The International Global Atmospheric Chemistry (IGAC) Programme

A Core Project of the International Geosphere-Biosphere Programme

Commission on Atmospheric Chemistry and Global Pollution
of the
International Association of Meteorology and Atmospheric Physics

Front Cover: . Sampling for Combustion Products in a Primary Forest Fire in Mato Grosso, Brazil 1979 (P. J. Crutzen, P. Zimmerman).

Back Cover Photographs. (Top) Falcon 2 Research Aircraft undertaking Aerosol Sampling, Institute for Atmospheric Physics, German Aerospace Research Establishment, Oberpfaffenhofen, FRG. (Bottom) Cape Grim Baseline Air Pollution Monitoring Station, Tasmania, Australia (David Whillas).

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Editor
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Organised by the IAMAP Commission on Atmospheric Chemistry and Global Pollution, with the cooperation of the Cloud Physics Commission, the Ozone Commission, the Radiation Commission, and the IUPAC Commission on Atmospheric Chemistry.

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Contents

Executive Summary of the IGAC Programme

The global atmosphere is chemically complex and evolving; it possesses fundamental chemical connections to the oceans, the solid Earth, and most importantly to the biota. The atmospheric concentrations of several trace gases are observed to be increasing over the globe at rates that are leading to important changes in both the chemical and radiative properties of the global atmosphere. The challenge and responsibility that faces us today is to understand quantitatively the chemical, physical, and biological processes that determine atmospheric composition and to use this knowledge to address the past and future evolution of the Earth's atmosphere.

The International Global Atmospheric Chemistry (IGAC) Programme has been created in response to the growing international concern about these rapid atmospheric chemical changes and their potential impact on mankind. This programme, while emphasising atmospheric composition and chemistry, recognizes that the Earth's atmosphere, oceans, land, and biota form an interacting system that collectively determine the global environment and its susceptibility to change. The International Geosphere-Biosphere Programme (IGBP) is a broad-ranging interdisciplinary international undertaking that addresses all major aspects of this latter interactive system. The IGAC Programme is intended to be a vital contributor to the broader interdisciplinary programme of IGBP, providing the important atmospheric chemistry component and recognizing its linkages with the biosphere and human activities.

The overall goal of IGAC is to measure, understand, and thereby predict changes now and over the next century in the chemistry of the global atmosphere with particular emphasis on changes affecting the oxidising power of the atmosphere, the impact of atmospheric composition on climate, and the interactions of atmospheric chemistry with the biota. This goal is broad and encompasses several urgent environmental issues including the increasing acidity of rainfall, the depletion of stratospheric ozone, the greenhouse warming due to accumulation of trace gases, and the biological damage from increased oxidant levels.

In many cases the IGAC Programme will build on existing national programmes. It is not intended to replace these programmes but to provide the international cooperation whereby essential scientific endeavours can be accomplished that involve large demands for man-power, technology, geographic coverage, or monetary resources beyond the capability of any single nation.

Under the auspices of the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Physics (IAMAP) an international workshop attended by some 50 scientists from 13 nations was convened in Dookie, Australia in November 1988 to develop a plan for action for IGAC over the next decade.

The IGAC plan, which is described in detail in this report, has adopted six major foci. Each of these foci addresses important problems in global atmospheric chemistry whose solution requires international cooperation. These foci are intended collectively to address areas of greatest current uncertainty and/or perceived importance. They are not intended to be exhaustive and we expect further foci will be added as time proceeds.

The six initial foci that have been identified for IGAC are:

Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere

The oceans cover about 70% of the planet and act as both a source and sink of many important atmospheric constituents. In the marine atmosphere chemical species of continental origin are processed without disturbances of new anthropogenic inputs.

The marine atmosphere is, therefore, also a favourable area to study transformation processes in detail. Three IGAC projects are proposed to address this environment and perturbations to it due to continental emissions:

- North Atlantic Regional Study
- Marine Gas Emissions, Atmospheric Chemistry and Climate
- East Asian - North Pacific Regional Study

Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry

Tropical continental areas play an important role in the chemistry of the global atmosphere and its oxidising power. Large emissions of gases and particles are associated with rain forest and savanna regions and many tropical areas are experiencing rapid land use change. Four IGAC projects are proposed to address the tropics and their changes due to human activities:

- Biosphere-Atmosphere Trace Gas Exchange in the Tropics
- Deposition of Biogeochemically Important Trace Species
- Impact of Tropical Biomass Burning on the World Atmosphere
- Chemical Transformations in Tropical Atmospheres and their Interaction with the Biosphere

The Role of Polar Regions in Changing Atmospheric Composition.

The Arctic and Antarctic regions play important roles in atmospheric chemistry involving long-range transport of anthropogenic pollutants, exchange of trace gases between the atmosphere and snow/ice surfaces, atmospheric chemistry in a seasonal light/dark atmosphere and the concentration and storage of atmospheric constituents in ice. These regions have a special sensitivity to anthropogenic emissions (e.g. ozone destruction by halocarbon decomposition products, albedo changes due to soot particles). The polar regions are especially important because the expected greenhouse warming of the Earth is most pronounced at high latitudes during the winter half year. Two IGAC projects are proposed for these regions:

- Polar Atmospheric Chemistry
- Polar Air-Snow Experiment

The Role of Boreal Regions in Changing Atmospheric Composition

An understanding of the cycling of trace gases between the atmosphere and ecosystems in the boreal region is of special importance for assessing the impact of a coming climate change on these cycles and how fluxes from this region alter climate (e.g. through positive feed-back mechanisms). This arises because these regions both contain major carbon reservoirs that may be very sensitive to the effects of future climate change and are predicted to experience very large effects of a change in the climate. One IGAC project is proposed for these boreal and subantarctic regions:

- Northern Wetlands Study

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 reflect the net effect of all the relevant atmospheric processes: emissions, circulation, transformation and removal. The global distributions and trends of chemically and radiatively important species are signatures not only of atmospheric changes but also of the fundamental processes underlying them. The IGAC Programme has four projects addressing this important

globally integrating research area, involving a ground-based network, aircraft-based surveys, experimental studies, and relevant theory and modelling:

- Global Tropospheric Ozone Network
- Global Atmospheric Chemical Survey
- The Chemical and Physical Evolution of Cloud Condensation Nucleii as Controllers of Cloud Properties
- Development of Global Emission Inventories

International Support Activities.

Scientific programmes of the scope of IGAC require, for their success, an essential support infrastructure. Three international supporting activities are proposed for IGAC:

- Education in Atmospheric Chemistry and Global Change
- Communication (IGAC Newsletter)
- Intercalibrations and Intercomparisons

The six initial foci of the IGAC Programme have three important common elements that underpin the proposed projects and need to be emphasised here. These are:

- theory and modelling. A major challenge in this area is the development of global chemical transport models. We plan that these will be developed in cooperation with the World Climate Research Programme (WCRP).
- laboratory determinations of fundamental molecular properties, including absorption cross-sections, rate constants, and homogeneous and heterogeneous reaction mechanisms.
- new instrument development. Major challenges are provided by the need to accurately measure highly reactive free radicals and a wide variety of key species at very low concentrations.

The implementation of the IGAC Programme will be guided by the IGAC Steering Committee (contact names and addresses are provided in the appendix). Each of the IGAC projects will have a Scientific Coordination Committee responsible for planning and conduct of the project. The urgency of the issues addressed by IGAC suggests an immediate start on each of these projects. For some projects this start will involve development of detailed plans for action while for others that are in a greater stage of readiness the work will commence immediately.

Funding of work within the IGAC projects will largely come from individual national programmes although mechanisms for funding activities in nations without significant available resources will be sought.

Global Atmospheric Change and the Goals of IGAC

The Earth's atmosphere is a vital natural resource that until recently appeared unaffected by human activities, except on local scales. However, during the past decades, it has become abundantly clear that the worldwide strongly growing anthropogenic activities have impacts on the atmosphere over large areas of the continents, and even globally. Through industrial and agricultural activities, humans are moving millions of tons of chemicals into the atmosphere, where they are chemically processed and from where the products of reactions are transferred back to the Earth's surface. The rates of these transfers are now so large, and the products of the chemical reactions so hazardous, that the atmosphere, vegetation, land and oceans can no longer cope with the assault.

World-wide, the amounts of numerous key chemicals are increasing above their natural background levels in the atmosphere: of special importance are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Simultaneously, synthetic chemicals like chlorofluorocarbons (CFCs) are building up and causing a man-made loss in the stratospheric ozone layer; the concentration of ozone in the stratosphere is now decreasing. Moreover, the sizes of these changes are not small. Convincing data from the gases trapped in polar ice cores tell us that the present atmospheric CO_2, CH_4, and N_2O concentrations are unprecedented, at least for the Earth of the last 160 000 years. Continued increasing trends are elevating these concentrations to ever more uncharted territories. Simultaneously, there are demonstrable human-caused disturbances to the global cycles of essential nutrient elements like carbon, nitrogen and sulfur.

There are even sharper changes occurring on less than world-wide scales but still in large regions. Air pollutants such as ozone and sulfur and nitrogen oxides from combustion of coal and oil are afflicting many regions with losses of air quality, photochemical smog formation, acid rain, damage to crops and other plants, and detrimental impacts on soils, forests and lakes.

Scientists have learned remarkable things about the roles of chemicals in the atmosphere and how our climate and the ozone layer are controlled. Chemicals present in minute amounts are now known to have important influences far beyond what their small amounts in the air would suggest. Trace gases like CO_2, CH_4, N_2O, O_3 and the CFCs are very effective greenhouse gases that alter the energy balance of our planet and hence its climate. Similarly, extremely small amounts of chemicals can destroy the stratospheric ozone layer that protects us from the Sun's ultraviolet radiation.

The kinds of atmospheric changes that are happening now and the speed of those changes demand attention. It is essential that we accelerate research in the science of the environment. We now recognize that interdisciplinary approaches to the problems are essential. Collaboration between such diverse specialists as plant physiologists, marine chemists, microbiologists, cloud physicists, boundary layer dynamicists, meteorologists, oceanographers and photochemists are required to understand adequately both the vital interactions among the Earth's component systems and the complex processes taking place in the atmosphere itself. A basic scientific goal for this research is to observe and quantify the changes that are under way now. Another basic goal is to develop enough understanding, as quickly as possible, to permit predictions to be made so that environmental damage can be restricted, avoided, or reversed in the future. With such predictive capability in hand, sensible management of resources and the environment can be undertaken to maintain a habitable planet for a growing human population.

National programmes addressing global atmospheric chemistry now exist in several countries. However, the scope and nature of the needed research dictates that international collaborative efforts be developed urgently; no one nation or

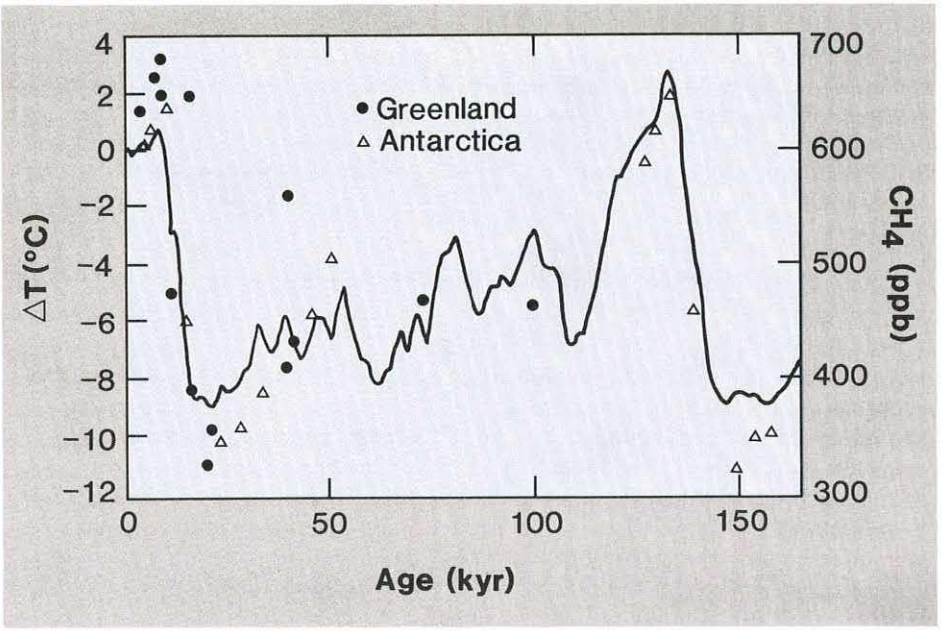

Figure 1 Methane concentrations (ppb by volume) from ice cores plotted against age of air before present. Solid circles are data from Greenland ice cores, and triangles represent data from Antarctic ice cores. The solid line is the isotope based temperature. The data show that methane increased from about 320 ppb to 620 ppb between the end of the next to last glaciation and the subsequent interglacial period, about 160 000 to 120 000 years ago. These changes suggest that exposing and warming ice-covered soils produced more methane as glaciers retreated. The data also show that contemporary methane levels of 1600 ppb and their rate of increase are unprecedented, at least during the last 160 000 years.

(Reprinted with permission from R.J. Cicerone and R.S. Oremland, *Biogeochemical Aspects of Atmospheric Methane, Global Biogeochemical Cycles*, Vol 2, p301, 1988).

group alone possesses or can develop the scientific expertise, advanced instrumentation, remote sensing capabilities and platforms for all of the measurements that are required.

The International Global Atmospheric Chemistry (IGAC) Programme has been formed in response to growing concern in many countries about these observed and predicted chemical changes in the global atmosphere and their potential impacts on humanity. Atmospheric chemistry in addition plays a very important role in a larger interactive global system comprised of the atmosphere, oceans, land and biota that determines the global environment and its susceptibility to change. The IGAC Programme is therefore intended to be a vital contributor to the International Geosphere-Biosphere Programme (IGBP) of the International Council of Scientific Unions (ICSU), that addresses this overall global system.

The present study will focus on plans for scientific study of the chemistry of the troposphere. There is a vital existing base of research in the stratosphere that has been coordinated under the Middle Atmosphere Programme (MAP). Plans for new research in upper atmospheric chemistry are presently being formulated as part of the Middle Atmosphere Responses to Changes (MARC) programme jointly sponsored by the International Association of Meteorology and Atmospheric Physics (IAMAP) and the International Association of Aeronomy and Geomagnetism (IAGA). We

emphasise that the division of atmospheric chemistry into tropospheric and upper atmospheric components is an artificial one and the IGAC Steering Committee intends to cooperate with, and review the development of the MARC programmes to ensure that vital investigations involving chemical and dynamical interactions between the upper and lower atmosphere receive appropriate attention. The IGAC goals pertain to the entire atmosphere and an objective of the IGAC Steering Committee is to develop an integrated plan comprising the present document and the relevant MARC plans augmented and/or modified where necessary.

IGAC Goals

The goals of the International Global Atmospheric Chemistry Programme are:

- To develop a fundamental understanding of the chemical processes that determine the chemical composition of the atmosphere.
- To understand the interactions between atmospheric chemical composition and biological and climatic processes.
- To predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere.
- To provide the necessary knowledge for the proper maintenance of the biosphere and climate.

These goals address our understanding of several anthropogenic pressures leading to ubiquitous stresses on the biosphere, such as:

- Increasing acidification of precipitation.
- Increasing oxidant concentration in surface air.
- Warming due to increases in the concentrations of trace-gases involved in the greenhouse effect.
- Alteration of biospheric exchange fluxes due to land use and climatic changes.

