THE INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY PROGRAMME

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The International Global Atmospheric Chemistry (IGAC) Program is a core project of the International Geosphere Biosphere Program (IGBP) and seeks to understand quantitatively the chemical and physical processes that determine atmospheric composition. IGAC provides a response to the growing international concern about rapid atmospheric changes and their potential impact to mankind.

The IGAC plan has adopted six major foci. These are:

(i) Natural variability and anthropogenic perturbations of the marine atmosphere;

(ii) Natural variability and anthropogenic perturbations of tropical atmospheric chemistry;

(iii) The role of polar regions in changing atmospheric composition;

(iv) The role of Boreal regions in changing atmospheric composition;

(v) Global distributions, transformations, trends and modelling; and

(vi) International support activities.

An outline of the major regional foci are given. For each region, the research is shaped by the characteristics of these parts of the globe and their susceptibility to change. These six IGAC foci are intended, collectively, to address areas of greatest current uncertainty and/or perceived importance.

INTRODUCTION

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, under the auspices of the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Physics (IAMAP), 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 a Core Project of 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.

The IGAC plan, which is described in this paper, 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 exclusive and we expect further foci will be added as time proceeds.

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.

Worldwide, 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_2O). 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 CO_2, CH_4, and N_2O concentrations are unprecedented, at least for the Earth of the last 160,000 years, see Figure 1. 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 worldwide 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 and 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

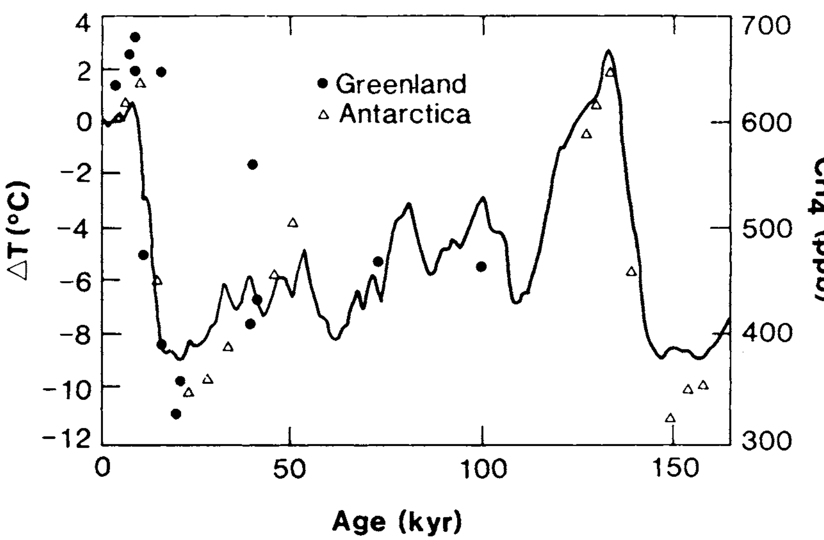

Fig. 1. Methane concentrations (ppb by volume) from ice cores plotted as age of air before present. Solid circles are data from Greenland ice cores, and triangles represent data from Antarctic ice cores. The solid line is the isotope based temperature. The data show that methane increased from about 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 and their rate of increase are unprecedented, at least during the last 160,000 years. (Reprinted from R.J. Cicerone and R.S. Oremland, Biogeochemical Aspects of Atmospheric Methane, Global Biogeochemical Cycles, Vol 2, p 301, 1988).

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 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 (IAAG). 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:

(i) To develop a fundamental understanding of the chemical processes that determine the chemical composition of the atmosphere;

(ii) To understand the interactions between atmospheric chemical composition and biological and climatic processes;

(iii) To predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere; and

(iv) 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:

(i) Increasing acidification of precipitation, see Figure 2;

(ii) Increasing oxidant concentration in surface air;

(iii) Warming due to increases in the concentrations of trace gases involved in the greenhouse effect; and

(iv) Alteration of biospheric exchange fluxes due to land use and climatic changes.

