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The World Climate Research Programme*

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The World Climate Research Programme (WCRP) was established in 1979 as a joint activity of the World Meteorological Organization and the International Council of Scientific Unions. In recognition of the primary contribution of the oceans to the climate system, the Intergovernmental Oceanographic Commission is now expected to share the formal responsibility for the WCRP. The WCRP consists of a number of programs that focus international research on major problems of the climate system, including the development and application of climate models, the hydrologic cycle, and the causes of low-frequency variability in the climate system.

Introduction

For ten million years man has lived with changes in climate. Over the last two million years there have been about seventeen glacial-interglacial cycles with a period of about 100 000 years. These Milankovitch cycles, caused by small variations in the sun-earth geometry, bring about changes of 5° to 10°C in the globally-averaged surface temperature (Berger 1988). On shorter time-scales, the natural variability of climate leads to relatively smaller fluctuations in global temperature. Thus we find variations in the global mean temperature of 1° to 2°C over the last thousand years, and of about 0.5°C during the last century (IPCC 1990a). In addition to these long-term variations, both global and regional climates have large interannual variability.

For millions of years man has generally accommodated these vagaries of climate through the strategy of adaptation. Adaptation usually occurs after the event because any alternative strategy depends upon an ability to anticipate change. However, prediction of climate fluctuations is not straightforward. The climate system is very complex because of the interaction between a variety of processes on different space and time-scales.

Weather phenomena in the atmosphere vary on space-scales from a few metres to tens of thousands of kilometres. However, the atmosphere itself generally has a short 'memory', with maximum time-scales of weeks. These time-scales are affected by the low thermal and dynamic inertia of air.

The climate of the earth is made especially interesting because of the presence of water, and because its temperature is close to the triple point of water. The latter observation means that water can appear in all its phases, and so latent heat associated with phase changes of water is a significant source of internal energy in the climate system. Another unique characteristic of water vapour is that it is the primary greenhouse gas in our atmosphere. As it is also markedly variable in space and time, its dominant role in the earth's radiation balance is very complex.

Water has a high heat capacity and inertia, and hence the oceans are important in providing a long-term 'memory' for the climate system. Similarly the water on land can extend the time-scale of fluctuations in the climate system. These long-term components arise not only from groundwater, snow and ice, but also from the effect of water on the development of vegetation. Thus the overall climate system has internal time-scales extending from seconds (e.g. atmospheric turbulence) to thousands of years (e.g. ice sheets). The

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non-linearity of the system means that the prediction of fluctuations in climate requires appropriate incorporation of this range of processes.

It has been suggested over the last century (e.g. Callendar 1938) that, in addition to our usual strategy of adaptation to climate fluctuations, we may actually be modifying climate on a global scale. The main mechanism for this climate modification is an enhancement of the greenhouse effect, due to the release of increasing quantities of radiatively-active trace gases associated with modern industrial society. Any attempt to predict possible variations in global climate due to an enhanced greenhouse effect must clearly take into account the natural variability of the climate system. For the last couple of decades the international scientific community has been keenly aware of the potential problems associated with climate change, and has developed appropriate programs to respond to these problems.

Recent international activities

The World Meteorological Organization (WMO) has maintained an interest in both the natural and human-induced variability of climate, and in 1974 it established an Executive Committee Panel of Experts on Climate Change. The chairman of the panel was Dr W.J. Gibbs, Director of Meteorology in Australia at that time. The panel was formed during a period of great community interest in climate change; for example, a major continuing drought was affecting the Sahel and western Europe experienced several severe winters.

Following recommendations of the panel, the Executive Committee of WMO held the (First) World Climate Conference in February 1979. At its eighth congress in May of that year, WMO then established the World Climate Programme (WCP) with four components covering climate data (World Climate Data Programme), applications (World Climate Applications Programme), impacts (World Climate Impact Studies Programme) and research (World Climate Research Programme). The impacts program was coordinated by the United Nations Environment Programme (UNEP).

The research component of the WCP is the World Climate Research Programme (WCRP) and it was established in 1979 by WMO and the International Council of Scientific Unions (ICSU). There has been cooperation between WMO and ICSU for about 25 years. In 1967 they jointly sponsored the Global Atmospheric Research Programme (GARP), which focused on weather prediction and the physical basis of climate and so was the natural predecessor of WCRP.

During the early 1980s, the programs of WCRP were developed in a manner that provided a transition from the generally short time-scale focus of GARP and that accounted for the increasing community interest in the implications of an enhanced greenhouse effect and a possible depletion of stratospheric ozone. A significant event that affected public attitudes to longer-term climate change problems was the Villach Conference in 1985, which was sponsored by WMO, UNEP and ICSU. The conference concluded that an equivalent doubling of the concentration of carbon dioxide in the atmosphere during the next century would lead to a global mean temperature rise of between 1.5° and 4.5°C.