To achieve these goals a programme of fundamental research is needed to measure and understand

- Global distributions and trends.
- Surface exchange processes.
- Gas-phase chemical reactions.
- Multiphase processes.

To aid understanding and to predict future changes we need to formulate regional and global models for simulating the tropospheric chemical system and its interaction with marine and terrestrial ecosystems.

IGAC Foci

The varying soil, water, vegetation, fauna and climate of different regions over the globe cause marked differences in trace gas emission rates, trace gas composition, photochemical activity and chemical removal rates over the Earth. Because of this and for logistical reasons, we have found it convenient to focus the research activities in IGAC on a number of specific regions that are of special importance in atmospheric chemistry. For each region, the research is shaped by the characteristics of these parts of the globe and their susceptibility to change. The major regional foci are:

Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere

The oceans cover about 70% of the planet and act as both a source and sink of many important atmospheric constituents. The marine atmosphere has a distinctly different

composition from continental air and thus different oxidation processes and rates of conversion. Also in the marine atmosphere, atmospheric chemicals of continental origin are processed in an environment with no new anthropogenic inputs thus simplifying the study of various transformation processes.

Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry

Tropical continental areas play an important role in global atmospheric chemistry. Large emissions of gases and particles are associated with rain forest and savanna regions. Under the pressure of rapidly expanding human populations many tropical areas are experiencing rapid land use change. These regions play a major role in the global budgets of several radiatively and chemically important trace species.

The Role of Polar Regions in Changing Atmospheric Composition

The Arctic and Antarctic regions play important roles in atmospheric chemistry involving seasonal cycles of darkness and light, oceanic uptake of trace gases, concentration and storage of atmospheric constituents in ice and special sensitivity to anthropogenic emissions (e.g. ozone destruction by halocarbon decomposition products, albedo changes due to soot deposition). These regions are also important for a variety of ecological and climatic reasons.

The Role of Boreal Regions in Changing Atmospheric Composition

These regions are major carbon reservoirs that may be both very sensitive to warming and experience greater greenhouse warming than lower latitudes. An understanding of the cycling of trace gases between the atmosphere and ecosystems in this region is therefore of special importance for assessing the impact of global warming on chemical cycles. Specifically we need to understand how fluxes of gases like CH_4 from these regions may increase following warming and whether or not this will cause a positive feed-back to the warming.

The above four regional foci are integrated and extended by a global focus:

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 reflect the net effect of all the relevant atmospheric processes: emissions, circulation, transformation and removal. The global distributions and trends of chemically and radiatively important species are signatures not only of global changes but also of these fundamental processes underlying them.

Finally, the need for certain essential supporting activities for international cooperation is met by an additional focus:

International Support Activities.

These activities include the setting of international standards for measurements to be achieved by intercalibration and intercomparison exercises, and international education and communication on topics in atmospheric chemistry and related issues.

These six IGAC foci are intended collectively to address areas of greatest current uncertainty and/or perceived importance. They are not intended to be exhaustive and we anticipate further foci will be added as time proceeds. For each of the above foci specific scientific goals and one or more specific scientific projects that address

these goals have been identified . These projects, defined in the following chapters, may consist of several phases and have been categorised according to their state of readiness.

Proposed scientific investigations relevant to these foci will in many cases build on existing national programmes. IGAC is not intended to replace these programmes but to provide the strategy whereby essential scientific endeavours can be accomplished that involve large demands for manpower, technology, geographic coverage, or monetary resources beyond the capability of any single nation.

The specific research activities proposed in IGAC have important common elements that must be emphasised. First, theory and modelling are an integral part of each of the IGAC foci. A whole hierarchy of models are required for the successful pursuit of the IGAC projects. Theory and modelling are important in the planning phases to identify the species to be measured and the locations, spatial resolutions and frequency of these measurements. Techniques for chemical data synthesis and analysis using diagnostic models and inverse methods need further development in order to deduce more accurate quantitative information on emissions, transformations and loss rates from global data sets. Valid theories and improved models are needed in the areas of surface exchange, stratosphere-troposphere exchange, gas-phase chemical and photochemical mechanisms, cloud and precipitation chemistry, hydrometeor-gas-aerosol interactions and aerosol physics.

A major challenge in this area is the development of global chemical transport models (GCTMs). This task, that requires accurate models of atmospheric dynamics, will require cooperation between the World Climate Research Programme (WRCP) and IGAC. This cooperation should be fruitful for both programmes. Specifically, while IGAC chemical modelling will be dependent on progress in general circulation modelling in WRCP, we also expect atmospheric tracers measured in IGAC to provide an important test of the predicted circulations in these models.

A second common element in many IGAC scientific investigations involves the laboratory determinations of fundamental molecular properties including absorption cross-sections, rate constants and homogeneous and heterogeneous reaction mechanisms. Such studies form the underpinning for instrumental design, data interpretation and development of new chemical theories.

A third common element involves new instrument development. Major challenges are provided by the need to accurately measure highly reactive free radicals (OH etc.), a wide variety of inorganic and organic compounds at concentrations sometimes as low as 1 part in 10^{12} in air, and key aerosol properties. Both in situ and remote sensing techniques are needed in IGAC to provide both local and global measurements of these key atmospheric constituents.

IGAC Timetable

Although the scientific goals and foci described in the programme are all of urgent concern, some of the specific research projects under the foci may require instrument development, international coordination and detailed planning before they can be implemented. For this reason each project in IGAC has been placed in one of three categories:

(1) **Active**: These projects have already begun (e.g. because they are extensions of on-going research) or are ready to commence essentially immediately. A project coordinating committee with a designated convener exists comprised of scientists who will be actively involved in the project. The manpower, technical, and monetary resources exist for the project and a timetable for specific action is in hand.

(2) **Planning**: These projects are important and feasible but require further planning due to lack of clearly defined international agreements and/or resources and/or

coordinating committee and/or timetable. These projects are expected to graduate to the active category within 2-3 years.

(3) **Conceptual**: These projects are important but for one reason or another their feasibility needs to be better established. These projects will have a coordinating committee whose primary task will be to demonstrate the broad technical and scientific feasibility of the proposed work that will allow it to graduate to the planning or active categories. The membership of the coordinating committee may change if necessary after this graduation (or at other times) to include scientists who become actively involved in the project implementation.

Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere

For a proper understanding of global atmospheric chemistry one needs to consider the fact that about 70% of the surface of our planet is the oceanic environment. The oceans act both as a source and a sink for many atmospheric constituents. Biogenic exchanges of gaseous sulfur, carbon and nitrogen compounds between the atmosphere and ocean waters modulate the natural variability of the atmosphere's oxidizing capacity, cloud properties and climate. Atmospheric transport of substances from continental sources resulting from both natural and anthropogenic processes also can exert a profound influence on the chemistry of the marine atmosphere. The deposition of these substances onto the ocean can perturb the marine environment through the natural inputs of nutrients (N, P and essential micronutrients such as Fe) or through anthropogenic inputs of air pollutant gases and particles. The latter issue is closely connected to the objectives of the JGOFS programme (Joint Global Ocean Flux Study) of the Scientific Committee on Ocean Research (SCOR).

Goals

- To assess the impact of emissions of pollutants and natural substances from the continents on the chemical properties of the marine atmosphere.
- To determine the role of marine gas emissions in cloud processes, atmospheric chemistry and climate of oceanic atmospheres.
- To evaluate the importance to the chemistry and biology of the ocean of deposition of trace species transported from the surrounding continents.

Project 1: North Atlantic Regional Study (NARE)

Status: Active

The industrial regions on the continental rim of the northern Atlantic are major global sources of the compounds that influence the oxidizing capacity of the Earth's atmosphere. In the North Atlantic region the compounds move from the continental coastal areas where they are emitted into the relatively source free marine environment where the airborne compounds are processed. This combination of a well defined source region followed by a vast relatively source-free region of ocean provides an excellent regime to study the mechanisms involved in the chemical processing of the compounds and the persistence of these compounds and their products in the marine atmosphere. This regional study will assess the long range transport of photochemically active compounds and/or their products and the impact of this transport on hemispheric air quality. Finally, the regional study permits estimation of the amount of these compounds that are deposited in this marine environment and the impact of this deposition on surface sea-water chemistry and marine biological processes.

Although this is a new undertaking, the programme will build upon several existing programs including AEROCE, WATOX, GAGE AND EUROTRAC (TOR, ASE). The programme will combine measurements taken at ground based sites, from ships and from aircraft, with detailed model developments.

Goals

To understand:

- the fate of continental emissions transported over the Atlantic Ocean,

- the impact of these compounds on the oxidative properties of the atmosphere over the Atlantic Ocean, and
- the delivery of these compounds and their oxidation products to the ocean and their subsequent impact on surface sea-water chemistry and marine biological productivity.

Implementation

Phase I. Preliminary inventory of the chemical climatology and meteorology as provided by routine and special measurements made by existing programs (e.g. ALE/GAGE, AEROCE and TOR/EUROTRAC). This phase of the programme determines the locations, seasons and meteorology that will allow the most definitive study of the chemical production/destruction and transport of the compounds of interest.

Phase II. Determination of a detailed chemical climatology along with preliminary investigations of important chemical mechanisms. This phase will involve intensive ground based measurements using state-of-the-art instrumentation. In addition to the existing measurements (phase I above), the compounds to be measured include O_3, CO, H_2O_2, NO, NO_2, PAN, HNO_3, particulate nitrate, NO_y, SO_2, particulate sulfate, NMHC, DMS, and CFCs (as tracers). During the latter stages of this phase there will be vertical soundings of O_3 and H_2O_2, depending on the development of the required instrumentation. The measured chemical composition at the sites will be compared to model simulations.

Phase III. Development of a comprehensive chemical climatology of the remote marine region and comprehensive tests of the key chemical mechanisms involved in the processing of chemicals contained in continental plumes. This phase of the programme will be carried out using ground-based, shipboard and aircraft studies.

Intercalibration of instrumentation will be done on a routine basis as part of all three phases. Intercomparisons of instrumentation will be done if necessary to certify the reliability of critical measurements. These intercalibrations will be of great use not only for this, but for all IGAC activities. Modelling will be done as an integral part of the study (i.e. in both planning and interpretation of the study).

This project consists of a number of activities that include:

- Determination of the reactive nitrogen oxide climatology for this region throughout the year. Since NO_x plays a key role in global oxidant formation, an important part of this programme will be to develop a budget of reactive nitrogen oxides (NO_y compounds) over the North Atlantic. This is important both from the stand-point of intercontinental pollution and the impact on the chemistry of the marine environment.
- Determination of the wintertime chemistry of sulfur and nitrogen compounds. The chemical conversion of SO_2 to sulfate and NO_x to organic and inorganic nitrates that occurs during the winter period, when solar ultraviolet intensity and temperatures are low and photochemistry is limited, will be investigated. The importance of NO_3 as a primary oxidant and the role of aerosols in this chemistry will be studied.
- Investigation of photochemical processing. During the summer period, the simultaneous measurement of the NO_y family and the NMHC emitted from the well defined continental coastal source regions will provide data to test the processes involved in photochemical oxidation.
- A study of the processing of the Northern Hemisphere's wintertime build-up of NO_y and NMHC. This experiment will be carried out in the winter/spring transition to follow the photochemical destruction of precursors that have been stored at high latitudes in the Northern Hemisphere winter.
- Investigation of source-receptor relationships in the North Atlantic. Examples will include the transport to the Atlantic of gases and aerosols from biomass burning in

the tropics, and air pollutants from the US and Europe, to the Atlantic.

- Impact of the atmospheric inputs of nutrients on ocean biological productivity. This experiment will focus on compounds such as N, P, Fe, and their biological availability to the ocean system primarily in ocean regions downwind of large continental sources.
- Chemical and physical evolution of cloud condensation nuclei in the oceanic atmosphere resulting from continental industrial emissions. This activity is described more fully later in this document (cf. Project 3: "The Chemical and Physical Evolution of CCN as Controllers of Cloud Properties", under the focus "Global Distributions, Transformations, Trends and Modelling").

Timetable

1989	A first meeting of the Project was held at University of East Anglia, Norwich, England, in July.
1990	Complete phase I experiments to identify sites and seasons for phase II and III experiments.
1991–2	Complete planning for phase III and implement phase II experiments.
1993	Complete phase II experiments and commence phase III experiments and modelling.
1994–5	Complete phase III.

Logistical requirements

It is estimated that for phase III experiments two ships and two aircraft will be required. Studies will be centred in several island locations in the northern Atlantic. These sites include Barbados, Tenerife, Bermuda and Mace Head (Ireland). Additional coastal stations on the coast of North America, and Europe (perhaps Africa and Latin America as well) may be added. Present site locations (above) will be evaluated and improved as required. The programme will involve 50–100 people. Several planning workshops will be necessary.

Project 2: Marine Aerosol and Gas Exchange, Atmospheric Chemistry and Climate (MAGE)

Status: Planning

Several classes of gases emitted from marine areas affect the atmosphere, including reduced sulfur compounds, hydrocarbons, halogenated organics, and nitrogenous compounds. A partial list includes DMS, COS, DMDS, H_2S, alkanes and alkenes (in the range C_1 to C_4), haloalkanes and haloforms (particularly those containing bromine and iodine), amines, nitrous oxide, and perhaps NO_x. Many of these compounds are either known or thought to be the product of biological activity (algae) in marine waters.

The specific ways that gases emitted from marine areas affect the atmosphere are:

- They strongly influence the biogeochemical cycles of some elements (C, S, halogens).
- They can be the dominant source of species that determine the acid balance of aerosols and rain in oceanic areas (S, halogens, hydrocarbons, and NH_3).
- Some are precursors of atmospheric oxidants (hydrocarbons) or have other photochemical roles (halocarbons).
- Sulfur gases are believed to form cloud condensation nuclei in the troposphere (DMS, SO_2) or radiatively and chemically active aerosol particles in the stratosphere (COS, CS_2).
- Some cause direct radiative effects (CO_2, N_2O).

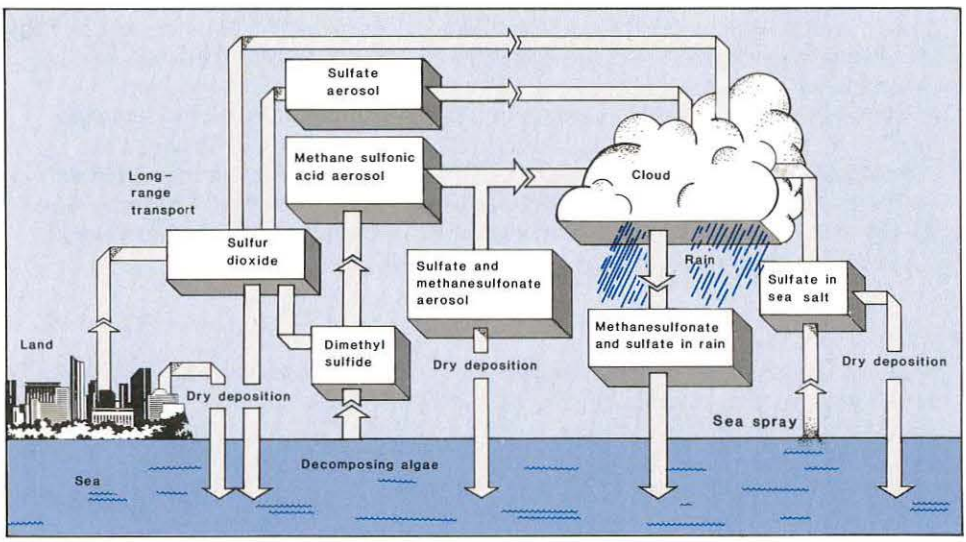

Figure 2 The atmospheric sulfur cycle over the Southern Ocean. A proposed pathway links cloud formation with algae in the sea. Decomposing algae produce dimethyl sulfide gas, which after emission to the atmosphere, turns into particles of sulfuric acid and methane sulfonic acid. These sulfur particles provide nucleii for cloud droplets to form around.

