for participants to plan future CAAP activities. In addition, the Workshop provided an essential forum for cementing links with relevant activities carried out by other international groups.

Summary documents for the workshops are available from G. Ayers, the Convener of DEBITS. Most of the completed work presented at the workshops will be published in refereed journals.

The broad aims of the CAAP Experiment are to:

- Quantify the tropospheric S and N cycles in the Asia/Oceania region via (a) field measurements for relevant rainwater, gas and aerosol species throughout the region,

with particular emphasis initially on rainwater composition, and (b) development and validation of a range of transport/chemistry models for simulation of S and N emissions, transport, transformation and deposition.

- Produce measured and modelled deposition fluxes of major ionic species for the region in a form appropriate for comparison with critical loads estimates. Via this comparison, to evaluate current and future potential for damage to regional ecosystems caused by acidic atmospheric deposition.

CAAP will not attempt to produce gridded emissions inventories for the region, since this work is already being done by other international groups. However, individual measurement programmes focused on specific components of emissions and specific processes, e.g., biomass burning, will be addressed at all levels of observations within CAAP.

The most significant recent development within DEBITS has been a move to widen the DEBITS effort beyond the initial Asian focus. A South American DEBITS Sub-committee, chaired by P. Artaxo (Brazil), was established in December, 1991, and an African DEBITS Sub-committee was formed by J.-P. Lacaux (France) in August, 1992, to initiate and coordinate DEBITS activities in these tropical regions. Both sub-committees are currently in the planning phase. Emphasis will be placed on cooperation with existing facilities in many countries in these regions in a bilateral or trilateral way, with the ultimate aim of producing regional understanding which is necessary to address atmospheric questions that by their nature transcend national boundaries.

#### Timetable

- |         |  |
|---------|--|
| 1992    | Establishment of African DEBITS Sub-committee in August.                 |
| 1992    | Second CAAP Workshop in Bombay, India in September.                      |
| 1993    | South American DEBITS Sub-Committee Planning Workshop.                   |
| 1994    | African DEBITS Sub-committee Planning Workshop in Ivory Coast, December. |
| 1994 or |  |
| 1995    | Third CAAP Workshop in Stockholm, Sweden.                                |

#### Activity 2.3: Biomass Burning Experiment: Impact on the Atmosphere and Biosphere (BIBEX)

Convener: M.O. Andreae

Biomass burning has only recently been recognised as a major source of important trace gases and aerosol particles. Through burning, the chemical elements in vegetation are cycled back to the atmosphere and to soils in chemical and physical forms and proportions which make biomass burning an important biogeochemical process. Before the advent of humans, fire was ignited naturally by lightning strikes in dry vegetated regions. Today, however, the process is driven almost exclusively by human activity which includes the burning of forested areas to facilitate land clearing, the burning of

harvest debris to maintain cleared land, the extensive burning of natural grasslands and savannas to sustain nomadic agriculture, and the burning of biomass as fuel for heating.

The emissions from biomass burning represent a large perturbation to global atmospheric chemistry, especially in the tropics. Satellite observations have revealed elevated levels of O<sub>3</sub> and CO over vast areas of Central Africa and South America, over the tropical Atlantic, and the Indian Ocean. This is due to biomass burning, which represents a major global source for a number of important gases, including CO<sub>2</sub>, NO, CO and CH<sub>4</sub>, as well as aerosols. The gaseous emissions affect regional O<sub>3</sub> concentrations and the oxidative characteristics of the tropical atmosphere. The aerosols affect regional, and possibly global, radiation budgets by their light-scattering effects and by their influence on cloud microphysical processes.

Fire also has both short and long term effects on trace gas emissions from affected ecosystems which, for instance, in the case of CO<sub>2</sub> and N<sub>2</sub>O, may be more significant than their immediate release during the fire. Fire also alters the long term dynamics of the cycling and storage of elements within terrestrial ecosystems, thereby altering their significance as sources or sinks of various trace gases. Finally, deposition of compounds produced by biomass burning on pristine tropical ecosystems may affect their composition and dynamics.

Due to the paucity and difficulty of measurements in burning regions, and the complexity of the ecosystem and combustion dynamics involved in biomass burning and its subsequent effects, our understanding of trace gas emissions resulting from biomass burning is very limited. The importance of biomass burning is well recognised in IGAC and this Activity, *Biomass Burning Experiment: Impact on the Atmosphere and Biosphere* (BIBEX), was established to address this phenomenon. It is being carried out by a multi-national science team headed by M.O. Andreae of the Max Planck Institute for Chemistry, Germany. It is aimed at quantifying the extent of the temporal and spatial distribution, dynamics, species emissions, and atmospheric consequences of biomass burning.

The first meeting of the BIBEX Coordinating Committee took place in September, 1990, in Chamrousse, France. Additional meetings have been and will be held periodically, often in conjunction with IGAC Symposia or other appropriate scientific meetings. Details can be obtained from the convener. As with all IGAC Activities, BIBEX utilises and builds on existing international programmes with common goals. It has since developed STARE (Southern Tropical Atlantic Regional Experiment) and FIRESCAN (Fire Research Campaign Asia-North) as a BIBEX programme and efforts are underway to carry out the plans for STARE. BIBEX will continue to adopt or initiate new programmes in the future. In its activities, BIBEX focuses on biomass burning in the tropics, but will also consider extratropical fire regions when appropriate. Figure 4 summarises BIBEX efforts as presently envisioned.

#### Goals

- Characterise the production of chemically and radiatively important gases and aerosol species from biomass burning to the global atmosphere.
- Assess the consequences of biomass burning on regional and global atmospheric chemistry and climate.

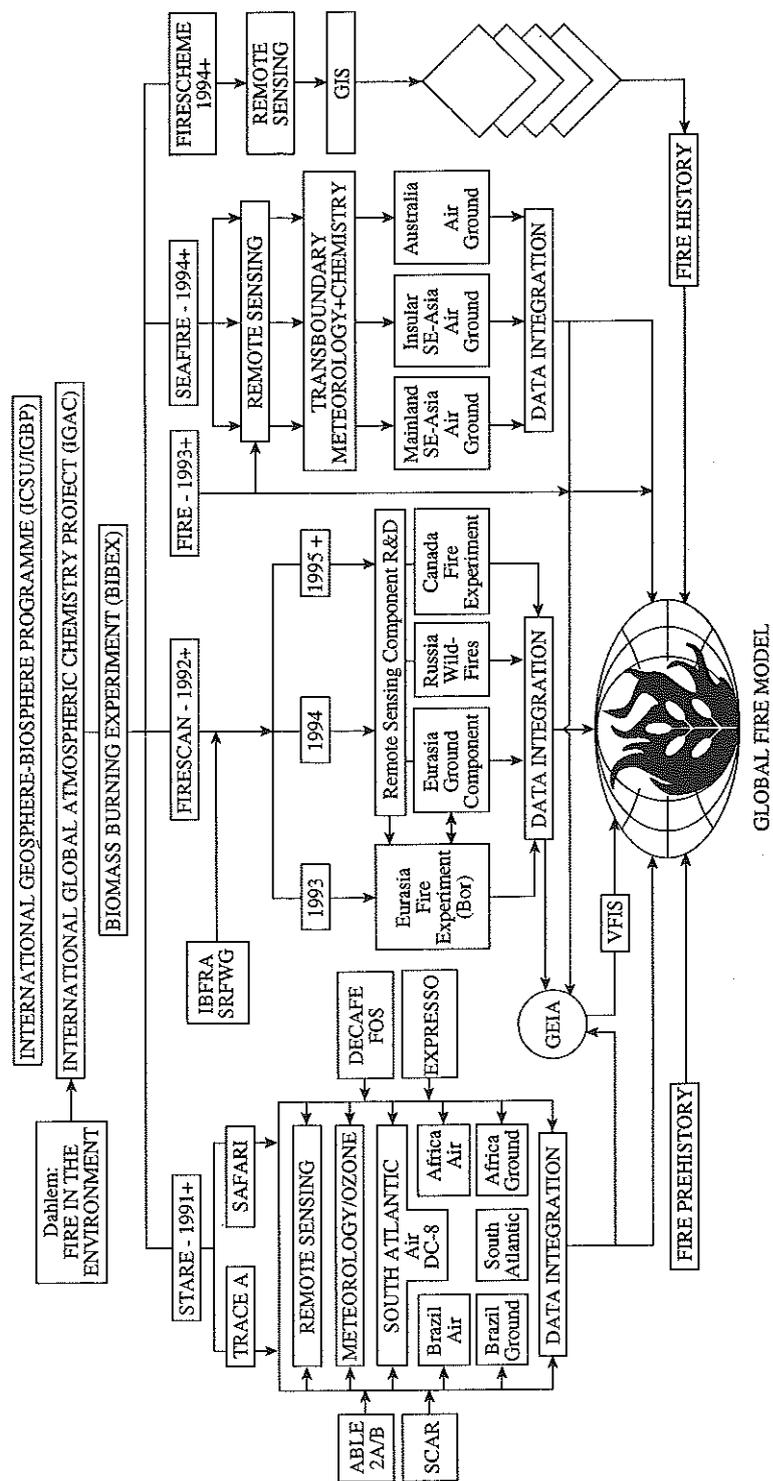


Figure 4. BIBEX organisational chart.

- Determine the short- and long term effects of fire on post-fire exchanges of trace gases between terrestrial ecosystems and the atmosphere.
- Understand the biogeochemical consequences of atmospheric deposition of products of biomass burning.

### Implementation Strategy

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 smouldering fires in various ecosystems, of trace gas emission factors, of the chemistry within biomass plumes and of the impact of biomass burning on ecosystems. The following Tasks have been proposed and developed to address the major gaps in our knowledge on biomass burning:

#### Task 2.3.1: Global Inventories of Biomass Burning

At present, the information available on the spatial and temporal distribution of biomass burning in the tropics is insufficient. Due to 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 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 improvement in our ability to map the geographical distribution and frequency of fires, and will also provide information on their temperatures and spatial extent. They will have to be linked to geographical information systems (GISs) in order to obtain reliable quantitative estimates of fire and emission characteristics.

Emissions to the atmosphere from biomass burning are directly related to the loading characteristics of above-ground biomass. The above-ground carbon loading determines the amount of CO<sub>2</sub> and other carbon compounds emitted to the atmosphere. Distinction must be made between flaming and smouldering phases of burning, as the emissions of combustion products are quite different for both phases. Current estimates of above-ground loadings in forests and savannas are uncertain and preclude the compilation of sufficiently accurate global emissions inventories.

The objectives of this Task are: 1) to construct global inventories of biomass burning, with particular emphasis on establishing spatial and temporal statistics, 2) to forecast future trends in biomass burning, and 3) to quantify the above-ground biomass loadings of diverse ecosystems subjected to biomass burning and their relationship to weather, nutrient status of the soil and land-use patterns (agricultural practices, grazing activities).

Efforts are underway to construct worldwide regional inventories of the areal extent of burning and the quantities of biomass burned both at present and also in the past, as well as the quantities of biomass which potentially can be burned in the relevant terrestrial ecosystems. These inventory data, together with existing and future measurements of the composition and yields of gases and aerosols from burning at representative sites over the globe, are expected to provide the necessary estimates of the contributions of emissions

from biomass burning to the global budgets of each species. They will also provide the basis for development of realistic fire dynamics and combustion chemistry theories and models, which are essential to predict future emissions due to biomass burning.

Remote sensing methods provide important means for compiling geographical statistics of fire frequencies, e.g. the AVHRR (Advanced Very High Resolution Radiometer) sensor carried on board the NOAA series of satellites is suitable for studying fires and vegetation characteristics. A limitation of AVHRR is its spatial resolution (1-4 km). This limitation will be significantly reduced in the future by using sensors such as the *Earth Observing System/Moderate Resolution Imaging Spectrometer* (EOS/MODIS), which has 500 m resolution, and other EOS sensors such as HIRIS (*High Resolution Imaging Spectrometer*) and MISR (*Multi-angle Imaging Spectro-Radiometer*).

Ground-based data compilations are essential complements to remote sensing efforts. Collaboration with FAO (Food and Agriculture Organisation) will be initiated to compile country-by-country biomass burning practices. On-site investigations will be targeted in selected areas (e.g., the savannas of Africa and South America).

Biomass loadings of wet savannas, which are a major global source of biomass burning emissions, will be documented. Models will be developed to relate biomass loadings to land-use types and meteorological variables.

#### Task 2.3.2: Chemical Characterisation of Biomass Burning Emissions and Plume Chemistry

Biomass burning releases large quantities of reactive compounds to the atmosphere, in particular  $\text{NO}_x$ , hydrocarbons and  $\text{CO}$ . Large quantities of soot and organic carbon aerosol are also emitted. Chemical reactions involving  $\text{NO}_x$  and hydrocarbons produce large amounts of  $\text{O}_3$ , consuming the precursors in the process. Aircraft observations of relatively aged plumes from biomass burning have documented an almost total conversion of  $\text{NO}_x$  to less reactive  $\text{NO}_y$  species, and elevated levels of  $\text{O}_3$ . 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 characterisations 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.

The objectives of this Task are: 1) to quantify the gas and aerosol emissions resulting from biomass burning in diverse ecosystems under conditions of flaming and smouldering combustion, 2) 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, and 3) to document and model the reactivity of the chemical species in biomass burning plumes.

This Task will be implemented using several different approaches:

#### (A) Aircraft Sampling:

The recent advances in aircraft instrumentation technology have improved considerably the detection limits and measurement accuracies for many trace gases. The chemical composition of plumes from biomass burning in various environments will be studied through repeated aircraft-based sampling programmes.

Biomass burning plumes are cooled rapidly as they mix with the local atmosphere and are then transported with the prevailing winds. The chemical evolution of a plume can be documented by small aircraft through cross-sections of the plume at successive distances from the burned site. Such studies can provide key information for evaluating the rates of chemical transformations within the plumes. The chemical measurements must be supported by ancillary meteorological measurements and photographs, allowing documentation of the spread of the plume over time.

#### (B) Remote sensing Measurements:

Satellite observations providing a global survey of the composition of biomass burning plumes and their dispersal in the global atmosphere will become available by the middle to late 1990s and will be an important contribution to this task. Global mapping of  $\text{CO}$  and  $\text{O}_3$  columns will be achieved by the *Global Ozone Monitoring Experiment* (GOME) and *Scanning Imaging Absorption Spectrometer for Atmospheric Chartography/Chemistry* (SCIAMACHY) sensor, scheduled for inclusion on the ESA ERS-2 (*European Space Agency Remote Sensing Satellite*) in 1993-94 and/or later launches. Global mapping of  $\text{CO}$  will also be available on the EOS-A platform in the late 1990s, using the MOPPITT (*Measurement of Pollution in The Troposphere*) 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  $\text{CO}$ ,  $\text{O}_3$ ,  $\text{NO}_x$  and  $\text{HNO}_3$ .

#### (C) Combustion Chamber Experiments:

Programmes to measure the products of biomass burning in combustion chambers are currently underway in several laboratories. These chamber experiments provide a unique opportunity for measuring emissions of molecular nitrogen ( $\text{N}_2$ ) and of short-lived trace gases from biomass burning.

#### (D) Modelling:

Photochemical models simulating the chemical evolution of biomass plumes will be developed to interpret the aircraft observations. The plume chemistry can be complicated by heterogeneous reactions involving aerosols. Comparison of model results with observations will identify the gaps in the current understanding of photochemical processes in biomass burning plumes. A programme of laboratory kinetic studies will accompany this activity.

Chemical models will also be developed to interpret the observations from combustion chambers and to relate them to easily measurable variables, such as biomass composition, biomass flammability, oxygen availability and flame temperatures found in the field.

### 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, microclimate 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 fires. In contrast, biogenic emissions of NMHCs 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. Consequently, biological productivity in burned sites may eventually become limited by low nitrogen availability, and the storage of carbon and fluxes of N and C containing gases may be reduced in the long term.

The objectives of this Task are: 1) to determine the short- and long term effects of fire on post-fire exchanges of trace gases between terrestrial ecosystems and the atmosphere, and 2) to determine the long term effects of fire on carbon and nitrogen storage and turnover.

The effects of biomass burning on terrestrial ecosystems will be assessed in several key areas that include the tropical forests and pastures, savannas and boreal forests. Long term post-fire sampling of well characterised sites that differ in fire history will be based on the pattern of nutrient dynamics at particular times post-fire. Field experiments and models will be used to determine, integrate and extend knowledge of post-fire trace gas exchanges.

In the longer term, a set of experimentally burned plots will be established in tropical savanna and cleared forest regions and the long term effects of fire on the dynamics of C, N and other nutrient elements, as well as vegetation composition and flammability, will be studied.

### Task 2.3.4: Ecological Effects of Deposition of Biomass Burning Products

While the impact of atmospheric O<sub>3</sub> on vegetation processes has received attention in the temperate zone, the potential for similar effects has not been studied in the tropics. Levels of O<sub>3</sub> 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. In the longer term, deposition of anthropogenically fixed nitrogen and other products of biomass burning could alter biogeochemical dynamics in tropical regions. The objective of this Task is to understand the biogeochemical consequences of atmospheric deposition resulting from biomass burning.

Information from measurements of plume dispersion and regional deposition will be used to establish studies of the effects of burning-derived oxidants on pristine tropical

ecosystems and agricultural yields. A sampling network will be established across forest-savanna boundaries to address the magnitude of burning-induced transport across biome boundaries.

### BIBEX Research Initiatives:

The objectives of BIBEX Tasks have been and will continue to be addressed through a variety of interrelated research projects (see Figure 5).

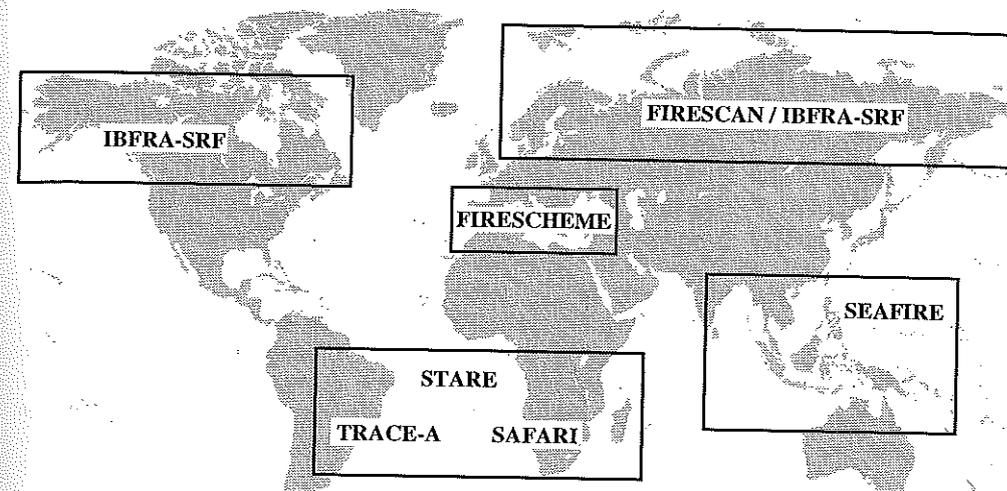


Figure 5. BIBEX regional fire research campaigns in the decade 1990 - 2000.

### *Southern Tropical Atlantic Regional Experiment (STARE)*

STARE is an aircraft- and ground-based measurement programme that was initiated in May, 1990, by an ad hoc committee of scientists from Europe, Brazil and the United States, to investigate the sources of trace gases, their atmospheric transport, and the chemical processes in the atmosphere which lead to elevated levels of O<sub>3</sub>, CO, and other trace gases over the southern tropical Atlantic Ocean. This project was subsequently incorporated into BIBEX at the first meeting of the BIBEX Coordinating Committee in September, 1990, in Chamrousse, France. Three field campaigns have been conducted under STARE.

*Transport and Atmospheric Chemistry Near the Equator - Atlantic (TRACE-A)* covered the western portion of the STARE region. The main objective of TRACE-A, conducted in August-October, 1992, was to investigate the chemical composition, transport and chemistry of the atmosphere over the southern tropical Atlantic Ocean and the adjacent South American continent. The research focused on understanding the seasonal enhancement in O<sub>3</sub> that has been observed over the tropical Atlantic Ocean and that is

most likely caused by widespread burning of vegetation (forest conversion, savanna fires) in South America and Southern Africa. It also investigated the potential contribution of land-use changes on both continents to the observed levels of other trace gases such as CH<sub>4</sub> and N<sub>2</sub>O. TRACE-A activities involved chemical and meteorological measurements in Brazil (ground and aircraft component, jointly by Brazilian and American research groups), ozonesonde launches in the Congo Republic and on Ascension Island, and an aircraft component (NASA DC-8) spanning the South Atlantic. This was coordinated with Brazilian and African aircraft components.

*Southern African Fire-Atmospheric Research Initiative (SAFARI-92)* covered primarily the African portion of the STARE region. The research objectives of SAFARI were similar to those of TRACE-A, but also included the investigation of the ecological role of fire in African savannas and the study of trace gas emissions from burned soils. SAFARI-92 involved ground and airborne chemical and meteorological measurements in the source or near-source regions of South Africa, and was carried out primarily as a cooperative international campaign. It also involved international participation in measuring emissions from savanna fires and other biomass burning as well as remote sensing of fires by satellites. The source related measurements were complemented by regional airborne and ground-based studies on pyrogenic pollutant distribution and transport. A TRACE-A workshop took place in May of 1993 in the United States. The first SAFARI data workshop was held in June, 1993 at Stellenbosch, South Africa.

During May, 1994 a follow-up activity (*SAFARI-94: SAFARI Without Fire*) took place. Measurements of O<sub>3</sub>, aerosols and CO were made over southern Africa at a time of the year when fire activity is low. This experiment was conducted as a collaboration between South African and German researchers, and will be followed up with a series of flight experiments which will characterise the seasonal change in atmospheric composition over southern Africa.

It is expected that BIBEX will continue research in Africa, with emphasis on more northerly and easterly burning. An ongoing activity in southern Africa appears crucial in order to assess the effects that the drought has played in changing biomass burning patterns during the 1992 experiment. Transport of smoke from southern Africa both towards the Atlantic and the Indian oceans will be investigated. Burning in Madagascar will be investigated, as the fires there may represent an important source of pyrogenic emissions for the Indian Ocean region.

#### *Fire Research Campaign Asia--North (FIRESKAN)*

FIRESKAN is an effort of institutions and individual scientists working jointly under the umbrella of BIBEX and the International Boreal Forest Research Association (IBFRA). The first field phase, a large fire experiment (The Bor Forest Island Fire Experiment), was conducted in the north of the Krasnoyarsk Region of Russia, in July, 1993. The aim of the experiment was to investigate a high-intensity stand-replacement fire in a boreal coniferous forest using research methodologies developed in the East and in the West. Research institutions from all boreal countries were represented in the experiment. The experimental site will be re-examined in 1994. In 1995 a large stand-replacement fire experiment is planned in Canada.

#### *Fire Information Systems Research in the Ecology, Socio-Culture and History of the Mediterranean Environment (FIREScheme)*

FIREScheme is the suggested working title of a proposed Pan-Mediterranean research project. The founding meeting will be in November, 1995 in connection with the Second International Conference on Forest Fire Research at Coimbra, Portugal. The aim of this regional project is to develop Fire Information Systems which include the:

- History/prehistory of fire ecology in the Mediterranean Basin
- History of Mediterranean vegetation and vegetation treatment; potential natural vegetation
- Socio-economical, cultural historical and political background of fires
- Present state of vegetation as related to, e.g., wildfire hazard, consequences of fire (i.e., stabilising and destabilising effects)

FIREScheme will be a research activity coordinated with ongoing and planned regional fire research programmes under the umbrella of IGAC, GCTE, IUFRO and IBFRA.

#### *South East Asia Fire Experiment (SEAFIRE)*

In the second half of the 1990's BIBEX research activities will gradually move eastward from Africa and southward from boreal Eurasia into tropical continental and insular South East Asia. SEAFIRE will be designed to investigate this highly complex and diverse fire theatre of SE-Asia (slash-and-burn agriculture, other forest conversion fires, regularly occurring fires in seasonally dry deciduous and semideciduous forests on mainland SE-Asia, regularly occurring fires in the submontane and montane coniferous (pine) forests of insular and mainland South Asia, agricultural residue burning, mainly rice straw, throughout the whole region). Objectives and technical procedures of the campaign will be discussed and planned during a BIBEX Coordinating Committee meeting in association with the Second IGAC Scientific Conference in Japan in September, 1994. It is envisaged to have a subsequent local focus meeting in Samarinda, East Kalimantan, in mid-January, 1995.

#### *EXPeriment for REgional Sources and Sinks of Oxidants (EXPRESSO):*

Tropical biomes are the most dynamic yet most poorly understood on Earth. Tropical forests are being cleared at a rate of about 1% per year. Biomass burning, ubiquitous in African savannas, exerts a dominant influence on ecology and atmospheric chemistry. Biogenic fluxes of reactive or radiatively active trace gases are concentrated in tropical land areas and are strongly influenced by land-use change and biomass burning. Future human population increase is projected to be higher in tropical areas than in any other region and will accelerate changes in land-use. The interplay of global change, climate change, biogeochemical processes, population increases and resource limitations are likely to affect more people in the tropics than anywhere else.

Plans are being developed for an international experiment, EXPRESSO, to investigate tropical biogeochemistry. EXPRESSO will take place in the Central African Republic (CAR) and the Congo with some aircraft missions extending over South Africa. The goals of EXPRESSO are: 1) to better quantify the exchange fluxes of reactive trace gases and aerosols between the biosphere and the atmosphere in the tropics; 2) to analyse chemical

interactions between the savanna and the tropical forest; 3) to isolate the roles of photochemical and meteorological processes; 4) to characterise the effects of ecological processes on trace gas fluxes; 5) to assess the impact of these tropical processes and land-use change on the global atmosphere.

Two field intensives are planned for a 1996-1997 time frame. One is planned for the wet season of the CAR savanna, and one for the dry, biomass burning season. Preparations to allow the future field campaigns to occur have already begun. These preparations include instrument development efforts, laboratory studies to elucidate biological processes which control trace gas emissions from soils and vegetation, and chemical mechanistic and kinetic studies to determine the fates of atmospheric constituents. The field campaign will include: 1) ground based field studies in the savanna and in the tropical forest to determine the fluxes of important carbon and nitrogen containing trace gases, 2) aircraft studies to define the chemical and meteorological climatology of the study region, 3) remote sensing studies to define the location and extent of biomass burning and to aid in vegetation characterisation, and 4) modelling efforts for a hierarchy of models which operate on scales ranging from micro-scale processes which occur in soil and leaves, to coupled regional/global models of atmospheric chemistry and dynamics.

#### *Vegetation-Fire Information Engine (Biomass Burning Information System):*

This project came out of the discussions at the Dahlem Conference on the role of fires (Spring, 1992). A system is to be designed which combines fire detection by remote sensing with a geographic information system. This approach will be used to interpret data from remote sensing and derive parameters of interest for atmospheric chemistry, fire ecology and land-use planning.