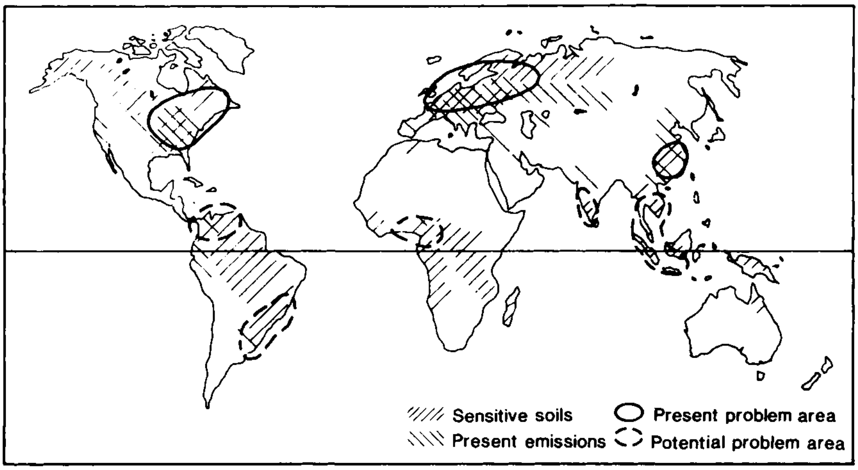

Fig. 2. Rough estimates of (a) the sesitivity of soils to surface water acidification due to acid deposition; and (b) present emission of acidifying compounds from human activities. Areas circled by solid lines represent a combination of a and b and are thus problem areas today. Areas encircled by dashed 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 "Acidification in Tropical Countries", eds H.Rodhe and R.Herrera. SCOPE 36, John Wiley and Sons Ltd.).

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

(i) Global distributions and trends;

(ii) Surface exchange processes;

(iii) Gas-phase chemical reactions; and

(iv) 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:

1. 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. The complexity of the marine atmospheric cycle of one species, sulfur, is shown in Figure 3. Three IGAC projects are proposed to address this environment and perturbations to it due to continental emissions:

(i) North Atlantic Regional Study;

(ii) Marine Gas Emissions, Atmospheric Chemistry and Climate; and

(iii) East Asian—North Pacific Regional Study.

2. 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:

(i) Biosphere-Atmosphere Trace Gas Exchange in the Tropics;

(ii) Deposition of Biogeochemically Important Trace Species;

(iii) Impact of Tropical Biomass Burning on the World Atmosphere; and

(iv) Chemical Transformations in Tropical Atmospheres and their Interaction with the Biosphere.