Since deposition to the oceans is an important sink for many atmospheric species, the rate of this deposition strongly affects atmospheric composition. The production of marine sulfate aerosol, for instance, is limited in part by the deposition of precursor SO_2. For many species, global deposition rates are used in budget studies to estimate hard-to-measure source terms.

The wet and dry processes which contribute to these downward surface fluxes are especially difficult to measure in remote marine areas. One key unknown is what happens in very rough seas, when there is no distinct "surface", but rather a spray zone. The dynamics of this spray zone may drive some very large exchange rates.

Atmospheric deposition is also an important source of some nutrients essential for the growth of marine biota, such as certain nitrogen species, iron, and possibly phosphorous. In the northern Pacific, for example, the deposition of iron from airborne Asian dust may limit biological productivity. This situation, in which deposition controls the biota which in turn control emissions, demonstrates why we propose to address these questions using an interdisciplinary approach.

Goals

- To understand the chemical, biological, and physical mechanisms that control the exchange of trace gases and particulate materials between the atmosphere and the surface of the open ocean.
- To develop formulations of ocean exchange processes for inclusion in global-scale climate and air chemistry models.
- To extend the experimental knowledge of air-sea exchange to conditions of strong winds, rough seas, and spray.

Implementation

Understanding the exchange between the atmosphere and oceans requires studies both of emissions from the ocean surface and of deposition to it from the atmosphere. Since somewhat divergent technologies have developed to study these two types of processes, MAGE starts with two stages of separate emission and deposition experiments and brings them together into larger, common field programs in the third stage. MAGE offers a real opportunity to improve the overlap between the deposition/exchange community (which has historically focussed on measurements in the lower atmosphere) and the gas emission community (which has tended to work in the upper ocean and at the air-sea interface), so that the chemical, biological and physical controlling factors can be understood as a unified whole.

a) *Gas Emissions*

Phase I. A workshop will plan the experiments for the following two phases and identify those measurements that require intercalibration. The work at this stage will build on to the existing Pacific Stratus Investigation (PSI) and EUROTRAC/ASE programs

Phase II. Emission measurements will be carried out in three oceanic regimes of contrasting biological status, during two one-month cruises in succeeding years. The study regimes will include one consistently high-productivity area, and an oligotrophic area with and without its spring bloom. This will be a process-oriented aqueous experiment, with only a few essential atmospheric measurements. A large research vessel will be needed, since a scientific staff of 20–25 chemists, biologists, and support staff would be involved.

b) *Deposition/Exchange*

Phase I. A planning workshop will be held to define the experiments for the following two phases and identify those field locations where existing facilities would offer the greatest benefit. Instrument development and intercomparison activities will build on the existing efforts of air-sea exchange research being conducted in The Netherlands, Canada, Denmark, France, the UK, and the USA.

Phase II. Studies will concentrate on quantifying and reducing the uncertainties associated with the measurement of exchange rates, using in-air instrumentation (both tower-mounted and airborne). Studies will be conducted in extremes of surface and atmospheric conditions, so as to provide demanding tests of instrumentation. Several near-shore sites in the Atlantic will be used; these sites will be identified in Phase I.

Phase III. A series of studies will be conducted in light and moderate winds, using a floating platform deployed in open ocean as well as aircraft and ships, and a parallel series of experiments conducted in stronger winds, using research towers in near-shore environments. These studies would begin around 1993-1994 and end with the comprehensive emission/deposition experiments.

c) *Coupling of Approaches*

Phase III. This phase will couple air and water experiments for those species whose lifetimes are short enough that their atmospheric chemistry is immediately affected by the observed emissions. It will also try to close some cycles by looking at emissions and deposition of related species. The work will probably be most successfully conducted in either the Pacific or South Atlantic, because there are fewer anthropogenic sources of gases in those regions to interfere with the measurement of the natural emissions of interest. A large ship and one or more large aircraft would be needed for this experiment.

The atmospheric chemistry community has not yet benefitted from the close coupling of the upward-looking (water-column) and downward-looking (micrometeorological) approaches to studying air-sea interactions. The parallel development of technologies, combined with joint planning in the MAGE project offers a unique opportunity to maximize the interaction between these historically separate scientific communities. The Project Scientific Coordinating Committee is also exploring interactions with the Joint Global Ocean Flux Study (JGOFS), to ensure that the related projects are complementary.

Timetable

A planning meeting will be held in conjunction with the American Meteorological Society Air/Sea Interaction Symposium in Anaheim, USA, in February, 1990.

Phase I. Planning workshop and intercalibration activities, , 1990–1991.

Phase II. Two shipboard emissions experiments, 1992–1995. Exploratory shoreline air-sea flux studies, 1991–1993.

Phase III. A shipboard emissions experiment combined with airborne measurements of atmospheric transformations, chemistry, and deposition. 3-4 years, during the mid-1990s.

Logistical Requirements

Phase I. Support for a workshop and intercalibration activities.

Phase II. (a) Emissions: use of ships, aircraft, and fixed towers. Two months of ship time and 20 personnel, including some graduate students, and instrumentation.

(b) Deposition/exchange: a total of four months of field studies, with supporting ship and aircraft time, totalling about thirty scientific and technical personnel, with appropriate field support.

Phase III. as for Phase II, but with additional personnel and longer field programs.

Project 3: East Asian/North Pacific Regional Study (APARE)

Status: Planning

The region of East Asia containing China, Japan, North Korea, South Korea and Taiwan, is characterized by high, and rapidly growing anthropogenic emissions of air pollutants due to its high population density and energy consumption. Further increases in both population and energy consumption are anticipated in the following decades; these will bring about increases of emissions of NO_x, SO_2 and hydrocarbons due to human activity.

The anthropogenic emissions probably already influence the chemistry of the Pacific troposphere. Evidence has already accumulated that the concentration of "background" ozone in high pressure systems passing through the East Asian continent and north-western Pacific islands contains substantially elevated ozone levels compared to that in the central Pacific troposphere. Long range transport of continental aerosols from the north-western Pacific region to the Hawaiian islands has been reported also.

A systematic study of the atmospheric chemistry in this mid-latitude region has been conducted neither nationally nor internationally. Quantifying the emissions and the fate of the atmospheric constituents in the East Asian plumes necessitates international cooperation among scientists in East Asian countries. The composition of pollutants in the north-western Pacific region will, because of the different lifestyle and technology of the region, be quite different from that over the Atlantic.

Goals

- To assess the transport and chemical transformation of air pollutants over the East Asian region both over land and over the north-western Pacific Ocean.
- To determine the deposition of primary and secondary pollutants (sulfate, nitrate, organics) in the East Asian region.

Implementation

The study will be centred on the oceanic region bounded by the coast of South-East China, Japan and Taiwan.

Phase I. Develop an emission inventory for the region.

Phase II. Conduct ground-based measurements of NO_x, SO_2, O_3, NMHC, PAN and the composition of aerosol and precipitation. Incorporate the emissions inventory and meteorological data into a numerical model incorporating transport and chemical processes covering the region. Conduct aircraft and shipboard measurements to verify model predictions. The NASA Pacific Exploratory Mission-West will be part of this project.

Timetable

A planning meeting will be held during 1989.

Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry

About 50% of the world net primary production of biomass takes place in tropical forests and savannas. Large emissions of gases and particles occur from both biomass burning and the growth and decay of plants and organic matter in savanna and equatorial rain forests. These emissions can be rapidly transported to the free troposphere by convective cloud fields and subsequently carried to other regions of the world.

Tropical areas are experiencing rapid changes in land use and, in certain regions, accelerated industrialization. The stresses on the tropical environment will increase in the future as countries develop and their populations grow. These stresses will produce changes in the biogeochemical cycles in various tropical ecosystems.

Global climate change cannot be fully addressed in the absence of understanding about the chemical state of the tropical biological/atmospheric system. Therefore, currently within this IGAC focus, four projects are defined that should enlighten our understanding of the present state of, and ongoing perturbations to, tropical atmospheric chemistry. These are:

- Biosphere–Atmosphere Trace Gas Exchange in the Tropics.
- Deposition of Biogeochemically Important Trace Species.
- Impact of Tropical Biomass Burning on the World Atmosphere.
- Chemical Transformation in Tropical Atmospheres and their Interaction with the Biosphere.

Goals

To understand:

- the cycling of climatically and chemically active atmospheric constituents in the tropical region,

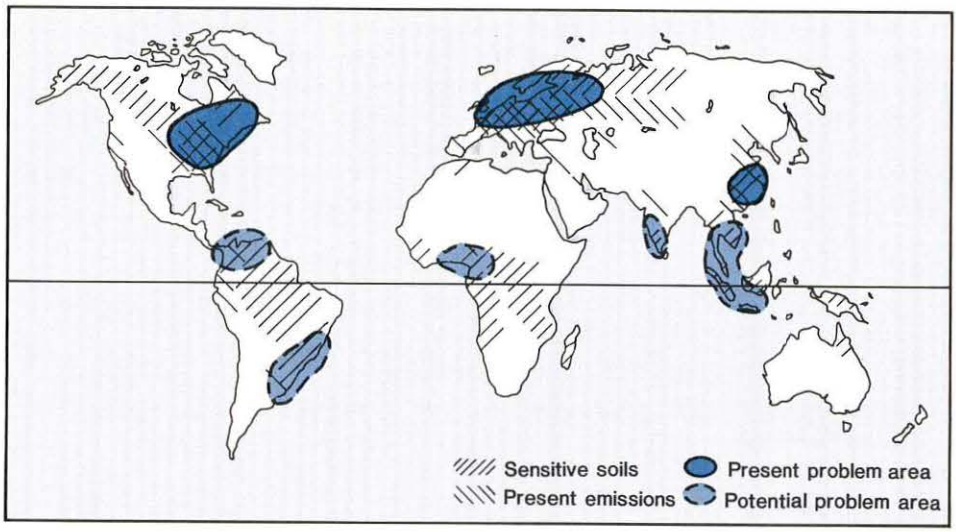

Figure 3 Rough estimates of (a) the sensitivity of soils to surface water acidification due to acid deposition, and (b) present emission of acidifying compounds from human activities. Areas circled by solid lines represent a combination of (a) and (b) and are thus problem areas today. Areas encircled by dashed lines represent a combination of sensitive soils and regions with projected rapid increases in emissions due to increasing industrialisation and population growth. Such areas are potential future problem areas of acid deposition.

(Reprinted with permission from Rodhe *et al.* 1988, Acidification and regional air pollution in the tropics. In *Acidificaton in Tropical Countries,* (Eds) H. Rodhe and R. Herrera. *SCOPE* **36,** John Wiley and Sons Ltd.)

- the effect of changing land use, agriculture, industrialization and climate on this biogeochemical cycling.

Background

During the past decade some national and international bilateral experimental campaigns have been conducted to study the tropical atmospheric chemical system. These campaigns, e.g. the NCAR 1979/1980 and ABLE II experiments of 1985 and 1987 in Brazil, and DECAFE programme in 1988 in Africa have proven highly informative. Additional experiments of this kind, including DECAFE II and TRACE are planned for the next 3 years. These campaigns involve ground-based and aircraft field measurements to assess the respective roles in atmospheric and precipitation chemistry of processes in equatorial forest and savanna areas, including biomass burning.

Because of the complexity of the biological/atmospheric system, it is essential that coordinated IGAC projects, pooling the resources of several nations and the expertise of several scientific disciplines, be developed. This is necessary in order to extend our knowledge of tropical atmospheric chemistry and to estimate the impact of expanding human activities in the tropics on atmospheric chemistry and climate.

Project 1: Biosphere-Atmosphere Trace Gas Exchange in the Tropics (BATGE)

Status: Active

Current fragmentary knowledge indicates that trace gas emissions from the tropics are a major global sources of NO_x, NMHC, N_20, CH_4, and CO. These chemical species have a profound influence on atmospheric chemistry and climate.

This project is being developed in close cooperation with the SCOPE activity and

IGBP related activities on biosphere/atmosphere interactions. The SCOPE Project on "Trace Gas Exchange between Terrestrial Ecosystems and the Atmosphere" is concerned with reviewing present understanding of the biological controls on trace gas exchange, the status of contemporary measurement techniques and the development of a conceptual framework for describing the exchange over different time and space scales. The project described here, BATGE, is focused on measurements and the development of models that simulate the emission process. As such, the BATGE and SCOPE Projects are complementary.

Goals

- To determine the fluxes of chemicals between representative tropical biological environments (biomes) and the troposphere.
- To determine the factors that control these fluxes.
- To develop the ability to predict the impact on these fluxes of both climatic and land use changes.

Implementation

The first activity in this project will be the conduct of an experiment on the "Exchange of Oxidized Nitrogen Compounds (NO_y) between the Tropical Biosphere and the Atmosphere".

The goals of the first experiment are:

- To quantify the rates of exchange of odd nitrogen oxides (e.g. NO, NO_2, HNO_3) between the tropical biosphere and the atmosphere in representative biomes.
- To assess the effects of land use change including agricultural expansion and forest harvesting on the rates of NO_y emissions in the tropics.
- To formulate the exchange in terms of external properties, including soil physical, chemical, and microbial status, the surface vegetation, and atmospheric processes. This formulation should be suitable for incorporation in larger-scale biosphere-atmosphere environmental models.

This experiment will consist initially of as many as four multi-national field studies, conducted on different continents. These studies are necessarily multi-disciplinary, involving soil science, microbiology, plant physiology, and meteorology. One of the first tasks is to develop a protocol, and make practical arrangements for conducting a flux measurement technique comparison experiment. At the same time an attempt will be made to formulate a model of the exchange process, suitable for later inclusion in larger-scale environmental models. Upon completion of a satisfactory comparison study, further field studies will be conducted to verify the performance of this model.

Naturally it is desirable that experiments concerning the exchange of other trace gases (e.g. N_2O, NH_3 and CH_4) be set up in parallel with this one. At the earliest practical stage this work should be merged with other experiments of this overall project. Parallel studies of the exchange of other gases e.g. N_2O, NH_3, and CH_4, may be of considerable assistance in the interpretative phase of this NO_y experiment.

Timetable

1989 Preliminary discussion of interested scientists in Berlin (February), exchange of information, definition of experiment.

1990 Scientific Coordinating Committee to meet at the SCOPE Meeting in February on Trace Gas Exchange between Terrestrial Ecosystems and the Atmosphere, in Stockholm. Field studies.

1991-onward. Flux measurement technique comparison experiment. Formulation of process model for NO_y exchange in tropical ecosystems. Process model evaluation experiments. Integration of this work with other atmospheric trace gas exchange projects. Development of a further experiment to understand the relationship between local exchange representing 10^0-10^4 m^2 and exchange over large regions ($\geq 10^8$ m^2).

Logistical Requirements

Well-characterised and well supported field sites, in representative areas. This includes (a) micrometeorological support, including heat, water vapour and CO_2 flux measurement, (b) soil physical, chemical, and biological characterization and plant status measurements. 10–20 scientists plus normal support for flux comparison experiment.