#### **Timetable**

- 1990-1996 Construction of a global land cover map using existing data from remote sensors such as NDVI (Normalised Difference Vegetation), SPOT, SMMR (Scanning Multifrequency Microwave Radiometer) and TM (Thematic Mapper).
- 1990-1995 Compilation of existing information on patterns of oxidant distribution in the tropical troposphere and the deposition of other species derived from biomass burning.
- 1990-1995 Combustion chamber experiments to characterise biomass burning products under different combustion conditions, and for different biomass types.
- 1990-1996 Aircraft measurements of the composition of biomass burning plumes, with focus on documenting the chemical evolution of individual plumes.
- 1990-1996 Field studies of biomass burning plumes, focusing on detailed characteristics of the plume composition.
- 1991-1995 Development of photochemical models to interpret the chemical evolution of the plumes observed from aircraft.

- 1992-1996 Measurements of short- and long term exchanges of trace gases following fire and their regulation in a range of ecosystems.
- 1991-1998 Select and establish long term experimental sites; initiate and maintain burning treatments.
- 1991-1998 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.
- 1996-1998 Initiation of measurements of oxidant effects on productivity and yields of tropical crops.
- 1996-1998 Development of an experimental programme to study the effects of N and acidic deposition on the functioning of tropical ecosystems.
- 1994-1998 Design and execution of coordinated studies to evaluate models.
- 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.

#### **Activity 2.4: Rice Cultivation and Trace Gas Exchange (RICE)**

Convener: H.-U. Neue, R.L. Sass

Wetland rice cultivation is considered to be among the most important sources of atmospheric CH<sub>4</sub>, on a par with natural wetlands. Although atmospheric CH<sub>4</sub> concentration has been increasing at rates up to 1% per year, it is an open question as to how much of the increase is due to increased emissions from flooded rice fields or should be attributed to other sources or processes. It is projected that to meet the demand of increased population, the world's annual rough rice production must increase 65% over the next three decades, or an increase of 1.7% per year. In south Asia, rice production will need to be doubled by the year 2020. Because arable land is highly limited in major rice growing countries, the increased production has to be achieved mainly by intensifying cropping (i.e., two or three crops per year) rather than by expanding the area of rice cultivation. The irrigated rice areas will continue to dominate production. Irrigated rice land now comprises about half the total harvested area but contributes more than two thirds of the total grain production. With present agronomic practices, this will lead to increased CH<sub>4</sub> emissions.

Methane emission from agricultural wetlands is a direct result of soil bacterial activity. It is influenced by temperature, water regime, root exudates, organic residues, plant physiology and soil physical, chemical and biological properties. It is the net result of opposing bacterial processes, production and consumption or oxidation, that occur in different micro-environments; it is also the net result of two opposing plant-biophysical processes, transport of oxygen to the rhizosphere and transport of CH<sub>4</sub> out of the rhizosphere, inside the plant. These processes may well show independent responses to

the same environmental forcing function. Thus, emission measurements must be obtained in conjunction with and correlated with measurements of the opposing processes.

For other trace gases, there is insufficient evidence to indicate that flooded rice fields constitute a greater source than other land-use systems, but increased rice production can be expected to increase their emission also. It might well be that a consequence of changing rice management practices to reduce CH<sub>4</sub> emissions would be to increase emissions of other gases, such as N<sub>2</sub>O.

Recognising the important contribution of CH<sub>4</sub> emissions from rice cultivation to the global CH<sub>4</sub> budget and the consequence on global climate change, IGAC established this Activity (formerly 2.5, now 2.4), *Rice Cultivation and Trace Gas Exchange (RICE)* under the *Tropical Focus* in 1990. The aims are to determine how much CH<sub>4</sub> and other climatically relevant trace species are emitted from rice fields now, to predict how much will be emitted in the future given no change in present agronomic practices, and to develop new management practices which will reduce emissions, yet will meet the need for increased rice production. Much of the research currently undertaken or planned under this Activity requires an integrated and interdisciplinary approach as well as international cooperation involving scientists from rice-producing countries.

#### Goals

- Determine if rice cultivation is an important cause for the increase in atmospheric concentration of CH<sub>4</sub> and other trace gases.
- Understand the causes of the variability in CH<sub>4</sub> emission from rice cultivation from region to region and over time.
- Identify management practices for rice cultivation in the future that will stabilise or reduce the emission of CH<sub>4</sub> as grain production is increased to meet the demands of an expanding world population.

#### Implementation Strategy

The RICE Coordinating Committee first convened in 1990 and defined three tasks to meet the goals: Establish several sites in different, representative rice-cultural systems where core investigations would be conducted to determine the magnitude of the CH<sub>4</sub> emission and the interaction of CH<sub>4</sub> production, consumption and transport processes in the field; establish a number of ancillary field and laboratory investigations to improve measurement techniques and to determine the effects of soil, plant and management factors; develop empirical, process and predictive models to coordinate, direct and integrate the trace gas emission studies.

The committee also agreed to continue to develop a research plan and to choose sites in Asia and help to identify local scientists to collaborate with, particularly with respect to locating funding and preparing proposals. This Activity has been carried out successfully to a certain extent by some members of the committee working independently, and experimental results relating to CH<sub>4</sub> emissions from rice fields have been obtained from several Asian countries.

A second meeting of the Coordinating Committee was held in August, 1991, in San Francisco to define more specific goals and discuss possible mechanisms for collaboration with scientists from major rice-growing regions. A plan to train and involve Asian students and scientists in the studies was recommended.

The current RICE research activities are organised around four major tasks:

#### Task 2.4.1: Survey of CH<sub>4</sub> Exchange in Different Agricultural Management Regimes within the Major Rice Growing Regions of the World

The objectives of this Task are: 1) to establish uniform methods of measurement for the field determination of the emission of CH<sub>4</sub> and other trace gases and develop new and improved measurement technologies, and 2) to accurately assess and compare the daily, seasonal and annual CH<sub>4</sub> emission from rice cultivation at representative sites.

In 1989, almost all of our knowledge of emission from flooded rice fields came from a few investigations in the U.S. (California), Spain and Italy employing static flux chamber measurements, backed up by some isotopic evidence involving <sup>13</sup>C and <sup>2</sup>H. Today data have been collected in a variety of locations, including China, India, Indonesia, Japan, Philippines, Thailand and the U.S. (California, Louisiana, Texas). Progress in these studies was reviewed by various participants in the CH<sub>4</sub> and N<sub>2</sub>O Workshop held in conjunction with the RICE Coordinating Committee meeting in Tsukuba, Japan in March, 1992, and again in March of 1994.

Static chambers have continued to be the main measurement tools for the study of many of the process questions raised (i.e., fertiliser practices, management practices, comparisons between cultivars). A need remains for corroborative measurements which integrate over larger space and time scales and which do not disturb the natural environment. Micrometeorological measurements represent one such alternative, when implemented with sufficiently sensitive gas sensors which are now becoming available. There are great expectations for eddy-correlation techniques employing tunable diode or gas (He-Ne) lasers. Field-scale emission values obtained with these systems will provide comparisons with chamber measurements and can provide additional data on water vapour loss and CO<sub>2</sub> uptake. A comparison of CH<sub>4</sub> fluxes in rice fields by micrometeorological techniques based on a tunable diode laser system and the closed chamber technique is in progress.

To determine clearly the detailed patterns of CH<sub>4</sub> emission, new measurements have been made on daily and seasonal time scales. For the proper interpretation of the data obtained, CH<sub>4</sub> emission studies at some locations were accompanied by measurements of air, water and soil temperatures; soil Eh; flooding intervals; water depth and additions; soil pore-water gas concentrations; fertilisation schedule; soil chemical, physical and biological parameters; above and below-ground biomass; and CH<sub>4</sub> production levels.

#### Task 2.4.2: Process Level Studies on the Regulation of CH<sub>4</sub> Emission from Rice Fields

This Task will be implemented in three components:

##### Task 2.4.2.1: Effects of Agricultural Practices and Soil Properties on Trace Gas Emission from Paddy Soils

**Background:** Differences in agricultural practices can have major effects on annual CH<sub>4</sub> emissions. Application of rice straw significantly increases CH<sub>4</sub> emission rates. The effects of compost application on CH<sub>4</sub> emission have been found to be negligible at low amounts but to enhance emission strongly at high amounts. Tillage operations vary according to water availability, soil texture, topography, rice culture and mechanical resources available. Hand and animal powered tillage are still common in most Asian countries and wet tillage is the preferred land preparation method, resulting in earlier seasonal anoxic conditions than those found in soils that have better drainage characteristics. Significant variations in CH<sub>4</sub> emissions have been observed under different water management treatments. Both fertilisation practices and water management affect trace gas emissions; consequently flux measurements need to be conducted in areas that represent the spectrum of these agronomic practices around the world.

The role of soil differences in CH<sub>4</sub> emission from rice fields is open to question. A study in Japan found that there was no significant difference among nine Japanese rice soils, whereas a study in Texas reported a three-fold emission difference between rice fields on different soil types, even though they were treated similarly and were in close proximity. Another study found that 40% of tropical rice soils have at least 45% clay. Soils with such high clay content have a poor structure and are hard when dry. Soils with a greater proportion of sand will have different water movement characteristics and may have different seasonal CH<sub>4</sub> emission characteristics

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

**Implementation:** It is proposed to examine the effects of agronomic practice and site on trace gas production and emission. This is being done on several sites around the world.

##### Task 2.4.2.2: Methane Oxidation Processes and Transport of Trace Gases

**Background:** The emission pathways of CH<sub>4</sub> generated in flooded rice soils are: Diffusion into the floodwater, loss through ebullition and transport through the aerenchyma tissue of rice plants. Transport through the rice plant is currently thought to be the major pathway. From the few data available it appears that over 90% of the CH<sub>4</sub> emitted from flooded rice fields is transported via the plant into the atmosphere. The amount of CH<sub>4</sub> emitted to the atmosphere is also controlled by the oxidation state at the root surface and in the upper few millimetres of the soil.

**Objectives:** To determine the effects of oxidation processes on the emission of CH<sub>4</sub> and other trace gases from flooded rice fields, and to determine the role of plant transport anatomy in the emission of CH<sub>4</sub> and other trace gases from flooded rice fields.

**Implementation:** The rates of CH<sub>4</sub> and other trace gas emission from flooded fields have been determined in the presence and absence of plants. Different rice varieties and different soils have been studied. Both cultivar difference and soil type affect CH<sub>4</sub> emission levels. Trace gas emissions in experiments where plants are separated from the water surface, and gas bubbles collected separately will distinguish efflux via plants, ebullition, or diffusion. Experiments will be performed at different times of plant development, and will be correlated with anatomical studies on aerenchyma development in the root and the shoot. Oxygen transport will be quantified. Experiments will be performed mainly in the field.

Currently, the following techniques are available to study oxidation processes in rice fields:

- Mass balance of produced and emitted trace gases.
- Stable isotopic methods to measure the isotopic fractionation that occurs during oxidation and reduction.
- Methane oxidation potentials (by laboratory measurements).

Efforts are underway to:

- Develop methods to quantify CH<sub>4</sub> oxidation in the field;
- Study the effects of field variables (e.g., nitrogen, organic carbon, etc.) on CH<sub>4</sub> oxidation;
- Integrate the results with field flux measurement programmes.

##### Task 2.4.2.3: The Influence of Different Cultivars and Sources of Organic Matter on Trace Gas Production and Emission from Flooded Rice Fields

**Background:** The production of trace gases in flooded rice fields is driven by organic matter which is generated by living plants (e.g., exudates, roots), senescent rice plants and the biotic community in the flood water. The degree to which these various sources can be rapidly oxidised follows the pattern of: (living things) > (organic matter produced photosynthetically in the water column) > (senescent plant material), and is highly dependent on the structures and functions of the associated microbial community.

**Objectives:** To assess the influences of rice cultivars and various sources of organic matter on trace gas production and emission from flooded rice fields, and to evaluate the origin of CH<sub>4</sub>-carbon as predicated on the variety of rice, soil characteristics and propagation strategies, i.e., depth and structure of the flood water community.

**Implementation:** 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 2.4.3: Empirical, Process and Predictive Models of CH<sub>4</sub> and other Trace Gas Emissions from Rice Fields

The objectives of this Task are to provide a retrospective analysis of the role of rice production on increasing atmospheric concentrations of CH<sub>4</sub> and other trace gases, to provide direction, integration and coordination of field research activities, and to predict the influence on trace gas exchange of environmental, physiological and agronomic changes that may occur in rice production.

Three different sets of models concerning the exchange of CH<sub>4</sub> and other trace gases from flooded rice fields will be developed. These will include:

- Model 1: An empirical model to provide a retrospective examination of the role of rice production in increasing atmospheric CH<sub>4</sub> and N<sub>2</sub>O concentrations;
- Model 2: Process models to assist in understanding the complex processes of trace gas production, CH<sub>4</sub> oxidation, N<sub>2</sub>O reduction and gas transport which control net gas emission or uptake in the system;
- Model 3: A global predictive model to predict the influence on gas exchange of environmental, physiological and agronomic changes that may occur in rice cultivation.

#### Task 2.4.4: Cooperative Training Effort between Scientists of Initiating Countries and Scientists from Core Site Countries

The objective of this Task is to promote continued research cooperation between participating countries. The Coordinating Committee plans to meet every six months, preferably in countries where rice agriculture is important and where data need to be collected. Members of the Asian scientific community and other developing country scientists will be invited to attend the meetings either as guests or as new members. Joint research projects with scientists from major Asian rice growing regions and cooperative training efforts would be further facilitated through the proposed establishment of a Rice Research Center discussed below.

Following the third RICE meeting in Tsukuba, Japan, in March 1992, a proposal to establish a Rice Research Center has been prepared and submitted to funding agencies for support. The main goals of the Center would be to:

- Identify, facilitate and cooperate in initiating joint research projects investigating trace gas emissions from rice cultivation and mitigation of these emissions while sustaining rice productivity; field research will be primarily in major Asian growing regions;
- Assist in the development of training opportunities for research scientists from major Asian rice growing regions who are interested in establishing programmes to study CH<sub>4</sub> emissions from rice cultivation in their country;

- Conduct forums for information exchange which would bring together scientists working in this area from around the world to discuss recent findings with an emphasis on participation of scientists from South, East and Southeast Asian research centres; and
- Gather, organise and disseminate information and data on the current status of research on the effects of CH<sub>4</sub> and other atmospheric trace gases emitted from rice fields.

An Asian office associated with the centre would also be established.

#### Timetable

1992	Third Meeting of the RICE Coordinating Committee in Tsukuba, Japan, in March.
1993	Fourth Meeting of the RICE Coordinating Committee in Eilat, Israel in April.
1993	Field investigation of the relationship of CH <sub>4</sub> production/oxidation and N <sub>2</sub> O formation.
1993-1995	Field and laboratory experiments on the effect of organic amendments, water regimes and rice varieties on CH <sub>4</sub> emission.
1993-1998	Field measurements of CH <sub>4</sub> emission at several sites in Asia representing irrigated rice, rainfed rice and deepwater rice (to be conducted by IRRI (International Rice Research Institute) in collaboration with National Rice Research Institutions in China, India, Indonesia, Philippines and Thailand).
1994	Fifth Meeting of the RICE Coordinating Committee at the International Rice Research Institute (IRRI) in the Philippines and in Tsukuba, Japan, in March.
1994-1998	Development of mitigation technologies.

#### Focus 3: The Role of Polar Regions in Changing Atmospheric Composition

The overall objectives of IGAC Focus 3 are to understand the role of polar tropospheric chemistry in global change, to establish the relationship between atmospheric chemical composition and that of glacier snow and ice, and to document present and planned studies of the polar troposphere and of snow chemistry relevant to global change. The Arctic and Antarctic play an important role in global atmospheric chemistry and climate. For example, they are major players in the global climate feedback system, and are the main regions where anthropogenically-induced O<sub>3</sub> depletion occurs, increasing ultraviolet radiation at the Earth's surface. At very high latitudes, the cold polar regions have a unique one-day/one-night per year light regime, and they possess ice sheets and glaciers whose chemical composition can be used to recover historical records of the Earth's atmospheric composition. Contrasts between the two polar regions help us to better

understand the chemical processes that influence climate. In 1993, the two initial Activities in this Focus (Polar Atmospheric Chemistry, PAC and the Polar Air-Snow Experiment, PASE) were merged into a single comprehensive Activity.

### Activity 3.1: Polar Atmospheric and Snow Chemistry (PASC)

Conveners: L.A. Barrie, R.J. Delmas

Many of the underlying processes and the effects of human activities on the sensitive polar regions are still largely unexplored. In order to assess the impact of anthropogenic activities on polar habitats and climate, it is necessary to study the current spatial and seasonal distributions, the chemical-meteorological origins, and the chemical transformations of key constituents in air and precipitation of the polar troposphere. In addition, chemicals trapped in polar glaciers offer priceless clues to global atmospheric chemistry and other Earth processes (e.g., volcanic activity, forest fires, natural sulphur emissions, wind blown dust) dating back hundreds of thousands of years. The data obtained from deep ice core analysis already have provided extremely useful information for a better understanding of the atmospheric system and of the changing status of the global environment. The processes of atmosphere-to-glacier chemical exchange and of preservation of chemical signatures in glacial ice require a knowledge of glaciers, of chemical reactions in the surface snow layer, of ventilation of surface snow by air forced by wind and pressure fluctuations and, finally, of the processes of conversion of snow to firn (ice with interconnected air inclusions) to glacial ice containing air trapped in bubbles. Furthermore, the firn holds a vast reservoir of air that has ages and chemical composition covering the last two decades.

#### Goals

- Understand the role of tropospheric chemistry of the polar regions in global change.
- Establish the relationship between atmospheric chemical composition and that of glacial snow and ice in the polar regions.
- Document present and planned studies of the polar troposphere and of snow chemistry relevant to global change.
- Identify knowledge gaps in polar atmospheric and snow chemistry and encourage coordinated efforts to fill those that cannot be addressed by individual studies.

#### Implementation Strategy

Several Tasks built on existing programmes are currently underway in order to obtain a better understanding of the factors that shape the physical and chemical properties of the polar atmosphere and precipitation. Scientists from many different countries have developed experiments at various Arctic and Antarctic sites. However, many of them are not coordinated. PASC aims to coordinate comprehensive international studies at key places, and to reinforce the links between the various science teams involved in these studies.

#### Task 3.1.1: Arctic Sunrise Experiments

Studies conducted during the late 1980's revealed the uniqueness of the Canadian observational station at Alert, Northwest Territories for studying chemical and physical processes in the northern polar troposphere around the time of Arctic sunrise. In this cold environment, chemical reactions involving sunlight are much slower than they are further south. Thus, the abundance of photochemically reactive compounds in the atmosphere is high prior to sunrise. Between complete dark in February and complete light in April, a number of chemical changes in the lower troposphere take place, the most spectacular being the destruction of lower tropospheric O<sub>3</sub> accompanied by production of filterable bromine (Br). This Br is likely of marine origin, although its production may involve anthropogenic compounds. Other changes include a shift in the fraction of total sulphur in its end oxidation state (VI) from 20% to 90% and a rise in MSA of marine biogenic origin.

The objectives of this Task are: 1) to investigate night-time chemical and physical reactions in the Arctic troposphere and their impact on northern hemispheric oxidant formation, and 2) to understand better the role of marine-derived halogens and heterogeneous reactions in lower tropospheric O<sub>3</sub> destruction at polar sunrise.

The first field campaign in this series, *Polar Sunrise Experiment 1992*, took place between January and April of 1992. It involved several levels of intensification of existing baseline observational activities. The first was a considerably enhanced long term measurement programme during the period January 18 to April 20, 1992. The second was two intensive efforts of several weeks' duration; a dark-period one (January 18 to February 15) and a light-period one (April 1 to April 20). The dark period intensive constituted the first detailed characterisation of lower Arctic tropospheric composition in the dark that had ever been made. The light period intensive involved a ground-level measurement effort and the use of a Canadian research aircraft to provide vertical profile information. In addition, it took advantage of the Canadian Defense Research Establishment (DRE) Ice Camp, 200 km to the northwest of Alert, to make some surface observations of air composition at the surface of the Arctic Ocean. During both the dark and light period intensives unique, new observations with a sophisticated differential optical absorption spectrometer (DOAS) by German scientists, together with contributions from research groups in Sweden and Japan, complemented observations of a large contingent of Canadian scientists. Collaboration with two groups of U.S. scientists in the ground-based observations was also involved.

Three Arctic tropospheric chemistry studies are to be conducted during 1994 to study O<sub>3</sub> depletion chemistry further. First was *Polar Sunrise 1994*, a Canadian effort on an ice floe near the North Pole in April; second, a European study at Ny Ålesund, Spitsbergen; and third, a joint German/Russian aircraft study of the Arctic in April and in summer. Subsequent studies of northern hemispheric oxidant chemistry and the biogeochemical cycling of sulphur, halogens and hydrocarbons are planned for 1997 or 1998 in parallel with IGAC Activity 1.1 (NARE).

#### Task 3.1.2: Arctic Gas and Aerosol Sampling Programme (AGASP)

Over the past two decades, NOAA has pioneered research in the Arctic atmosphere through operation of a research and baseline monitoring station at Barrow, Alaska, and

through WP-3D deep Arctic expeditionary aircraft research projects including the Arctic Gas and Aerosol Sampling Programmes (AGASP-I, -II, -III and -IV in 1983, 1986, 1989 and 1992, respectively). AGASP-IV was conducted as part of IGAC's former PAC Activity and in conjunction with the Arctic Leads Dynamics Experiment (LEADEX).

The objectives of AGASP-IV/LEADEX were: 1) to define the spatial distribution of pollution in the Arctic troposphere in spring, and 2) to study the effect of open water (leads) on tropospheric composition.

During AGASP-IV/LEADEX, a NOAA WP-3D flew 10 research flights over the Arctic ice studying: Arctic Haze, gas and aerosol chemistry, energy fluxes from leads, and energy transfer to the ice surface from winds. Three of the WP-3D flights were tied to the LEADEX ice camp, one to the NOAA baseline station at Barrow, and one flight had a formation intercomparison component with a Russian AN-26, which was part of the Russian component of AGASP-IV. The balance of the flights was Arctic Haze related. The combined AGASP-IV and LEADEX programmes involved 120 scientists from seven countries (the U.S., Canada, Russia, Norway, Germany, Denmark and Finland), one ice station, seven aircraft, and covered the Arctic from the New Siberian Islands, Russia to Barter Island, Alaska. The Canadian Atmospheric Environment Service operated the complementary *Polar Sunrise Experiment 1992* out of Alert over the same period.

Analyses of the data from these experiments will continue through 1995. No further field campaigns in the AGASP series are being planned currently.

#### Task 3.1.3: Chemistry of the South Polar Troposphere and Snow

The Antarctic environment is generally regarded as the most pristine on Earth. Ironically, the increasingly dramatic reductions in O<sub>3</sub> concentrations in the lower Antarctic stratosphere observed during austral spring over the last decade -- the so called "Ozone Hole" -- indicate that the southern polar atmosphere has been seriously perturbed by human activities. Projects underway in this Task seek to improve understanding of the effects of this phenomenon on the chemistry of the underlying troposphere and ice sheet.

##### Project 3.1.3.1: Antarctic Tropospheric Chemistry Symposia

An international symposium and workshop on *The Chemistry of the South Polar Troposphere* was held in June, 1991, in Boulder, Colorado. The objective of this meeting was to review current knowledge and develop closer international cooperation amongst the research community concerned with Antarctic tropospheric chemistry. The symposium covered tropospheric gases, aerosols and clouds, air-snow exchange, glacial records, transport and troposphere/stratosphere exchange. The workshop sessions addressed the research in Antarctic tropospheric chemistry that is necessary for a better understanding of global change and its impact on the Antarctic region. A workshop report is available from L. Barrie, PASC Co-Convener. A summary of the symposium was published in *Tellus 44B* in 1992, and contributed papers were published there and in *Tellus 45B*, No.2. Future meetings on the topic of Antarctic tropospheric chemistry will be organised to continue to stimulate high quality research on the complex and evolving problems of the southern polar troposphere and its role in global change.

##### Project 3.1.3.2: Coastal Antarctic Site Studies

A research project to coordinate the efforts of scientific groups from France, Germany and the United Kingdom was initiated in 1990 in the frame of the Commission of the European Communities (CEC) Science and Technology for Environmental Protection (STEP) programme.

The objectives of this project are: 1) to assess better the influence of local Antarctic phenomena on inland atmospheric chemistry, and 2) to document sub-Antarctic trace gas and aerosol sources in order to improve the interpretation of ice cores.

The following compounds have been measured daily in the air, and in falling, freshly deposited, and aged snow: Sea-salt aerosol, crustal aerosol, highly soluble trace gases (HNO<sub>3</sub>, hydrogen chloride (HCl), formic acid (HCOOH), acetic acid (CH<sub>3</sub>COOH)), soot, radionuclides (<sup>7</sup>Be, <sup>10</sup>Be, <sup>210</sup>Pb) and SO<sub>2</sub>. Three coastal Antarctic bases have been selected as the sites for this project: Dumont d'Urville (East Antarctica), Georg von Neumeyer and Halley (West Antarctica). The experiments initiated in the first phase of the project will be continued for at least several years in order to obtain a long term record of the measured parameters at the three study sites, e.g., an aethalometer (measuring black carbon) continues to operate at Halley and other experiments will be carried out to look at specific processes. A workshop is planned in order to finalise synthesis papers about the data obtained during the initial 3-year period. The British Antarctic Survey (BAS) is currently developing an automated year-round aerosol sampling system for deployment at future ice core sites. It will be tested in 1995 and deployed in 1996 at the Berkner Island drilling site. The development of automated samplers is a major PASC aim for 1994-1998 and the system developed will be available, if successful, as one option for others to copy.

##### Project 3.1.3.3: Antarctic Plateau Site Studies

An initial one-year experiment on the central Antarctic plateau is planned which will include measurement of atmospheric trace gases and aerosols and the composition of falling snow, firn snow, ice and air in the ice pores. This Task will be coordinated with the IGBP Past Global Changes (PAGES) Project. The central Antarctic plateau is chosen because major ice-core chemistry records are retrieved there, so that the process studies will have the greatest relevance to these records.

The objective of this project is to document transfer functions in the climatic conditions (temperature, wind, accumulation rate) of the sites where deep ice core records have been retrieved, so that process studies will have the greatest relevance to these records.

Experiments to be performed include measurements of concentrations of atmospheric gases and aerosols and the composition of falling and deposited snow and firn. After the end of the two current major drilling operations at Summit, Greenland, glaciologists will work again in central Antarctica as part of the International Trans-Antarctic Scientific Expedition (ITASE) Programme. Traverses are planned for joining several sites selected for future deep ice core drilling. Shallow firn cores will be retrieved along these routes for chemical studies relevant to the PASC scientific activities, in particular for documenting the spatial variability of deposition of compounds relevant to the stratospheric O<sub>3</sub> depletion issue (e.g., HNO<sub>3</sub>). One of the first new inland stations to be

operated will be Dome C (Dome Concordia), where a French-Italian base and ice coring camp will be set up for 1995-1996. The base will be progressively equipped for atmospheric and glaciochemical experiments.

#### Task 3.1.4: Glaciochemical Studies in Greenland

As in the Antarctic, many research programmes have addressed processes influencing trace chemical constituents in the Greenland ice sheet. In general, these programmes have had one or more of the following objectives: 1) to determine the source regions and atmospheric transport pathways for constituents reaching the atmosphere over polar ice sheets, 2) to determine the mechanisms and rates of deposition for constituent transport from the atmosphere to the surface of the ice sheet, and 3) to understand the processes that affect the constituents deposited on the surface as the snowpack deepens and densifies to firn and ice. Several efforts have been or are being conducted within this Task.