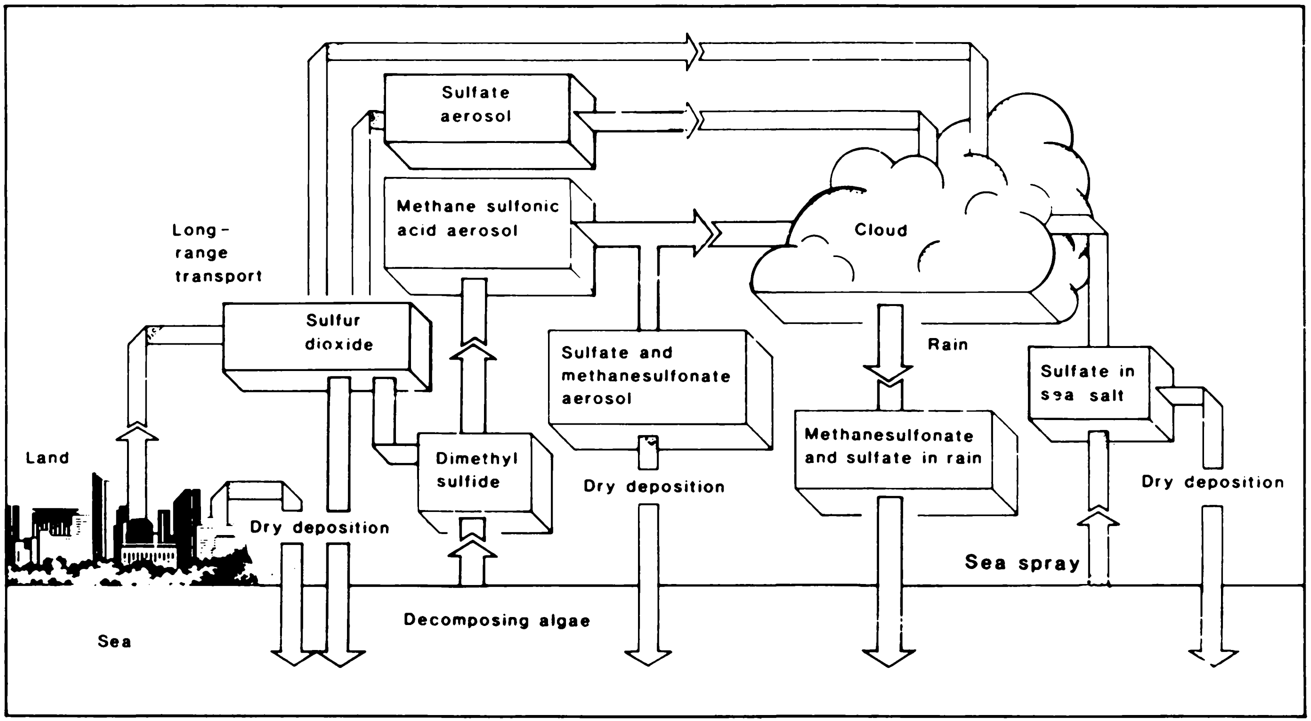

Fig. 3. The atmospheric sulfur cycle over the Southern Ocean. A major pathway (shaded) links cloud formation with algae in the sea. Decomposing algae produce dimethyl sulfide gas, which after emission to the atmosphere, turns into particles of methane sulfonic acid and sulfuric acid. These sulfur particles provide nucleii for cloud droplets to form around (Reprinted from CSIRO Division of Atmospheric Research Annual Report, 1983-1985).

3. 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, see Figure 4. 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:

(i) Polar Atmospheric Chemistry; and

(ii) Polar Air-Snow Experiments.

4. The Role of Boreal Regions in Changing Atmospheric Composition

An understanding of the cycling of trace gases between the asmosphere 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 feedback mechanisms). This arises because these regions both contain major carbon reservoirs that may be very sensitive to the effects of future climate change, see Figure 5, 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:

(i) Northern Wetlands Study.

5. 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 atmosphere 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 see Figure 6. 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:

(i) Global Tropospheric Ozone Network;

(ii) Global Atmospheric Chemical Survey;

(iii) The Chemical and Physical Evolution of Cloud Condensation Nucleii as Controllers of Cloud Properties; and

(iv) Development of Global Emission Inventories.