Project 2: Deposition of Biogeochemically Important Trace Species (DEBITS)

Status: Planning

The deposition of chemical species to the Earth's surface plays an essential role in limiting the atmospheric concentration of many biogeochemically important trace species. Important redistributions of both plant nutrients and toxic substances within the biosphere result from such deposition. Both dry and wet deposition pathways must be understood if the biogeochemical cycles of many species are to be quantitatively assessed. This is especially so in tropical regions, where current knowledge is very limited and must be expanded if the impacts of environmental change are to be properly assessed.

Goals

- To determine the rates of deposition from the atmosphere of a range of biogeochemically important chemical species.
- To identify the factors which regulate these deposition fluxes.

Implementation

The project will involve experiments covering various tropical regions, aimed at producing data on both wet and dry deposition on a range of chemical species (N, S, P, and C species and major sea-salt components, plus species of special interest such as organic acids, organic N compounds, H_2O_2 etc.).

This project will commence with an experiment based on a network of precipitation chemistry stations covering the South-East Asian region. Future expansion of the project will be considered after 3 years. Possibilities include: (1) new experiments in other tropical regions, (2) consideration of additional measurements at each operating site. 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 this and other regions.

The first activity of the project is an experiment on the Composition and Acidity of South-East Asian Precipitation (CAAP). This experiment will be based on a precipitation chemistry network in the SE Asian region, from India through to China, south to Australia and the Pacific islands.

The goals of CAAP are:

- To quantify the wet deposition component of the atmospheric cycles of nutrient/reactive species (S,N,C,P and sea-salt species).
- To assess the current state of rainwater acidity across the region and identify the acid/base species involved.

During the first year the work on CAAP by the scientific coordinating committee involves identification of appropriate scientists and sites in the Asian region. Emphasis will be placed on sharing or otherwise cooperating with existing facilities in many countries, in particular sites already part of the World Meteorological Organization BAPMoN network, and other sites run for nutrient accession studies by local institutions. Other avenues for support will also be explored; however a strong commitment to utilising existing local resources is intended.

Timetable

1989 Form Scientific Coordinating Committee; establish contacts with appropriate scientists in regional countries; conduct experimental design.

1990 Meeting of the Scientific Coordinating Committee. Formulation of Plan of Activities.

1991 Conduct precipitation collection and perform analyses at chosen sites; on-going review of incoming data quality.

1992 Workshop at one regional centre to evaluate usefulness of data. Decision regarding future of network; revise protocols if necessary; consider expansion of programme.

1993-onward. Continue observations with triennial meetings to discuss results and progress.

Logistical Requirements

Appropriate sites, with commitment from local institutions to maintain sites for 10 years. Appropriate hardware including measurement and quality control systems. A central analytical laboratory with funding for analyses. Finances for international travel/triennial meetings.

Project 3: Impact of Tropical Biomass Burning on the World Atmosphere

Status: Planning

Biomass burning in the tropics results in a dramatic perturbation to the chemical and physical characteristics of the atmosphere in this part of the world. Furthermore this biomass burning modifies the biosphere, in currently poorly understood ways, by its impact on the potential development and degredation of vegetation. The consequences of this biomass burning are likely to extend to higher latitudes due to the intense convective activity in the equatorial region and the resulting injection of material from the fires into the upper troposphere.

Goals

- Characterise the fluxes of chemically and radiatively important species (especially carbon monoxide, nitrogen, oxides, methane and other hydrocarbons, sulfur compounds, and cloud condensation nuclei) from biomass burning into the global atmosphere.
- Assess the consequences of biomass burning emissions on chemical and physical climate. Particular emphases will be placed on the photochemical formation of tropospheric ozone in the tropics and on other perturbations of the oxidative characteristics of the atmosphere.

Implementation

The Biomass Burning Experiment (BIBEX) will be organised to reflect the scales that characterise the burning phenomenon. The smallest scale, that of an individual flame or fire, is best studied by laboratory investigations and will not be part of IGAC. At the scale of individual burns (1–100 km) BIBEX will employ a coordinated multi-platform design, with characterisation of emission fluxes as the main objective. At the

ground, pre- and post-burn chemical inventories of carbon, nitrogen and sulfur will serve to provide mass balance and to calibrate (ground-truth) satellite-based estimates of amounts of biomass burnt. Aircraft and ground sampling of emissions will be used to obtain emission ratios (amount of species emitted per amount of carbon burnt). Experiments will be conducted in different regions (Latin America, Africa, Asia) to address the variability of emission characteristics. Where possible, joint studies will be conducted with fire ecologists.

Following their injection into the lower and middle troposphere, the emissions from biomass burning are subject to the intense solar ultraviolet radiation characteristic of the tropics, resulting in rapid photochemical reactions. This takes place on the time scale of days and the space scale of hundreds to thousands of kilometres. At this scale, BIBEX will combine the use of long-range aircraft with remote sensing platforms. Satellites will be used for large scale mapping of the emissions and photochemical products, especially smoke, CO, CH_4, and O_3. Aircraft measurements will be used to relate these measurements to the detailed chemistry in the large-scale (100–1000 km) biomass burning plumes produced on the tropical continents and advected over the oceans. Product ratios i.e. the amount of final product (ozone, nitrate, etc.) per amount of biomass burnt, will be derived from these measurements. When combined with satellite measurements and ground-based inventories, these data will make it possible to quantify the impact of biomass burning on the world atmosphere. Long-term observations at selected stations in global networks e.g. the ozone, carbon monoxide, methane and precipitation chemistry networks, will be used to complement the airborne and satellite observations.

Timetable
Some investigations related to BIBEX objectives are currently being proposed. Within the next 2–5 years, some of the ground-truthing of satellite measurements and some aircraft measurements of emission ratios will take place. On the 3–10 year time scale, investigations into large-scale atmospheric transport and transformations will be conducted. When space-borne sensors of tropospheric chemistry become available (in the latter half of the 1990s), the final phase of BIBEX can be implemented.

Logistical Requirements
Several aircraft appropriate for low and slow operations in the lower troposphere (Electra, F27-type); at least one large jet aircraft; satellite sensors for vegetation characterisation, burn and aerosol mapping, tropospheric chemistry requirements. Ground expeditions. 20–30 scientists plus normal support. Availability of 2 months of aircraft time per expedition.

Project 4: Chemical Transformation in Tropical Atmospheres and their Interaction with the Biosphere

Status: Conceptual
The chemical composition and photochemical transformation in the tropical atmosphere are strongly influenced by emissions from the biosphere (NMHC and NO_y), by biomass burning during the dry season, and increasingly also by industrial emissions. Under the pressure of strongly increasing human populations, large conversions of land are likewise taking place, leading to loss of tropical forests and strongly enhanced industrial and agricultural activities. In the atmosphere these changes will manifest themselves on the one hand as decreasing emissions of reactive non-methane-hydrocarbons from tropical forests and on the other hand as increased emissions of NO and CO from the savanna areas. Because there is a general tendency for air to move from the savanna regions towards the tropical forest regions in the lower troposphere, the two effects will interact. This will lead to substantial changes in the overall photochemistry of the continental tropics.

Goal

- To understand the photochemistry of the tropical atmosphere and how this is affected by changing gaseous emissions from changing industrial and agricultural developments.

Description

Many important facets of the atmospheric chemical effects of these rapid developments in human activities will be studied regionally by smaller interdisciplinary research groups in Latin America, Africa and South-East Asia. However, in order to obtain a view of the total atmospheric chemical effects, it will be necessary in coming years to conduct major field expeditions requiring the participation of a substantial number of researchers to make possible denser ground-based and airborne observations. Over succeeding years, such field campaigns, that typically last for 1–2 months, are planned to be carried out in each of the above mentioned regions during the wet and the dry season. Such expeditions may consist of a network of fixed and mobile land-based observation sites, including aircraft research flights.

Atmospheric chemical constituents to be measured will be primarily O_3, H_2O, CH_4, CO_2, CO, the suite of non-methane hydrocarbons, NO_x, HNO_3 and H_2O_2. In addition, gaseous sulfur species and the physical, optical and chemical characteristics of airborne particulate matter should be measured and analysed.

The comprehensive field experiments require very careful planning and design and probably should consist of an intermediate phase of experiments carried out through an extension of the on-going efforts with aircraft surveys in the geographical regions of research.

Timetable

A Scientific Coordination Committee will be formed to guide the further development of an IGAC initiative on this research topic. This committee will meet following the SCOPE workshop on Trace Gas Exchange between Terrestrial Ecosystems and the Atmosphere in Stockholm, February 1990.

The Role of Polar Regions in Changing Atmospheric Composition

The Arctic and Antarctic regions of the Earth play an important role in global atmospheric chemistry and climate. These regions are potentially major contributors to feed-back in the global climate system through processes involving ice-albedo, cloud-albedo and carbon dioxide uptake by subsiding polar ocean water. Unique historical records of atmospheric composition going back tens of thousands of years are locked away in trapped air and ice in the glaciers of both polar regions. The complex processes of transport of chemicals to the glacier and their subsequent incorporation into snow and ice, involving chemical meteorology and chemical glaciology, need to be understood for the reconstruction of the past chemical climate of the Earth. The presence of the cold ice/snow surface promotes the destruction and production of trace atmospheric constituents that affect both the chemistry of the polar atmosphere and the composition of the material incorporated into the glacial ice.

Human influences are becoming increasingly apparent in these remote regions, particularly in the Arctic. Long range transport brings anthropogenic substances (acids, metals, black carbon) released in the northern hemisphere to the Arctic region, and these are of significant concern for the environment. The pathway and

fate of anthropogenic toxic organics and metals in the polar regions requires investigation. The phenomenon of cold-trapping whereby synthetic organic vapours (pesticides, herbicides) released around the globe condense out into snowpacks at the poles, is of real concern. These compounds reach both northern and southern hemisphere poles.

Open water can occur in the polar regions even in winter as a result of shear zones in oceanic circulation. It is estimated that 5% of the surface of the Arctic ice in winter consists of open leads. Gases important in atmospheric chemistry, such as CO_2 and biogenic halogen and sulphur compounds, can be exchanged between the atmosphere and ocean waters across these zones. In the sub-antarctic ocean huge ice-free marine surfaces (polynya) can continuously supply biogenic sulfur gases to the winter polar troposphere. The chemical evolution of these gases (mainly DMS) in the polar night is entirely unknown. This IGAC Project will promote studies of these phenomena as part of wider multi-disciplinary studies of air/sea exchange including that of heat and water vapour in polar regions.

Goals

- To achieve a comprehensive understanding of atmospheric chemical processes in the polar regions and their impact on global atmospheric chemistry and climate.
- To understand the relationship between the composition of air and that of snow and ice in polar regions.
- To deduce records of the past chemical climate of the atmosphere from glacial deposits.

Project 1: Polar Atmospheric Chemistry (PAC)

Status: Planning

It is necessary to understand the chemical climatology of the polar troposphere to assess the impact of anthropogenic activities on polar habitats and climate, and to use glacial ice chemistry records to reconstruct past change in physical and chemical climate. In order to do this we must know the current spatial and seasonal distributions, the chemical-meteorological origin and the atmospheric chemical transformations of key atmospheric constituents and precipitation in the polar troposphere.

There are many chemical changes that take place in the polar atmospheres at polar sunrise whose study can reveal insight into atmospheric chemistry relevant to global change (witness the stratospheric ozone hole generated by polar stratospheric clouds and the return of sunlight in Antarctica and the destruction of lower atmospheric ozone by biogenic bromine in the Arctic). As air pollution is transported into the Arctic Region from mid-latitudes, it undergoes chemical reactions that alter its gas and particle composition and hence its influence on the arctic solar radiation budget and climate.

Goals

To understand:

- local sources of chemical compounds in the polar regions particularly from ice-free ocean surfaces,
- the transport of chemical compounds from mid-latitudes to the polar region,
- the transformations that determine the chemical composition of the polar troposphere,
- the influence of polar atmospheric composition on climate.

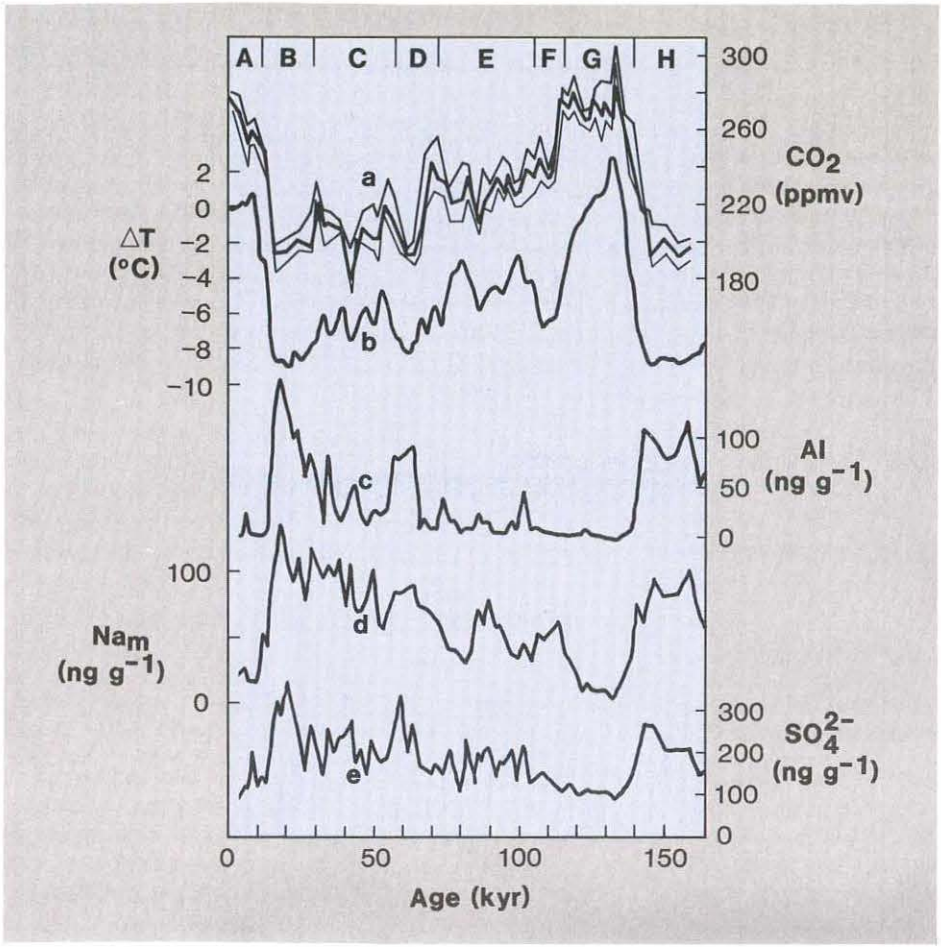

Figure 4 Vostok ice core records; a) CO_2 concentrations (ppmv) with envelope of uncertainty; b) Smoothed Vostok isotope temperature record; c) Aluminium content; d) Marine sodium content; e) Sulfate content. The Vostok records show a large variation on a 100 000 year time scale with changes of isotope-based temperature and CO_2 of the order of 10°C and 70 ppmv respectively. Ice deposited during the coldest times is characterised by high concentrations of marine and terrestrial aerosols; these peaks likely reflect strengthened sources and meridional transport during full glacial conditions. There is no indication of long term relationship between volcanism, as indicated by sulfate, and climate. (Oceanic phytoplankton are also a source of this sulfate.)