##### Project 3.1.4.1: Dye 3 Gas and Aerosol Sampling Programme (DGASP)

A comprehensive year-round programme to address Task 3.3.4 objectives for the Greenland Ice Sheet was the DGASP (Dye 3 Gas and Aerosol Sampling Programme), a one-year continuous effort that involved several research groups from the U.S., Canada and several European countries. During the period August 1988 - August 1989, samples of fresh snow were obtained from nearly all precipitation events at the Dye 3 site, and aerosol sampling was conducted at frequent intervals. The amount of precipitation was measured for each event; the overall net accumulation of snow was determined at intervals throughout the year. Older surface snow was sampled on a few occasions to assess dry deposition. Snow pits were excavated and sampled at the end of the DGASP time period; this permitted comparison of constituent levels in the aged snow with those in the fresh snow collected earlier in the programme. The fresh and older surface snow, aerosol samples, and snowpit samples were analysed for major anions and cations and for radionuclides. Some samples were also analysed for trace metals, polycyclic aromatic hydrocarbons, elemental and soot carbon, and individual particle morphology and chemical composition. All the snow samples were analysed for oxygen isotopes. Beside these samples, individual snowflake replicas were obtained from most of the precipitation events to identify snow crystal habit and extent of riming. Samples of air were collected for analysis of several trace gases; continuous monitors provided concentration data for condensation nuclei (CN) and O<sub>3</sub>. Airmass back-trajectories were computed to identify possible source regions and atmospheric transport pathways.

The DGASP effort has been assisted by a variety of North American air chemistry sampling programmes. These include ground-based as well as aircraft programmes (e.g., see Task 3.1.2). A number of ground-based sites around the Arctic have been used to establish relatively long term air monitoring programmes (>1 year). These include stations at Barrow, Alaska, and at several sites in the Canadian Arctic. Several aircraft sampling programmes have been undertaken to improve our understanding of Arctic Haze and related air pollution problems. The detailed results of DGASP have been published in a special issue of *Atmospheric Environment* on Arctic Air, Snow and Ice Chemistry (vol. 27A, No. 17/18, 1993). Information from DGASP is currently being used to identify the most important transport and deposition mechanisms for southern Greenland. This information will be applied to interpret both atmospheric chemistry data

and ice core/snowpit data from other programmes. Further activities in this programme are not currently planned. Most glaciochemical efforts are being transferred to ATM Camp (see next section).

##### Project 3.1.4.2: Summit Activities

###### *The ATM (Atmospheric Camp) Programme*

The sampling procedures for the ATM programme are similar to those set up for DGASP, with a number of improvements based on the DGASP experience. A network of snow accumulation measurements has been established to determine spatial variations in accumulation over very small and longer distance scales. The ATM effort also includes a detailed meteorological component. A network of automated weather stations provides data on basic ground-level meteorological variables and on snow accumulation. Furthermore, an acoustic echosounder is being used to provide information on atmospheric temperature structure over the sampling site, in order to identify periods of stability. In 1990, French scientists studied the gaseous and aerosol phases of nitrate and chloride in the air in order to compare the results with the snow measurements. Sampling by nylon filters and denuders was tested. In all aerosol and snow samples, all major ions and organic acids were determined. In the absence of snow falls, a 6 m deep snow pit was sampled in order to study seasonal variations of these components in greater detail. The same type of experiment was carried out in the summers of 1991 and 1992 at the ATM by a reinforced scientific and technical staff and with the aid of improved techniques.

About forty sampling programmes have been conducted since the beginning of this operation (1990) and connected closely to the American Greenland Ice Sheet Project II (GISP II) and the European Greenland Ice Core Project (GRIP) drilling efforts. Experiments relevant to PASC have been developed, and some preliminary results were discussed in March, 1993, at the NATO Advanced Research Workshop on *Ice Core Studies of Biogeochemical Cycles* in Annecy, France.

The ATM programme is expected to continue through the GISP II and GRIP projects (through summer 1994) and, hopefully, beyond. Data from DGASP and ATM will be used with ice core data to determine the possible source regions, transport pathways, deposition mechanisms and post-deposition processes affecting the constituents of ice cores. The results will enable the determination of the extent to which trends in ice core data can be used to estimate trends in airborne concentration and in atmospheric properties such as temperature. Efforts are under way to establish a longer term ATM facility at the Summit site in order to explore changes in atmospheric chemistry and meteorology from year to year. The date of the closing up of the GRIP and GISP II camps as well as the availability of the airborne support available in the future in central Greenland remain uncertain after the 1994 and 1995 summer campaigns.

###### *Eurocore*

The main objective of the Eurocore project was to drill a 300-meter deep ice core at Summit (central Greenland) in order to:

- Study the atmospheric chemistry changes and the composition of the pre-industrial atmosphere in the Northern Hemisphere over the last millennium,

- Investigate more specifically the changes in composition, chemical element concentrations and seasonal deposition patterns caused by anthropogenic activities,
- Improve the Central Greenland ice core record on climatic changes since 800 AD, and
- Scrutinise, in combination with other paleoclimate records, the interplay between climate and atmospheric chemistry characteristics.

Eurocore was a 4-year (1988-1992) environmental project involving mainly the Geophysical Institute of Copenhagen (Denmark), the Physikalisches Institut of the University of Bern (Switzerland) and the Laboratoire de Glaciologie et Géophysique de l'Environnement of Centre National de la Recherche Scientifique (CNRS) in Grenoble (France). Additional European scientific groups also participated in the project to make specific measurements. The main field operation of the project took place in June and July, 1989, at Summit (elevation 3230 m). A 304 m ice core covering the last twelve centuries, and six additional firn cores (50-100 m deep) were recovered. From the surface down to 24 meter depths several sets of snow samples were collected for special purposes either by drilling or in pits. The interstitial air present within the firn was sampled from 10 to 80 meters in depth. All in all, more than 10,000 samples for stable isotope and chemistry measurements were obtained. New, specially developed analytical methods were used for continuous measurements in the field ( $H_2O_2$ , HCHO,  $NH_4^+$  and  $NO_3^-$ ). All the results obtained through early 1993 were discussed at the Annecy NATO ARW (Advanced Research Workshop), (March 26-31, 1993), but analytical work is being continued even though the project has officially ended.

#### Timetable

- |            |   |
|------------|---|
| 1990-1995  | Air and snow sampling experiments at Summit (Central Greenland) during the summer field seasons (ATM, GISP II/GRIP programmes).   |
| 1991       | Chemistry of the South Polar Troposphere Meeting in Boulder, Colorado.  |
| 1992-1995  | Polar Sunrise Experiments in the spring in Alert, Canada.   |
| 1993-1995  | Joint German-Russian Aircraft Studies of the Arctic troposphere.  |
| 1993       | Meeting of the PASE Coordinating Committee during the GISP II/GRIP meeting (March 23-25) and a NATO-ARW in glaciological/atmospheric chemistry (March 26-31) in Annecy, France. |
| 1993, 1994 | Field experiments on air and snow chemistry at a Greenland high elevation site (Summit, Central Greenland) from May to August.  |
| 1994       | PASC Workshop at CACGP/IGAC Conference in Japan (Sept.).  |

- |           |  |
|-----------|--|
| 1995      | NATO ARW to be held in March in Tuscany on "Processes of Chemical Exchange between the Atmosphere and Polar Snow". This meeting aims to further the aims of both the ICSI Snow Atmospheric Chemistry Exchange Working Group and the IGAC PASC. |
| 1995-1996 | Beginning of experiments at Dome C, East Antarctica to be continued for several years.   |
| 1994-1995 | European air chemistry study in spring at Ny Ålesund, Spitsbergen  |
| 1997      | Common field experiment with NARE in the North Atlantic and Greenland areas (discussions in progress).   |

#### Focus 4: The Role of Boreal Regions in Biosphere-Atmosphere Interactions

The overall objective of this Focus is to examine the role of the boreal regions as sources and sinks of trace gases and the ecosystem dynamics controlling these fluxes. The forests, lakes and wetlands covering vast areas of North America and northern Eurasia have significant influences on global climate and atmospheric composition because they are strong sources of  $CO_2$ ,  $CH_4$  and other radiatively active gases. Current climate change modelling results imply that warming due to increases in greenhouse gases will intensify towards the poles, which could strongly enhance emissions of these gases from northern wetlands and permafrost regions. These regions also emit other chemically active compounds and act as significant recipients for trace gases and aerosols transported from mid-latitudes. Emissions of trace gases like  $CH_4$  are sensitive to changes in soil temperature and the amounts of water vapour and organic matter in the soil. Detailed field surveys and experimental manipulations are required to develop an understanding of current atmosphere-biosphere exchanges, as well as predictions of future responses to global warming. This Focus currently consists of one Activity.

##### Activity 4.1: High-Latitude Ecosystems as Sources and Sinks of Trace Gases (HESS)

Convener: W.S. Reeburgh

As in other IGAC Activities, HESS built on established international programmes during its initial phase. The field component of a major US-Canadian effort, the *Northern Wetlands Study* (NOWES), carried out in northern Canada as the first Task under this Activity has already been completed. A summary of NOWES is included as an annex to this Focus 4 section of the Operational Plan.

Initially, HESS focused on tundra and wetlands, but new research in boreal forest regions warrants expanding the scope to include these areas. Many national and international agencies are addressing these scientific questions through support of multi-investigator and individual projects. Several tasks are in the planning stages and are expected to be implemented within two to three years.

## Goals

- Estimate trace gas emissions and uptake in high-latitude ecosystems.
- Determine the principal ecological and environmental characteristics that control ecosystems trace gas production, consumption and transport in high-latitude ecosystems.
- Estimate the sensitivity of high-latitude sources-sinks of trace gases to environmental change.

## Implementation Strategy

Several large campaigns addressing the role of boreal regions in changing atmospheric composition were well underway when IGAC was approved as an IGBP core project. One of these field campaigns - the NOWES, a joint United States-Canadian expedition endorsed by IGAC as the first Task under this Activity - was completed in 1990. The results are summarised in the annex to this section. Currently, three major Tasks have been undertaken or are being planned and are described below.

### Task 4.1.1: Estimation of High-Latitude Ecosystems in Trace Gas Emissions

There are large discrepancies in the modelling efforts in estimating the northern wetlands as a source of atmospheric CH<sub>4</sub>. This is attributed to the differences in (1) data bases on ecosystem type and areal extent of each ecosystem; (2) flux estimates used for each ecosystem type; and (3) annual duration of flux period. This Task is designed to alleviate the uncertainties in the estimates of these three key factors.

The objectives of this Task are: 1) to develop a standardised classification and ecosystem characterisation data base for high-latitude ecosystems, 2) to develop measurement protocols for keeping inventories of trace gas fluxes in high-latitude ecosystems, and 3) to test extrapolation models.

There are three components under this Task:

#### 1. Standardised High-Latitude Ecosystem Data Base:

Standardised classifications, based on a combination of vegetation, soil types, hydrology and nutrient status will be developed for high-latitude ecosystems. Existing data-base systems will be evaluated and new data sets will be obtained, where necessary, for use in modelling studies.

#### 2. Ecosystem/Geographical Trace Gas Flux Data:

Year-round field measurements of fluxes of CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O, COS (carbonyl sulphide), H<sub>2</sub>S (hydrogen sulphide), DMS, NO<sub>y</sub> and VOCs will be made using chamber, tower and aircraft techniques covering temporal and spatial variability. CH<sub>4</sub> and CO<sub>2</sub> flux measurement systems are relatively advanced, but appropriate techniques for several of the other gases will have to be developed. The study of the atmospheric chemistry of the Hudson Bay Lowland and Labrador regions of northern Canada, conducted under the

NOWES expedition in 1990, has initiated this kind of experiment. Similar measurements are planned to be made in other major boreal regions in western Siberia, Scandinavia and Alaska.

### 3. Extrapolation Models and Test of Extrapolation:

There are two approaches for extrapolation of gas fluxes: 1) linear extrapolation based on areal extent of ecosystem types, and 2) extrapolation based on some environmental and/or ecosystem factor(s) which correlates with the trace gas flux (e.g., temperature, moisture). Several intercomparisons between modelled fluxes (extrapolation) from an ecosystem and fluxes measured from towers and aircraft have been or are being undertaken presently. Examples of these are FIFE (*First ISLSCP (International Satellite Land-Surface Climatology Project) Field Experiment*), ABLE-3A (*Atmospheric Boundary Layer Experiment*) and NOWES/ABLE-3B. Investigations into the isotopic comparison of CH<sub>4</sub> sources and atmospheric composition of CH<sub>4</sub> are also being performed.

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 region. Areal estimates of heat and water vapour have been obtained from a 15 x 15 km site in FIFE and these results are useful in developing scaling-up techniques for other trace gases. A more detailed intercomparison between models, chamber, tower and aircraft measurements over a relatively homogeneous area of at least 4 x 4 km are desirable.

Second, a comparison between flux-extrapolated estimates of emissions from high-latitude ecosystems and isotopic reconstruction of trace gas sources and sinks must be carried out. These investigations may refine source strength estimates and reveal how much aged carbon is released to the atmosphere. Isotopic analysis and time series measurements of atmospheric CH<sub>4</sub> from these source regions would reveal temporal trends in the CH<sub>4</sub> emissions from high-latitude ecosystems.

Finally, intercomparisons of chamber techniques and the <sup>222</sup>Rn technique are needed, where possible. 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, but they remain an operationally defined compromise.

Generally the resources are in place to carry out this Task. 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 NOWES are analysed.

### Task 4.1.2: Controlling Factors and Processes of Trace Gas Exchange in High-Latitude Ecosystems

Numerous studies have indicated variables that correlate with CH<sub>4</sub> flux, including temperature, moisture regime and net primary production. There are other factors in high-latitude ecosystems that are probably important in controlling trace gas fluxes such as microbial CH<sub>4</sub> oxidation, quality of litter, soil chemistry, soil physical properties, water flow and plant structure as it affects transport. The little information available on the factors that correlate with the exchange of NMHCs, NO<sub>y</sub>, DMS, COS and H<sub>2</sub>S suggests 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 task is designed to elucidate broad environmental and edaphic controls, and to understand the key biological processes controlling trace gas emissions and exchange.

The objectives of this Task are: 1) to examine the relationship between trace gas production, consumption and transport to environmental and ecosystem characteristics in high-latitude ecosystems, and 2) to resolve the influence of the environmental controls on production, consumption and transport rates.

On an ecosystem and regional basis, trace gas exchange will be examined over a range of different physical and environmental conditions. These studies must include the below-surface processes responsible for both production and the partial oxidation of CH<sub>4</sub> prior to release into the atmosphere, as well as processes related to trace gas release to the atmosphere, e.g., by vascular transport in plants. Such studies have been initiated in the NOWES expedition, but will be extended and also carried out at other sites around the world for extended measurement periods. Models will be developed to relate these process studies to the flux measurements.

#### **Task 4.1.3: Sensitivity of High-Latitude Trace Gas Sources and Sinks to Climate Change**

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. 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.

The objectives of this Task are: 1) to evaluate the year-to-year variations and directional changes in trace gas emissions, 2) to evaluate the impact of environment and ecosystem changes on trace gas emissions, and 3) to develop a mechanistic framework linking environmental factors to processes related to trace gas production, consumption and exchange.

There are three components under this Task:

##### **1. Long term Measurement Programme:**

Long term atmospheric observatories to measure trace gas emissions will be established at a range of research sites. An important part of this task will be long term studies of ecological processes and changes affected by anthropogenic factors, including climate changes

The NOWES has established an atmospheric chemistry observatory in Fraserdale, Ontario, Canada to measure several trace gases at the junction of the Hudson Bay Lowland wetlands and boreal forest zone, in which CH<sub>4</sub> and other chemical

climatological data are gathered on an ongoing basis over a period of several years. Similar observatories should be established in the tundra region. Whenever possible, these sites should tie in with the proposed IGBP Terrestrial Transects.

A second component is the establishment of long term chamber programmes in key ecosystems at existing research facilities that are part of Long Term Ecological Research (LTER) sites or have been in existence for more than 10 years. The U.S./Canada Boreal Forest Experiment will be reviewing potential sites. In Russia, there are several Biosphere Reservations, but no developed facilities for trace gas monitoring currently exist.

Low altitude north-south aircraft measurements of CO<sub>2</sub>, H<sub>2</sub>O 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 in optimising the use of remotely sensed spectral data to parameterise exchange of radiatively important gases.

##### **2. Experimental Analogues of Sensitivity of Trace Gas Flux:**

The studies of trace gas emissions will take place at sites along primary and secondary successive sequences to examine the control of vegetation, soil and microclimate on fluxes. Ecosystem manipulations are planned in order to examine the influences of changing environmental factors on trace gas fluxes.

The NOWES transect from the Hudson Bay coast provides an example of successive change in ecosystems, associated with the emergence of Lowlands from Hudson Bay over 5000 years. Major recent disturbances also provide opportunities to address changes in trace gas flux along successive gradients. Similar transects should be established in the boreal forest and the Arctic and sub-Arctic tundra biomes.

The impact of acidic precipitation on bog ecosystems is being addressed at the Experimental Lakes Area, Ontario. Simulated acid rain is being added to a bog and peat water chemistry and plant response are being monitored. Additional experiments should take place in the major trace gas producing ecosystems in each of the boreal, subarctic and Arctic regions.

##### **3. Process-based Trace Gas Exchange Models:**

Predictive ecosystem process models will be developed that incorporate relationships between forcing variables and trace gas exchanges. Landscape models will be constructed to improve estimates of trace gas fluxes for present and potential future climate conditions.

One of the major gaps in understanding the role of boreal regions in atmospheric chemistry is the lack of data and collaboration in Siberia. Some very strong possibilities for establishing collaborative sites and transects with Russian colleagues have developed recently. The U.S.-Russia Bilateral Agreement provides the mechanism, but there have been several unsuccessful attempts at convening a planning meeting. Several HESS Coordinating Committee members have pursued individual contacts through meetings. The International Conference on Cryopedology in Puschino, Russia, (November, 1992) and the International Conference on Arctic Ecosystems in Norway (August, 1993)

provided forums for developing means to fill this important gap. A task team constituted in early 1994 by the IGBP to recommend priorities for future collaborative studies among BAHC, IGAC and GCTE emphasised the importance of the Siberian region, and a follow-up meeting to address this issue specifically is planned for late 1994.

#### Timetable

- |           |   |
|-----------|---|
| 1992      | Continue and initiate further studies in areas where work is required.  |
| 1992-1994 | Establish long term chamber programmes at representative ecosystem sites.   |
| 1992-     | Establish field programmes and determine control emissions.   |
| 1993      | Intercomparison and assessment workshop.  |
| 1993-94   | BOREAS (Boreal Ecosystem Atmosphere Study) campaign.<br><br>Completion of a northern wetland data base.<br><br>Initiate measurement programme. Develop field techniques for measuring biogenic trace gases other than CH <sub>4</sub> .<br><br>Chamber intercomparison studies and isotopic reconstruction.<br><br>Establish long term atmospheric chemistry observatories in the Arctic/subarctic zones. |
| 1993-96   | ARCSS/LAII campaign.  |
| 1994      | HESS Workshop of the Coordinating Committee during the Spring AGU (American Geophysical Union) Meeting. Planing of Tasks 2-3 and develop new tasks.   |
| 1994-1995 | Boreal Forest Experiment.   |
| 1995      | Synthesis of process studies.   |
| 1996      | Completion of a boreal forest and the tundra/polar data base.   |
| 1996      | Completion of CH <sub>4</sub> flux measurements from identified ecosystems and regions, and initiate measurements of NMHC (VOC) fluxes.   |
| 2001      | Completion of measurement of non-CH <sub>4</sub> biogenic trace gases from high-latitude ecosystems.  |

#### Annex: Synopsis of the Northern Wetlands Study (NOWES):

The Northern Wetlands Study (NOWES) was a multi-disciplinary investigation designed to assess the importance of northern wetlands as a source/sink of biogenic gases to the

atmosphere. The primary emphasis was on the exchange of CH<sub>4</sub> between wetland ecosystems and the atmosphere, but the fluxes of N<sub>2</sub>O, NO<sub>x</sub>, VOC, DMS and CO<sub>2</sub> were also examined.

NOWES was coordinated by the Canadian Institute for Research in Atmospheric Chemistry (CIRAC) in collaboration with the National Aeronautics and Space Administration (NASA) and involved more than 50 scientists from university, government and private sectors. The principal field site for the study was the Hudson Bay Lowland (HBL), the second largest contiguous wetland in the world. A second field site was located in the subarctic/boreal region of Quebec and Labrador where the wetland coverage is discontinuous. This was the site of NASA's ABLE-3B experiment. This study was endorsed as a key component of IGAC in 1988; it was the initial Task of the HESS Activity.

Research activities at both sites included flux measurements using chambers, micrometeorological towers and aircraft. These measurements were supplemented by studies of the factors that control gas fluxes. Land characterisation by remote sensing and ecology were used to develop a classification for the spatial extrapolation of the results. Preliminary studies and reconnaissance were undertaken in 1989, the main experiment was conducted during the summer of 1990, and the modelling effort and extrapolation are on-going.

Molecule-for-molecule, CH<sub>4</sub> is some 32 times more effective than CO<sub>2</sub> as a greenhouse gas. The concentration of CH<sub>4</sub> in the atmosphere has increased by more than a factor of two since the beginning of the industrial era. It is currently increasing at a rate of about 1% per year for reasons which are not fully understood, although its increase closely parallels population growth. Anthropogenic sources include increased rice cultivation, cattle breeding, coal and natural gas industries, solid waste burial, and biomass burning.

The largest sources of CH<sub>4</sub>, however, are believed to be natural wetlands. The amount of atmospheric CH<sub>4</sub> produced from the combination of all northern wetland areas was estimated to be 16% of the total emissions to the atmosphere. But these estimates were based partially on very limited data from northern wetlands and largely on measurements taken in much more southerly wetland areas. Since the HBL accounts for some 12% of global peatland area, NOWES was designed to measure the flux of CH<sub>4</sub> from this area. Also, the wetlands of the HBL are similar to the larger wetland complexes of western Siberia from which no CH<sub>4</sub> flux data are available. Thus, NOWES data also serve as a basis for estimating the CH<sub>4</sub> contribution of the vast wetlands of Russia.

The most important finding of the CIRAC study is that the actual emissions of CH<sub>4</sub> from the HBL are some 20 times less than earlier estimates. If this finding is extrapolated to the Siberian wetlands, it has been estimated that the combination of northern wetlands areas contribute 2-4 times less CH<sub>4</sub> to the atmosphere than previously believed. This means that other sources (natural and anthropogenic) of CH<sub>4</sub> are being underestimated or the sink overestimated. Tropical wetlands may represent one such natural source, although it is not likely that they could account for the increasing levels of atmospheric CH<sub>4</sub>. Landfills and natural gas production and transmission are two anthropogenic sources which are gaining increased attention.

Another significant finding is that the amount of CH<sub>4</sub> emitted from the HBL is highly variable, and strongly dependent on temperature and wetness. This becomes particularly significant if global warming, caused by increased emissions of greenhouse gases, also results in the northern wetlands becoming wetter. A strong positive feedback could result in which more CH<sub>4</sub> would be emitted from the wetlands leading to still further warming. On the other hand, if the northern wetlands become drier as a result of global warming, more CO<sub>2</sub> would be formed from the large accumulation of carbon in the peatlands of this vast area.

The NOWES is now completed. Preliminary results of the project were documented in the *Northern Wetlands (NOWES) Study Report*. Further data analysis and interpretation were reported in a large compilation of papers in a special issue of the *Journal of Geophysical Research - Atmospheres* (99(D1), January, 1994). It is anticipated that the analysis of NOWES data will continue for several years. The NOWES data set will be utilised to attempt to model the carbon exchange between northern wetlands and the atmosphere. This will involve a wider group of scientists than those involved in the NOWES field experiment.

Numerous research questions have been generated from the NOWES and some are being pursued as part of several principal investigators' ongoing research programmes and other collaborative projects. For example, as a direct result of contact made between representatives of the Nordic countries visiting the NOWES campaign in 1990, there is now a Nordic Countries (Finland, Sweden, Norway and Denmark) initiative on trace gas exchange, with some collaboration from North American scientists. Other questions are being pursued as part of the upcoming Boreal Ecosystem Exchange Study.

### Focus 5: Trace Gas Fluxes in Mid-Latitude Ecosystems

This Focus addresses the temperate region, particularly of the Northern Hemisphere, which is densely populated with most of its ecosystems subject to strong human disturbances, including conversion of forests to grasslands and agricultural lands. These mid-latitude ecosystems experience extreme atmospheric chemical conditions such as high O<sub>3</sub> concentrations and acid deposition due to industrial emissions. Strong chemical interactions occur between gases of industrial (e.g., NO<sub>2</sub>) and biogenic (e.g., isoprene and terpenes) origin, which lead to enhanced O<sub>3</sub> concentrations with detrimental influences on some ecosystems. These processes are already being studied in some industrialised areas, but the investigations need to be expanded to other regions and extended to include their impact on overall nutrient cycling and trace gas exchange in the relevant ecosystems. In addition to the disturbances caused by atmospheric inputs, the roles of various agricultural practices, including heavy use of fertilisers, on trace gas emissions and uptake need to be better determined.

Two Activities comprise this Focus. One Activity (5.1, MILOX), which entered its planning phase in late 1993, will focus on assessing and understanding the complex interplay between an urban-industrial society, natural and cultivated ecosystems, and atmospheric photochemical oxidants in the northern mid-latitudes. GCTE and LUCC (Land-Use/Land-Cover Interactions) scientists are participating in the planning process from an early stage and it is hoped that MILOX will develop as a joint effort among these other IGBP Core Projects and IGAC. The second Activity (5.2, TRAGEX) is underway. It

seeks to document contemporary fluxes of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and CO between the soil and atmosphere, to determine the factors controlling these fluxes, and to improve the ability to predict future fluxes. This Activity was planned and is being implemented in conjunction with GCTE as well.

### Activity 5.1: Mid-Latitude Ecosystems and Photochemical Oxidants (MILOX)

Conveners: W.L. Chameides, W. Seiler

An appraisal of human activity on a global scale reveals two striking statistics with regard to the northern mid-latitudes. It is the region where most of the world's fossil fuel burning takes place and it is also the region where most of the world's food and forest products are harvested. The co-location of these two activities is not coincidental, but rather the inevitable result of the structure of modern urban-industrial society that typifies large portions of the northern mid-latitudes. This social structure requires large sources of energy to power the factories and transportation systems needed for the production and distribution of industrial products. It also requires highly productive agricultural and forestry practices to feed and house an ever increasing non-agrarian population living in urban centres. As a result, on a regional scale, areas devoted to industrial activities with relatively large rates of fossil fuel usage tend to be located near areas devoted to agriculture and forestry.

The relative proximity of fossil fuel usage and agricultural activities has some potentially significant economic as well as environmental implications. It is now well established that gaseous emissions from the burning of fossil fuels can have a deleterious impact on regional air quality. It is not unreasonable to expect that agricultural crops and forests located near these emissions would be adversely affected by this poor air quality. Because of the importance of the northern mid-latitudes, a loss in agricultural and/or forestry productivity in this portion of the world would likely have significant ramifications for the global economy as a whole.