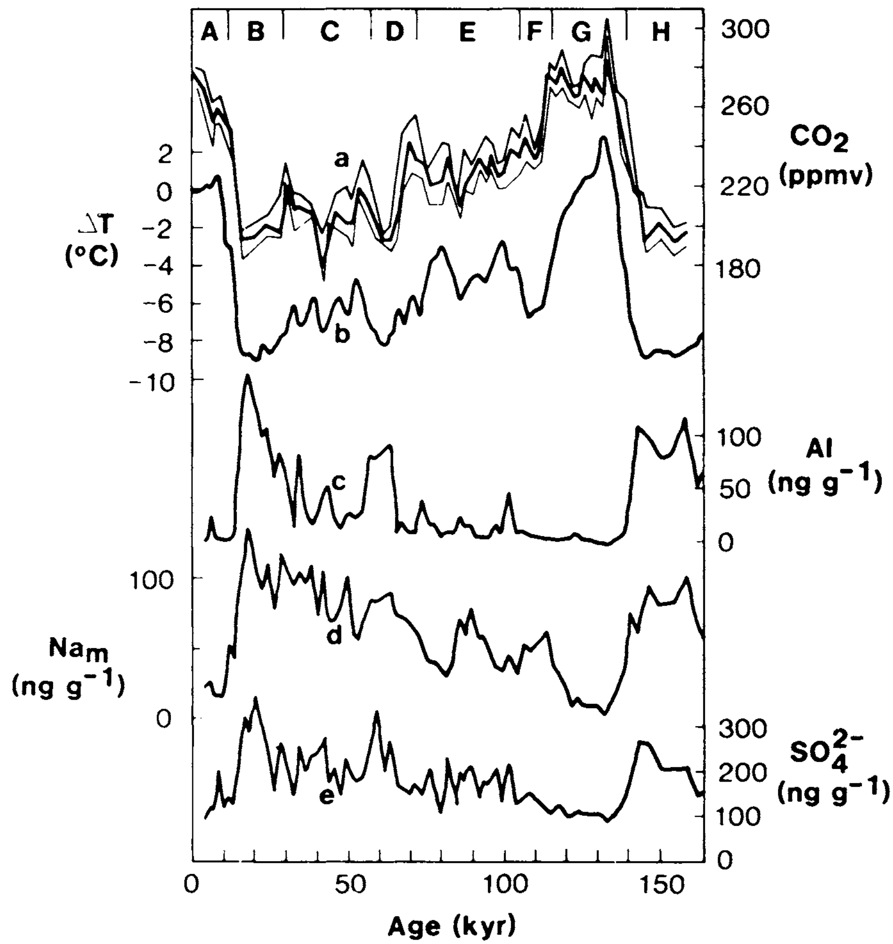

Fig. 4. Vostok ice core records; (a) CO_2 concentrations (ppmv) with envelope of uncertainty; (b) Smoothed Vostok isotope temperature record; (c) Aluminium content; (d) Marine sodium content; and (e) Sulfate content. The Vostok records show a large variation on an 100,000 year timescale with changes 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. (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).

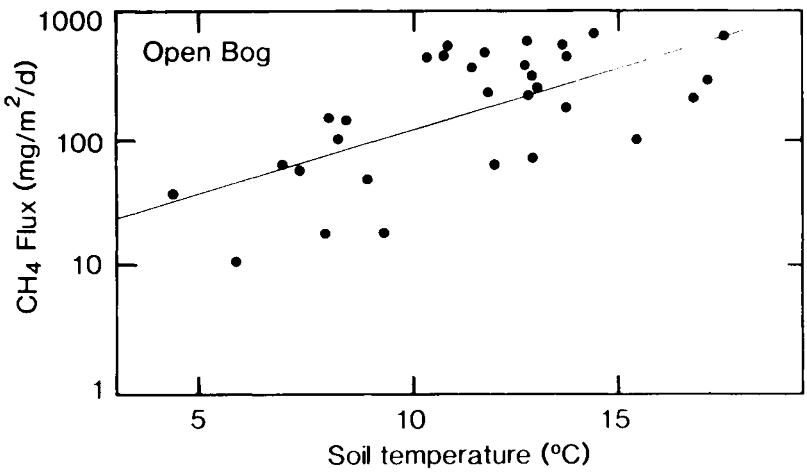

Fig. 5. Effect of soil temperature on methane emissions to the atmosphere from an open bog in the Marcell Experimental Forest, Minnesota (Reprinted from R.C. Harris, 1989, Historical Trends in Atmospheric Methane Concentration and the Temperature Sensitivity of Outgasing from Boreal and Polar Regions, in "Ozone Depletion, Greenhouse Gases and Climate Change", National Academy Press, Washington DC, USA).

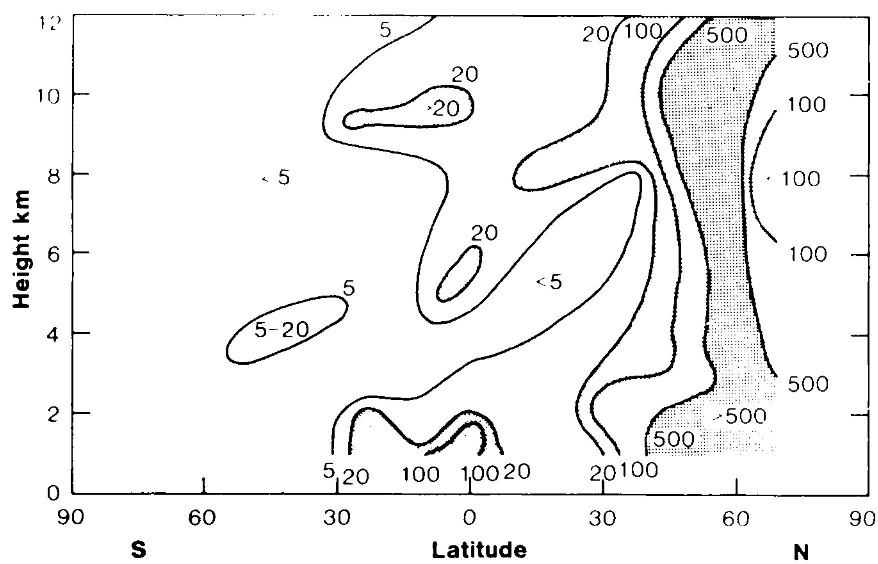

Fig. 6. Two dimensional distribution of isopentane concentration measured during the southward arm of the STRATOZ III flight from Sondestrom, Greenland to Punta Arenas, Chile. Such global distributions of key species are needed to define the oxidation capacity of the atmosphere (Reprinted with permission from D.H.Ehhalt and J.Rudolph (1987). Die globale Verteilung von Stickoxid und Kohlenwasserstoffen in der Troposphare. Jahresbericht 1986/87 der Kernforschungsanlage Julich GmbH).