(Reprinted with permission from Lorius *et al.*, 1988, Long-term climatic and environmental records from antarctic ice, in *Contribution of Geophysics to Climate Change Studies*, (Eds) A. Berger and R. R. Dickinson, Geophysical Monograph, AGU, Washington DC., USA)..

Implementation

One activity of this IGAC Project is the study of the atmospheric chemistry of polar sunrise. Experiments are planned that utilize the unique shift from total darkness to total light in a few weeks, without the accompanying change in meteorology, to study atmospheric chemical processes in the Arctic. Multi-national studies of these phenomena were commenced in spring 1988 at Alert, Canada, coordinated by the Canadian Institute for Research in Atmospheric Chemistry.

A second activity concerns the long range transport of air pollution into the Arctic. As

air pollution is transported into the Arctic Region from mid-latitudes, it undergoes chemical reactions that alter its gas and particle composition and hence its influence on the arctic solar radiation budget. The fourth Arctic Gas and Aerosol Sampling Programme (AGASP IV) in 1991 is to be an IGAC activity. This experiment will be undertaken using aircraft and ground-based observational platforms and involving both measurements of inert tracers to follow air parcels over long distances while simultaneously studying their changing chemical composition.

The study of Arctic tropospheric chemistry is well coordinated through a variety of international field studies and symposia. The same is not true for the southern polar region. To review current knowledge and develop closer international cooperation amongst the research community concerned with Antarctic tropospheric chemistry, the IGAC Scientific Coordinating Committee of this project will organise an international symposium, "The Chemistry of the South Polar Troposphere". This Symposium will be held in March, 1991 in tandem with a NOAA GMCC meeting in Boulder, USA

Timetable

1991 Field experiments in the Arctic.
Scientific Coordinating Committee will convene an international symposium, "The Chemistry of the South Polar Troposphere" in Boulder, USA.

Project 2: Polar Air-Snow Experiment (PASE)

Status: Planning

The history of atmospheric composition obtained from ice core analysis assumes that the transfer mechanisms of atmospheric impurities to the ice are known. The case of occlusion in ice of most permanent and trace gases may now be considered as nearly solved. On the other hand deposition mechanisms of aerosols and reactive gases at very low temperature (-20° to -50°C) are still uncertain. These processes of exchange of chemicals between atmosphere and snow/ice need more investigation. This involves study of the incorporation of constituents into polar snowfall and the exchange of gases and particles between the atmosphere and snowpack to the point of ice formation from firn. There may be production and destruction of compounds by reactions on snow and ice. Key constituents to be studied include greenhouse gases, H_2O_2, H_2SO_4, black carbon, potentially toxic organics and essential nutrients. The latter two sets of compounds are studied because they may enter polar oceans via ice.

Goal

- To establish the relationship between atmospheric composition and the chemical composition of ice in the central polar areas.

Implementation

The first step will be a theoretical approach, to establish a model of the major processes occurring in the atmosphere at the extremely low temperatures. This will be attempted, following preliminary experiments in Greenland, during a three day workshop involving atmospheric chemists, glaciologists and meteorologists in 1990.

An initial one year experiment on the central Antarctic plateau is to be designed for 1991. Coordinated observations will include measurements of atmospheric trace gases (CO_2, CO, CH_4, organic acids, halocarbons, O_3, NO_x, SO_2, S-bearing gases), aerosol (dust, H_2SO_4 and other major ions), and composition of falling snow, firn snow, ice and air in the ice pores. The central Antarctic plateau is chosen because it is in this region that major ice core chemistry records have been retrieved. The

Amundsen Scott base is selected as the first site to be studied as it is a good ice core region possessing a long term baseline air chemistry station and year round facilities. Other sites may be added in future, in particular the new station to be opened at Dome C (East Antarctica).

This activity will be coordinated with the IGBP studies of palaeoclimate from glacial records. Strong collaboration with all relevant Antarctic glaciology and atmospheric chemistry programmes is sought.

Timetable

1990 Preliminary phase. Air snow sampling at Summit (Central Greenland) during the summer field season as part of the GISP II (USA) and Greenland Ice Project (GRIP) by French, Danish and American teams. First meeting of the Project Scientific Coordinating Committee after the Seventh International Symposium of the CACGP in Chamrousse, France, 5-11 September, 1990.

1991 PASE Experiment at Amundsen Scott Base in Antarctica. The experimental programme will include one year of air and snow sampling and in situ analysis.

1992 Meeting of the Project Scientific Coordinating Committee in the USA. Discussion of the South Pole data. Definition of new experiment.

1993 Experiment at Dome C, East Antarctica.

1994 Symposium on PASE experiments.

The Role of Boreal Regions in Changing Atmospheric Composition

Boreal regions of the Earth consisting of forest, wetlands and lakes play an important role in the global ecosystem and climate. Climate change scenarios unanimously agree that warming will intensify towards the poles. Northern wetlands methane production is potentially a major contributor to positive feed-back in the global climate system. Present estimates indicate that northern wetlands may contribute about half of the global emission of CH_4 from natural wetlands. Large boreal regions provide an extensive anaerobic habitat that also could be a substantial contributor of other reduced compounds in the atmosphere (e.g. hydrocarbons, reduced sulfur compounds). Fluxes of climatically and chemically important atmospheric trace gases from boreal ecosystems may change considerably in response to changes in soil temperature, water tables and stored organic material during a period of global or regional warming. In addition the boreal regions may be significant areas for the deposition of chemical species transported from lower latitudes.

Goals

To understand:

- the cycling between the atmosphere and boreal ecosystems of trace gases, particularly greenhouse gases,
- how emissions of these trace gases are affected by climate change, and
- the importance of these processes as positive feed-back mechanisms for changing climate.

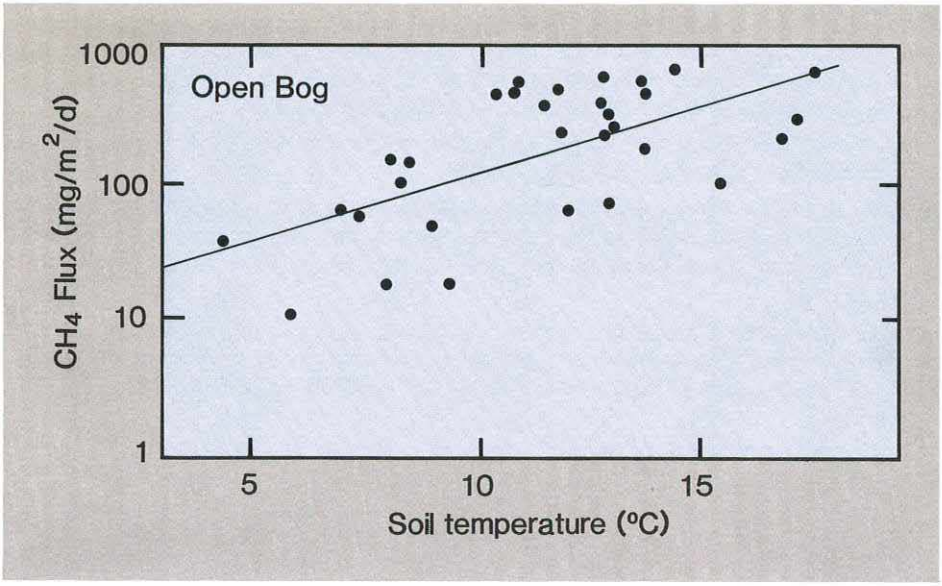

Figure 5 *Effect of soil temperature on methane emissions to the atmosphere from an open bog in the Marcell Experimental Forest, Minnesota.*

(Reprinted from R.C. Harris, 1989, Historical Trends in Atmospheric Methane Concentration and the Temperature Sensitivity of Outgasing from Boreal and Polar Regions, In *Ozone Depletion, Greenhouse Gases and Climate Change*, National Academy Press, Washington DC USA).

Project 1: Northern Wetlands Study (NOWES)

Status: Active

This project is concerned with the wetlands area of the boreal region. Little is known about the influence of this vast biome on atmospheric composition. It occupies large areas of North America, Scandinavia and the Soviet Union. The project will commence with a study in Northern Canada. This will provide a base to build a broader hemispheric study in the mid 1990s.

Goals

- To quantify sources and sinks of atmospheric trace gases in northern wetlands and to assess the effects of northern wetlands on the biogeochemical cycles of radiatively active gases under projected climate change scenarios.
- To formulate a gas-exchange model for quantitative estimates of the source/sink strength of wetlands and assessing the response of boreal wetlands to future climate scenarios. This model of wetland processes should be suitable for ultimate incorporation into global models.

Primary attention will be paid to the carbon cycle (CH_4, CO_2, NMHC) but N, S and P cycles will also be studied.

Implementation

This project, will build on an established international research activity during the initial phase in the early 1990s.

In this first phase the Canadian Institute for Research in Atmospheric Chemistry (CIRAC) in collaboration with the NASA ABLE 3-B project and other scientists, will coordinate a study of the atmospheric chemistry (particularly surface exchange) of the Hudson Bay Lowland (HBL) and Labrador regions of northern Canada.

The project has a number of components:

- Surface characterization; the HBL region will be characterised on a 100 km square grid scale compatible with climate models. This will involve use of both current land-use data banks and satellite remote sensing information.
- Studies of processes affecting gas exchange including atmospheric chemistry, soil and water chemistry and biology.
- Short term flux measurements will be made of CH_4 and CO_2 from aircraft and long term measurements of these gases plus NO, NO_2 and sulfur compounds will be made from ground stations using micrometeorological and chamber techniques.
- Development of a "gas exchange" model (on a 100 km square grid scale) simulating the biogeochemical processes of methane production for use in global model assessments of the positive-feedback of wetlands in climatic change scenarios.
- Atmospheric composition measurements of trace constituents exchanged by wetlands (including CO_2, CH_4) and substances that affect the atmospheric chemistry of the wetland area (including O_3, NO_x, PAN, NMHC), will be made during the warm season at field camps in the HBL and Labrador. Similar measurements will be made all year round at a baseline air chemistry observatory in boreal wetlands on the southern edge of the HBL.

Timetable

1989 Establish wetland sites to characterise each 100 km square grid. Establish chemical observatory at edge of wetland area. Assemble and intercalibrate instruments and chambers. Begin model development.

1990 Undertake measurement programme from thaw to freeze-up. Conduct intensive summer measurement programme in collaboration with NASA ABLE-3B. Continue model development.

1991 Maintain wetland site. Maintain chemical observatory. Apply model to measurement results to obtain an estimate of the methane source strength.

1992 Extend Project studies to boreal wetlands in Scandinavia and the Soviet Union.

Global Distributions, Transformations, Trends and Modelling

The differences in the chemical composition of the atmosphere around the globe and the short- and long-term variations in this composition reflect the net effect of the major relevant processes in the atmosphere: emissions, transport, transformation and removal. Both natural and man-made sources emit a diversity of trace constituents whose concentrations are characteristic of the nature of the sources and their geographical locations. Atmospheric circulation distributes gases and aerosols into regions that are often distant from their origins. During this transit, chemical transformations and physical processes can produce new constituents markedly different from the precursors. Finally, a variety of removal processes terminate the transport and chemistry, thereby yielding a spectrum of atmospheric residence times that reflect the properties of the constituents and the mechanisms of the removal. As a consequence, these spatial and temporal variations of the trace constituents are quantitative signatures of the budgets and processes that must be understood if the atmosphere is to be comprehended as a global biogeochemical system.

Goals

- To determine the global distributions and temporal variabilities of the trace constituents that are subject to long-range transport.
- To establish the distributions and temporal variabilities of the trace constituents that play important roles in the atmospheric portion of the key biogeochemical cycles.
- To quantify both through modelling and experimental studies, the atmospheric transformations that affect long-term trends in the concentrations and distributions of the environmentally sensitive constituents, especially those that are chemically and radiatively active.

Project 1: Global Tropospheric Ozone Network (GLONET)

Status: Active

Ozone plays a central role in most of the key physical, chemical and radiative processes in the troposphere. Because of this role it is imperative that we have much more detailed knowledge of its global horizontal and vertical distribution and long-term trends in the troposphere than provided by current ozone measurements.

Goal

- To define the climatology and trends of ozone in the troposphere.

Implementation

The development and implementation of this project will be closely coordinated with the World Meteorological Organization and the IAMAP International Ozone Commission.

From considerations of the causes of ozone variability, the size of the region of the atmosphere effectively sampled above a fixed observing station, and trend prediction analysis, it has been recently concluded that an increase in measurement frequency and a doubling of the current number of ozone measurement stations would result in a network that will greatly improve our knowledge of the global climatology of ozone. Also this improvement would mean that we would be able to detect regional and global trends of tropospheric ozone with an accuracy of ±1% per year or better.

An appropriate strategy for development of GLONET is to start with the existing ozone sonde network together with the available ozone lidar stations and proceed to optimize their use for accurate measurements of tropospheric ozone profiles by appropriate intercalibrations, intercomparisons and agreements on measurement frequency and timing. Uniform procedures for data processing, analysis, archival, distribution and publication are necessary.

This project will include theoretical work on the modelling of atmospheric ozone. A close interaction between modelling and the development of measurement strategy is essential. The network will be closely coordinated with the Dobson and Brewer total-column network, the network for the detection of stratospheric change, and the surface-ozone measurement programmes.

GLONET should grow incrementally from the present multi-national base of tropospheric ozone measurements by opening new stations over the globe where the scientific need is greatest and when the necessary resources become available.

Timetable

A first meeting of the Coordinating Committee including representatives from WMO and the IAMAP International Ozone Commission (IOC) is planned for the second half of

1989. Agenda items will include how the present network can be better coordinated to optimize information on vertical profiles of tropospheric ozone and possibilities for additional stations in areas presently poorly served by this present network.

Logistical Requirements

About 40 to 50 stations are required. More stations are needed over the oceans, and in Asia, Africa, and Latin America. This network will require the cooperation of many nations. The resources required for a station launching one ozone sonde each week are such that many countries could potentially become actively involved in IGAC through GLONET.

The use of two complementary measurement techniques (balloon ozone sondes and ground-based differential absorption lidars) is a promising approach that allows solutions to problems involving the need for high frequency measurements and observations in cloudy conditions.

Project 2: Global Atmospheric Chemical Survey (GLOCHEM)

Status: Planning

The reactive gases O_3, CO, NO, NO_2, several abundant reactive hydrocarbons and H_2O play central roles in oxidizing 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_3Cl, CH_4 and the incompletely substituted hydrocarbons. Current knowledge of the global distributions and annual cycles of these reactive gases and of solar ultraviolet fluxes, that drive tropospheric chemistry, is insufficient to define and understand the fundamental oxidation processes operating over most of the globe.

Goal

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

Implementation

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 these reactive gases involves a series of coordinated campaigns of both ground based and aircraft observations in major regions of the globe.

This work would be multinational: the Scientific Coordinating Committee of this project have identified 8 nations with suitable research aircraft and a total of some 16 aircraft potentially available for such an undertaking. Some of the instruments required for this work are generally available, but other instruments are in the hands of relatively few scientists. Hence there should be opportunities for multinational participation in each flight, in an attempt to ensure that the more complex measurements requiring the less available instrumentation are made during as many campaigns as possible.

Intercalibration and intercomparisons between the individual instruments used on all the flights is clearly essential to the success of these coordinated campaigns in defining the global climatology, as it is to many other IGAC projects. Also essential is a uniform approach to processing, analysis, archival, distribution and publication of the data.