Of particular concern for MILOX is the production of tropospheric O<sub>3</sub> and its impact on mid-latitude ecosystems. Ozone, an allotrope of oxygen with known phytotoxic properties, is produced in the Earth's lower atmosphere from a series of photochemical reactions involving VOCs and NO<sub>x</sub> in the presence of sunlight. During the past 50-100 years, tropospheric O<sub>3</sub> concentrations appear to have increased significantly (as much as a factor of three) over significant portions, if not all, of the northern continental mid-latitudes. The elevated concentrations appear to be greatest in those regions of the northern mid-latitudes where fossil fuel usage is greatest. While the impact of these elevated concentrations on agriculture and forests has yet to be quantified, a recent study indicating that 10 to 35% of the world's cereal crops are presently exposed to harmful concentrations of O<sub>3</sub> suggests that the effect might be significant.

Moreover, while O<sub>3</sub> may be adversely affecting northern mid-latitude ecosystems, these same ecosystems may be having a significant influence on O<sub>3</sub> concentrations. Scientific investigations have shown that natural VOC emissions from these ecosystems can be large and, in the presence of NO<sub>x</sub> from anthropogenic sources, can lead to the generation of large amounts of O<sub>3</sub>. While natural VOC emissions are known to be affected by environmental conditions (e.g., temperature), it is not yet possible to predict accurately how these emissions will respond to long term changes in climate and air quality. Nor is

it possible yet to project how atmospheric O<sub>3</sub> concentrations will respond to modifications in ecosystems that might occur as a result of changes in agricultural practices, land-use patterns and forest management. It is this complex interaction between anthropogenic activities, natural emissions, atmospheric photochemical oxidants, and ecosystem response that MILOX research will endeavour to understand. In order to maintain close relevance to contemporary policy issues, a significant fraction of the MILOX effort will be devoted to direct assessment of oxidant effects on managed and natural ecosystems.

It is evident that MILOX research must be highly interdisciplinary and that, therefore, strong links must be forged with related efforts within and outside the IGBP. Toward this end, it is envisioned that MILOX research tasks will be closely coordinated with Activity 5.2 (TRAGEX), Activity 6.1 (GLONET), as well as with related efforts in the GCTE and LUCG core projects. Collaboration with elements of the Human Dimensions of Global Environmental Change Programme (HDP) is also anticipated.

### Goals

- Assess the effects of atmospheric oxidants and related compounds on northern mid-latitude agricultural and forested ecosystems.
- Understand and quantify the contributions of northern mid-latitude ecosystems in providing a source or sink of atmospheric oxidants on local, regional and global scales.
- Understand the photochemical and transport processes that control the production and deposition of O<sub>3</sub> in northern mid-latitudes.
- Understand how atmospheric oxidants interact with the biosphere.
- Develop predictive capabilities for the effects of future ecological/ societal/ climatic changes on O<sub>3</sub> concentrations in northern mid-latitudes and the concomitant effects of these changes on ecosystems and society.

### Implementation Strategy

To address the scientific questions outlined above, it is proposed that MILOX be implemented using a matrix organisation that divides the project into three interdependent, Regional Subprojects that simultaneously and collaboratively focus on seven Research Tasks.

#### *The Regional Subprojects*

The production and transport of O<sub>3</sub> near the Earth's surface occurs on time scales of days and, thus, is fundamentally a regional scale process. Moreover, the northern mid-latitudes are climatologically, ecologically and demographically heterogeneous, and these heterogeneities will give rise to geographic heterogeneities in the emissions of O<sub>3</sub> precursors, the dynamics of O<sub>3</sub> transport and micrometeorology and biochemistry of O<sub>3</sub> deposition. It is likely, therefore, that the processes that control the production, transport and deposition of O<sub>3</sub> vary considerably on regional scales over the northern mid-latitudes. By the same token, the effects of increasing concentrations of O<sub>3</sub> and other photochemical

oxidants on both natural and managed ecosystems probably also varies from region to region in the northern mid-latitudes. Thus, to understand the scientific questions identified for MILOX, it will be necessary to undertake regionally specific studies. Therefore, it is proposed that MILOX be divided into Regional Subprojects that simultaneously and collaboratively focus on three specific regions of the northern mid-latitudes: 1. MILOX/North America; 2. MILOX/Europe; and 3. MILOX/East Asia. As summarised below, these regions represent the three areas of the globe that are probably most heavily impacted by modern urban-industrial-agricultural society, but still offer contrasting trends in anthropogenic emissions.

**Subproject A: MILOX/North America:** The North American continent represents a region of significant industrial activity and urbanisation coupled with large adjoining rural tracts of land devoted to agriculture and forestry. Because of relatively stringent emission controls already in place on the continent, with the exception of Mexico, it is projected that emissions of O<sub>3</sub> precursors will remain relatively flat over the next few decades. Nevertheless, the continent is plagued with frequent O<sub>3</sub> pollution episodes during the summer months; the United States' National Crop Loss Assessment Programme estimated that these pollution episodes cost the nation several billion dollars annually in crop losses. Moreover, despite more than two decades of O<sub>3</sub> abatement efforts, O<sub>3</sub> concentrations remain high and problematic. In response to concerns over these O<sub>3</sub> concentrations, an international, multi-agency research programme is being planned to better understand the causes of urban and regional scale pollution in North America and develop effective strategies for its mitigation. This programme, the North American Research Strategy for Tropospheric Ozone (NARSTO), will serve as a foundation around which an IGAC programme can be built for addressing the MILOX scientific questions as they relate to North America.

**Subproject B: MILOX/Europe:** The European continent represents another large part of the northern mid-latitudes that is industrially developed and urbanised. The continent is characterised by a sharp geographic division in the severity of its air pollution, with the most severe pollution and largest ecological damage generally found in the eastern portion. It is not known to what extent O<sub>3</sub> pollution is a factor in this ecological damage. Because of major political and economic upheavals in eastern Europe, it is projected that there will be significant shifts in the emissions of O<sub>3</sub> precursors from these regions. These emissions shifts represent a unique opportunity to study the atmospheric and biospheric response to changing anthropogenic inputs. As in North America, concern over the adverse effects of air pollution over the European continent has given rise to a major research programme on atmospheric chemistry and air quality over Europe - a EUREKA initiative, supported by national funding agencies entitled: The European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe (EUROTRAC). It has been proposed that a Second Phase of this programme (EUROTRAC-2) be undertaken that will focus on source-receptor relationships for photochemical oxidants and acidic species in Europe. If this proposed programme proceeds it should represent a good foundation on which to build a subproject aimed at addressing the MILOX scientific questions as they relate to Europe.

**Subproject C: MILOX/East Asia:** The initial emphasis in MILOX/East Asia is proposed to be on China, but other countries should become involved as this subproject proceeds. China, as a nation, contains roughly 20% of the world's human population; it also produces about 20% of the world's food crops, but is responsible for less than 10% of the

world's total consumption of energy, according to FAO statistics. China has recently embarked on a policy aimed at significantly expanding its economy and industrial productivity over the coming decades; it is likely that this economic expansion will be largely fuelled by the burning of the nation's vast reserves of coal. At the same time, China will need to increase its agricultural output significantly if it is to keep pace with its growing population and maintain food self-sufficiency. Thus China, in stark contrast to North America and Europe, represents a region where O<sub>3</sub> precursor emissions from both the industrial and agricultural sectors is likely to increase significantly in the coming years. The increasing levels of O<sub>3</sub> pollution that are likely to result from these emissions could conceivably limit agricultural output, with potentially significant impact on the global as well as the Chinese economy. For these reasons, a high priority for MILOX will be to organise and implement a series of research studies and regional field programmes focusing on the Chinese subcontinent to better understand and predict the impact of increased emissions from its growing economy, and provide policy makers with the technical information needed to adjust to, or mitigate against, these impacts.

### **The Research Tasks**

The MILOX Research Tasks will be implemented in three phases starting with initial assessment and scoping exercises (Tasks 5.1.1 and 5.1.2), followed by the deployment of a series of regional scale process-science field and laboratory studies (Tasks 5.1.3 through 5.1.5), and culminating in integration and analysis aimed at the development and application of forecasting tools for estimating future O<sub>3</sub> concentrations and their impacts (Tasks 5.1.6 and 5.1.7).

#### ***Phase 1: Initial Implementation***

As a first step in the implementation of MILOX research activities, Tasks 5.1.1 and 5.1.2 will be devoted to obtaining preliminary estimates of the severity of the O<sub>3</sub> effects in the northern mid-latitudes, and to expand, as targets of opportunity, the scientific infrastructure needed to improve these estimates in the future.

#### **Task 5.1.1: Initial Assessment of Oxidant Effects**

Task 5.1.1 will represent a first step in the implementation of the MILOX research activity; an initial estimate of the magnitude and character of the effects of O<sub>3</sub> on ecosystems of the northern mid-latitudes. This Task will involve the integration of existing air quality data and land-use/cover information into a GIS database for the northern mid-latitudes. This database, coupled with model calculations where needed, will be used to estimate the effects of present O<sub>3</sub> concentrations on yield/productivity of managed ecosystems in the northern mid-latitudes.

#### **Task 5.1.2: Expansion of Ozone/Ecosystem Networks**

To improve the accuracy of future assessments of O<sub>3</sub> effects, Task 5.1.2 will be devoted to the development of an expanded and coordinated mid-latitude network of surface measurement sites for monitoring ecosystem exposure to surface O<sub>3</sub>. This will be accomplished by the promulgation of uniform quality assurance/quality control (QA/QC) procedures for surface monitoring stations run by local, regional and national agencies in the northern mid-latitudes, the deployment of additional O<sub>3</sub> monitoring sites

in areas of poor data of particular ecological and/or economic importance, and the establishment of (O<sub>3</sub> + CO<sub>2</sub>) effects monitoring stations at a few existing ecological research sites, ideally along appropriate proposed IGBP Terrestrial Transects.

#### ***Phase 2: Regional scale Process Science Research***

Task 5.1.3, 5.1.4 and 5.1.5 identified for the MILOX research activity will be focused on the planning, coordination and implementation of regional scale field programmes designed to elucidate the processes controlling photochemical oxidant concentrations in three contrasting portions of the northern mid-latitudes.

#### **Task 5.1.3: Laboratory Studies/Instrument Development**

The production of O<sub>3</sub> and its deposition involve complex photochemical and biochemical reactions and mechanisms that are still not completely understood and/or have yet to be fully validated through comprehensive field measurements. To address these gaps in our understanding, Task 5.1.3 will be devoted to the use of laboratory experiments to elucidate key elementary chemical pathways of relevance to the study of O<sub>3</sub> and photochemical oxidants, and to the development and evaluation of new, high-sensitivity, high-specificity instrumentation capable of quantifying the concentrations and fluxes of trace species involved in the photochemistry and deposition of O<sub>3</sub> and related photochemical oxidants.

#### **Task 5.1.4: The Deployment of Regional Oxidants Networks**

The photochemical generation of O<sub>3</sub> is a highly non-linear process that can depend strongly on local hydrocarbon concentrations, local nitrogen oxide concentrations, or both depending on the relative abundances of hydrocarbons and nitrogen oxides and the local climatological conditions. In order to establish how these so-called O<sub>3</sub> precursor relationships vary on intra- and inter-annual time scales and as a function of geographical location and regional emission rates, Task 5.1.4 will endeavour to deploy and coordinate regional oxidants networks that monitor O<sub>3</sub>, speciated hydrocarbon and nitrogen oxide concentrations in selected locations in North America, Europe and China on a continuous basis.

#### **Task 5.1.5: The Implementation of Regional Scale Field Intensives**

A comprehensive understanding of the photochemistry of O<sub>3</sub> and related oxidants, its transport within the northern mid-latitudes, its export to other regions of the global troposphere, and its impact and interaction with ecosystems will ultimately require the implementation of a series of comprehensive field intensives. These will typically encompass a coordinated programme of simultaneous chemical and meteorological measurements carried out over a period of a few to several weeks. They combine a hierarchy of routine monitoring at a multitude of sites with more sophisticated, research-grade suites of measurements at a limited number of surface sites and on airborne platforms. Task 5.1.5 will involve the deployment of a series of such field intensives in North America, Europe and China over a 5-10 year period.

### Phase 3: Integration and Analysis

Tasks 5.1.6 and 5.1.7 of the MILOX activity will be devoted to the integration of the data obtained from Tasks 5.1.1 through 5.1.5 and related non-MILOX activities and the analysis of these data using diagnostic and prognostic/ forecasting models. The aim will be to estimate future trends in O<sub>3</sub> and related oxidants in the northern mid-latitudes, the long term consequences of these trends on ecosystems in the northern mid-latitudes, and the efficacy of regional, national and international mitigation strategies.

#### Task 5.1.6: Establishment of Virtual Data/Forecasting Center

Task 5.1.6 will encompass the establishment of a networked clearinghouse for collating and analysing data from MILOX and related non-MILOX activities and formatting the data into forms and derived products that are useful and accessible to the scientific and relevant regulatory/policy communities. This task will be carried out in collaboration with IGBP-DIS (Data and Information System). Derived products from the Data Center could include seasonal estimates of selected ecosystem exposures to O<sub>3</sub> and related photochemical oxidants, as well as weekly semi-empirical forecasts of O<sub>3</sub> concentrations in selected regions of the northern mid-latitudes, where air quality data can be made available in real time.

#### Task 5.1.7: Integrated Regional/Global Modelling

As the final and ultimate step in the MILOX research plan, Task 5.1.7 will undertake to integrate the knowledge and insights gained from MILOX into comprehensive and integrated models to forecast long term effects of agricultural and forestry practices, land-use changes, new technologies, and demographic changes on regional and global tropospheric O<sub>3</sub> concentrations and the impact of these concentrations on ecosystems of economic and environmental importance. Because of the comprehensive nature of this research task, it will require close collaboration with other activities of IGAC (e.g., GEIA, GIM) as well as other IGBP projects (e.g., LUCC, GAIM (Global Analysis, Interpretation, and Modelling)).

#### Timetable

- 1993 Preliminary planning meeting in U.S. (September)
- 1994 MILOX - IGAC/LUCC/GCTE Planning and Scoping Meeting (May).  
Initiate development of air quality database.
- 1995 Undertake scoping workshop/study to assess possible impact of oxidants on agriculture and forests.  
Initiate limited number of (O<sub>3</sub> + CO<sub>2</sub>) effects studies at GCTE sites.  
Begin deployment of O<sub>3</sub> monitoring network in China.  
Coordinate analysis and exchange of data from North American and European Oxidants Networks.

Begin planning for joint field programmes in North America, Europe and China.

Establish Science Team for development and application of forecasting models.

1996-? Initiate Virtual Data Center Activity.

Undertake regional scale field studies.

#### Activity 5.2: Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere (TRAGEX)

Convener: G.P. Robertson, K. Smith

The atmospheric concentrations of trace gases such as CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O have increased substantially during the past decades, and are expected to result in global warming and changes in precipitation patterns. Our understanding of the contemporary fluxes of these gases between the land and atmosphere and the factors controlling these fluxes is incomplete. For example, there are large regions of the Earth, including most of the former Soviet Union, China, and temperate South America for which we have very little information. Furthermore, we do not understand how global change, or land-use change, will affect the emission or uptake of these gases by the biosphere.

The mid-latitude or 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, e.g., between NO<sub>x</sub> and NMHCs, with consequences for tropospheric chemistry and biological function.

There have been many studies of trace gas exchange in the temperate region, but because of the infrequency of the measurements or the restricted area used for the study (individual field or forest plots), it is difficult to define accurately the magnitude of the emissions on a regional or global scale. The consequences of converting natural lands to agricultural use and the effects of loading ecosystems with nutrients and toxins on trace gas exchange are just beginning to be understood.

A programme designed to study trace gas fluxes in mid-latitude ecosystems, *Exchanges of N<sub>2</sub>O, CH<sub>4</sub> and CO between Terrestrial Ecosystems and the Atmosphere in Mid-Latitudes*, was identified as an Activity of the IGAC Project in 1990. An open workshop meeting was held at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, in September, 1991 to establish the main priorities for research within the area of responsibility of this Activity. This workshop was followed by a meeting of the Activity Coordinating Committee in Edinburgh, Scotland in January, 1992 to finalise an Action Plan for this Activity. The original focus of this Activity was primarily on CH<sub>4</sub>, N<sub>2</sub>O and CO. Another IGAC Activity, *Mid-Latitude Ecosystems as Net Carbon Dioxide Sinks*, focused on CO<sub>2</sub>. However, during a joint meeting of the two Activities in September 1992 in Colorado, it was decided that their merger would lead to more efficient use of resources and significantly enhance their goals. This new IGAC Activity 5.2 resulting from the merger, *Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and the Atmosphere*

(TRAGEX), is undertaking a research programme for the next decade that addresses major gaps in our knowledge of trace gas fluxes ( $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ,  $\text{CO}$ , and  $\text{CO}_2$ ) in mid-latitude ecosystems.

### Goals

- Document contemporary fluxes of  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$  and  $\text{CO}$  between the soil and the atmosphere.
- Determine the factors controlling these fluxes and improve our ability to predict future fluxes.

### Implementation Strategy

This Activity will be undertaken by the establishment of a sampling network that includes the main temperate zone ecosystems in each continent; the data that should be collected within this network will be specified. The need to identify and quantify all potentially important fluxes requires a number of exploratory research tasks, including filling data gaps in previously studied regions, developing programmes in poorly studied geographic areas, and studying how fluxes will change in response to global change.

Many of the data collection activities within the trace gas network will need to be long term, encompassing a wide range of temporal variation that will be helpful for understanding how fluxes will respond to global change. Data acquired from manipulation experiments will complement those obtained from the network. Both will be used for the development of trace gas flux models that will be used to quantify the diverse factors that control these exchanges. These models will form the nucleus of a larger modelling activity capable of predicting trace gas exchanges at ecosystem scales. The linking of ecosystem models to atmospheric chemical transport models and, ultimately, to general circulation models will permit elucidation of trace gas fluxes at regional and global scales. Three types of research activities will be carried out to achieve the major goals of this Activity:

#### Task 5.2.1: Measurement of Trace Gas Fluxes at an International Network of Representative Sites

Establishing a comprehensive site matrix is necessary to the goal of characterising contemporary fluxes within the mid-latitudes. A well defined matrix of sites will also produce the data necessary to quantify critical variables controlling fluxes of trace gases across the region. This matrix must include the main ecosystem types, both natural and managed, within each geographical component of the temperate zone. Most importantly, the network must focus on areas where fluxes are presently not well known.

Of special importance in the mid-latitudes are broad agricultural and forested areas for which few data exist, including areas of intensive agriculture in eastern Europe, the former Soviet Union and China, and major wetlands in the same regions. The network must include sites representative of the large areas of the mid-latitudes that have been affected by atmospheric deposition of nitrogen and acidity. Semi-industrial biogenic fluxes that are unique to the temperate zone, such as those from landfills and agricultural

wastes in anaerobic lagoons, must also be quantified. The availability of several well characterised sites within the mid-latitudes will allow for a diversity of activities to occur at different sites. Manipulation studies will be carried out and state-of-the-art measurement techniques will be developed at well instrumented sites, and less intensive work will be done at remote locations, especially those where contemporary fluxes are not well known.

The basic design calls for sites representing the major ecosystem/land-use types, approximately 10 sites within each type, of the mid-latitude zone: Forests, rangeland, agriculture and within each of the major geographical components of the zone: Europe, North America and Asia. In addition to major sites, there is a need for data from a small number of specific wetland areas that are poorly characterised, and for data from several representative industrial/urban sites. In South America and Australasia, there are significant areas of distinctive agricultural, forest and rangeland systems that should be investigated.

Existing research networks in the mid-latitude zone should be very useful for site selection. Specific site types that can be found in existing networks are noted in Table 1. Within the forest and rangeland classes, it is important to select sub-sites to account for edaphic factors such as soil texture, site wetness, soil fertility, topography, and forest management when establishing sampling regimes for each site. Within the agricultural class, it is important to study the effects of differences in nutrient inputs (fertilisers, legumes, manures), crop types and cultural practices. Clearly, not all of these factors will be studied at each site. The basic site matrices for each geographical area are outlined in Table 1.

Although temperate wetlands are not thought to be important in global trace gas budgets, selected wetland sites will play several roles in this study. First, there are two large areas of temperate wetland for which no trace gas flux data are available - the Pripet marshes in central/eastern Europe, and the large area of peatlands in Western Siberia. Second, there are two large areas of temperate wetlands in North America, northern U.S./southern Canada and southern U.S.- Gulf Coast, Everglades, that are marginally significant in global budgets but which are relatively well studied, and which may be useful for manipulation studies. Third, wetland areas will also be included in the sub-site layout at many of the main forest, rangeland and agricultural sites. Local topographic variation within generally well drained landscapes, throughout the mid-latitudes, often produces small to moderate sized areas with high fluxes. In agricultural areas, wetland trace gas fluxes may be strongly influenced by outputs of nitrate from agricultural fields. Much of the agricultural influence on trace gas fluxes may be expressed in off-site effects on adjacent natural ecosystems such as wetlands.

There is a variety of urban and intensive agricultural land-use practices that contribute significantly to global trace gas budgets. These are most highly concentrated in mid-latitude regions (Table 2). They include landfills and other types of waste disposal practices (feedlots, manure collection, storage and distribution systems). These will be studied as part of the programme. In addition, there are large numbers of ruminants in mid-latitude regions, but the question of measurement of trace gas fluxes associated with them is one that should be addressed by IGAC as a whole.

It is clear that data collection will vary significantly from site to site depending on the specific scientific questions relevant to the site, and on personnel and technological resources available. There is a basic set of site characterisation data that is required for all sites (Table 3). Information is required on fluxes of CH<sub>4</sub>, N<sub>2</sub>O and CO<sub>2</sub>, although the methods of flux measurement will vary from site to site. Carbon monoxide and NMHC fluxes will be measured at some sites. At some sites, manipulations of soil water content, soil temperature, and/or nitrogen availability will be carried out to investigate the processes controlling fluxes and to provide information for modelling. It would be preferable if these data were available in a spatially explicit format, e.g., in a GIS. It will be desirable to establish protocols for intercalibration, data handling and storage to be used generally throughout the network.

Table 1. Proposed Locations of Sampling Site Networks

Continent	Ecosystem/Land Use Type	Key Ecosystems for Study	Existing Site Network
N. America	Forest	Temperate rainforests (northwest coast)	LTER
		Mixed hardwoods (northwest, midwest)	LTER
		Southern coniferous	
		Montane coniferous	
	Rangeland	Desert	LTER
		Semi-arid shrubland	LTER
		Shortgrass steppe	LTER
		Tallgrass prairie	LTER
	Agricultural	Western irrigated	
		Western dry land Corn Belt Southeast Intensive animal-based	LTER
Europe/ N. Africa	Forest	Scots pine	NITREX
		Spruce	NITREX
		Beech	NITREX
	Rangeland	Rangeland	Desert (N. Africa)
		Semi-arid shrubland (Mediterranean)	
		Shortgrass steppe	
		Tallgrass prairie	
	Agricultural	Intensive pasture	TIGER
		Conventional arable	TIGER
		Intensive irrigated (horticultural) Semi-arid	

Table 1. (cont.) Proposed Locations of Sampling Site Networks

Continent	Ecosystem/Land Use Type	Key Ecosystems for Study	Existing Site Network
Asia	Forest	Mixed hardwood Coniferous	CERN
	Rangeland	Desert	
		Semi-arid shrubland Shortgrass steppe Tallgrass prairie	CERN CERN
	Agricultural	Irrigated	CERN
S. America/ Australasia	Forest	Southern beech ( <i>Nothofagus</i> )	
	Rangeland	Desert	
		Semi-arid shrubland Shortgrass steppe Tallgrass prairie	
	Agricultural	Temperate arable Intensive pasture	including legume-based

CERN Chinese Ecological Research Network  
 LTER Long Term Ecological Research  
 NITREX Nitrogen Saturation Experiments  
 TIGER Terrestrial Initiative in Global Environmental Research

Table 2. Urban/Intensive Agricultural Waste Disposal Sites

Landfills

Agricultural Waste:  
 Feedlots  
 Manure collection, storage and distribution\*

\* This may be accounted for in the "Intensive pasture" agricultural sites.

**Table 3. Data Needs**

Purpose/Activity	Data Required
Gas Flux Measurement (methods will vary from site to site) CO <sub>2</sub>	CH <sub>4</sub> NO <sub>2</sub>  CO* NMHCs*
Site Characterisation	Climate (physical and chemical) Soils (classification, physical, chemical, biological) Soil moisture Vegetation (history, description, productivity) Management history Terrain map
Other Activities (will not occur at all sites)	Manipulative experiments Modelling

\* Will not be measured at all sites

**Task 5.2.2: Manipulation of Perceived Controlling Variables to Determine Their Impact on Fluxes**

One of the key components of TRAGEX is to understand how trace gas fluxes in natural ecosystems are likely to change in response to changes in climate and anthropogenic input. This need to understand how fluxes will change in response to physical and chemical changes in climate requires manipulation experiments at both the laboratory and field scales and the development of mechanistic models to describe the production or consumption of trace gases in the biosphere. Long term monitoring programmes which encompass a wide range of temporal variation will help in understanding how fluxes may alter as climate changes. However, these data will not include combinations or extremes of conditions beyond those that have occurred in recent times. Manipulation experiments are needed to address these new ecosystem states. The long term monitoring data and manipulation experiments will allow us to develop trace gas flux response functions that will account for the diverse factors that control these gas exchanges. These response functions will form the nucleus of models capable of depicting trace gas exchanges at the ecosystem scale. Manipulation studies should be based at sites where gas fluxes are already well characterised.

Scenarios for future climatic conditions include warmer conditions across much of the temperate mid-latitude portions of the globe, changes in precipitation, and possibly an increase in extreme weather events. Since there is considerable uncertainty regarding major controlling parameters for trace gas fluxes, we do not know how changes in climate will influence trace gas fluxes. In particular, the influence of changes in temperature,

moisture, anthropogenic nitrogen input and CO<sub>2</sub> concentrations on trace gas fluxes need to be better understood. More subtle changes in ecosystems affecting soil acidity and plant litter carbon quality may also alter trace gas fluxes.

Manipulation studies will need to be performed at a range of sites from natural to intensively managed systems, and will need to be appropriate to the system in question. Agricultural systems are especially amenable to a wide range of manipulation experiments since these systems will change dynamically in response to new technologies, climate change and the implementation of mitigation strategies to reduce trace gas emissions. The suite of manipulations must be comprehensive enough to allow for the development of models capable of depicting how fluxes will change under a variety of climate and management scenarios.

**Task 5.2.3: Modelling of the Processes Responsible for Trace Gas Fluxes**

*Process Models*

One of the primary objectives of TRAGEX is to improve our ability to predict future mid-latitude fluxes of CH<sub>4</sub>, N<sub>2</sub>O, CO<sub>2</sub> and CO in response to global climate change. A set of models arranged in a hierarchy will serve as an important tool for achieving this objective. This hierarchy includes:

- (1) Process-based models of specific gas fluxes
- (2) Process-based models of soil biogeochemistry
- (3) Higher level models, including:
  - (a) Process-based models of ecosystem biogeochemistry
  - (b) Plant population/community models

These models will have a modular structure so that different versions of a module can be used as part of the overall modelling approach. One critical aspect of the modular approach is that the inputs to and the outputs from a particular module will be clearly defined. This will permit all versions of a module to be used interchangeably, facilitating model comparisons and future revisions.

This entire hierarchy of models is known as the Community Terrestrial Model - a model developed by and available to the terrestrial ecosystem research community. The process-based models for specific gases represent the first level of the hierarchy. These define exchanges between soils and the atmosphere and the factors that control them - temperature, moisture, carbon and nitrogen availability.