In 1986, soon after the Villach Conference, ICSU established the International Geosphere-Biosphere Programme (IGBP), which is a research program that aims to describe and understand the interactive physical, chemical and biological processes that regulate the total earth system. The IGBP and WCRP are now seen by ICSU to be complementary, with IGBP focusing on biological and chemical aspects of the climate system.

Public interest in climate change continued to mount in the late 1980s to the extent that WMO and UNEP decided to establish the Intergovernmental Panel on Climate Change (IPCC), which first met in November 1988. The purpose of the IPCC was to provide a broadly representative international mechanism to assess the scientific basis of the climate change issue related to the enhanced greenhouse effect, to determine estimates of the impacts of such climate changes, and to formulate realistic response strategies for the management of impacts. By mid-1990 the IPCC had completed three reports covering the three aspects of climate change; these are IPCC (1990a) on the scientific assessment, IPCC (1990b) on the impacts assessment, and IPCC (1991) on the response strategies.

The reports of the IPCC and the achievements of the World Climate Programme were reviewed at the Second World Climate Conference in Geneva in November 1990. The importance and success of WCRP were recognised by the conference, and it was recommended that the program should continue. However, the interest in climate had clearly spread to other technical and political groups, and so it was recommended that the overall WCP should be reorganised to take into account these interdisciplinary interests. It was also recommended that a Global Climate Observing System (GCOS) should be set up in order to meet the needs for climate monitoring, applications of climate data, and climate research (WMO et al. 1991).

The WMO Congress in May 1991 reconstituted the World Climate Programme with four components: the World Climate Data and Monitoring Programme, the World Climate Applications and Services Programme, the World Climate Impact Assessment and Response Strategies Programme, and the World Climate Research Programme. The new WCRP is to be coordinated jointly by WMO, ICSU and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). Thus the significant contribution of oceanography to the WCRP is now recognised explicitly.

Objectives and scope

The WCRP has two basic objectives: (a) to determine the extent to which climate can be predicted, and (b) to determine the extent of human influence on climate. These objectives are sequential in the sense that we must understand the natural climate system in order to detect the signal of climate change against the noisy background of natural climate variability. This linkage does not mean that work on the second objective cannot proceed, rather that progress on the second is limited by progress on the first objective.

Although the climate system has variations on all time-scales, the WCRP has been limited to time-scales out to about a century. Three time-scales or streams of activity have been identified. Stream 1 is aimed at the basic 'fast' component of the climate system, and so it extends weather prediction to scales of weeks or months. This stream was seen as a natural extension of the GARP objectives in the early 1980s. Stream 2 is associated with seasonal variations and interannual fluctuations in seasons. Stream 3 covers the 'slow' time-scales of the oceans and land surfaces, extending from years to decades.

The WCRP now has major programs associated with these three time-scales. They are the Global Energy and Water Cycle Experiment (GEWEX), the Tropical Ocean and Global Atmosphere (TOGA) program, and the World Ocean Circulation Experiment (WOCE). The ocean-related programs, TOGA and WOCE, were carried out in cooperation with the Committee on Climate Changes and the Ocean (CCCO) before the decision for IOC to cosponsor the WCRP. (The CCCO is a committee of IOC and the Scientific Committee on Oceanic Research (SCOR) of ICSU.) There is a fourth program, that covers all time-scales and acts to combine all WCRP activities, and it is the Global Climate Modelling (GCM) program.

Organisation

Before outlining each of the programs, it is appropriate to explain the organisational structure of WCRP. The program was initially directed by the Joint Scientific Committee (JSC) consisting of thirteen scientists appointed jointly by the governing bodies of WMO and ISCU for terms of about four years. Because of the vital importance of the oceans to climate, ICSU arranged in 1990 for an executive group of CCCO to attend the annual JSC meetings and to take part in all decisions on WCRP. The new arrangements for the structure of the JSC have not been determined by WMO, ICSU and IOC at the time of writing this paper (June 1991).

The JSC has a scientific steering group to coordinate the activities of each major program. Thus these main groups are:

- the Scientific Steering Group for GEWEX;
- the Scientific Steering Group for TOGA (jointly with CCCO);
- the Scientific Steering Group for WOCE (jointly with CCCO); and
- the Scientific Steering Group for GCM.

Each steering group generally has a small number of working groups to coordinate the program activities. In addition to the steering groups, there are a number of working groups which focus on particular aspects of the overall climate problem. Each group has five to ten members, appointed for their personal expertise. At present there are seven Australian scientists on the main groups of the JSC. The additional working groups of the JSC are:

- the Working Group on Numerical Experimentation (jointly with the WMO Commission for Atmospheric Sciences (CAS));
- the Working Group on Data Management;
- the Working Group on Radiative Fluxes (jointly with the International Radiation Commission and CAS);
- the Working Group on Sea Ice and Climate;
- the Working Group on Atmospheric Transport and Chemistry;
- the Working Group on Air-Sea Fluxes (jointly with CCCO); and
- the Ocean Observing System Development Panel (jointly with CCCO).