Theoretical models should be used to help plan these campaigns as well as to provide the major vehicle for interpretation of the observations, and the extrapolation of knowledge to times and regions where there are no measurements.

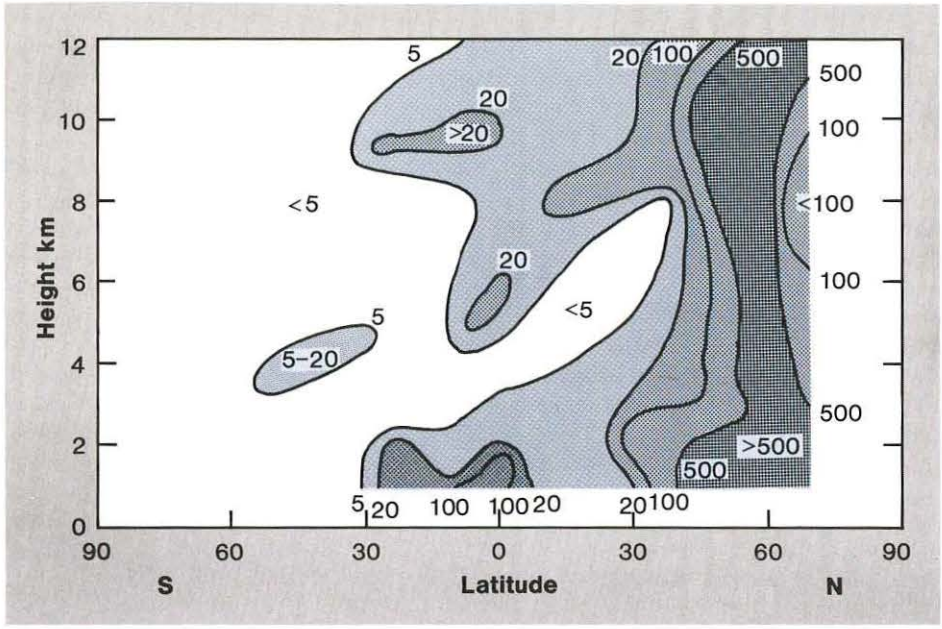

Figure 6 Two dimensional distribution of isopentane concentration in parts per trillion (10^{-12}), measured during the southward arm of the STRATOZ III flight from Sondrestrom, Greenland to Punta Arenas, Chile. Such global distributions of key species are needed to define the oxidation capacity of the atmosphere.

(Reprinted with permission from D.H. Ehhalt and J. Rudolph (1987). *Die globale Verteilung von Stickoxid und Kohlenwasserstoffen in der Troposphäre. Jahresbericht 1986/87 der Kernforschungsanlage* Julich GmbH FRG)

The major species to be measured are O_3, CO, NO, NO_2, the major reactive hydrocarbons and H_2O. The photochemically important UV fluxes should be measured at the same time. Other important species (H_2O_2, PAN, sulfur gases, CH_2O, organic acids, etc.) should be included when possible.

Obviously, the measurements of global trace gas distributions and trends will provide information for those regional projects that are in areas covered by the global missions. Similarly, data from regional projects will strengthen the global data base. Strong links between GLOCHEM and the appropriate regional projects will be established.

The development of remote sensing techniques for tropospheric composition will be explored in coordination with the International Radiation Commission.

Timetable

1989 Identify available platforms. Define possible experiments starting with aircraft missions.

1990 November, joint French and German aircraft mission, TROPOZ, 65°N to 65°S.

1991-onwards. Continuation of aircraft experiments. Feasibility studies of trace composition measurements in the upper tropical troposphere by floating balloons, and tropospheric composition measurements from satellites.

Project 3: The Chemical and Physical Evolution of CCN as Controllers of Cloud Properties

Status: Planning

The extent and properties of clouds strongly influence global climate because the reflectivity of clouds is a major factor controlling global albedo. Conversely, climate changes will cause the clouds to vary in type, area and properties. Chemical transformations in clouds play a major role in the atmospheric cycles of many compounds of global significance, and the hydrological cycle depends on clouds to make rain and snow. Understanding cloud processes is also crucial to retrieving information about past global climates from studies of glacial ice cores. Central to all these influences, and greatly sensitive to human activities, are the chemical and physical characteristics of the nuclei on which all cloud droplets form.

Most cloud condensation nuclei (CCN) are apparently formed from gas-phase precursors via atmospheric chemical reactions and physical transformations. Although an understanding of the chemical and physical evolution of CCN is central to cloud and climate modelling, knowledge of the dynamics of this system is virtually non-existent. It is possible that these dynamics include feedback processes involving, for example, modification of the Earth's surface temperature via CCN-modulated cloud reflectivity, or modification of rainfall patterns and aerosol particle lifetimes via CCN modulated cloud droplet size distributions. Present national efforts to address this problem are limited by the availability of both instrumentation and capable personnel. International collaboration could achieve the critical mass that the national programmes lack.

Goals

- Identification: develop a complete chemical and physical characterisation of particles that act as CCN in different climate regions.
- Dynamics: understand the physical and chemical factors that produce CCN and control their evolution.
- Modelling: relate the factors controlling CCN to large scale variables used in climate model calculations.
- Extrapolation: evaluate the means to utilize and interpret remote sensing to estimate CCN concentrations, possibly conducting experiments as ground truth for satellite observations.

Definition

The measurement portions of this project should provide a complete chemical and physical characterisation of the precursor gas/CCN/cloudwater system, including cloud microphysical and macrophysical properties.

The ideal experiment would include simultaneous measurements of: gas-phase precursor concentrations; primary aerosol production rates and properties; total particle (Aitken) concentration; sub-cloud size distribution and size dependent aerosol chemical composition of particles from 0.01 - 10 μm; morphology, physical state, and surface chemical properties of CCN; CCN concentration, size distribution and chemical composition as a function of supersaturation; size spectra and size-resolved chemical composition of cloud droplets; updraft velocities and rate of entrainment of clear air; reflectivity and/or albedo of cloud, and meteorological factors.

There is a need for instrument development because some of these measurements are either at or slightly beyond the current state of the art. As well as this, measurement standardisations and intercalibrations are needed to evaluate the potentially large uncertainties in many of the current measurement techniques.

Models are now available for describing gas-to-particle conversion and subsequent

particle growth by condensation and coagulation and to predict the evolution of cloud droplet size distributions from known CCN populations. Models must be extended to link the chemical composition of various parts of the aerosol population to activation under conditions favourable to cloud formation and to describe the chemical changes of CCN after they are cycled through clouds one or more times.

This work should lead to the development of comprehensive models capable of predicting cloud droplet populations and size distributions as functions of precursor material (gases and pre-existing particles) that exist in a reactive atmosphere. These comprehensive models would then serve as a basis for parameterising cloud processes in terms of the larger scale processes used in climate models and also providing the input parameters necessary for describing cloud properties in the presence of changing chemical concentrations.

Implementation

The problems of understanding the evolution of CCN and their influence on cloud properties are truly prodigious.

Both the International Commission on Cloud Physics and the International Radiation Commission have parallel projects on aerosols and clouds in the International Aerosol Climatology Project, IACP, and the International Satellite Cloud Climatology Project, ISCCP, respectively.

Collaborative opportunities with these projects, as well as with other IGAC projects, will be pursued. An example is the ISCCP, which is already deeply involved in measuring the radiative properties of clouds. Adding a full complement of aerosol, CCN and cloud chemistry measurements to this existing project will be more efficient than starting from scratch.

Also this IGAC project is focused on a specific set of chemical and physical processes that occur globally. The Project Scientific Coordinating Committee expects that several of the field studies of the evolution of CCN and their interactions with clouds will be conducted in three geographical regions as a part of the following IGAC Projects:

Marine Gas Emissions, Atmospheric Chemistry and Climate

A majority of marine CCN are thought to be the products of oxidation of dimethylsulfide (DMS), with only a few (perhaps 1%) originating as sea salt. Since DMS is of biological origin, simultaneous studies of reduced gas emissions from marine phytoplankton would be an essential complement to our aerosol, CCN and cloud measurements.

Chemical Transformation in Tropical Atmospheres and their Interaction with the Biosphere

In the remote continental case the aerosol is probably largely organic, the product of atmospheric terpene oxidation or incomplete biomass combustion or both. There is a clear need for cooperation in the study of the role of biota in producing CCN, particularly for the study of terpenes and biomass burning emissions.

North Atlantic Regional Study and *West Pacific Regional Study*

In these industrially impacted regions the anthropogenic aerosols completely dominate the natural ones. Here sulfur chemistry may generate the majority of CCN, via the oxidation of SO_2.

The CCN-related studies could be much more complete and economical because of the complementary measurements being made by the regional IGAC Projects. Thus, we expect to be able to obtain the data required to validate and verify the comprehensive models of condensation nuclei and clouds.

Although some experiments could be ground or ship-based, many experiments will require a fairly large aircraft to get into the clouds themselves, with substantial range for operation over the open ocean.

Timetable

1989	Scientific Coordinating Committee to meet at least once to define and plan pilot experiments.
1990-1991	Pilot experiments; instrumentation comparisons; selection of complete suite of field apparatus and field team.
1992-1993	Initial major field study; probably the marine case in conjunction with "Marine Gas Emissions, Atmospheric Chemistry and Climate".

Logistical Requirements

About 20 scientists and technicians, 100 hours/year of aircraft time and instrumentation development funds.

Project 4: Development of Global Emission Inventories

Status: Planning

Detailed and accurate emission inventories are essential for accurate model simulation of the behaviour of chemically and radiatively important atmospheric species. Currently, model simulations of the atmosphere are limited by the lack of quality emissions data for input. A comprehensive and uniform programme needs to be instituted to establish an inventory of the natural and anthropogenic sources of radiatively important and chemically active species.

Goals

- To establish a framework for the development and evaluation of global emission inventories.
- To conduct a critical survey of emission inventories of compounds of major importance in global atmospheric chemistry.
- To publish inventories in the open literature for use by scientists worldwide.

Implementation

The general approach will include two steps.

- An international working group will be formed to review the inventories presently available both for natural and man-made substances. Based on this review, they will choose one or two substances for a pilot study.
- An archive for the pilot substances will be established. Problems such as consistency and coverage in these inventories will be examined as part of the programme to develop generalised strategies for the construction of accurate emission inventories. Further emission inventories will be added to the pilot study group based on the judgement of the working group.

The following substances should be considered:

Gases: CO_2, CH_4, N_2O, NMHCs, halons and other halocarbons, CO, NO_X, SO_2, NH_3

Aerosol: soot, trace metals and others.

If possible, these substances should be resolved on a one degree by one degree grid.

Timetable

1989 Establish a Scientific Coordinating Committee and communications network.

1990 The first full meeting of the Scientific Coordinating Committee is expected to be at the Seventh International Symposium of the CACGP in Chamrousse, France, 5-11 September, 1990.

Agencies such as UNEP, IUPAC, IAEA, USEPA, ISRIC, NILU, research programs such as EUROTRAC and PHOXA, and also individual scientists involved in developing emissions inventories will be invited to participate.

International Support Activities

Scientific programmes require, for their successful pursuit, a complex support infrastructure. At the national level this includes organisations and laboratories to employ the scientists and house their work. At the international level there are other requirements. Three international support activities have been identified as essential to the IGAC Programme. These lie in the fields of education, communicatioh and measurement calibration standards.

Project 1: Education in Atmospheric Chemistry and Global Change

Status: Planning

Large portions of the scientific community, the general public, governments, and national and international institutions are aware of growing problems of global change on human time scales. Their awareness has called for an ambitious and wide ranging initiative for education concerning these problems, especially as they are related to the changing chemistry of the atmosphere. The IGAC Programme recognizes the importance of a strong emphasis on education and will contribute to those portions of the education initiative that can build on the expertise of its scientists and university educators.

The initial emphasis of the IGAC Programme will be on university-level education directed to the beginning general student, i.e. the freshman level student who may not seek advanced scientific training. A dual objective of the initial programme emphasis should be to provide a broad factual and intuitive basis for understanding global change in the chemistry of the atmosphere, biosphere, and geosphere that can be perceived on human time scales and training in some fundamentals of science that will help the general student deal effectively with future technological problems, including global atmospheric environmental management and control.

Subsequent extension of the initial emphasis should be made to more specialized science students, pre-university students, members of the general public and officials in governments and government services.

Goal

- To coordinate education activities aimed at promoting understanding of global change in the chemistry of the atmosphere, and its relationship to the biosphere and geosphere, internationally, both in the developing and developed countries and countries in all climatic regions.

Implementation

The principal effort planned for the IGAC Programme in education is in workshops and meetings.

Several kinds of workshops and meetings are envisaged. These may attract participants within nations, among nations within world regions, or from a larger world community. The workshops may include:

- *Conferences.* These may bring together educators to compare teaching experiences and share teaching materials with the intent of enhancing the effectiveness of their educational programmes.
- *Short courses.* These may bring together educators for the purpose of learning the most recent scientific developments in atmospheric chemistry and global change and facilitating the incorporation of this information into university teaching programmes.
- *Travelling education meetings.* These may be scheduled as a series of regional meetings of educators with one or more experts who travel from one to another meeting scheduled sequentially. The purposes may be similar to those of the conferences and short courses, but the network style may bring larger audiences of university educators into contact with the most recent IGAC materials and presentations by its experts.

Logistical considerations

It is recognized that the IGAC education programme will interface with other national and international programmes in science education of the human environment. These include the existing programmes of the ICSU, the IGBP, the Third World Academy of Sciences in Trieste and the World Meteorological Organization. The IGAC Education Coordinating Committee will liaise with these and other organisations early in the IGAC planning phase so as to take full advantage of their experience and to help contribute effectively to the world effort in environmental science education.

Project 2: The IGAC Newsletter

Status: Active

One of the most important tasks within the IGAC Programme will be to keep atmospheric chemists around the world, particularly those involved with and concerned about global scale problems, aware of significant new results, programmes and opportunities in the international atmospheric chemistry community. One useful way to help accomplish this important communication role is through the initiation of an active IGAC Programme Newsletter.

Goals

The primary objectives of the IGAC Newsletter are to provide:

- information on joint programmes being developed by the IGAC Programme.
- information on other atmospheric chemistry research programmes of interest to the international community.
- rapid pre-publication information on new scientific results from IGAC research programmes.
- information on field stations that are available for atmospheric chemistry studies.
- information on and schedules of international and national intercalibration programmes in atmospheric chemistry.
- schedules of national and international atmospheric chemistry meetings.

- education and training opportunities in atmospheric chemistry.
- information on the development of new instrumentation.

Implementation

There will be an Executive Editor of the IGAC Newsletter. To simplify the production of the IGAC Newsletter, Regional Editors will be appointed for the following major global geographical regions: North America, Latin America, Europe, Africa, Asia and Australia/Oceania.

The Regional Editors will gather information from their regions and provide this information at regular intervals to the Executive Editor. IGAC project conveners are expected, from time to time, to provide news of their projects for the IGAC Newsletter. The Regional Editors and the Executive Editor will serve as the Editorial Board of the Newsletter and would be responsible for changes in emphasis, style, production method etc.

Logistical Requirements

The Newsletter should be issued twice per year for the first year or two, after which a frequency of four times per year will probably be necessary. Future changes in frequency will be based on need. The first issue should be released during the spring, 1989. The Canadian Institute for Research in Atmospheric Chemistry at York University has agreed to be responsible for publication of the initial issues of the Newsletter. Regional Editors will distribute the Newsletter within their regions. An initial circulation of approximately 1000 is expected.