Inputs that define these controlling factors come from the next level in the hierarchy, the process-based soil biogeochemical models. The soil biogeochemical models define how soil carbon and nitrogen dynamics are influenced by abiotic factors (temperature, moisture, soil texture), as well as by plant processes. In addition to conveying information *down* to the gas flux modules, the soil biogeochemical modules permit transfer of information *up* to the whole ecosystem biogeochemical models.

Whole ecosystem biogeochemical models will receive information from and provide information to plant population/community models. The coupling of these models is essential for predicting how ecosystem biogeochemical changes will affect plant community structure and how changes in plant community structure will affect ecosystem biogeochemistry.

It is envisaged that either the whole ecosystem biogeochemical model or the linked models (biogeochemical/community) can be coupled with data from a geographic information system to yield regional estimates of trace gas fluxes. After model development using data from selected sites within the monitoring network, the models will be validated by applying them to measured fluxes from other sites in the network.

### *Scaling*

Scaling is central to modelling large scale fluxes of trace gases: Without consideration of the different scales at which processes occur it is impossible to extrapolate appropriately to regions and to the globe as a whole. The primary goal of this Activity is to develop a practical and theoretical framework for extrapolating mid-latitude trace gas fluxes to regional scales. There are two primary objectives for this work:

- 1) To determine appropriate field measurement strategies for large scale, long term flux estimates; measurement strategies range from chamber and tower networks to aircraft campaigns.
- 2) To develop linkages between process-level simulation models and spatial databases that allow long term, large scale fluxes of gases to be represented for heterogeneous landscapes.

The first step toward addressing these objectives must be to identify the appropriate spatial scales for model extrapolation. These scales will vary both with the process and within the landscape under investigation. For many processes (e.g., N<sub>2</sub>O production), the scale of maximum variation may occur at the level of soil aggregates or plant rhizospheres; for such processes landscape models may need to link process models across a wide range of geographic units. For other processes, the scale of maximum variation may be at larger spatial scales and landscape-level models will be concomitantly coarse. Determining scales appropriate for specific fluxes in various environments will require significant early effort. Understanding these scales will define appropriate measurement strategies for the different gases. The choice of chamber, micrometeorological and aircraft based techniques will differ, depending on the nature of the gas and the landscape.

A second step that can be taken in parallel with the identification of appropriate scales at which measurements are made is to establish matching scales for the purpose of modelling. Spatially explicit models now under development for other biogeochemical processes will require modification to incorporate modules relating to gas fluxes at the process level. These spatial models will link spatial databases, such as GIS, to the process-specific models. The process-specific models will define the key parameters at the system level needed in these databases; it is likely that there will be a need for additional information to be added to existing databases.

Finally, once the appropriate scales are identified and the spatially-explicit models developed, the models will require validation. At the ecosystem level, validation will be performed by comparing actual fluxes to predicted fluxes within individual systems. At regional scales, validation will be performed by comparing model output with inverse modelling approaches based on analysis of atmospheric trace gas concentrations.

### **Timetable**

- 1992 Planning meetings in Fort Collins and Pingree Park, Colorado, in September.
- 1993 Planning meeting on European site networks in Munich in April.
- 1994 Network initiation in the U.S.  
Further planning meeting in Czech Republic in October.
- 1995- Measurement and modelling activities.  
Network workshops.

### **Focus 6: Global Distributions, Transformations, Trends and Modelling**

The differences in the composition of the atmosphere over the globe, and the short- and long term variations in this composition, are the net effect of several atmospheric and biospheric processes: Biospheric emissions, atmospheric circulation, atmospheric chemical transformations and, finally, deposition and its feedbacks (if any) to emissions. The rates of all these processes can also be affected by climate changes. Thus, the global distributions and trends of chemically, radiatively and biologically important atmospheric species are signatures of the global distributions and changes in their controlling processes.

IGAC Focus 6 addresses this important globally-integrating research area. Distinct from the regional Foci, this Global Focus is concerned with long term and global coverage of the most important processes regulating the composition of the atmosphere. The various observational Activities under this Focus utilise fixed sites, aircraft, balloons and satellites as observational platforms, and require the cooperation of many nations through international and national programmes. Six Activities currently exist under this Focus. Four are dedicated to the worldwide coordination of measurements of O<sub>3</sub> and other chemical species that drive atmospheric oxidation, to CO<sub>2</sub>, and to studies designed to characterise the entire life-cycle of aerosols and their precursor gases. The other two Activities are devoted to development of global emissions databases and to global integration and modelling.

## Activity 6.1: Global Tropospheric Ozone Network (GLONET)

Conveners: J.M. Miller, V.A. Mohnen

Ozone plays a central role in most of the key physical, chemical and radiative processes in the troposphere. It has become apparent that: 1) O<sub>3</sub> vertical distribution significantly influences the radiative forcing of the troposphere-surface climate system; and 2) the photodissociation of O<sub>3</sub> defines the "oxidation efficiency" of the free troposphere. Because of these roles, it is imperative that we gain a much more detailed knowledge of its global horizontal and vertical distribution and long term concentration trends in the troposphere than current O<sub>3</sub> measurement programmes will permit. Attainment of the following goals is an essential prerequisite for defining a global climatology and trends of O<sub>3</sub> in the troposphere with known uncertainty.

### Goals

- Promote high quality measurements of tropospheric O<sub>3</sub>.
- Facilitate the expansion of existing stations capable of profiling tropospheric O<sub>3</sub>.

### Implementation Strategy

Recent WMO assessment reports and articles in the reviewed literature characterise the state of knowledge regarding tropospheric O<sub>3</sub> trends as very sketchy. The majority of stations are located in northern mid-latitudes. There are less than 15 stations with long term records (>15 years), and most of these are located in Canada, Europe and Japan, with only one in the U.S. and one in Australia. Among these stations the data quality and sampling frequency are uneven. There is only one station in the tropics with a record from 1979, but the sampling frequency has been low. An increase in measurement frequency is needed at many of the existing stations, and new stations are required in regions where there are none. The assurance of continuity is required at several of the stations established in recent years. By far the greatest need is for improved data quality, for both present and future measurement stations. This is the focus of two of the three initial Tasks of GLONET.

From considerations of the causes of O<sub>3</sub> variability, the size of the region of the atmosphere effectively sampled above a fixed observation station, and trend prediction analysis, it has been concluded that an increase in measurement frequency and a major expansion of the current number of O<sub>3</sub> measurement stations would be necessary to detect regional and global trends of tropospheric O<sub>3</sub> with an accuracy of  $\pm 1\%$  per year.

In order to address the stated problems, GLONET is organised initially into three Tasks. The first emphasises improvements in the quality of O<sub>3</sub> profile measurements. The second identifies geographic regions where new stations are critically needed for achieving representative global coverage and develops a strategy for needed network expansion. A third encompasses initial planning for a worldwide O<sub>3</sub> and related species intensive measurement programme in the 1998-1999 time frame to establish a global database for validation of chemistry/transport models: The International Tropospheric Ozone Year (ITOY).

## Task 6.1.1: World Calibration Facility for Ozonesondes

There are several national and international efforts underway towards building a representative global network of ozonesonde stations, and GLONET is committed to support such efforts. However, prior to any expansion, and in order to optimise the use of existing networks for accurate measurements of tropospheric O<sub>3</sub> profiles, it is absolutely essential that certain tasks be accomplished:

- Intercalibration and intercomparison of existing ozonesonde types
- Agreement on measurement frequency and timing
- Agreement on procedures for data processing and analysis

Previous intercomparisons, carried out by launching several different kinds of ozonesondes simultaneously, have left many questions unanswered about differences in instrument performance because there was no reference standard to which the ozonesondes could be compared. The calibration facility at the Forschungszentrum Jülich, Germany, operated by Prof. Dieter Kley now provides the needed facilities to resolve a number of the outstanding questions. In particular, there is a specially designed test chamber, with a reference ultraviolet O<sub>3</sub> photometer, that can be used as a standard for intercomparison under realistic simulated O<sub>3</sub> profiling conditions and to assess cross-interferences from co-pollutants.

The short term objectives of this Task are: 1) to bring together from around the world scientists from the current ozonesonde measurement programmes, and 2) to compare instrument performance in a controlled environment and, thus, determine the accuracy and other characteristics influencing data comparability of the field instruments. The long term objective is to establish a permanent facility for ozonesonde intercomparison and calibration.

The first field campaign at the Jülich Environmental Chamber is planned for 1995. The primary instrument performance related issues to be resolved during this initial campaign are as follows:

- What is the sensitivity of each ozonesonde type to O<sub>3</sub> and does this sensitivity vary with O<sub>3</sub> amount and altitude?
- Does the procedure for measuring the O<sub>3</sub> "zero" of each ozonesonde type properly account for the zero level throughout its flight profile?
- What is the time response of each sensor type to O<sub>3</sub> changes?
- Are losses in pumping efficiency properly accounted for in the current correction procedure?
- How does the current procedure of normalising integrated O<sub>3</sub> profiles to an independently measured column amount affect the accuracy of the profile?

Answering these questions will allow for standardised data processing procedures capable of producing accurate, comparable results from different programmes. It is envisioned that these experiments will require a total of four weeks at the Jülich facility.

During this time other open problems related to measurement frequency/timing and data processing/analysis will be discussed and resolved, based partially on results from the intercomparisons. It is anticipated that as a result of this GLONET effort, the Jülich controlled environmental chamber will be designated as the world intercalibration/intercomparison facility for ozonesondes.

#### **Task 6.1.2: Network Expansion for Measuring Tropospheric O<sub>3</sub> Profiles and Representative Tropospheric O<sub>3</sub> Concentrations**

This Task is strategically designed to coordinate with and build upon existing multinational research/monitoring programmes aimed at measuring and assessing long term tropospheric O<sub>3</sub> concentrations. In particular, the GLONET approach will complement ongoing efforts in WMO's Global Atmosphere Watch (GAW) programme, IAMAS's International Ozone Commission (IOC) and other major programmes concerned with surface O<sub>3</sub> measurements.

In addition, GLONET will participate in the planning of IGAC Activity 5.1 (MILOX) to encourage and promote: 1) the accurate and representative measurement of tropospheric O<sub>3</sub> profiles using ozonesondes, differential absorption lidars or other profiling techniques; and 2) the establishment of long term surface O<sub>3</sub> stations that representatively measure free tropospheric O<sub>3</sub> concentrations. This effort will also include theoretical work on the modelling of atmospheric O<sub>3</sub>. A close interaction between the modelling and the development of measurement strategy is essential.

The inaugural meeting of the GLONET Coordinating Committee, including representatives from WMO/GAW, IAMAS/IOC, EUROTRAC-2 and MILOX, is planned for 13-16 March 1995 in Garmisch-Partenkirchen, Germany. The major purpose of this workshop is to design an appropriate strategy for GLONET to promote the expansion of tropospheric O<sub>3</sub> measurements by opening new stations over the globe where the scientific need is greatest. Definition of further Tasks and milestones for GLONET is contingent upon the outcome of this workshop and on the early success of the initial Tasks outlined here.

#### **Task 6.1.3: International Tropospheric Ozone Year (ITOY)**

The aim of this task (which is still in a very early planning state) is to carry out a global scale measurement campaign of O<sub>3</sub> and its most important precursors, including hydrocarbons, CO and NO<sub>x</sub>, during a period of at least one year. The main purpose of such a campaign is to establish a global data base for validation of chemistry/transport models to be used for assessing the current and potential future anthropogenic impact on the chemical composition of the troposphere. A key component of ITOY will be an expanded network of ozonesonde (and perhaps lidar) stations, with additional sites particularly in tropical and subtropical areas. Measurements from aircraft, ships and satellites will also be a fundamental part of ITOY.

The first informal planning meeting for ITOY was held in Geneva in July, 1994. A larger meeting is planned for late 1994 or early 1995. It is hoped that the campaign itself can take place in the 1998-1999 time frame.

#### **Timetable**

1994	Initial ITOY planning meetings
1995	First GLONET Coordinating Committee Meeting in Germany (March 13-16)
	First Jülich Environmental Chamber Experiment (mid-1995)
1996-1997	Initiation of ozonesonde network expansion
1998-1999	Implementation of ITOY

#### **Activity 6.2: Global Atmospheric Chemistry Survey (GLOCHEM)**

Conveners: E.L. Atlas, D.H. Ehhalt, O. Schrems

The reactive gases O<sub>3</sub>, CO, NO, NO<sub>2</sub>, several abundant hydrocarbons and H<sub>2</sub>O play central roles in oxidising processes in the atmosphere. Their global three-dimensional distributions help to define the oxidation capacity of the atmosphere and, thus, the rate of destruction of longer lived gases like CH<sub>3</sub>Cl (methyl chloride), CH<sub>4</sub>, and the incompletely substituted hydrocarbons. Current knowledge of the global distributions and annual cycles of these reactive gases and of solar ultraviolet fluxes, which drive tropospheric chemistry, is insufficient to define and understand the fundamental oxidation processes operating over much of the globe. Obviously, the measurements of global trace gas distributions and trends will also provide information for those regional projects that are in areas covered by the global missions. Similarly, data from regional Activities will strengthen the global data base. Strong links between GLOCHEM, GLONET and the IGAC regional Activities will be maintained.

#### **Goal**

- Establish a global picture of the spatial and temporal distributions of key chemically reactive species and photochemically active solar radiation.

#### **Implementation Strategy**

Three Tasks have been outlined through which the goal of GLOCHEM will be pursued:

##### **Task 6.2.1: Field Campaigns**

In studying the available measurement modes (ships, aircraft, balloons, satellites, ground based remote sensing) it is apparent that the most practical way of substantially improving our knowledge of the climatology of reactive gases involves a series of coordinated field campaigns involving both surface based and aircraft observations in major regions of the globe. This work must necessarily be multinational. Some 15 research aircraft, several dozen research ships and a variety of land sites are potentially available for such an undertaking. Some of the instruments required for this work are generally available, but other key instruments are virtually one of a kind. Hence, there should be opportunities for multinational participation in each campaign, in an attempt to

ensure that the more complex measurements requiring the less available instrumentation are made during as many campaigns as possible. The highest priority species to be measured are O<sub>3</sub>, CO, NO, NO<sub>2</sub>, the major reactive hydrocarbons (i.e., CH<sub>4</sub> and abundant, reactive NMHCs) and water vapour, along with ultraviolet radiation fluxes in the relevant wavelength range. Other important species (H<sub>2</sub>O<sub>2</sub>, PAN, sulphur gases, HCHO, organic acids, etc.) should be included when possible. Summaries of field campaigns contributing to GLOCHEM are given in the following paragraphs. The campaign list is not all inclusive, but provides examples of the various ways in which GLOCHEM goals can be addressed.

#### Land-based Campaigns:

An understanding of the distribution and photochemical interactions of reactive trace gases in the remote troposphere is fundamental to questions about the budgets and trends of tropospheric O<sub>3</sub> and longer lived trace species, including some greenhouse gases. On the global or hemispheric scale there have been insufficient measurements of the interrelated chemical species necessary to test our understanding of photochemical transformations which control concentrations of radical species and rates of O<sub>3</sub> formation and destruction. The lack of measurements is notable, especially for the free troposphere and for areas distant from direct anthropogenic sources. Simultaneous measurements of an extensive suite of active species, made at ground-based sites at low and high altitudes over significant time periods, provide important constraints for tests of the validity of photochemical models of the troposphere. Furthermore, the development of large scale global three dimensional transport/chemistry models needed in global change studies requires a much larger database for the distributions and temporal behaviour of trace species.

#### *Second Mauna Loa Observatory Photochemistry Experiment (MLOPEX-II)*

As one example of a land-based campaign, a coordinated experimental and modelling effort has been started by the U.S. National Center for Atmospheric Research (NCAR) as a contribution to GLOCHEM. The experimental component has been carried out at the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) site which is at an elevation of 3.4 km on the island of Hawaii. The site allows free tropospheric measurements to be made during some portions of most days. The basic objectives of MLOPEX-II are: 1) to evaluate the budgets and photochemical processes of O<sub>3</sub>, odd nitrogen, and some odd hydrogen species, and 2) to build a climatology of the distributions of photochemically important short lived trace species in the remote marine troposphere.

The first objective is being pursued by making concurrent measurements of the key species that play controlling roles in the photochemical transformations of O<sub>3</sub>, odd nitrogen and odd hydrogen species in the remote troposphere. The budgets of these species and the photochemical processes involved can be evaluated as a function of air mass origin, synoptic conditions and season. The measurements provide important constraints to test algorithms for many photochemical and transport processes incorporated in models. Model assessment and evaluation will emphasize the budget of O<sub>3</sub> and the budget, partitioning and photochemical transformations of odd nitrogen and some odd hydrogen species. Relative to the second objective, to address the contribution

of atmospheric chemistry to global change, MLOPEX-II will contribute to developing such a climatology through interactions with other campaigns, both in GLOCHEM and formulated elsewhere within IGAC.

MLOPEX-II is a follow-on to and builds on the results of MLOPEX-I, which was carried out in the spring of 1988, prior to IGAC. The results of MLOPEX-I have been published in a special issue of the *Journal of Geophysical Research - Atmospheres* (97(D10), 1992).

#### Ship-based Campaigns:

Seventy percent of the Earth's surface is covered by oceans. Consequently, the marine atmosphere plays a major role in the global cycles of many important atmospheric trace constituents. Although the major sources of many atmospheric trace gases are located on the continents, the remote marine atmosphere is relevant for all trace components with atmospheric residence times long enough to allow transport from the continents to open ocean regions (a few days or more). Also, the oceans themselves are a substantial source for several relevant trace gases, in particular DMS and light hydrocarbons.

Shipborne measurements allow investigations of the composition and chemistry of the marine atmosphere on a global scale (e.g., latitudinal or longitudinal distributions). This includes both coastal regions with substantial continental influence and remote ocean areas. Experimental techniques suitable for measurements in the remote marine atmosphere are presently available for most of the relevant trace gases. State of the art techniques provide not only sufficient sensitivity for background investigations, but also measurement frequencies which give good spatial resolution of 50-100 km or better on a ship moving at typical cruising speeds. Such a horizontal resolution is adequate to identify the large scale structures in surface air trace gas distributions which are relevant on a global scale. Furthermore, this allows not only an economical use of ship time, but also the conduct of global-scale surveys within a reasonable time frame (e.g., a nearly complete latitudinal transect within 4-6 weeks).

Another major advantage of large scale, shipborne investigations is the possibility to make a substantial number of different but complementary measurements simultaneously. The capacity of many of the available research vessels is sufficient to accommodate a relatively complete range of measurement techniques for a good characterisation of marine surface air composition. It should be noted that shipborne experiments generally do not provide information about the vertical profiles of atmospheric trace substances and, therefore, cannot replace aircraft campaigns. However, they are an essential complement to aircraft experiments in ocean regions since instruments which are not suitable for aircraft due to weight, space, or electric power requirements, or slow measurement frequency may still be adapted for shipboard operation. The number of instruments that can be accommodated on an aircraft is limited compared to those which can be operated on a ship; consequently, shipborne experiments allow much more chemically detailed investigations. Three examples of shipborne campaigns are provided here.

#### *R/V Polarstern Cruises*

In 1987, 1988 and 1991, three cruises were conducted between Bremerhaven, Germany and Rio Grande, Brazil aboard the German R/V *Polarstern*, the 1991 cruise being in the

IGAC time frame. The focus for the 1988 cruise was on photochemically relevant trace gases, but ancillary studies of sulphur compounds and aerosols were conducted as well. Concentrations of NMHCs in ocean surface water were measured in order to determine the emission rates of NMHCs into the marine boundary layer. Measurements during the 1987 and 1991 cruises focused on NMHCs and CO. The results of the 1988 cruise were published as a special issue of the *Journal of Atmospheric Chemistry* (15, November, 1992).

#### *The North Atlantic Chemistry Experiment (NATAC)*

During NATAC in 1991, a cruise was carried out aboard the Russian R/V *Ernst Krenkel* in the Mediterranean Sea, the mid-latitude North Atlantic and the North Sea. Several German, Ukrainian and Russian research teams investigated the interaction of clean marine and polluted continental air masses. The studies included detailed measurements of trace gases related to photochemistry of the atmosphere (NO, NO<sub>2</sub>, PAN, NMHCs, CO, O<sub>3</sub>, etc.) as well as tracers for continental air masses (<sup>222</sup>Rn, <sup>212</sup>Pb). Meteorological observations, aerosol studies and precipitation sampling and analysis complemented the trace gas part of the programme. Also, detailed hydrological studies were conducted, including the biological characterisation of the ocean and measurements of volatile organic trace substances in the ocean. Thus, this cruise contributed results relevant to MAGE as well as GLOCHEM. The results of this cruise are available in a 1993 report from the Forschungszentrum Jülich.

#### *1996/1997 Atlantic Transect Cruise*

The next major GLOCHEM cruise is planned for 1996 or 1997 aboard *Polarstern*, and is expected to cover the latitude range from 60°N to 35°S over a time period of about 5 weeks. The main focus will be on the photochemistry of the marine atmosphere, with emphasis on the OH radical and related trace constituents. Measurements will include NO<sub>x</sub>, NO<sub>y</sub>, CO, NMHCs, O<sub>3</sub>, PAN, aldehydes, photolysis rates of O<sub>3</sub> and NO<sub>2</sub>, aerosols, CCN and meteorological parameters. The first direct measurements of OH itself from a ship will be attempted by laser-induced fluorescence and laser differential long path absorption spectroscopic techniques. This cruise is part of the German "AGF-Verbund" programme *Ozone in the Tropospheric Boundary Layer*, and will be conducted jointly by Forschungszentrum Jülich and the Alfred-Wegener-Institut für Polar- und Meeresforschung.

#### **Aircraft Campaigns:**

Aircraft campaigns are essential for the study of the vertical distribution of trace gases. They can also provide access to geographical areas which are difficult to reach on the surface, e.g., the Arctic during winter.

The vertical profiles of trace gases are influenced by vertical and horizontal transport, atmospheric losses and production, and underlying surface sources. In turn, they contain and provide information on all these processes. Because of the convoluted nature of this information, however, it generally requires the simultaneous measurement of a number of trace gases to extract useful information in an unambiguous manner. As a consequence, there has been a tendency to move towards more comprehensive and, thus, logistically more extensive campaigns requiring large aircraft.

Aircraft measurements are made in a difficult environment. Aircraft space and electric power are limited. There are large gradients between ambient and cabin temperature and pressure which induce memory effects and spurious signals in the measurement of some trace gases. Occasional encounters with clouds and pollution events in an otherwise pristine atmosphere also cause contamination problems. Finally, aircraft move at a high speed. Thus, for good spatial resolution, instruments with fast response times are required. To overcome these problems, aircraft equipment for trace gas analysis often involves sophisticated, specialised and dedicated instruments whose operation requires significant experience. Such instruments and the required experience currently exist in a limited though, fortunately, slowly increasing number of research groups. Examples of relevant aircraft campaigns follow.

#### *Pacific Exploratory Mission - Central (PEM-Central)*

PEM-Central is part of the PEM series of the NASA Global Tropospheric Chemistry Experiment (GTE) programme. It is an aircraft mission designed to provide a latitude-altitude transect of atmospheric composition over the central Pacific Ocean. The transect will extend latitudinally from Alaska to the Antarctic coast, and vertically from the boundary layer to the upper troposphere. The principal objectives of PEM-Central are to document the concentrations of photochemically active gases over remote regions of the Pacific (in particular O<sub>3</sub>, NO<sub>x</sub>, NO<sub>y</sub> and CO), and to identify the processes regulating the concentrations of these gases. A secondary objective is to provide data for constraining and evaluating global models of atmospheric CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and OH (via CH<sub>3</sub>CCl<sub>3</sub> (methyl chloroform) and <sup>14</sup>CO proxies). The mission is expected to be flown in 1995 or later. Supporting measurements planned are: C<sub>2</sub>-C<sub>10</sub> NMHCs, halocarbons, carbonyls, peroxides, aerosols, HCl, DMS, <sup>85</sup>Kr, <sup>222</sup>Rn, <sup>210</sup>Pb, <sup>7</sup>Be and NH<sub>3</sub>.

PEM-Central will use a DC-8 aircraft operated by the NASA Ames Research Center. The mission will require extensive meteorological support. Mission meteorologists will be deployed at major operational locations (Hawaii, Tahiti, New Zealand) to access satellite imagery, sonde data, weather forecasts and real-time back trajectories.

#### *The Tropospheric Ozone (TROPOZ) Campaigns*

The TROPOZ-II campaign was carried out successfully during January and February, 1992. It followed the same flight path as STRATOZ-III between 70°N and 60°S. Six laboratories were involved. A future TROPOZ-style campaign, the Global Inventory in the Northern Hemisphere (GINA) campaign, is being planned that would use an Airbus A340 aircraft converted specifically for research purposes. Airbus Industries has made the proposition to European scientists to make the latter prototype A340 aircraft available as a dedicated research platform after February, 1995.

#### *The Measurement of Ozone on Airbus In-Service Aircraft (MOZAIC) Project*

MOZAIC consists of installing automatic instrumentation for measuring O<sub>3</sub>, water vapour and temperature aboard five long range commercial aircraft (Airbus A340). Its purpose is to improve basic knowledge of the distributions of O<sub>3</sub> and H<sub>2</sub>O in the mid- and upper troposphere and to evaluate the impact on these distributions of the subsonic aircraft fleet. The programme began in January 1992 for a period of 28 months, and may be extended. Presently it is supported by the European Community (50%) and includes 15 participants

(institutions, universities, instrument manufacturers, airlines). It is hoped that the programme eventually can be expanded to have five aircraft from each of three airlines flying many thousands of hours per year across all seasons in order to obtain an extensive database.

#### Satellite Observations:

The use of satellite information to study the distributions of certain tropospheric trace gases has so far been achieved using a direct measurement technique to quantify CO in the middle and upper troposphere, and using an indirect method to determine the amount of integrated O<sub>3</sub> in the troposphere. In addition, it should be possible to extract some information about the distribution of O<sub>3</sub>, and possibly NO<sub>2</sub>, in the upper troposphere directly using limb scanning techniques.

Remote sensing of CO from two U.S. Space Shuttle flights in 1981 and 1984 was achieved with the Measurement of Pollution from Satellite (MAPS) instrument. MAPS was flown again in 1994 and is scheduled to fly on two more Space Shuttle missions between 1995 and 1996. Before the turn of the century, the international space community will launch a series of platforms collectively called the Earth Observing System (EOS). One of the scientific priorities for EOS is the capability to measure CO from space using an instrument such as MAPS. At that time, a true global climatology of CO above the planetary boundary layer should be realised.

Studies in recent years have also shown that concurrent, coincident measurements from two satellite mounted instruments can be used to derive an indirect measurement of the integrated amount of O<sub>3</sub> in the troposphere. This technique uses nadir measurements of total O<sub>3</sub>, which is the sum of the amounts in the stratosphere and troposphere, in conjunction with limb profiling measurements of just the stratospheric contribution. The difference between these two integrals, the tropospheric residual, becomes an indirect measure of how much O<sub>3</sub> is present in the troposphere. Validation studies have shown that the climatological distribution of the tropospheric residual agrees to within 15-20% with *in situ* climatological values derived independently from ozonesonde measurements.