6. 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:

(i) Education in Atmospheric Chemistry and Global Change;

(ii) Communication (IGAC Newsletter); and

(iii) Intercalibrations and Intercomparisons.

These six IGAC foci are intended collectively to address areas of greatest current uncertainty and/or perceived importance. They are not intended to be exclusive 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, that are 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 heirarchy 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 (WCRP) 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 WCRP, 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.

STRUCTURES OF IGAC, 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 under a different name, 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 (Australia) Conference 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 scientific project 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 contains 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 (WCRP) 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 WCRP, 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. One illustration of the changing nature of tropospheric ozone is shown in Figure 7.

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

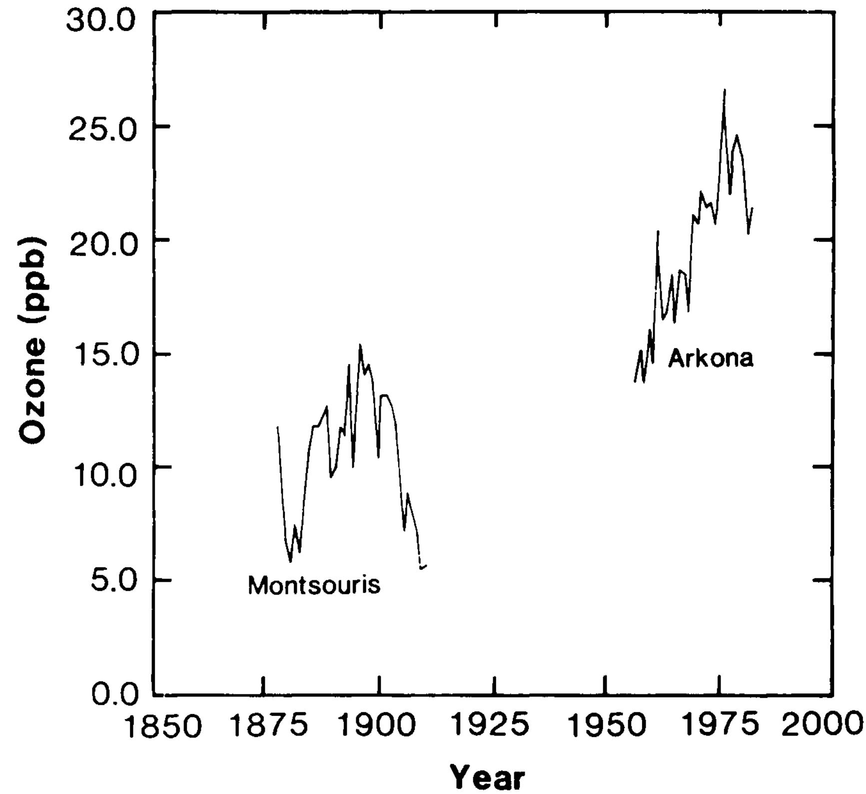

Fig. 7. Annual averages of ozone mixing ratio at Montsouris, near Paris (1876 - 1910) adjusted for SO_2 interference and at Arkona in the Baltic (1956-1983). Such unique reconstructions of past records, and comparisons of present records, are only possible with detailed documentation about experimental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

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).

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 things. Background atmospheric observatories were set up in such remote clean air locations 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 (GO_3OS) 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 worldwide 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 chemistry 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 US 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 successful research. This report concluded that an 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 US NAS/NRC Global Tropospheric Chemistry Report adopted three main goals: (i) to obtain quantitative understanding of the cycling of tropospheric chemicals globally, (ii) to develop a capability to predict future changes in atmospheric chemistry, and (iii) 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:

(i) Understanding the oxidising capacity of the atmosphere; and

(ii) The roles of atmospheric chemistry in influencing the Earth's climate.

Five main areas of research were proposed:

(i) Global distributions and trends;

(ii) Biological and surface exchange;

(iii) Gas-phase transformations;

(iv) Multi-phase processes; and

(v) 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, 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, GO_3OS, 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.

APPENDIX

Copies of the IGAC Report can be obtained from the following distribution points:

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