Project 3: Intercalibrations/Intercomparisons

Status: Active

Use of the data from separate measurement programmes requires an understanding of the relative agreement of the separate standards used in each of the measurement programmes. There is not a well developed set of international standards for measurements of trace constituents in the atmosphere. Conflicting calibration standards exist for some species. The WMO has tackled the problems of standards for precipitation chemistry analyses and the International Ozone Commission has established recommended absorption coefficients for ozone. A number of problem areas remain.

Activity 1: Gas Standards for CO, CH_4 and Chlorinated Hydrocarbons

Goal

- To solve the current inadequacies in the standards for CO, CH_4, and certain chlorinated compounds.

Use of the data from separate long-term measurement programmes requires an understanding of the relative agreement of the separate gas standards involved. Three of the cases where this has not been done are for the gases CO, CH_4, and certain chlorinated compounds. These gas standards are not known to a precision that allows differences measured by seperate groups to be interpreted as true atmospheric properties, rather than as possible differences among standards

We see the immediate need for an interlaboratory comparison of CH_4 measurements so that the vast data sets now being acquired by different laboratories can, for example, be confidently used in inversion models. This could be followed by the development of an absolute standard for CH_4, the standard being at ambient concentration (1700 ppbv).

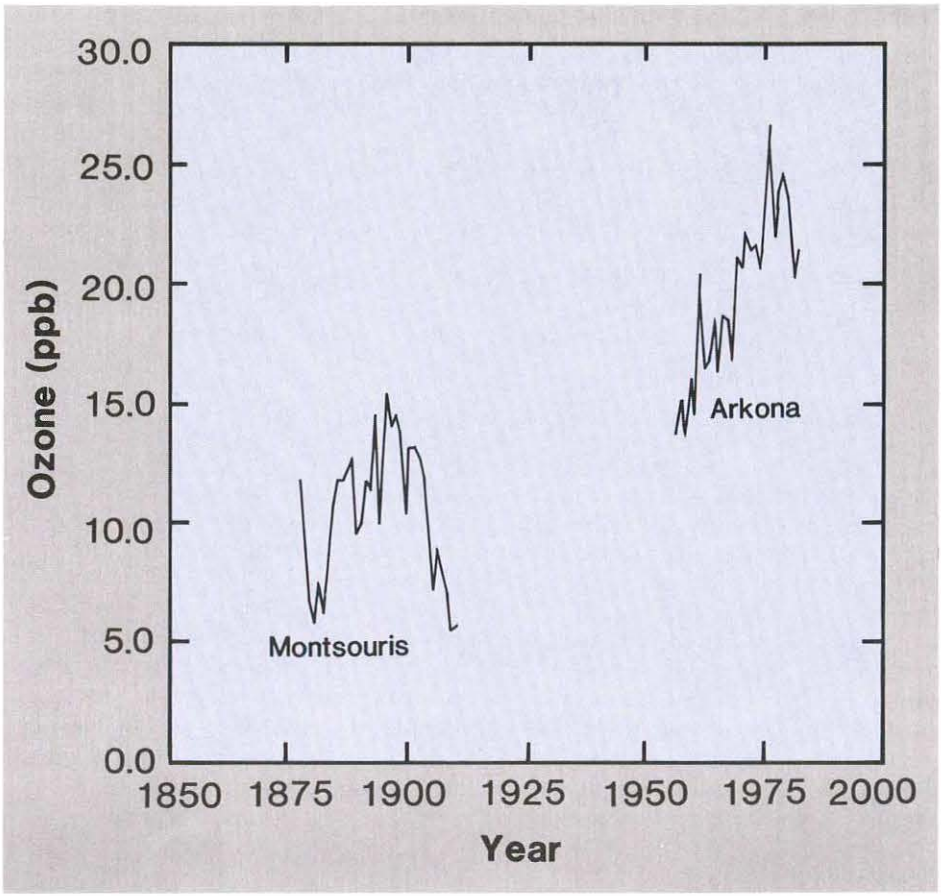

Figure 7 *Annual averages of ozone mixing ratio at Montsouris, near Paris (1876-1910) adjusted for SO_2 interference and at Arkona at the Baltic coast (1956 -1983). Such unique reconstructions of past records, and comparisons of present records, are only possible with detailed documentation about experimental technique and comprehensive intercomparisons of measurement techniques.*

(Reprinted with permission from A.Volz and D.Kley, 1988, Evaluation of the Montsouris series of ozone measurements made in the nineteenth century. *Nature* Vol 332, p. 242).

Two halocarbon species have been identified whose absolute calibration is important in the determination of average tropospheric hydroxyl radical concentrations; methylchloroform (CH_3CCl_3) and HCFC-22 ($CHClF_2$). A major uncertainty (50%) exists for CFC-113 (CCl_2FCClF_2), which should be resolved since this compound is the fastest growing significant source of stratospheric chlorine.

Implementation

A three phase programme is envisaged. This will include conduct of the following studies:

- Stability experiments on containers
- Inter-laboratory comparisons, so that various data sets collected around the world by various groups can be compared
- Supply and dissemination of absolute standards.

The laboratories coordinating the logistics of the intercomparisons are:

- Carbon Monoxide: CSIRO Division of Atmospheric Research (Australia)
- Methane: NOAA GMCC Laboratory (USA)
- Chlorinated Compounds: Scripps Laboratory (USA)

Timetable

The Project Scientific Coordinating Committee will decide during 1989 on a timetable for the intercomparisons.

Activity 2: **Non-Methane Hydrocarbon Intercomparison Experiment**

Goal

- To assess how accurately the non-methane hydrocarbons can be measured

The non-methane hydrocarbons (terpenes, isoprene, alkanes, alkenes, alkynes and aromatics) play several crucial roles in atmospheric chemistry: they are involved in ozone formation; they form the carriers of active nitrogen compounds; they are a tracer of atmospheric motions; they are a source of carbon monoxide; and they are a source of reactive hydrogen species. Thus, information on their global distributions are currently needed in atmospheric chemistry. Several research groups have made measurements of the non-methane hydrocarbons at different times and places on the globe. 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 these investigators. The intercomparison will be international and provide opportunity for short-term payoff. It will result in a global data set with a common basis.

Implementation

The accuracy to which the NMHC 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 artifacts, independent "third-party" evaluation and publication of all details in a premier journal.

This intercomparison will be done in three phases:

Phase I. Standards and cross referencing. A travelling standard will be made (e.g. by NBS) and circulated to groups. The goals for this phase will be to check the transfer matrix and to determine a measure of absolute accuracy of current measurements.

Phase II. Whole-air surface measurements. "Blind" whole-air samples will be circulated. Also there will be simultaneous ground-based measurements at 3 sites:

- a mountainous area (free troposphere)
- a remote area (low NMHC levels) and
- a heavily forested area (high NMHC levels).

The goals are to assess identification, storage losses, saturation and artifacts.

Phase III. Aircraft sampling. These intercomparison campaigns will be done in a remote and a perturbed area (e.g., USA West Coast). It will include onboard analyzers and 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

1988 Rough-draft plan and mini-workshop

1989 Circulation of standards

1990 Whole-air ground-based intercomparison

1991 Airborne intercomparison

Logistical Requirements

Resources to make up and circulate standards for interlaboratory comparisons. Ground sites and an aircraft for the on site intercomparisons.

The Structure of IGAC, its Mode of Operation and Relationship to IGBP and other International Scientific Organisations

The International Global Atmospheric Chemistry (IGAC) Programme has been created during 1983-87 in response to the growing concern over the rapid changes observed in the Earth's atmosphere during the past decade, and from their obvious potential for impact on human activities. The IGAC Programme has been developed and is directed by the Commission on Atmospheric Chemistry and Global Pollution (CACGP), an international commission of the International Association of Meteorology and Atmospheric Physics (IAMAP), an association of the International Council of Scientific Unions (ICSU). The CACGP has been in existence for several decades, including some years as the Commission on Atmospheric Chemistry and Radioactivity, and was originally formed because of general scientific concern about problems relating to atmospheric chemistry, including the emission, transport and final fate of various chemical species added to the atmosphere by the activities of man.

Representation in CACGP has always been intended to be global in coverage, and now includes members from all areas of the world with active programs in atmospheric chemistry. The current members of CACGP are listed in the Appendix.

The overall plan for IGAC is to develop research programmes of broad regional or global extent in that the most advantageous approaches require the participation of personnel and equipment from many countries. Initial projects for IGAC have been defined during the Dookie Conference in Victoria, Australia, in November, 1988, and an IGAC Steering Committee has been appointed to furnish oversight for these. In the coming years, it will be the responsibility of the IGAC Steering Committee and the individual Project Scientific Coordinating Committees to develop detailed project proposals at scientific workshops. These Committees will also carry the responsibility for finding ways to implement and carry out the projects. Neither IGAC nor CACGP has direct funding capability or responsibility for the proposed activities, but rather they serve as initiators and coordinators of the programs. Participation in IGAC is open to all interested scientists, and is strongly encouraged, because the extent and complexity of the problems under consideration require the participation of scientists with wide varieties of experience and skills.

The major problems in atmospheric chemistry usually have important components, e.g. biological, that lie outside the traditional, albeit somewhat vague, boundaries of chemistry and meteorology. Effective research requires coordination and interaction with other parts of the scientific community and partnership with commissions in other branches of ICSU. The major importance of many environmental problems, as recognised in the 1980s, has caused the formation of a special interdisciplinary programme, the International Geosphere-Biosphere Programme (IGBP). IGAC has a special relationship with IGBP.

A brief outline of the IGBP and its special relationship with IGAC

IGBP Objectives: To describe and understand the interactive physical, chemical and biological processes that regulate the Total Earth System, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions on timescales of decades to centuries.

Goal: With improved understanding of the system, the primary goal of the programme is to advance our ability to predict change in the global environment. This capability will build upon the results of physical models of the Earth System by incorporating understanding of relevant biogeochemical processes.

Initial objectives: To obtain the information that is necessary to understand more completely the cycling of key elements among the terrestrial and marine ecosystems and the atmosphere, taking into consideration the natural and anthropogenic factors affecting these cycles and the interactive effects of climate-induced feedback within and between biosphere, oceans and atmosphere.

The special committee (SC-IGBP), which directs IGBP, recognizes that many activities outside the direct coordination of the SC-IGBP are as essential to the overall "Global Change Programme" as the "core Global Change Projects" directly coordinated by the SC-IGBP. The CACGP of IAMAP has, therefore, been invited, and agreed, to accept the task to develop the IGAC Programme as an atmospheric chemistry core project of the overall "Global Change Programme".

Projects developed by the IGAC Programme that contain substantial biological components should be developed in close cooperation and coordination with the SC-IGBP to promote the effective involvement of the biological community. For this purpose, it will be necessary to establish especially close links between the CACGP/IGAC Committee and the IGBP Coordinating Panels on the Terrestrial Biosphere-Atmospheric Chemistry and Marine Biosphere-Atmosphere Interactions.

Other International Scientific Organisations

The International Union of Pure and Applied Chemistry (IUPAC) has a Commission on Atmospheric Chemistry within its Applied Chemistry Division. There is a designated person for liaison between the Commission and IGAC/CACGP.

The aim of the IUPAC Commission on Atmospheric Chemistry is "to identify problems related to the chemistry of the atmosphere and to advise and cooperate in international activities designed to address these problems. The Commission is concerned with indoor/workplace air quality, urban and regional environment as well as the global atmosphere. Among other considerations it will be necessary to review and harmonise the sampling and analytical procedures for studying atmospheric chemistry."

IUPAC also has a Commission of Chemical Research Applied to World Needs, (CHEMRAWN). This commission has a current interest in the chemistry of the atmosphere and its impact on global change, and through the IUPAC Commission on Atmospheric Chemistry has contact with IGAC.

IGAC has established links with the WMO BAPMoN Programme and joint talks were conducted at the Dookie Workshop. Eight of the IGAC Projects involve scientists who also participate in BAPMoN activities. The collaboration of these two programmes should considerably enhance long term global atmospheric chemistry studies.

Plans for new research in upper atmospheric chemistry are presently being formulated as part of the Middle Atmosphere Responses to Changes (MARC) programme jointly sponsored by the International Association of Meteorology and Atmospheric Physics (IAMAP) and the International Association of Aeronomy and Geomagnetism (IAGA). The IGAC Steering Committee intends to cooperate with, and review the development of the MARC programmes to ensure that vital investigations involving chemical and dynamical interactions between the upper and lower atmosphere receive appropriate attention.

There is cooperation between the World Climate Research Programme (WRCP) and IGAC on the development of global chemical transport models (GCTMs). This cooperation should be fruitful for both programmes. Specifically, while IGAC chemical modelling will be dependent on progress in general circulation modelling in WRCP, we also expect atmospheric tracers measured in IGAC to provide an important test of the predicted circulations in these models.

The development and implementation of the IGAC tropospheric ozone project is

closely coordinated with the World Meteorological Organization and the IAMAP International Ozone Commission who have traditional interests in this area.

The development of remote sensing techniques for tropospheric composition in IGAC will be explored in coordination with the International Radiation Commission. Both the International Commission on Cloud Physics and the International Radiation Commission have parallel projects on aerosols and clouds in the International Aerosol Climatology Project, IACP, and the International Satellite Cloud Climatology Project, ISCCP, respectively. IGAC Projects are designed to interface with these and these Commissions are represented on the IGAC projects.

IGAC marine studies will be conducted in cooperation with the JGOFS Programme of the Scientific Committee on Ocean Research (SCOR) and the Polar studies with Scientific Committee on Antarctic Research (SCAR).

Appendices

The History of IGAC

The history of IGAC is one small part of the history of international programmes of research and monitoring of atmospheric composition.

The International Geophysical Year (IGY), 1957–1959, heralded the first global multiphase, multispecies study of atmospheric composition, with background measurements of CO_2, tropospheric O_3, aerosols, composition of precipitation, radionuclides and many other species. Background atmospheric observatories were set up in remote clean air locations such as Mauna Loa, Hawaii and at several places in Antarctica. Fortunately some of the work initiated as part of IGY was not stopped with the completion of IGY and so we have some long term records that are invaluable today, e.g. CO_2, antarctic total O_3.

A network for global total ozone measurements was initiated in the 1930s and received much impetus from IGY. This total ozone network continued to grow during the 1960s through the activities of WMO and the IAMAP International Ozone Commission, to the global ozone observing system (GO3OS) today. During the 1970s the issue of man-made destruction of the ozone layer by nitrogen and chlorine compounds emerged. As well as the IAMAP and WMO activities, the Middle Atmosphere Programme (MAP), of SCOSTEP was an international scientific response to this problem. Now there exist the UN Convention for the Protection of the Ozone Layer and the 1986 Montreal Protocol on Substances that Deplete the Ozone Layer.

In the 1950s a European network for the Chemical Composition of Air and Precipitation was established. Data from this network provided the first view of regional air pollution problems. By 1970 the problems of trans-national pollution of sulfur and nitrogen oxides and acid rain were recognized and the precipitation chemistry network was supplemented by EUROTRAC and EMEP today.

The International Atomic Energy Agency (IAEA) in cooperation with the WMO has, since 1961, conducted a world-wide survey of hydrogen and oxygen isotopes in precipitation, in order to provide data for hydrological applications of environmental isotopes. More recently the IAEA has provided data on the chemical composition of these precipitation samples to the station operators.