These same limb scanning satellite instruments can often obtain data for the upper troposphere and sometimes as low as the middle troposphere, especially if no clouds are present. Thus, it should presently be possible to obtain direct measurements of O<sub>3</sub>, and possibly even NO<sub>2</sub>, if the data from these instruments can be reprocessed as far into the troposphere as possible. To date, no attempt to retrieve this possible source of tropospheric data has been attempted. The further development of remote sensing techniques for tropospheric composition will be explored in coordination with the International Radiation Commission.

#### Task 6.2.2: Measurement Intercalibration and Intercomparison

While a separate IGAC Activity (7.1, ICIC) is concerned in general with measurement standardisation, its current Tasks are limited to just a few species and species classes (N<sub>2</sub>O, halocarbons, NMHCs and CO<sub>2</sub>). Intercalibration and intercomparisons between the individual instruments used for other measurements during GLOCHEM campaigns is clearly essential to the success of these coordinated campaigns in defining the global

climatology. At the moment, relevant intercalibration and intercomparison is done through individual investigators but a more comprehensive formal mechanism needs to be instigated for GLOCHEM and many other activities.

#### Task 6.2.3: Data Handling and Modelling

Also essential to the development of global chemical climatologies is a uniform approach to processing, analysing, archiving, distributing and publishing of the data. Theoretical models should be used to help plan field campaigns as well as to provide the major vehicle for interpretation of the observations, and the extrapolation of knowledge to times and regions for which no data exist. These tasks will be taken up primarily by cooperation with the GIM Activity.

#### Timetable

1987 - 1991	Cruises conducted between Bremerhaven, Germany and Rio Grande, Brazil aboard the German R/V <i>Polarstern</i> .
1991	Cruise aboard Russian R/V <i>Ernst Krenkel</i> for NATAC in the Mediterranean Sea, mid-latitude North Atlantic and North Sea.
1992	Initiation of the Measurement of Ozone on Airbus In-Service Aircraft (MOZAIC) Project.
1992	TROPOZ-II campaign.
1996 or 1997	Cruise aboard <i>Polarstern</i> , covering latitude range from 60°N to 35°S over a time period of about 5 weeks.

#### Activity 6.3 Global Tropospheric Carbon Dioxide Network (GLOCARB)

Convener: C.D. Keeling

Carbon dioxide, because of its central role in the carbon cycle, is closely associated with reactive gas species that display strong interactions with the terrestrial biosphere and oceans. Its lack of reactivity in the atmosphere, but strong association with chemical processes in the oceans and on land, renders it a highly valuable gas to compare with reactive gases involved in the carbon cycle. By including measurements of the <sup>13</sup>C/<sup>12</sup>C and <sup>14</sup>C/<sup>12</sup>C ratios of CO<sub>2</sub>, as well as of its mixing ratio with respect to dry air, the major releases and uptakes of CO<sub>2</sub> at the Earth's surface by the oceans can be assessed from atmospheric data separately from the releases and uptake of the terrestrial biosphere.

Atmospheric CO<sub>2</sub> measurements, when interpreted by global transport models, provide broad-scale estimates of emissions and uptakes of CO<sub>2</sub> at the Earth's surface that are of critical importance to the global budget of CO<sub>2</sub>. Regional integrals of the net flux of CO<sub>2</sub> over water can be determined and used in the validation of studies of air-sea gas exchange. Similar integrals of flux over land provide validation of studies of net primary productivity and respiration of land plants and soils, and of man-made perturbations of the global carbon cycle.

Measurements of CO<sub>2</sub> should be carried out together with measurements of more reactive species to aid in the study of a wide range of processes, including forest and grassland fires, deforestation and the mechanism of gas exchange at the sea surface, because CO<sub>2</sub> data can give clear indications of the global scale aspects of these processes.

Global atmospheric CO<sub>2</sub> measurements were formalised internationally by the World Meteorological Organisation (WMO) in 1970 to be part of a new programme on Meteorological Aspects of Air Pollution. To assist in the implementation of this activity, WMO convened a Panel of Experts on Carbon Dioxide Monitoring which first met in March 1975, and subsequently approximately every three years. At their meeting in 1990 in Lake Arrowhead, California, USA, the WMO CO<sub>2</sub> experts requested inclusion of atmospheric CO<sub>2</sub> studies in IGAC. The *Global Tropospheric Carbon Dioxide Network* (GLOCARB), was accepted as IGAC Activity 6.3 later that year. A separate but intimately related endeavour, the *Carbon Dioxide Intercalibration Experiment* (CARBICE), was also accepted as Task 3 of Activity 7.1. The goals and initial action plans for these two new IGAC activities were discussed by the panel and their recommendations were included in the WMO Report No. 77. A meeting under the joint sponsorship of IGAC and WMO was held in September 1993 in Rome, Italy, to coordinate the international CO<sub>2</sub> programmes.

#### Goals

- Define the synoptic scale and seasonal variations, and the interannual trends of atmospheric CO<sub>2</sub>.
- Establish the important regional and global scale sources and sinks of the CO<sub>2</sub> cycle.

#### Implementation Strategy

Five Tasks have been outlined for this Activity:

##### Task 6.3.1: Maintain Existing Global Station Network

The monitoring of CO<sub>2</sub> and its isotopic ratios <sup>13</sup>C/<sup>12</sup>C, <sup>18</sup>O/<sup>16</sup>O and <sup>14</sup>C/<sup>12</sup>C is an on-going activity. The goals are to document accurately the increase of CO<sub>2</sub>, and to determine the components of its global budget (sources and sinks). The latter is done by carefully measuring at different sites the relatively small spatial and temporal differences of the CO<sub>2</sub> mixing ratio in dry air and its isotopic ratios.

There are about 50 sites worldwide at which CO<sub>2</sub> measurements are being made regularly, either through the collection of flask samples or with analysers *in situ*. Additional measurement sites are gradually being added, and isotopic ratios are being obtained for more sites. Coordination is being provided by the WMO through its *Global Atmosphere Watch* (GAW) programme. The original emphasis of this programme was on the observation of well-mixed marine boundary layer air. Newer initiatives are now also intended to provide a picture of the mixing ratios and the isotopic ratios at higher altitudes in the free troposphere, and in the continental boundary layer. Very precise intercalibration is a necessary condition for the success of this monitoring programme (see Task 7.1.3).

##### Task 6.3.2: Augmented Network over Land and Aircraft-based Observations

Systematically collected data over land and above the boundary layer are needed to validate transport models and to provide closer surveillance of terrestrial CO<sub>2</sub> exchanges. Present observing stations for CO<sub>2</sub> mainly sample marine air in the atmospheric boundary

layer. These stations should be augmented to include continental sites in rural areas. Also, aircraft sampling should be carried out on a regular basis, including sampling in the vertical column and on broad transects, and isotopic measurements should be included at additional locations where concentration data are obtained.

##### Task 6.3.3: Isotopic Data Base

To distinguish sources and sinks of terrestrial origin from those that are oceanic, isotopic data would be more valuable if certain critical isotopic fractionations were better known. Field investigations are needed to establish how the fractionations of <sup>13</sup>C/<sup>12</sup>C involved in the growth and decay of terrestrial vegetation vary in time and space. Also, the isotopic fractionation involving exchange with the oceans needs to be better established. In addition, sampling of air downwind of cities should be carried out for at least a year to assess the <sup>13</sup>C/<sup>12</sup>C of industrial CO<sub>2</sub> from combustion of fossil fuels. Investigations of the still poorly understood processes affecting the <sup>18</sup>O/<sup>16</sup>O ratio of atmospheric CO<sub>2</sub> should be continued.

##### Task 6.3.4: Model Development

Models to relate atmospheric CO<sub>2</sub> distributions to sources and sinks at the Earth's surface should be further developed to establish the transport of CO<sub>2</sub> in the atmosphere. These models should be compared with, and coupled to models of the terrestrial biospheric and oceanic carbon cycles to investigate the response of the global carbon cycles to changing environmental conditions. Model development should be coordinated so that simulations of the global carbon cycles can be constrained by atmospheric observations of the three major carbon cycle gases (CO<sub>2</sub>, CH<sub>4</sub> and CO).

##### Task 6.3.5: Balancing the Global Carbon Cycle

At present the global carbon cycle cannot be balanced to better than about 50% of anthropogenic CO<sub>2</sub> emissions. As a consequence, the time that excess CO<sub>2</sub> produced by human activities will remain in the atmosphere is so poorly known that the long term greenhouse warming potential of CO<sub>2</sub> cannot be established or compared to that of other greenhouse gases. In order to bring the carbon budget into balance to the desired closure (within 10% or better), improved measurements of CO<sub>2</sub> must be brought together with measurements of CO and CH<sub>4</sub> and with improved oceanic and terrestrial measurements through a coordinated effort with all appropriate IGBP projects able to contribute to resolving this problem. Modelling studies as well as gathering and interpreting the additional data are necessary components of this task.

#### Timetable

1993 Fourth International CO<sub>2</sub> Conference in Carqueiranne, France in September.

Joint WMO CO<sub>2</sub> Experts and GLOCARB/CARBICE meeting in Rome, Italy, in September.

1995 Symposium on "The Breathing of the Earth: Observational Constraints for Models of the Terrestrial Biosphere" at IUGG (International Union of Geology and Geophysics) meeting in Boulder, Colorado, in July.

#### Activity 6.4: Multiphase Atmospheric Chemistry (MAC)

Conveners: T.S. Bates, J.L. Gras

While the forcing of global climate by anthropogenic, infrared light absorbing gases is widely accepted and given high priority for research, it is now recognised that anthropogenic aerosol particles also have globally significant radiative effects. Even though the residence time of aerosol-borne substances is short and their areal extent is limited, the sum-total of the effects over the globe are calculated to be comparable in magnitude but opposite in sign to the "greenhouse forcing" by CO<sub>2</sub>, CH<sub>4</sub>, etc. For example, anthropogenic sulphate alone has been estimated to cause a change of approximately -1 watt m<sup>-2</sup> in the Northern Hemisphere heat balance. This forcing is similar in magnitude but opposite in sign to the effect of anthropogenic CO<sub>2</sub> (approximately +1.5 watt m<sup>2</sup>).

Multiphase atmospheric chemistry, i.e., the combination of physical and chemical processes that control the evolution and properties of the atmospheric aerosol, influences global heat balance by at least two mechanisms: 1) direct forcing of the radiative balance occurs mainly due to backscatter of solar radiation to space by aerosol particles (the direct

impact on long wave radiation usually is small); and 2) indirect forcing occurs because some aerosol particles act as CCN, thereby influencing the albedo of clouds and possibly their areal extent and longevity.

These two effects are expected to influence global climate strongly, although not uniformly in a geographical sense. Conversely, changes in climate could also influence both the concentration and properties of the aerosol particles, e.g., through cloud microphysical processes or removal by precipitation. Chemical transformations occur within the condensed phases of clouds; these play an important role in the cycling of many compounds that are of global significance. Multiphase atmospheric chemical processes can affect the ultimate composition of aerosols and precipitation; hence an understanding of these processes is crucial to retrieving information about past global climates from studies of snow and ice cores. The chemical and physical properties of the aerosol particles are central to all these influences, and these properties are highly sensitive to human activities.

Most aerosol particles are formed in the atmosphere from gas-phase precursors via chemical reactions and physical transformation. Although understanding the chemical and physical evolution of aerosol particles is important to the modelling of clouds, atmospheric radiative properties and climate, knowledge of the dynamics of this system is virtually non-existent. Also, the most important aerosol species are derived from sulphur gas precursors, but an understanding of the global sulphur cycle and the role that clouds play in it is still largely incomplete. It is possible that atmospheric dynamics involves feedback processes, for example, the modification of the biological production of natural aerosol gaseous precursors via direct or indirect radiative forcing, or the modification of rainfall patterns and aerosol lifetimes via either radiative changes or CCN-modulated droplet size distributions. At present, mostly national efforts to address these issues are limited by the availability of instrumentation, observational platforms and scientific personnel. International collaboration could achieve the critical mass for the necessary comprehensive studies, and this is being actively sought.

This Activity was formerly called Cloud Condensation Nuclei under IGAC Focus 8 (Cloud Condensation Nuclei as Controllers of Cloud Properties) as described in IGBP Report No. 12. During a workshop of the Coordinating Committee held in Stockholm in June, 1991, the participants decided to refine and redefine the terms of reference for this Activity, which were originally developed at the Dookie Workshop in November, 1988, in order to more accurately reflect the present understanding of the role of multiphase atmospheric chemical processes governing direct and indirect roles of aerosols in climate. The name of this Activity was changed to the present title, Multiphase Atmospheric Chemistry (MAC), and the new research focus is the role of multiphase atmospheric chemical processes as determinants of those aerosol properties which are relevant to the radiative forcing of climate. The original IGAC Focus 8 is now merged into Focus 6 and MAC is Activity 6.4 under Focus 6. The MAC Coordinating Committee will continue to formulate plans for international, cooperative field experiments and modelling activities which will address these aerosol/climate issues. In addition, discussions are underway with an international group of aerosol researchers to augment and improve the aerosol science component in IGAC overall.

#### Goals

- **Characterisation:** To document the chemical, physical and optical characteristics of aerosols in the key air masses (i.e., clean vs. polluted marine air; clean vs. polluted continental air and upper tropospheric air) and investigate the relationships between these aerosol properties.
- **Processes:** To determine the key physical and chemical processes controlling the formation and fate of aerosols and how these processes affect their number size distribution, chemical composition and optical and cloud nucleating properties.
- **Modelling:** To develop and use improved aerosol and cloud parameterisations in order to relate the factors controlling the radiative and cloud nucleating properties of aerosols to sources of aerosols and aerosol precursors and large scale variables used in climate model calculations.
- **Spatial extrapolation:** To evaluate the means to utilise and interpret remote sensing to extend local aerosol concentration measurements to larger geographical areas.

#### Implementation Strategy

Reducing the uncertainties in estimates of aerosol forcing of climate will require a combination of laboratory experiments, long term continuous and short term intensive field studies, satellite observations and modelling analyses. Although much of this work can be accomplished by single laboratory groups, intensive process studies that seek to obtain closure (internal consistency) between various measured and modelled aerosol properties often require a large number of research platforms and investigators. IGAC provides the framework for international cooperation and leadership needed for these large process studies. The *Aerosol Characterisation Experiments* (ACE) are envisioned as a series of international field studies aimed at quantifying the role of the combined chemical and physical processes that control the evolution and properties of the atmospheric aerosol that are relevant to radiative forcing and climate. The ultimate goal

of this series of process studies is to provide the data necessary to incorporate aerosols into global climate models and to reduce the overall uncertainty in the calculation of climate forcing by aerosols. The strategy to achieve this goal mandates improved understanding of the multiphase atmospheric chemical system, including gas and aerosol exchange at the ocean surface, a goal shared by MAGE. ACE-1, the first experiment, is aimed at the minimally polluted marine troposphere. ACE-2 will examine the marine atmospheric gas/aerosol systems over the North Atlantic Ocean and Mediterranean Sea, with a primary focus on the anthropogenic perturbation of these systems.

ACE-1 will be conducted from 15 November to 14 December 1995 over the southwest Pacific Ocean, South of Australia and will involve the joint efforts of MAC and MAGE. The MAC and MAGE committees chose the remote marine atmosphere for the first ACE process study because non-sea-salt (nss) sulphate aerosol particles in the remote marine atmosphere are thought to have only one primary gaseous precursor, DMS, thereby simplifying studies involving the formation and growth of the aerosol. This environment also provides an opportunity to establish the chemical, physical and optical properties of the natural aerosol system and thus provides a background against which to compare and quantify any anthropogenic perturbation.

The specific goal of ACE-1 is to determine and understand the properties and controlling factors of the aerosol in the remote marine atmosphere that are relevant to radiative forcing and climate. To achieve this goal, the ACE-1 Science Team has identified six specific questions that must be answered.

1. Can the measured physical and chemical properties of the aerosol be used to predict the optical and cloud nucleating properties of that same aerosol?
2. Can the measured physical and chemical properties of the aerosol in a vertical column be used to accurately predict the integrated effect of aerosols on radiative transfer?
3. What are the biological, chemical and physical processes controlling the concentration of DMS in surface sea water and its flux to the atmosphere?
4. What are the rates and efficiencies of the processes controlling DMS and SO<sub>2</sub> oxidation in the marine boundary layer?
5. What are the rates and efficiencies of the processes controlling the nucleation, growth, distribution and removal of aerosols in the remote marine atmosphere?
6. How can observations be used to improve the accuracy of aerosol-climate models?

A simultaneous chemical, physical and optical characterisation of the atmospheric aerosol is needed to develop and test model calculations of aerosol radiative effects and to refine and validate the algorithms used to interpret satellite observations of the aerosol. These measurements will be made from ground, ship and aircraft platforms during the intensive experiment and during the transit flights (north- and southbound) and cruise (southbound only) between the U.S. and Australia. To validate these measurements the Aerosol Characterisation Experiments will attempt to obtain "closure" between the various parameters. These closure studies will over-determine aerosol properties or related processes using a variety of measurement and modelling techniques in order to examine the internal consistency of these different measurement and modelling strategies.

The climatic importance of the atmospheric aerosol also requires improved parameterisation of the processes that control the aerosol sources, properties, evolution and spatial distribution. While satellites offer observations on a planetary scale, they lack any capability for chemical analysis of the aerosol particles and for coupling the spatial distribution of the aerosol to spatially and temporally variable aerosol precursors and source processes. Modelling of the aerosol system, including gaseous precursors and sources, aerosol production processes and properties, and the three dimensional spatial and temporal distribution offer the only possibility for coupling locally measured properties to global forcing and effects.

The observational data collected during ACE-1 will be useful for testing and improving a hierarchy of related models:

- Detailed process models to describe DMS production and air-sea exchange, atmospheric gas and liquid phase chemical reaction rates and aerosol and cloud microphysical processes and properties,
- One-dimensional single column models to evaluate the performance of process parameterisations and to provide information on the vertical profiles of aerosol parameters needed for radiative transfer calculations,
- Cloud scale three-dimensional large-eddy simulation (LES) models with explicit cloud microphysics to assess the interaction between clouds and aerosols, and
- Regional and global three-dimensional models to reveal the geographical and temporal distributions of the aerosol.

Rather than simply providing the modelling community with data, ACE-1 is being planned in concert with members of the modelling community to ensure that the data will be useful for validating and refining models. ACE-1 will also include aerosol measurement workshops and intercomparisons. An additional goal of this programme is to establish measurement protocols that can be used to standardise aerosol sampling.

ACE-2 will examine the marine atmospheric gas/aerosol systems over the North Atlantic Ocean and Mediterranean Sea, with a primary focus on the anthropogenic perturbation of these systems. The intensive campaign is planned for summer 1997 in an area southeast of the Azores. The experimental strategy will include both this intensive campaign and a one year set of ground based and satellite observations that will put the intensive campaign in the context of the larger North Atlantic region and allow the observation/assessment of regional climate forcing.

#### Timetable

1994 ACE-1 planning meeting in Tasmania, Australia (February)

ACE-2 planning meeting in Ispra, Italy (October)

1995 ACE-1 planning meeting in Hilo, Hawaii (February)

ACE-1 aerosol measurement workshop in Seattle, Washington (August)

ACE-1 planning meeting in Boulder, Colorado (September)

ACE-1 field programme (October-December)

1996 ACE-1 data workshop

ACE-2 planning meetings

1997 ACE-1 data workshop

ACE-2 experiment (June-July)

1998 ACE-2 data workshop

ACE-3 planning meeting

1999 ACE-3 experiment

#### Activity 6.5: Global Emissions inventory Activity (GEIA)

Convener: T.E. Graedel

One of the most important scientific tools used in the assessment of atmospheric chemistry, air quality and climatic conditions of the past, present and future is mathematical models of transport and transformations in the atmosphere. These models rely in part on inventories of emissions constructed on appropriate temporal and spatial scales and including the required chemical species. The production of such inventories, initially regarded as adjunct to modelling activities, is now a separate area of research whose importance to the accuracy of results of modelling and assessment activities has been fully recognised. The myriad of problems involved in the compilation of accurate inventories on a local or regional basis is multiplied manifold when the geographic area of interest is extended to the multinational, hemispheric and global domains. Recognising that the most accurate information on emissions is usually developed by experts from individual countries, the IGAC Scientific Steering Committee has defined an activity whose main goal is the development of global emissions inventories by international teams of experts.

The ultimate goal of the *Global Emissions inventories Activity* (GEIA) of IGAC is to establish emissions inventories for a number of trace species, incorporating fluxes from both anthropogenic and natural sources, with recognised accuracy and enough spatial, temporal and species resolution to serve as standard inventories for the international community of atmospheric scientists.

The GEIA efforts started in September, 1990. As with all IGAC Activities, GEIA tries to include all interested parties on a volunteer basis. Emissions inventory experts from individual countries, supported by local organisations, conduct their own research while maintaining contact through a communications network and participation in periodic

meetings. The GEIA forum allows participants to discuss their work and to draw on combined expertise of their fellow members. This coordination of efforts ensures that results of their work are compatible and can be combined with a minimum of effort.

#### Goals

- Establish a framework for the development and evaluation of global emissions inventories.
- Conduct a critical survey of existing emissions inventories of compounds of major importance in global atmospheric chemistry.
- Publish inventories in the open literature and provide appropriate data files for use by scientists worldwide.

Existing inventories have been compiled for a variety of purposes. Their spatial, temporal and species resolution are dependent not only on their final use but also on the resources available for and the methodologies used in their development. Historically, emissions inventory development started with what may be termed effect inventories. These inventories were directed toward specific impacts, such as environmental acidification or atmospheric visibility, or towards species that contribute to those effects. These inventories were generally regional or national in scope and included only anthropogenic sources. With the advent of environmental regulations, inventories were also needed to develop and administer these regulations; additional details on emission sources were included in the inventories to help in these endeavours.

There are several categories of users for the inventories that are developed. The first is the international scientific community, especially the computer modelers. The second group includes those developing other inventories for various purposes; their activities are likely to be useful to GEIA efforts and vice versa. A third group consists of intergovernmental groups who may find the GEIA inventories useful for various diplomatic and covenant purposes.

The GEIA effort will encompass all the phases of the compilation of the desired emissions inventories. To help direct the work, inventories have been initially classified into five types:

#### 1. Supporting Inventories

These are the inventories needed for the derivation or apportionment of the actual emissions values, i.e., the ancillary data. These data may reflect natural conditions or human activities; examples include populations (human, animal, etc.), vegetation cover, topography, land use, soil type, etc.

#### 2. Effects Inventories

These inventories are directed to the study of a specific impact such as acidification, or towards a species that contributes to that effect. They may be global in extent, or may refer to a specific continent, country, or region. Single species emissions inventories are included in this category and are the most common of all the atmospheric inventories.

### 3. Process Inventories

Process inventories are those connected with a specific process or activity; biomass burning is a good example. Biomass burning is a significant contributor to many global atmospheric budgets and is a periodic event in many parts of the world.

### 4. Specific Event Inventories

These inventories comprise those emissions arising from specific events, e.g., emissions from large volcanic events. Development of inventories for some events, previously considered of short duration, is being extended to a more regular basis; an example is inventories of emissions from periodically degassing volcanoes.

### 5. Past/Future Inventories

These inventories refer to specific periods in the past, used in studies related to historical atmospheric chemistry, or present scenarios of emissions for some future period of time, used in connection with predictive studies of atmospheric chemistry and air quality. In connection with field data from sediments and ice cores, they provide the potential to link emissions with effects over very long time periods.

## Implementation Strategy

### A. Approach:

Work under the GEIA umbrella is directed by a Coordinating Committee and carried out by study groups. The Coordinating Committee is drawn from members of the individual study groups; it sets the overall direction for and coordinates all GEIA activities.

The Coordinating Committee has adopted three principles of operations to govern emissions inventory tasks:

1. The ultimate goal of GEIA is to produce emissions inventories for all species of interest on a 1\_ by 1\_ global grid.
2. All inventories shall be accompanied by point-by-point assessment of their degree of uncertainty.
3. The study groups formed for each GEIA activity shall be international and intercontinental in makeup.

### B. Current GEIA Activities:

Given the many possibilities for inventory development, the Coordinating Committee has decided to begin the GEIA Tasks by concentrating on evaluating and producing effects inventories targeted to individual species or groups of closely related species. Individual study groups will be established as the interest of participants develops. Table 4 presents a summary of currently active GEIA study groups, the director(s) of each study groups and the targeted temporal resolution for each inventory.

Supporting inventories, especially those used for the development of the effects inventories to be evaluated and used, will be encouraged but will not be a formal part of the GEIA. Part of the mandate of the Data Management group is to develop and implement GEIA policy towards this type of inventory. Event inventories, historical inventories and future scenario inventories are also within the GEIA purview and will be accomplished as time, personnel and funding allow. In fact, one of the current GEIA study groups is addressing what was previously defined as a regular specific event, biomass burning.

In advance of providing GEIA's internationally recognised emissions inventories, a GEIA subcommittee compiled a summary and description of existing inventories, together with their spatial and temporal attributes and a few interpretive comments. The only global ensemble emissions inventory that was regarded as good was that for CFCs. Those for CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, SO<sub>2</sub>, reduced sulphur and radon were regarded as fair. (Good implies an estimated accuracy of 20% or better, fair of 50% or better.) In selected regions, the spatial resolution of emissions was regarded as well-determined for CO<sub>2</sub>, CO, NO<sub>x</sub> and SO<sub>2</sub>. The temporal resolution of existing inventories was rated almost uniformly poor. This compilation provides the detailed justification for the GEIA inventory activities, while, in addition, serving to some degree the needs of the modelling community on the immediate time scale.

Emissions inventories produced under GEIA auspices began to be available to researchers in mid-1994.

### C. Support Services:

The present activities of GEIA are being performed as a cooperative effort of atmospheric scientists from around the world, rather than as a fully funded project of an institution or organisation. Given the importance of reliable global emissions inventories in the assessments of environmental conditions, a more highly structured approach to inventory development is needed.

A GEIA Secretariat has been established at the Norwegian Institute for Air Research, Lillestrom, to coordinate the activities of GEIA, e.g., organise workshops and meetings as needed, publish and distribute the resulting inventories. In addition, a Data Management Center has been established in Boulder, Colorado, to develop and implement data management protocols and to maintain the emissions inventories.

### D. Future Plans:

The ultimate goal of GEIA is to establish emissions inventories for all trace species of interest, incorporating fluxes from both anthropogenic and natural sources, so that the resulting inventories, periodically updated as needed, can become standard inventories for the international community of atmospheric scientists. The current GEIA study groups represent a vigorous start toward that goal, but many other topics also require attention.

Table 4. GEIA Active Emissions Inventory Projects

Project	Director	Spatial Resolution	Temporal Resolution	Ref. Year	Est. Date of Release
VOC (N) <sup>#</sup>	Hewitt, UK Guenther, USA	1° x 1°	2 Seasons	—	Jun 94
CO <sub>2</sub> (A)	Marland, USA	1° x 1°	Annual	1987	Jun 94
Aircraft <sup>‡</sup>	Wuebbles, USA	1° x 1° x 1 km	Annual	1990	Jun 94
NO <sub>x</sub> (A)	Pacyna, NOR Benkovitz, USA	1° x 1°	Annual	1985	Jul 94
SO <sub>2</sub> (A)	Pacyna, NOR Benkovitz, USA	1° x 1°	Annual	1985	Jul 94
NO <sub>x</sub> (A)	Voldner, CAN Scholtz, CAN	1° x 1° x 2 levels	Seasonal	1985	Aug 94
SO <sub>2</sub> (A)	Voldner, CAN Scholtz, CAN	1° x 1° x 2 levels	Seasonal	1985	Aug 94
Pb (A)	Pacyna, NOR	1° x 1°	Annual	1985	Aug 94
CFC (A)	Cunnold, USA	1° x 1°	Annual	1985	Oct 94
Radon (N)	Kritz, USA	1° x 1°	Annual	—	Mid-95
VOC (A) <sup>‡</sup>	Berdowski, NL Benkovitz, USA	1° x 1°	Annual	1985	Mar 95
NH <sub>3</sub> (A)	Bouwman, NL	1° x 1°	Annual	1985	May 95
Biomass burning (A+N)	Goldammer, GER Levine, USA Stocks, CAN	1° x 1°	Annual	1987	Dec 95
N <sub>2</sub> O (A+N)	Bouwman, NL	1° x 1°	Annual	1985	Dec 95
CH <sub>4</sub> (A)	Roulet, CAN Matthews, USA	1° x 1°	Annual	1985	Not determined
Organo-chlorides (A)	Voldner, CAN	1° x 1°	Annual	1985	Not determined
Reduced S (N)	Tarrason, NOR	1° x 1°	Annual	—	Not determined

Table 4. (cont.) Active Emissions Inventory Projects

Project	Director	Spatial Resolution	Temporal Resolution	Ref. Year	Est. Date of Release
Hg (A)	Pacyna, NOR	1° x 1°	Annual	1985	Not determined
CO (A)	Logan, USA	1° x 1°	Annual	1985	Not determined
Data Management	Middleton, USA	1° x 1°	Annual	1985	Not determined

% A = anthropogenic; N = natural

<sup>#</sup> Speciated into isoprene, terpenes, short-lived VOC, and long-lived VOC.

<sup>‡</sup> Will be speciated; divisions yet to be determined.

<sup>@</sup> The co-directors for the biomass burning emissions project are B. Stocks (Canada), J. Levine (USA), and J. Goldammer (Germany).

<sup>†</sup> This inventory is available through the courtesy of the NASA Atmospheric Effects of Stratospheric Aircraft Program.

GEIA will perform periodic updating of existing inventories to reflect changes in technology, regulation and culture that influence the emissions to and concentrations of species in the atmosphere. For many parts of the world, especially in the developing countries, current inventories are very poorly known, and the construction of reliable inventories on appropriate spatial scales will be a major undertaking.

Emissions inventory activities, like other scientific activities, will move forward in new and interesting ways over the next several years. One can foresee, for example, that inventories will be needed for species newly discovered to be of significance. The increased dimensionality of chemical models will make it important to do inventories in three dimensions rather than two in some instances, as for aircraft emissions of NO<sub>x</sub> in studies of stratospheric O<sub>3</sub> depletion. Another thrust will be in support of the evolving community of nested models, in which certain key regions are treated with higher spatial resolution than the entire geographical area of the parent model. As in other cases, the inventories will need to keep pace with these modelling advances.

Another evolving activity is the linking of information concerning the atmosphere with that of various systems at the Earth's surface. Thus, while current efforts tend to concentrate on the effects of surface activities on the atmosphere (e.g., rice cultivation

patterns are specified in order to estimate emissions of CH<sub>4</sub> to the atmosphere), much future activity will treat the impacts of the atmosphere on surface systems (e.g., the effects of sulphate deposition on soil acidity). As a consequence, a suite of inventories of deposition from the atmosphere in support of studies in plant ecology, ocean productivity, biodiversity and the like will be needed in the future.

#### Timetable

- 1992 Second GEIA Workshop in Oslo, Norway in June.  
Progress report on anthropogenic SO<sub>2</sub>/NO<sub>x</sub> inventories.
- 1992-93 Completion of global anthropogenic SO<sub>2</sub>/NO<sub>x</sub> emissions inventories.
- 1993 Third GEIA Workshop in Amersfort, The Netherlands in January.  
Inventories of CH<sub>4</sub>, biogenic VOCs, SO<sub>2</sub> and NO<sub>x</sub>.  
Joint GEIA/OECD (Organisation for Economic Cooperation and Development) workshop on methane emissions.
- 1993 Completion of inventories on biomass burning emissions and VOCs from natural vegetation.
- 1993 Fourth Workshop in Boulder, Colorado in December.  
Status reports on biomass burning and CH<sub>4</sub> emissions inventories; data management procedures.
- 1994 Fifth GEIA Workshop in Fuji-Yoshida, Japan in September.  
Concentration on emissions inventories for Asian countries.
- 1995 Sixth GEIA Workshop in Gothenburg, Sweden in June.  
Inventories of CH<sub>4</sub>, biogenic NO<sub>x</sub>, NH<sub>3</sub>, anthropogenic VOCs.
- 1996 Seventh GEIA Workshop (location and date to be determined).  
Inventories of emissions from biomass burning and aerosol inventory.

#### Activity 6.6: Global Integration and Modelling (GIM)

Convener: G.P. Brasseur

Aerobiochemical models are being developed and used to study the sources and fate of chemical constituents in the atmosphere and to assess their role in the climate system. The intents of GIM are: 1) to develop atmospheric chemical-transport (ACT) models capable of reproducing the observed global distribution of key chemical compounds and to validate these models, and 2) to use these models to determine global budgets of trace

constituents and to study processes which affect the distributions of these compounds. Particular attention will be given to the interactions between the atmosphere and the biosphere, and comprehensive models of surface exchanges will be developed. GIM will also help design field campaigns in support of IGAC objectives and contribute to the interpretation of data gathered during these campaigns. Eventually, aerobiochemical models will predict potential changes in the chemical composition of the atmosphere as a result of human activities.

GIM is an emerging project which is currently in the planning stage. It will make extensive use of data archived by IGBP-DIS and will cooperate directly with GAIM.

#### Task 6.6.1: Surface Exchanges

The chemical composition of the lower atmosphere is strongly influenced by exchanges between the surface and the troposphere. Emissions associated with biological processes on the continent and in the ocean, with volcanic eruptions and with anthropogenic (agricultural, industrial and domestic) activities need to be accurately estimated as a function of location and time. These emissions, which are used as lower boundary conditions in ACT models, will be adopted from the data base established by GEIA and from ecosystem models. Dry deposition needs to be estimated for several gases as a function of surface ecosystem. Exchange between the atmosphere and the ocean is another factor which has to be taken into account in ACT models.

The objectives of this Task are: 1) to adapt emission/deposition fluxes established by GEIA to the numerical grid appropriate for atmospheric chemical transport models, 2) to develop ecosystem models providing exchange fluxes between the biosphere and the atmosphere, and couple these models to atmospheric chemical transport models, and 3) to validate these exchange models for specific sites (ecosystems) for which data are available.

#### Task 6.6.2: Atmospheric Transport

Chemical compounds are transported from their source regions by the atmospheric circulation (winds). Because advective processes cannot be resolved at scales smaller than the spatial and temporal resolution of the models, "subgrid" transport needs to be parameterised. Different schemes are used to represent unresolved transport, including convective transport (e.g., in cumulonimbus clouds) and diffusion (e.g., vertical mixing in the boundary layer). These processes are generally complex and, in most cases, parameterisations are not accurate and need to be validated against information derived from observational data.

The objectives of this Task are: 1) to compare different numerical schemes used to simulate large-scale (advective) transport in ACT models and assess their performance in representing the distribution of atmospheric tracers (e.g., CO<sub>2</sub>, CFC-11 or -12, etc.), and 2) to compare different parameterisations used to simulate small-scale transport processes in ACT models and assess their performance in representing the distribution of atmospheric tracers (e.g., radon, CO, etc.).

### Task 6.6.3: Gas-Phase and Aqueous-Phase Chemistry

Aerobiochemical models must account for a large number of chemical processes occurring in the atmosphere. In addition to gas-phase chemistry, aqueous-phase reactions inside clouds and heterogeneous reactions on the surfaces of solid and liquid aerosols have to be taken into account. Due to the constraints associated with available computer capability, chemical schemes adopted in atmospheric models are simplified; in addition, several rate constants of potentially important reactions need to be better quantified.

The objectives of this Task are: 1) to develop "chemistry intensive" zero-dimensional models and assess potentially important reaction schemes of importance for the chemistry of the atmosphere, 2) to measure reaction rates of potentially important reactions, 3) to establish simplified chemical schemes to be implemented in global aerobiochemical models, 4) to assess the importance of aqueous-phase chemical processes, and 5) to develop parameterisations required to simulate wet deposition of soluble chemical compounds at the regional and global scales.

Finally, it should be stressed that each component of aerobiochemical models needs to be fully validated on the basis of existing data. GIM will therefore collaborate closely with IGBP-DIS.

#### Timetable

- 1994 Appoint initial GIM Coordinating Committee and establish long term work plan.
- 1995-1997 Implement work plan, analyse present status of existing tropospheric/stratospheric chemical-transport models, as well as of ecosystem models of interest to GIM
- Identify key questions and problems.
- Perform inter-comparison exercises between different models to address these questions.
- Establish relations with experimental projects and other IGAC groups.
- Establish links with WRCP to assess formulation of transport in atmospheric models.

### Focus 7: Fundamental Activities

Foci 1 through 6 of IGAC have important common structural elements which form the basis for a seventh **Fundamental Focus**. One element involves development of the most accurate calibrations for atmospheric measurements and the adoption of compatible measurement systems through a series of intercalibrations and intercomparisons. Current efforts are on calibrations for N<sub>2</sub>O, CO<sub>2</sub>, and several halocarbons and NMHCs. These continuously on-going major efforts require international cooperation in order to insure that globally consistent field data are obtained over the long term. A second element is

education, both to increase the number and capabilities of scientists contributing to IGAC, and to inform the public of the rationale, goals, objectives and accomplishments of the project.

It is anticipated that additional elements will be added to this Focus in the future. One may involve laboratory determinations of fundamental molecular properties including photon absorption cross sections for key species, reaction rate constants, homogeneous and heterogeneous reaction mechanisms, mass accommodation coefficients, etc. Another element may be new instrument development where major challenges are provided by the need to measure highly reactive free radicals and a wide variety of key species at very low concentrations.

### Activity 7.1: Intercalibrations-Intercomparisons (ICIC)

Three Tasks are underway within this Activity, all addressing issues of measurement standardisation of key trace gases whose determinations require somewhat different techniques.

#### Task 7.1.1: Nitrous Oxide and Halocarbon Intercalibration Experiment (NOHALICE)

Convener: P.J. Fraser

Measurements of trace gases in the background atmosphere are made for many purposes, principally to measure long term trends in and to identify and quantify regional and global sources and sinks of trace gases involved in stratospheric ozone depletion, climate change and tropospheric chemistry, and as tracers of atmospheric dynamics. Many different research groups are involved in programmes that involve the collection and interpretation of trace gas data and the ultimate utility of such data is often determined by its absolute accuracy and the precision with which data sets collected by different laboratories can be compared.

Such comparability of data between various programmes is best achieved by using common calibration standards or, in the absence of such standards, via well executed intercomparison experiments. In August 1987 at Peterborough, Canada, the CACGP held a preliminary workshop on the IGAC programme. The workshop recognised the importance of the availability of stable and accurate calibration standards for atmospheric trace gas measurements. The Peterborough meeting identified specific problems associated with intercomparability of methane (CH<sub>4</sub>) data from various global networks and with the absolute calibration of methyl chloroform (CH<sub>3</sub>CCl<sub>3</sub>) and carbon monoxide (CO) measurements.

The subsequent IGAC workshop at Dookie, Australia, in November 1988 reached the same conclusions and recommended the establishment of Project 3: Intercalibrations-Intercomparisons. Within Project 3, two Activities were identified: 1) Gas Standards for CO, CH<sub>4</sub> and Chlorinated Hydrocarbons, and 2) Non-Methane Hydrocarbon Intercomparison Experiment (NOMHICE). Project 3 was later redefined as Activity 7.1 (Intercalibrations-Intercomparisons) of IGAC Focus 7 (Fundamental Activities), and the first Activity of Project 3 was renamed the Methane and Halocarbon Intercomparison

Experiment (MEHALICE). Although the acronym MEHALICE implied that only methane and halocarbon standards would be compared in this programme, it was envisaged that a wider range of atmospheric trace species, for example CO and nitrous oxide (N<sub>2</sub>O), would also be involved. A coordinator for the methane and carbon monoxide has yet to be found, so for now it has been renamed and proceeds as the Nitrous Oxide and Halocarbon Intercomparison Experiment (NOHALICE).

#### Goal

- Compare the trace gas standards employed in various laboratories around the world that generate mixing ratio data for nitrous oxide and various chlorofluorocarbons (CFCs, particularly CFC-113 (CCl<sub>2</sub>FCClF<sub>2</sub>)), hydrochlorofluorocarbons (HCFCs, particularly HCFC-22 (CHClF<sub>2</sub>)) and chlorocarbons (particularly CH<sub>3</sub>CCl<sub>3</sub> and carbon tetrachloride (CCl<sub>4</sub>)).

Intercomparison experiments usually involve the preparation and analysis by a parent laboratory of air samples or gas mixtures containing stable levels of various trace gases, followed by their circulation to, and analysis by, participating laboratories. The samples are subsequently returned to the parent laboratory for repeat analysis to test for possible drifts in trace gas levels. Accurate comparisons require the trace gas levels to be stable throughout the duration of the experiments.

#### Task 7.1.1.1: Experiments to Determine Trace Gas Stabilities in Various Types of Containers

Because of their durability and ability to contain gases at several atmospheres pressure, metal containers or flasks are most suitable for interlaboratory comparison experiments. Flasks that are typically used are constructed from stainless steel (often internally electropolished) or aluminium (often chemically passivated). Several laboratories have conducted long term trace gas stability tests in these types of flasks. There are few publications that describe the results from this type of experiment and an attempt will be made to encourage the collation and publication of such results to the benefit of the community at large.

The stability of trace species in containers depends not only on the nature of the internal surface but also on the fittings attached to the container (usually all stainless steel valves or regulators) and the materials used to seal the connection between container and fittings (metal welds, metal compression fittings, Teflon tape, Teflon paste, etc.). Most laboratories involved in this research have compiled a wealth of information on the best types of valves and regulators to use, how to clean them, and how to attach them to containers so that the trace species contained are stable over time. Again little of this information is published and NOHALICE is envisaged as a mechanism to encourage the collation, interpretation and publication of such information.

#### Task 7.1.1.2: Interlaboratory Comparisons

There are currently a number of interlaboratory comparison experiments that have been completed, are ongoing, or planned, though not necessarily part of NOHALICE. For example there is an ongoing comparison of CH<sub>4</sub>, CO, CO<sub>2</sub>, H<sub>2</sub> and N<sub>2</sub>O data involving four laboratories using dry, compressed natural air samples in passivated aluminium containers, and one for CFC-11, -12, -113, CCl<sub>4</sub>, CH<sub>3</sub>CCl<sub>3</sub>, HCFC-22 and N<sub>2</sub>O involving six laboratories using wet, compressed air in electropolished stainless steel containers (Table 5). One of the functions of NOHALICE will be to identify these and other experiments, facilitate a broader community participation if desirable and possible, and encourage the publication of the results from the experiments.

Table 5. Inter-Laboratory Comparison Experiments

Species	Participating Laboratories	Status
CH <sub>4</sub> , CO, CO <sub>2</sub> , H <sub>2</sub> , N <sub>2</sub> O	CNRS-CFR (P. Monfray) CSIRO-DAR (P. Steele, R. Francey) NIWA (M. Manning) NOAA-CMDL (P. Tans)	current
CFC-11, -12, -113, CCl <sub>4</sub> , CH <sub>3</sub> CCl <sub>3</sub> , HCFC-22, N <sub>2</sub> O	CSIRO-DAR (P. Fraser) NOAA-CMDL (J. Elkins) SIO (R. Weiss) UB (P. Simmonds) UEA (S. Penkett) UTok. (Y. Makide)	current
CH <sub>4</sub>	AES (D. Worthy) CSIRO-DAR (P. Steele) NOAA-CMDL (E. Dlugokenky) UCI (D. Blake) UToh. (T. Nakazawa)	round 1 completed 1990
C <sub>14</sub> H <sub>4</sub>	NIWA (D. Lowe) SIO (M. Wahlen) UH (I. Levin) UW (P. Quay)	completed?
CO	CSIRO-DAR (P. Steele) NASA-Langley (G. Sachse) NOAA-CMDL (P. Novelli) FIAER (Scheel)	round 1 completed 1991

## Abbreviations for Table 5

AES	Atmospheric Environment Service, Canada
CACGP	Commission for Atmospheric Chemistry and Global Pollution
CNRS-CFR	Centre National de la Recherche Scientifique - Centre des Faibles Radioactivites
CSIRO-DAR	Commonwealth Scientific and Industrial Research Organization-Division of Atmospheric Research, Australia
FIAER	Fraunhofer Institute for Atmospheric and Environmental Research, Germany
IGAC	International Global Atmospheric Chemistry Project
MEHALICE	Methane and Halocarbon Intercomparison Experiment
NASA-Langley	National Aeronautics and Space Administration-Langley Laboratories, USA
NIST	National Institute for Standards and Technology, USA
NIWAR	National Institute for Water and Atmospheric Research, New Zealand
NOAA-CMDL	National Oceanic and Atmospheric Administration, Climate Monitoring and Diagnostics Laboratory, USA
NOMHICE	Non-Methane Hydrocarbon Intercomparison Experiment
NPL	National Physical Laboratory, UK
OGI	Oregon Graduate Institute, USA
SIO	Scripps Institution for Oceanography, University of California (San Diego), USA
UB	University of Bristol, UK
UEA	University of East Anglia, UK
UCI	University of California (Irvine), USA
UH	University of Heidelberg, Germany
UToh.	University of Tohoku, Japan
UTok.	University of Tokyo, Japan
UW	University of Washington, USA

### Task 7.1.1.3: Supply and Dissemination of Absolute Calibration Standards

There are only a few laboratories and commercial companies that are currently producing and disseminating absolute trace gas calibration standards. For halocarbons they are not produced with mixing ratios similar to ambient background levels (often orders of magnitude higher) and they are issued with batch average certification rather than each cylinder being individually certified. Individual laboratories are probably not equipped to produce such standards in quantities to satisfy potential global demand. Ideally, this Task should be undertaken by a national laboratory on a commercial basis. The role of NOHALICE could be to advise such a laboratory as to the community needs in terms of absolute standards and to act as a source of research information from participating laboratories concerning the outcomes of Task 1.

### Task 7.1.2: Non-Methane Hydrocarbon Intercomparison Experiment (NOMHICE) Conveners: J.G. Calvert, F.C. Fehsenfeld

The NMHCs, consisting of terpenes, isoprene, alkanes, alkenes, alkynes and aromatics, play several crucial roles in atmospheric chemistry: They are involved in O<sub>3</sub> formation, form the carriers of active nitrogen compounds, are tracers of atmospheric motions and are sources of CO and of reactive hydrogen species. Thus, information on their global distributions is currently needed in atmospheric chemistry. To form a global picture of these abundances, there is a need to know whether there are any systematic differences between the methods used by various investigators.

In September of 1987, a working group meeting was held in Virginia Beach, VA (USA), to assess field measurement opportunities for the NASA Tropospheric Chemistry Programme's Global Tropospheric Experiment (GTE). At this meeting an international committee of scientists (J. Calvert, Chair) was assigned to write a "White Paper" dealing with the status of ambient NMHC measurements. The committee met again in November of 1988 in Boulder, Colorado to discuss and refine the draft document and formed the International Hydrocarbon Intercomparison Committee (IHIC). The committee evaluated the role of NMHCs in atmospheric chemistry, the reliability of the current analytical techniques involved, and suggested a possible format within which an intercomparison of ambient NMHC measurements might be made. The intercomparison will be international and provide opportunity for short term payoff. It will result in a global data set with a common basis.

In recognition of the great difficulties involved in ambient NMHC measurements and the unevaluated reliability of the results of the analysis techniques currently employed, IGAC approved this international intercomparison programme as Task 2 of its Activity 7.1.

The IHIC has been enlarged to include diverse talents of an international group of atmospheric scientists concerned with the analysis of atmospheric NMHCs. The committee met in April, 1991, at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado to review the programme plans for the year and to refine the detailed operating plans. The committee met again in the fall of 1992 to review the progress of the past year and to review and modify, if needed, the plans for NOMHICE effort.

#### Goal

- Assess how accurately the NMHCs can be measured.

#### Implementation Strategy

The intercomparison has been designed to answer several important questions related to current state-of-the-art analyses of NMHCs in ambient air:

- 1) Can individual scientists and laboratories measure NMHC concentrations accurately for a large range of NMHCs from C<sub>2</sub> to C<sub>10</sub>?
- 2) Does the sampling method used give a true picture of atmospheric composition?

- 3) Does the analytical method employed give rise to artefacts or lose individual NMHCs?
- 4) How reliable are the standards used by individual laboratories?
- 5) Are the storage techniques employed by various workers adequate to minimise losses of the reactive NMHCs before analysis?
- 6) Is the error introduced from the overlap of chromatographic peaks of NMHCs and the oxidation products of the NMHCs from air samples a serious problem?

Answers to these questions are sought through a series of planned experiments which will involve all the common classes of the atmospheric NMHCs. The accuracy to which the NMHCs can be measured will be assessed with an experiment involving the major groups who have made and published extensive NMHC measurements. The ultimate features of this experiment will be intercomparisons under typical field conditions and simultaneous measurements at the same place. The protocols will include investigators having to pre-state expected uncertainties, blind ambient measurements, blind spikes of possible artefacts, independent third party evaluation, and publication of all details in a premier journal.

This intercomparison study will be done in six phases. The various phases have been arranged in increasing order of complexity in order to most readily define problems as they arise. The initial phases using standards are designed to help participating laboratories identify problems and establish the reliability of their analytical techniques.

The six phases are briefly described below. Phases 1 and 2 have been completed and Phase 3 is in progress. The remaining phases are being planned. It should be noted that it is still possible for interested scientists and laboratories to become involved in the intercomparison experiments. Additional information concerning participation in the intercomparison can be obtained from the conveners.

#### *Phase 1: Standards and Cross Referencing*

The objective of the Phase 1 study was to check on both the reliability of standards employed by each participating research group or laboratory and the basic analytical procedures employed by the group.

The original protocol for the intercomparison experiment was designed by the IHIC. Currently, there are 37 scientific groups participating in the programme. The U.S. National Institute of Standards and Technology (NIST) was selected to prepare the mixtures and NCAR was chosen as the referee laboratory to analyse and circulate the samples to the participants.

Stability tests of gaseous mixtures stored in the canisters were done by storing the samples in canisters with or without water treatment and in canisters with nitrogen-silicon co-polymer coated walls. Preliminary results show that even highly reactive components can be stored without significant losses in suitably conditioned canisters for several weeks. These studies will continue in the coming year with additional attempts to design the best storage procedures for mixtures which are sampled in canisters.

The IHIC planning committee chose a two-component mixture of n-butane and benzene (ppbv range) as the standard. NIST provided the standard mixtures in five separate cylinders of somewhat different concentrations. They were prepared by microgravimetric techniques and supplied to NCAR in Scott Acculife-treated aluminium cylinders at high pressure. The NIST standards were transferred quantitatively to the electropolished stainless steel canisters constructed at NCAR and placed in the sample canister shipping containers for distribution to participating laboratories. Before the samples were sent out by NCAR, the mixture in each canister was analysed at least twice using the NCAR GC/FID (Gas Chromatograph/Flame Ionisation Detector) system by the NOMHICE staff.

Each participating laboratory was asked to perform an analysis as soon as possible upon receipt of the canister. The participants then returned the canister along with an analysis report, including the nature and origin of the NMHC standard used to calibrate the system. NCAR scientists reanalysed the remaining mixture in the canister to track potential changes in canister sample concentrations with time.

#### *Phase 2: Synthetic Gaseous Hydrocarbon Mixture in Air*

The objective of Phase 2 is to check the participant's ability to separate, identify and quantify the amounts of individual components in a synthetic gaseous NMHC mixture in air.

In this phase, a complex NMHC mixture, containing 16 components, was analysed by the participants. The components were selected by the IHIC Committee and prepared by NIST in five separate high pressure aluminium (Acculife treated) cylinders, each with a somewhat different concentration. These samples were analysed by NCAR staff, placed in properly conditioned canisters and sent to the participating groups. The protocol was similar to that followed in Phase 1. A paper on the results for the first two phases is in press in the *Journal of Geophysical Research - Atmospheres*.

#### *Phase 3: Complex Synthetic Air Measurements*

Phase 3 of the study is underway and was designed to test the reliability of the participants' analytical methods in the analysis of NMHCs in whole air-like synthetic gas mixtures. The synthetic gas mixture contains more than 60 common NMHCs and was made by Scott Marrin, Riverside, CA. This mixture is not a gravimetric standard so the reference values for this phase were determined by the combined results of Dr. Eric Apel and Dr. William Lonneman of the NOMHICE staff on the same mixture. Methodology is being developed in order to most efficiently identify and quantify the species in the mixture using one GC column. More efficient data analysis strategies are being developed as well. Procedures and protocols employed in earlier phases are being followed.

#### *Phase 4: Whole-Air Measurements*

Phase 4 of the study will test the ability of the participants and the reliability of the participants' analytical methods in the analysis of NMHCs in selected whole air samples. Ambient air will be collected at sites preselected by the NOMHICE personnel in consultation with the IHIC committee. The collection site(s) is(are) to be finalised following further discussions of the IHIC planning committee. One of the areas for

sample collection being considered is the Como Creek research site of the Arctic and Alpine Research Station of the University of Colorado at Niwot Ridge, Colorado, where several studies of the concentrations of various trace gases in the ambient air have been conducted previously. The Niwot Ridge site is particularly attractive in that much useful information now exists on the composition of its atmosphere for various meteorological and seasonal conditions encountered there. This distribution is quite typical of that observed in studies at other rural sites. Complete NMHC speciations have been made by several research groups. Since most NMHC mixtures which are currently observed over continents contain urban sources of pollution, it is important that these real-world atmospheric samples contain anthropogenic NMHCs as well as the biogenic NMHCs. It is the present plan to obtain several mixtures which vary in the natural NMHC content which can be used as follow-up mixtures to be circulated to those requiring or seeking additional experience in these analyses.

#### **Phase 5: Surface Field Measurements**

The objective of this phase is to assess the precision and accuracy of the analytical methods used by the various scientific groups under actual field conditions. Some of the participants who have demonstrated their ability to analyse ambient levels of NMHCs in Phase 3 will be invited to participate in a field intercomparison study at a common location. In this phase, the ambient air will not be sampled through common inlets, since the inlets are an active element in the sampling system. Each investigator will sample through inlets similar to those which have been used in his/her previous field studies. However, the inlets will be located in close proximity to each other, and therefore should take in very similar air samples. The sampling will occur over time intervals which will be carefully controlled to allow a maximum overlap of the analytical data obtained by each group. Samples will be collected by the NOMHICE staff during the same period at the same location and returned to the NCAR laboratories for analysis. Each group will work independently on the analysis and will turn in a documented report to the NOMHICE group leader. Subsequently, the NOMHICE group will compare the data from each common time period during which their sampling occurred. The results of this intercomparison will allow an assessment of the precision and accuracy of the analytical procedures used by the various groups under actual field conditions.