Around 1970 scientists in CSIRO and NOAA recognized the need for long term high quality multiconstituent monitoring of background atmospheric composition. This was given tremendous impetus with the intergovernmental Stockholm Conference on the Human Environment in 1972. The UNEP Global Environmental Monitoring System (GEMS) and the WMO Baseline Air Pollution Monitoring Network (BAPMoN) were initiated. Mauna Loa, Cape Grim, and similar observatories took up the challenge.

By 1980 it had become clear that the chemistry of the atmosphere was being perturbed over large regions, even globally. The acidity of precipitation, chlorine-catalysed destruction of stratospheric ozone, the continued increase in atmospheric carbon dioxide concentrations and the altered cycling of major nutrient elements were clear signs of global changes. Scientists from around the world recognised that the scope of human activities had become large enough that each of these perturbations could grow and that other unanticipated problems were quite likely. A particularly sobering realisation concerned the chemisrty of the troposphere. This was that the presence of surfaces (oceans, clouds, plants, soils) and the interactions of the lower atmosphere with the global biota makes tropospheric chemistry even more complex than that of the stratosphere.

Concern over how to approach the complexities of atmospheric perturbations and the growing need for information that could lead to minimising future perturbations, led to a

study by the U.S. National Academy of Sciences. In 1984 their report *Global Tropospheric Chemistry: A Plan for Action* was published; it analysed the scope of the scientific issues and the likelihood of sucessful research. This report concluded that a major focussed research thrust was both necessary and feasible, and that an experimental framework for understanding the biogeochemical cycling of materials into and through the atmosphere was needed, due to evidence that the atmosphere, soils, oceans, plants and microbes comprise an interlocking system. An intellectually and physically broader approach than had been applied to urban and regional pollution problems was needed.

The U.S. NAS/NRC Global Tropospheric Chemistry Report adopted three main goals:

- to obtain quantitative understanding of the cycling of tropospheric chemicals globally,
- to develop a capability to predict future changes in atmospheric chemistry
- to use these capabilities to provide the information necessary for societal decisions to maintain a stable atmosphere.

To achieve these goals would obviously require the best efforts of scientists from many individual nations and their combined efforts would be truly international.

The scientific community responded very positively to this first report and in 1985 and 1986 a broader research planning effort was conducted. This involved about 150 scientists (one third international) over a one year period and produced the 1987 report *Global Tropospheric Chemistry: Plans for the US Research Effort.* The main goals of the 1984 NAS/NRC report were embraced and two sharper foci were advanced:

- understanding the oxidising capacity of the atmosphere, and
- the roles of atmospheric chemistry in influencing the Earth's climate.

Five main areas of research were proposed: global distributions and trends, biological and surface exchange, gas-phase transformations, multi-phase processes, and theoretical modelling and prediction. These US planning activities both stimulated and were stimulated by international scientific activities occurring at the same time.

In the early 1980s the ICSU was developing the International Geosphere-Biosphere Programme. Independently in 1983 the IAMAP Commission on Atmospheric Chemistry and Global Pollution (CACGP) began considering a coordinated research programme in atmospheric chemistry during its international symposium at Oxford, England. Following two years of discussions and evaluation of this idea by a small group of Commission members, CACGP agreed at the IAMAP General Assembly in Honolulu in 1985 to pursue vigorously the idea of such a programme. A special Commission meeting was convened in Stockholm in September, 1986 for the sole purpose of discussing such a programme in depth. At the end of the Stockholm meeting CACGP agreed to coordinate the development of the International Global Atmospheric Chemistry Programme.

Planning for the IGAC Programme continued during the workshop held at the CACGP's Sixth International Symposium on Global Tropospheric Chemistry held at Peterborough, Ontario, Canada, August 1987. This meeting identified research initiatives and international activities that are particularly amenable to international cooperation, and provided guidelines for the organisation of the more extensive one week planning meeting held in Dookie, Victoria, Australia, November 1988. The result of the Dookie meeting are contained elsewhere in this report.

This IGAC Programme is being undertaken by CACGP with the cooperation of and input from other IAMAP Commissions including the International Radiation Commission, the International Ozone Commission, the International Commission on Cloud Physics and the Commission on Climate.

Looking forward, it is the wish of those involved that during the coming years IGAC, along with IGBP, BAPMoN, JGOFS, GO3OS, MARC, WCRP and other international scientific endeavours, work together to understand global change in a holistic way to provide the information required by society for the wise use of our atmosphere and global environment.

The IGAC workshop at Dookie College, Victoria, Australia (7–11 November 1988)

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Background Papers presented or circulated at the Dookie Planning Meeting of the International Global Atmospheric Chemistry (IGAC) Programme, 7th–11th November 1988

Keynote addresses

Climatically important Trace gases, R. Cicerone
Trace gases: The Climate Response, A. Henderson-Sellers
Aerosols and climate, R. J. Charlson
Ozone and the oxidative state of the troposphere, S. Rowland and S. Penkett
Hydrocarbons in the Atmosphere, D. Ehhalt
Perturbation of the reactive nitrogen cycle, I. Galbally
Biosphere/troposphere interactions, M.O. Andreae

Discussion Papers including Proposed Experiments

Asia, Southeast Asia and Oceania, G. Ayers, T. Ogawa and W.-X. Yang
Tropical Latin America and Africa, E. Sanhueza, P. Buat-Menard
Proposals for IGAC Experiments in Europe and North America and elsewhere, F. Fehsenfeld, D. Whelpdale and O. Hov*
The Arctic and Antarctic, L. Barrie, J. Heintzenberg*
Marine environment, P. Liss, R. Duce
Networks, global distribution and trends, R. Prinn
Multiphase aerosol and cloud processes, V. Mohnen
Glaciological studies, R. Delmas

Existing International Programmes

The IGBP Programme, P. Crutzen
International CO_2 programs, G. Pearman
SCOPE projects (a) biospheric emissions of trace gases and (b) acidification in tropical countries. M.O. Andreae and H. Rodhe
IRC radiation programs and their relation to IGAC, H. Fischer
IUPAC Activities in Atmospheric Chemistry, H. Schiff
WMO BAPMoN Programs, D. Whelpdale and R. Bojkov*
The Middle Atmosphere Responses to Changes, IAMAP/IAGA Task Group, provided by R.A. Vincent*
EUROTRAC, J. Jerre* and W. Seiler*
Programs at NCAR for the IGAC Programme, J. Winchester
Atmospheric Chemistry Research in China, D. Zhao, A. Wang* and D. Wang*.
AEROCE, The Atmosphere/Ocean Chemistry Experiment, J. Prospero
WATOX, The Western Atlantic Ocean Experiment, D.M. Whelpdale, J.M. Miller, J.N. Galloway*, T.M. Church* and A.H. Knap*
The Global Precipitation Chemistry Project, W. Keene*, J.N. Galloway*, G.E. Likens* and J.M. Miller.

Support activities

Intercomparison, Intercalibration, Data Control: Gases, P. J. Fraser and D. Albritton
Communication in the IGAC Programme, R. Duce
Training and education for the IGAC Programme, (three papers) J. Winchester, H. Rodhe, H. Schiff

* *These authors did not attend the meeting*

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Project 2: Marine Gas Emissions, Atmospheric Chemistry and Climate (MAGE)

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Project 3: East Asian – North Pacific Regional Study (APARE)

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

Project 1: Biosphere-Atmosphere Trace Gas Exchange in the Tropics (BATGE)

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Project 2: Deposition of Biogeochemically Important Trace Elements (DEBITE)

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Project 3: Impact of Tropical Biomass Burning on the World Atmosphere

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Project 4: Chemical Transformation in Tropical Atmospheres and their Interaction with the Biosphere

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Project 1: Northern Wetlands Study (NOWES)

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Project 3: The Chemical and Physical Evolution of CCN as Controllers of Cloud Properties

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ACRONYMS used in the IGAC Report

ABLE:	Atmospheric Boundary Layer Experiment
AEROCE:	Atmosphere/Ocean Chemistry Experiment
AGASP:	Arctic Gas and Aerosol Sampling Programme
ALE:	Atmospheric Lifetime Experiment
APARE:	East Asian • North Pacific Regional Study
ASE:	Air Sea Experiment
BAPMoN:	Baseline Air Pollution Monitoring Network
BATGE:	Biosphere-Atmosphere Trace Gas Exchange in the Tropics
BIBEX:	Biomass Burning Experiment
CAAP:	Composition and Acidity of SE Asian Precipitation
CACGP:	Commission on Atmospheric Chemistry and Global Pollution
CCN:	Cloud Condensation Nuclei
CFC:	Chlorofluorocarbon
CHEMRAWN:	Chemical Research Applied to World Needs. (A Commision within the International Union of Pure and Applied Chemistry)
CIRAC:	Canadian Institute for Research in Atmospheric Chemistry
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
DEBITS:	Deposition of Biogeochemically Important Trace Species
DMDS:	Dimethyldisulfide
DMS:	Dimethylsulfide
EUROTRAC:	European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
GAGE:	Global Atmospheric Gases Experiment
GCTM:	Global Chemical Transport Model
GEMS:	Global Environmental Monitoring System
GISP:	Greenland Ice Sheet Project (USA)
GLOCHEM:	Global Atmospheric Chemical Survey
GLONET:	Global Tropospheric Ozone Network
GMCC:	Geophysical Monitoring for Climate Change
GO3OS:	Global Ozone Observing System
GRIP:	Greenland Ice Project (Europe)
HBL:	Hudson Bay Lowland
IAEA:	International Atomic Energy Agency
IAGA:	The International Association of Aeronomy and Geomagnetism
IAMAP:	International Association of Meteorology and Atmospheric Physics
ICSU:	International Council of Scientific Unions
IGAC:	International Global Atmospheric Chemistry Programme
IGBP:	International Geosphere Biosphere Programme
IGY:	International Geophysical Year
IOC:	International Ozone Commission
ISCCP:	International Satellite Cloud Climatology Project
ISRIC:	International Soil Reference and Information Centre
IUPAC:	International Union of Pure and Applied Chemistry
JGOFS:	Joint Global Ocean Flux Study
MAGE:	Marine Gas Emissions, Atmospheric Chemistry and Climate
MARC:	The Middle Atmosphere Responses to Changes
NARE:	North Atlantic Regional Study
NASA:	National Aeronautics and Space Administration
NBS:	National Bureau of Standards

NCAR:	National Center for Atmospheric Research
NILU:	Norwegian Institute for Air Research
NMHC:	Non-methane hydrocarbons
NOAA:	National Oceanographic and Atmospheric Administration
NOWES:	Northern Wetlands Study
PAC:	Polar Atmospheric Chemistry
PAN:	Peroxyacetylnitrate
PHOXA:	Photochemical Oxidant and Acid Deposition Model Application within the Framework of Control Strategy Development
PASE:	Polar Air-Snow Experiment
SC-IGBP:	Special Committee of the International Geosphere Biosphere Programme
SCOPE:	Scientific Committee on Problems of the Environment
SCOR:	Scientific Committee on Ocean Research
SCOSTEP:	Scientific Committee on Solar-Terrestrial Physics
TOR:	Tropospheric Ozone Research
TRACE:	Transport and Chemistry near the Equator
TROPOZ:	Tropospheric Ozone
UNEP:	United Nations Environment Programme
USEPA:	United States Environment Protection Agency
WATOX:	Western Atlantic Ocean Experiment
WCRP:	World Climate Research Programme
WMO:	World Meteorological Organization

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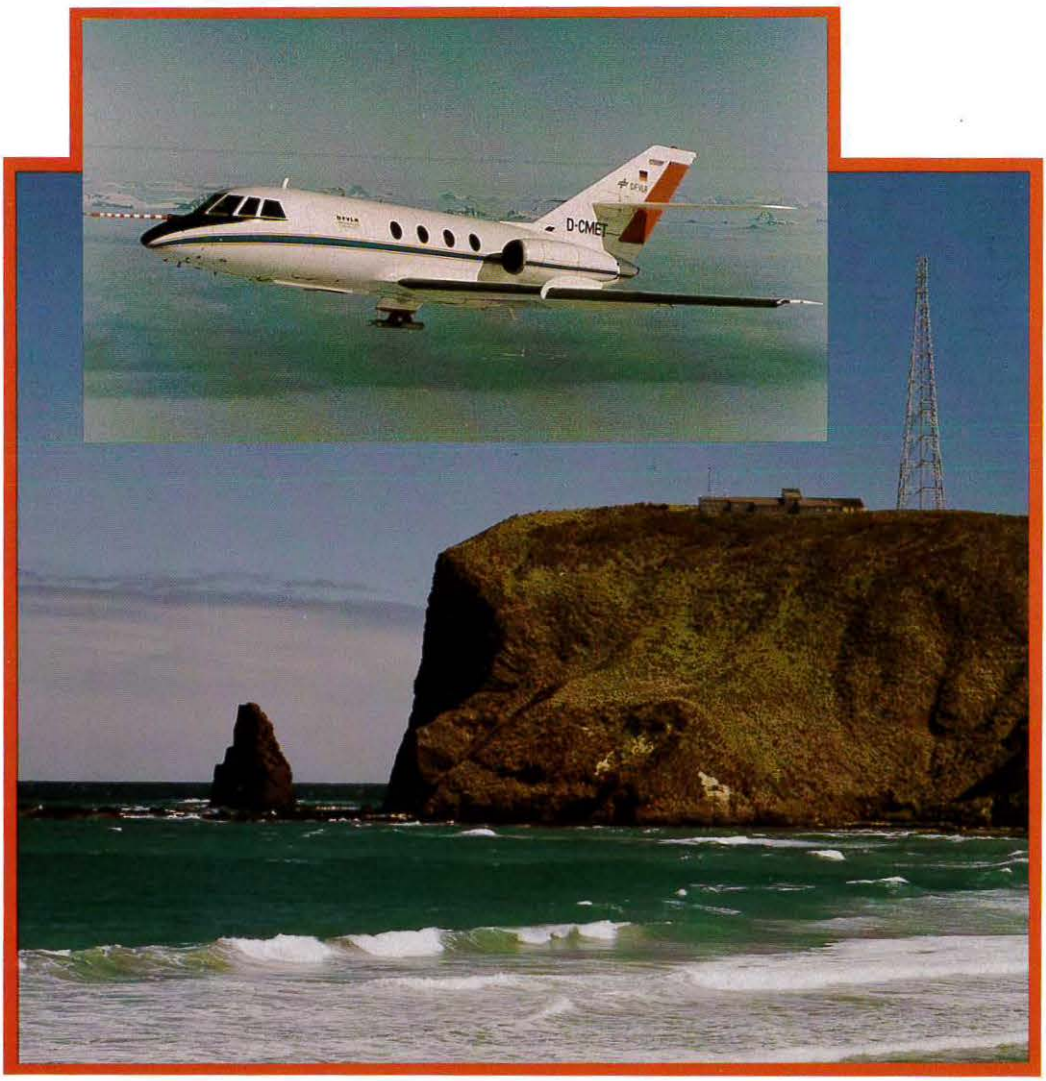
IGAC Goals

The goals of the IGAC Programme are:

- To develop a fundamental understanding of the chemical processes that determine the chemical composition of the atmosphere.
- To understand the interactions between atmospheric chemical composition and biological and climatic processes.
- To predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere.
- To provide the necessary knowledge for the proper maintenance of the biosphere and climate.



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