Two very important additional problem areas will be investigated systematically in these experiments. (1) What are the effects on the analyses for the reactive NMHCs with the use of various treatments to remove O<sub>3</sub> before the chromatographic analyses? (2) What are the effects on the components of the NMHC analyses of using Nafion (or other types of) dryers to remove water prior to the analysis? Obviously the selection of participants for this intercomparison will be determined not only by the successful completion of Phases 1, 2 and 3, but also the need to involve groups which employ several different procedures for O<sub>3</sub> and water removal.

#### **Phase 6: Aircraft Sampling**

In this phase, ambient air samples will be collected simultaneously on board aircraft by selected investigators who have satisfactorily demonstrated their ability to analyse the NMHC mixtures in the previous phases of this study. It will include onboard analysers and air sampling with flasks in order to obtain height profiles across the marine and continental boundary layer. The goals are to assess inlet problems, storage and shipping,

#### **Timetable**

- |           |   |
|-----------|---|
| 1991-1992 | Implementation and completion of Phase 1 (2-component synthetic mixture).     |
| 1992      | NOMHICE/IHIC Planning Meeting.  |
| 1992-93   | Implementation and completion of Phase 2 (multi-component synthetic mixture). |
| 1993-1994 | Implementation of Phase 3 (complex synthetic mixture).                        |
| 1994-1995 | Implementation of Phase 4 (whole air mixture).                                |
| 1995-1996 | Planning and implementation of field intercomparison studies (Phase 5).       |
| 1996-1997 | Planning and implementation of aircraft sampling studies (Phase 6).           |

#### **Task 7.1.3: Carbon Dioxide Intercalibration Experiment (CARBICE)** Convener: C.D. Keeling

Carbon dioxide is one of the most important trace gases in the atmosphere that influence climate and biological processes. The atmospheric carbon dioxide concentration has increased by 30% over the pre-industrial level as a result of human activities. Increasing CO<sub>2</sub> concentration in the atmosphere may have already modified the photosynthesis of land plants, it has noticeably altered the chemical composition of sea water. The atmospheric abundance and isotopic concentration of CO<sub>2</sub> should be studied as part of the general study of global change.

Global atmospheric CO<sub>2</sub> measurements were formalised internationally by the WMO in 1970 to be part of a new programme on Meteorological Aspects of Air Pollution. To assist in the implementation of this activity, WMO convened a Panel of Experts on Carbon Dioxide Monitoring which first met in March 1975, and subsequently approximately every three years. At their meeting in 1990 in Lake Arrowhead, California, USA, the WMO CO<sub>2</sub> Experts requested inclusion of atmospheric CO<sub>2</sub> studies in the International Global Atmospheric Chemistry Project (IGAC). This task, *Carbon Dioxide Intercalibration Experiment (CARBICE)*, was accepted later that year as Task 3 of IGAC's Activity 7.1. A separate Activity, *Global Tropospheric Carbon Dioxide Network (6.3, GLOCARB)*, was accepted to address the ambient air measurements aspect itself.

Relatively small temporal changes in concentration and isotopic composition of CO<sub>2</sub> in air can reflect major changes in the carbon cycle, and in the rate of change of the global average accumulation. These changes can be reliably detected only if primary reference standard gas mixtures are maintained over long periods and are intercompared with secondary standards distributed to the laboratories and field stations responsible for measuring the composition of atmospheric CO<sub>2</sub>. In recognition of the need for such standards, WMO established a Central CO<sub>2</sub> Laboratory in 1975 at the Scripps Institution of Oceanography in La Jolla, California, USA. This laboratory prepared and maintained standards and assisted in intercalibration until 1985 when financial sponsorship was terminated. There is a need to establish a permanent calibration laboratory and for

funding its operation on a long term basis as part of the study of global change. This should be accomplished in close cooperation with similar calibrating activities for other atmospheric gases of interest to the IGAC Project.

#### Goal

- Maintain primary and secondary gas mixtures certified to the highest feasible precision with respect to CO<sub>2</sub> concentration and isotopic composition.

#### Implementation Strategy

Two projects were identified by the WMO-CO<sub>2</sub> Experts at the Lake Arrowhead Meeting in 1990. A third project was added later as the need to attain greater precision in the study of <sup>13</sup>C/<sup>12</sup>C ratio of atmospheric CO<sub>2</sub> than previously anticipated has been recognised.

##### *Project 1: Establishment of a Permanent Central Carbon Dioxide Laboratory*

A major deficiency in the present CO<sub>2</sub> programme is a lack of long term funding for standardisation of measurements. WMO, through its secretariat, endorsed the establishment of a Central CO<sub>2</sub> Laboratory (CCL) to carry out standardisation in 1975. The CCL was operated at the Scripps Institution of Oceanography and provided standards for participants from 1975 to 1985, with the funding provided solely by the U.S.

The plan of NOAA to set up and maintain a permanent central carbon dioxide laboratory is currently underway. The existing WMO-CCL at the Scripps Institution of Oceanography has been restarted to carry out its previously assigned tasks until NOAA builds up its capability to take over the calibration function for the international CO<sub>2</sub> monitoring network. Partial support for the operation of the present laboratory at Scripps is provided by NOAA to facilitate the planned transition from Scripps to NOAA. A careful intercomparison between the old and the new primary calibration systems is being planned. It is anticipated that within two years the permanent CCL at NOAA will have established proven stable primary standards and have commenced distributing secondary standards to other institutions.

##### *Project 2: Improvements in Standardisation*

The possibility of new strategies for carrying out calibrations, and archiving the calibrational data and methodologies, has been explored with the view of providing the necessary reliability over decades and centuries of surveillance. A CO<sub>2</sub> standards laboratory intercomparison experiment coordinated by P. Tans (NOAA/CMDL) has been completed. The U.S. National Institute of Standards and Technology (NIST) provided two sets of reference gases, each consisting of three CO<sub>2</sub>-in-natural air gas mixtures with nominal CO<sub>2</sub> mixing ratios of 340, 350, 375 parts per million (ppm). Each set of three was sent on a different "circuit", one in Europe, and the other one in North America, Australia, New Zealand and Japan, starting in the fall of 1991. The desired target of 0.1 ppm intercomparability among laboratories was not met. Results are described in a WMO report (in press) coordinated by G. Pearman. A second "round-robin" experiment is being organised, with CMDL in the lead role again.

Progress is being made at CMDL in the design and construction of a new system for the calibration of CO<sub>2</sub>-in-air reference standards by primary methods. In their approach a calibration consists of the determination of the CO<sub>2</sub> mole fraction by the measurement of the pressures, temperatures and volumes of the whole air sample and the CO<sub>2</sub> fraction separately after it has been extracted. This is basically the same approach as has been taken for the CO<sub>2</sub> standards over the last decades at Scripps.

##### *Project 3: Establishment of New Isotopic Standards for Atmospheric CO<sub>2</sub>*

International isotopic standards suitable for calibrating atmospheric CO<sub>2</sub> do not appear to be available. Furthermore, the desirable precision of standardisation has narrowed to 0.01%, owing to the availability of more precise mass spectrometers and the need to attain greater precision than previously anticipated in the study of <sup>13</sup>C/<sup>12</sup>C ratio of atmospheric CO<sub>2</sub>.

The standardisation and intercalibration of stable isotopic measurements by different laboratories leaves much to be desired. The traditional isotopic standards NBS-16 and NBS-17 are no longer available. There have been a few intercomparisons between isotopic laboratories in the recent past. The International Atomic Energy Agency (IAEA) has undertaken to provide assistance in the coordination of the intercalibration of isotopic standards for CO<sub>2</sub>, CH<sub>4</sub> and CO. A meeting was organised by the IAEA in November 1992 in Heidelberg, Germany. For CO<sub>2</sub>, the participants agreed that standards of both pure CO<sub>2</sub> (with and without the interfering species N<sub>2</sub>O) and of CO<sub>2</sub>-in-air were needed. In the past, the IAEA and the University of Groningen (the Netherlands) have distributed carbonate, graphite and gas standards in the form of pure CO<sub>2</sub> and CO<sub>2</sub>-in-air. NIST is studying the feasibility of preparing multi-isotope (<sup>13</sup>C, <sup>14</sup>C, <sup>18</sup>O) gas standards of CO<sub>2</sub>, CH<sub>4</sub>, and CO, and blends of these. The permanent distribution of standards and a schedule of intercomparisons between laboratories were discussed at a joint meeting of WMO CO<sub>2</sub> Experts and GLOCARB/CARBICE in Rome, Italy, in September 1993. Recommendations were made with respect to laboratory procedures, ion correction algorithms and use of reference standards. The IAEA is providing some funding for calibration and distribution of isotopic standards, and isotopic measurements will be included in the next "round-robin" experiment to the extent possible.

#### Timetable

1993 Fourth International CO<sub>2</sub> Conference in Carqueiranne, France in September.

Joint WMO CO<sub>2</sub> Experts and GLOCARB/CARBICE meeting in Rome, Italy, in September.

1995 Symposium on "The Breathing of the Earth: Observational Constraints for Models of the Terrestrial Biosphere" at IUGG meeting in Boulder, Colorado, in July. A CO<sub>2</sub> Experts meeting is tentatively planned in association with this symposium.

## Activity 7.2: Atmospheric Chemistry Education in Global Change (ACE)

Convener: K.L. Demerjian

The growing need to understand the composition of the Earth's atmosphere and how and why it changes has become increasingly apparent in the last decade. Issues of stratospheric ozone depletion, global climate change and regional pollution are problems of great interest to today's society. They require substantial scientific insight to address them in a meaningful and cost effective manner.

Scientists trained and educated in atmospheric chemistry and the relevant biospheric sciences are in limited supply and the need for these scientists in developing and developed countries is especially critical. The IGAC programme recognises the importance of a strong emphasis on education and training. There is a specific need to create the appropriate infrastructure within developing countries in order to enhance their scientific capacity to enable them to realise the full benefits of participation in IGAC, and to deal with the scientific and environmental policy challenges facing the global community.

### Goal

The overall goal of ACE is to:

- Coordinate educational activities aimed at promoting understanding of global change in the chemistry of the atmosphere, and its relationship to the biosphere, geosphere and to anthropogenic activities, internationally, both in the developing and developed nations in all climate regions.

### Implementation Strategy

To promote education and training in this field, scientists in IGAC, GAW and GCOS have agreed to join forces with those in START (Systems for Analysis, Research and Training) and pool their expertise to design and execute an integrated approach to **academic capacity building** in developing countries. The mechanism involves the establishment of a pool of voluntary lecturers recruited from the international scientific community to carry out the educational mission. This highly interactive and inter-related education/training programme will:

- Establish atmospheric chemistry programmes, including atmospheric-biospheric interactions, at the undergraduate level at universities in developing countries
- Provide graduate research assistantships at cooperating universities in Europe, North America and other developed regions with PhD programmes in atmospheric chemistry for qualified students from developing countries who participate in the above undergraduate atmospheric chemistry programmes
- Initiate and expedite employment opportunities at all levels (BS, MS, PhD) in support of IGAC, GCOS, GAW and START activities in developing countries (open to all students who successfully participated in one or both of the above)

- Develop and offer short courses/training workshops on topics of interest to IGAC, GCOS and GAW (participants include professionals from universities, research projects and monitoring programmes)

The academic capacity building process is an extremely challenging opportunity and one that is long term in nature. The intent of ACE is to develop and help implement a strategic plan which incorporates a methodical approach, identifying the incremental steps to be taken in pursuit of the basic goals of the programme. In this context, the establishment of the **volunteer teaching/training cadre** is an important first step in the ACE strategic plan and is an essential component of the capacity building activity.

### Capacity Building in Atmospheric Chemistry for Developing Countries

Through the coordination of IGAC, START, IAI (Inter-American Institute) and GAW and a series of workshops under the auspices of the WMO, a plan to design and jointly implement a capacity building programme in developing countries for atmospheric-biospheric chemistry has been prepared. An initial first step in the implementation of this plan requires seed funds for the establishment of the international cadre of volunteer scientists.

The goal of the capacity building programme is to:

- Develop an integrated approach to academic capacity building in atmospheric-biospheric chemistry in cooperation with multinational research/monitoring/assessment programmes with the participation of an international cadre of volunteer scientists recruited by the American Geophysical Union (AGU) and the International Union of Pure and Applied Chemistry (IUPAC).

In the short-term, the objectives of this capacity building programme are:

- Coordination by the American Geophysical Union of the international recruitment efforts including publication of the "Announcement for Atmospheric Chemists" in EOS and elsewhere.
- Establishment of a steering committee responsible for the development of curricula and course design for:
  - Training professionals/researchers/teachers from the natural sciences in atmospheric chemistry and biosphere-atmosphere interactions as they relates to global change processes and related research monitoring and assessment activities
  - Training science faculty interested in introducing atmospheric chemistry and relevant biological sciences into their undergraduate programme
- Convene workshops made up of selected members from the volunteer teaching/training cadre to define course offerings for designated programmes and develop detailed outlines of course content.

- Prepare a proposal for submission to an international funding agency to establish a global education and training programme in atmospheric chemistry and biospheric-atmospheric interactions.
- Implement the first academic capacity building pilot project in Argentina

On the longer-term, ACE will seek to:

- Establish an atmospheric chemistry programme including its biospheric component at the undergraduate level at a university in a developing country
- Develop career opportunities at all professional levels within the multinational research/monitoring/assessment programmes that are operational in developing countries
- Design and conduct training workshops for the WMO Global Atmospheric Watch (GAW) programme responsive to the research and operational support needs for professional and technical personnel in developing countries
- Develop and offer short courses/training workshops on topics of interest to IGBP/IGAC, GCOS/GAW (participants include professionals from universities, research projects and monitoring programmes)

Start up funds have been secured to support the activities outlined in the short-term objectives. These funds will provide the opportunity to demonstrate a **proof of concept** of the approach as well as allow preparation of a detailed coordinated operational plan supported by the international scientific community. The plan and our demonstration of proof of concept will provide the basis of the more substantial proposal to one or more international funding agencies.

#### Timetable

- 1994 Development and submission of proposal for funding of pilot project in Argentina.  
Recruitment of international cadre of volunteer scientists.
- 1995 Implementation of pilot project.  
Development and submission of major proposal to international funding agencies for full implementation of ACE initial tasks.
- 1996 Begin full implementation.

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## Appendix 2

### Current IGAC Foci, Activities and Conveners of the Coordinating Committees for each Activity

\* Activity Status (A - Underway, P - Planning phase, C - Conceptual phase)

#### Focus 1 - Marine

##### Activity 1.1 - North Atlantic Regional Experiment (NARE), A

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##### Activity 1.2 - Marine Aerosol and Gas Exchange (MAGE), A

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##### Activity 1.3 - East Asian/North Pacific Regional Experiment (APARE), A

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#### Focus 2 - Tropical

##### Activity 2.1 - Biosphere-Atmosphere Trace Gas Exchange in the Tropics: Influence of Land Use Change (BATGE), A

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##### Activity 2.2 - Deposition of Biogeochemically Important Trace Species (DEBITS), A

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##### Activity 2.3 - Biomass Burning Experiment: Impact on the Biosphere and Atmosphere (BIBEX), A

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##### Activity 2.4 - Rice Cultivation and Trace Gas Exchange (RICE), A

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#### Focus 3 - Polar

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#### Focus 4 - Boreal

##### Activity 4.1 - High Latitude Ecosystems as Sources and Sinks of Trace Gases (HESS), A

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#### Focus 5 - Mid-Latitude

##### Activity 5.1 - Mid-Latitude Ecosystems and Photochemical Oxidants (MILOX), P

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##### Activity 5.2 - Trace Gas Exchange: Mid-Latitude Ecosystems and Atmosphere (TRAGEX), A

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## *Focus 6 - Global*

### **Activity 6.1 - Global Tropospheric Ozone Network (GLONET), A**

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### **Activity 6.2 - Global Atmospheric Chemistry Survey (GLOCHEM), A**

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### **Activity 6.3 - Global Tropospheric Carbon Dioxide Network (GLOCARB), A**

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## *Focus 7 - Fundamental*

### **Task 7.1.1 - Nitrous Oxide and Halocarbons Intercalibration Experiment (NOHALICE), P**

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### **Activity 7.2 - Atmospheric Chemistry Education in Global Change (ACE), C**

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## IGBP Reports

Available from the IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.

Reports marked with a \* are no longer available.

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- No. 13 Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Edited by P.A. Matson and D.S. Ojima. (1990)
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- No. 22 Report from the START Regional Meeting for Southeast Asia. (1992)
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- No. 30 IGBP Global Modelling and Data Activities 1994 - 1998. (1994)
- No. 31 African Savannas and the Global Atmosphere: Research Agenda. Edited by C Justice, R.J. Scholes and P.G.H. Frost. (1994)
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## Glossary of Terms

albedo	Reflective power; the fraction of incident light or electromagnetic radiation that is reflected by a surface or body, such as the moon or a cloud
cultivar	An organism of a kind originating and persistent under cultivation
ebullition	The act, process, or state of boiling or bubbling up
edaphic	Resulting from or influenced by the soil rather than the climate
Eh	Redox potential; the energy gained in the transfer of one mole of electrons from an oxidant to H <sub>2</sub> , expressed in volts
firn	Ice with interconnected air inclusions
lidar	Light direction and ranging
montane	Relating to, or being the biogeographic zone made up of relatively moist cool uplands slopes below timberline and characterised by the presence of large evergreen trees as a dominant life form.
nss	Non-sea-salt
ppbv	Parts per billion by volume
ppm	Parts per million
rhizosphere	Soil that surrounds and is influenced by the roots of a plant
sonde	Device for measuring physical (e.g., - temperature) or chemical (e.g., - ozone concentration) variables at high altitudes above the Earth's surface

## Acronyms and Abbreviations

ABLE	Atmospheric Boundary Layer Experiment
ACE	Atmospheric Chemistry Education in Global Change
ACE	Aerosol Characterisation Experiments
ACT	Atmospheric Chemical-Transport
AEROCE	Atmospheric/Ocean Chemistry Experiment
AGASP	Arctic Gas and Aerosol Sampling Programme
AGU	American Geophysical Union
APARE	East Asian/North Pacific Regional Experiment
ARCSS/LAII	Arctic System Science/Land-Atmosphere-Ice Interactions
ARW	Advanced Research Workshop
ASTEX	Atlantic Stratocumulus Transition Experiment
ATM	Atmospheric Camp
AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biospheric Aspects of the Hydrological Cycle
BAS	British Antarctic Survey
BATGE	Biosphere-Atmosphere Trace Gas Exchange in the Tropics: Influence of Land-Use Change
BIBEX	Biomass Burning Experiment: Impact on the Atmosphere and Biosphere
BOREAS	Boreal Ecosystem Atmosphere Study
Br	Bromine
CAAP	Composition and Acidity of Asian Precipitation
CACGP	Commission on Atmospheric Chemistry and Global Pollution
CAR	Central African Republic
CARBICE	Carbon Dioxide Intercalibration Experiment
CCL	Central CO <sub>2</sub> Laboratory
CCl <sub>4</sub>	Carbon Tetrachloride
CCN	Cloud Condensation Nuclei
CEC	Commission of the European Communities
CERN	Chinese Ecological Research Network
CFC	Chlorofluorocarbon
CH <sub>3</sub> CCl <sub>3</sub>	Methyl Chloroform
CH <sub>3</sub> Cl	Methyl Chloride
CH <sub>3</sub> COOH	Acetic Acid
CH <sub>4</sub>	Methane
CIRAC	Canadian Institute for Research in Atmospheric Chemistry
CMDL	Climate Monitoring and Diagnostics Laboratory
CNRS	Centre National de la Recherche Scientifique
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide
COS	Carbonyl Sulphide
CPO	Core Project Office
DEBITS	Deposition of Biogeochemically Important Trace Species
DECAFE	Dynamique et Chimie Atmosphérique en Forêt Equatoriale
DGASP	Dye 3 Gas and Aerosol Sampling Programme
DIS	Data and Information System
DMS	Dimethylsulphide
DOAS	Differential Optical Absorption Spectrometer

DRE Defence Research Establishment  
 EIPO European IGAC Project Office  
 EOS/MODIS Earth Observing System/Moderate Resolution Imaging Spectrometer  
 ESA ERS-2 European Space Agency Remote Sensing Satellite  
 EUROTRAC The European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe  
 EXPRESSO Experiment for Regional Sources and Sinks of Oxidants  
 FAO Food and Agriculture Organisation  
 FIFE First ISLSCP Field Experiment  
 FIRE First ISCCP Regional Experiment  
 FIRESCAN Fire Research Campaign Asia - North  
 FIREScheme Fire Information Systems Research in the Ecology, Socio-Culture, and History of the Mediterranean Environment  
 FOS Fire of Savannas  
 GAIM Global Analysis, Interpretation, and Modelling  
 GAW Global Atmosphere Watch  
 GC/FID Gas Chromatography/Flame Ionisation Detector  
 GCOS Global Climate Observing System  
 GCTE Global Change and Terrestrial Ecosystems  
 GEIA Global Emissions inventory Activity  
 GIM Global Integration and Modelling  
 GINA Global Inventory in the Northern Hemisphere  
 GIS Geographical Information System  
 GISP American Greenland Ice Sheet Project  
 GLOCARB Global Tropospheric Carbon Dioxide Network  
 GLOCHEM Global Atmospheric Chemistry Survey  
 GLONET Global Tropospheric Ozone Network  
 GOEYS Global Ocean Euphotic Zone Study  
 GOME Global Ozone Monitoring Experiment  
 GRIP European Greenland Ice Core Project  
 GTE Global Tropospheric Experiment  
 HBL Hudson Bay Lowland  
 HCFC Hydrochlorofluorocarbon  
 HCHO Formaldehyde  
 HCl Hydrogen Chloride  
 HCOOH Formic Acid  
 HDP Human Dimensions of Global Environmental Change Programme  
 HESS High-Latitude Ecosystems as Sources and Sinks of Trace Gases  
 HIRIS High Resolution Imaging Spectrometer  
 H<sub>2</sub> Molecular Hydrogen  
 HNO<sub>3</sub> Nitric Acid  
 HO<sub>2</sub> Hydroperoxyl  
 H<sub>2</sub>O<sub>2</sub> Hydrogen Peroxide  
 H<sub>2</sub>S Hydrogen Sulphide  
 H<sub>2</sub>SO<sub>4</sub> Sulphuric Acid  
 IAEA International Atomic Energy Agency  
 IAI Inter-American Institute  
 IAMAS International Association of Meteorology and Atmospheric Sciences  
 IBFRA International Boreal Forest Research Association  
 ICIC Intercalibrations-Intercomparisons  
 ICSU International Council of Scientific Unions  
 IGAC International Global Atmospheric Chemistry Project  
 IGAC-SSC IGAC Scientific Steering Committee  
 IGBP International Geosphere-Biosphere Programme

IHIC International Hydrocarbon Intercomparison Committee  
 IOC International Ozone Commission  
 IRRI International Rice Research Institute  
 ISCCP International Satellite Cloud Climatology Programme  
 ISLSCP International Satellite Land-Surface Climatology Project  
 ITASE International Trans-Atlantic Scientific Expedition  
 ITOY International Tropospheric Ozone Year  
 IUFRO International Union of Fire Research Organisations?  
 IUGG International Union of Geology and Geophysics  
 IUPAC International Union of Pure and Applied Chemistry  
 JEA Japan Environmental Agency  
 JGOFS Joint Global Ocean Flux Study  
 JRC Joint Research Centre (CEC)  
 LEADEx Arctic Leads Dynamics Experiment  
 LES Large-Eddy Simulation  
 LOICZ Land-Ocean Interactions in the Coastal Zone  
 LTER Long Term Ecological Research  
 LUCC Land-Use/Land-Cover Interactions  
 MAC Multiphase Atmospheric Chemistry  
 MAGE Marine Aerosol and Gas Exchange  
 MAPS Measurement of Pollution from Satellite  
 MBL Marine Boundary Layer  
 MILOX Mid-Latitude Ecosystems and Photochemical Oxidants  
 MISR Multi-angle Imaging Spectro-Radiometer  
 MLOPEX Mauna Loa Observatory Photochemistry Experiment  
 MOPPITT Measurement of Pollution in the Troposphere  
 MOZAITC Measurement of Ozone on Airbus In-Service Aircraft  
 MSA Methanesulphonate  
 N<sub>2</sub> Molecular Nitrogen  
 NARE North Atlantic Regional Experiment  
 NARSTO North American Research Strategy for Tropospheric Ozone  
 NASA National Aeronautics and Space Administration  
 NATAC North Atlantic Chemistry Experiment  
 NCAR National Center for Atmospheric Research  
 NDVI Normalised Difference Vegetation Index  
 NH<sub>3</sub> Ammonia  
 NIES National Institute for Environmental Studies  
 NIST National Institute of Standards and Technology  
 NITREX Nitrogen Saturation Experiments  
 NMHC Non-methane Hydrocarbon  
 NO Nitric Oxide  
 NO<sub>2</sub> Nitrogen Dioxide  
 NO<sub>3</sub> Nitrate Radical  
 NO<sub>x</sub> Nitrogen Oxides  
 NO<sub>y</sub> Total Reactive Nitrogen  
 N<sub>2</sub>O Nitrous Oxide  
 NOAA National Oceanic and Atmospheric Administration  
 NOHALICE Nitrous Oxide and Halocarbon Intercalibration Experiment  
 NOMHICE Non-Methane Hydrocarbon Intercomparison Experiment  
 NOWES Northern Wetlands Study  
 O<sub>3</sub> Ozone  
 OECD Organisation for Economic Cooperation and Development  
 OH Hydroxyl  
 PAC Polar Atmospheric Chemistry

PAGES	Past Global Changes
PAN	Peroxyacetylnitrate
PASC	Polar Atmospheric and Snow Chemistry
PASE	Polar Air-Snow Experiment
PEACAMPOT	Perturbation by East Asia Continental Air Mass to Pacific Oceanic Troposphere
PEM-Central	Pacific Exploratory Mission - Central
PEM-WEST	Pacific Exploratory Mission - West
QA/QC	Quality Assurance/Quality Control
RICE	Rice Cultivation and Trace Gas Exchange
RO <sub>2</sub>	Organic Peroxyl
SA'ARI	SAFARI Without Fire
SAFARI	Southern African Fire - Atmospheric Research Initiative
SCAR	Smoke, Clouds, Aerosols and Radiation Experiment
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography/Chemistry
SCOPE	Scientific Committee on Problems of the Environment
SC-IGBP	Scientific Committee of the IGBP
SEAFIRE	South East Asia Fire Experiment
SMMR	Scanning Multifrequency Microwave Radiometer
SO <sub>2</sub>	Sulphur Dioxide
SPOT	Système pour l'Observation de la Terre
SRFWG	Stand Replacement Fire Working Group (IBFRA)
STARE	Southern Tropical Atlantic Regional Experiment
START	Systems for Analysis, Research, and Training
STEP	Science and Technology for Environmental Protection
TES	Tropospheric Emission Spectrometer
TIGER	Terrestrial Initiative in Global Environmental Research
TLM	Two-layer Method
TM	Thematic Mapper
TRACE-A	Transport and Atmospheric Chemistry Near the Equator - Atlantic
TRACER	Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research
TRAGEX	Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere
TROPOZ	Tropospheric Ozone Campaign
VFIS	Vegetation Fire Information System (Dahlem Konferenz Model)
VOC	Volatile Organic Compound
WCRP	World Climate Research Program
WMO	World Meteorological Organisation