The JSC steering and working groups are set up in recognition of the complexity of the climate system. There are problems that cannot be readily solved by individuals working in isolation, and the JSC working groups are set up only when the problem requires international collaboration. Because the WCRP has no resources to fund projects, there is progress on problems only when the individual members of the working groups are able to work together. These constraints generally imply that individuals are nominated for the main working groups not only for their scientific expertise, but also for their ability to commit resources to help solve the group research problems. The groups are therefore true working groups in the sense that collaborative tasks are determined at each meeting and progress reports are made at subsequent annual meetings.

Useful links between WCRP and IGBP are formed through the establishment of common working groups. The JSC Working Group on Atmospheric Transport and Chemistry was set up in cooperation with the International Global Atmospheric Chemistry (IGAC) program of IGBP. More recently the GEWEX Working Group on Land Surface Experiments has been formed jointly with the IGBP Biospheric Aspects of the Hydrologic Cycle program.

Research programs

The research activities of the WCRP have grown substantially over the last decade, and so only an outline of the program objectives and methods is given in this summary. References to some of the research activities should allow more detailed information to be obtained.

GEWEX

The GEWEX program was formally established in 1988 with the primary objective to observe, model and predict the hydrologic cycle of the climate system. Because of the heavy dependence on meteorological satellites for global monitoring, GEWEX has a specific objective to develop climate data observing, management and assimilation systems. The program is closely tied to the Earth Observing System (EOS) programs of the USA, Japan and Europe. The science plan for GEWEX (WMO 1990) describes the long-term nature of the program and current research foci.

The Working Group on Numerical Experimentation (WGNE) provides the modelling support for GEWEX, and it coordinates projects on the representation of components of the hydrologic cycle and on the analysis of climate data. For example, there is a particular problem not only with the representation of cloud in models, but also with the validation of cloud processes. In order to validate the radiative impacts of cloud, WGNE proposes to conduct an intercomparison project in which model output is used to simulate the radiances observed directly from satellites (WMO 1991).

The data for the intercomparison will come from the International Satellite Cloud Climatology Project (ISCCP), which was initiated in 1983 with the objective of producing a continuous climatology of monthly mean cloud amounts and optical properties over the whole globe for at least five years (Schiffer and Rossow 1985). This project requires the analysis of three-hourly data from five different satellites. The ISCCP is one of several projects in GEWEX designed to observe and analyse the radiation budget of the atmosphere. The satellite-based projects, such as ISCCP and the Earth Radiation Budget Experiment (ERBE), are complemented by field experiments and surface-based monitoring projects.

Clouds have direct dynamical and thermodynamical effects on the climate system through convective mixing and precipitation processes. A new project, the GEWEX Multi-region Cloud System Study (GMCSS), is being developed to improve the parametrisation of cloud systems in climate models. The GMCSS aims to focus both theoretical and field work on the parametrisation problem, which has not evolved significantly since the early schemes such as Kuo (1965).

Although it is a primary component of the climate system, rainfall is not comprehensively measured over the globe. This deficiency arises because of the relatively small correlation scale for rain in both space and time. Thus measurements at one location cannot be easily used to infer the rainfall at neighbouring locations. Moreover the measurement of rainfall itself is not straightforward, and there is no absolute measurement technique. The Global Precipitation Climatology Project (GPCP) has been set up to obtain systematic monthly mean precipitation rates over the globe using satellite and ground-based observations. The primary data for GPCP is the infrared imagery from the geostationary meteorological satellites from which the thresholding method of Arkin (1979) provides rainfall estimates.

An outstanding problem in global climate modelling is the representation of the exchanges of water, heat and momentum between the atmosphere and the land surface. While some uncertainty remains with the microphysical description of these exchange processes, a major source of uncertainty lies in scaling differences between the microscale processes and the grid scales of climate models (50 to 500 km) on which the smaller-scale processes must be represented. In order to resolve some of these problems a number of Hydrological-Atmospheric Pilot Experiments (HAPEXs) have been carried out at sites with different vegetation types and on scales up to 100 km. On the other hand, a new project is being planned to relate the climate model grid scales to the natural hydrological scales of a water catchment region. The GEWEX Continental-scale International Project (GCIP) is proposed to carry out detailed observations and analyses of a continental-scale catchment area such as the Mississippi Basin in the USA.

The various projects in GEWEX will be developed over this decade so that maximum advantage will be taken of the new types of satellite measurements that are expected to become available at the end of the 1990s under the EOS programs.

TOGA

The origins of TOGA are in the work of Adrian Gill about a decade ago when he considered a simple model of the coupling between the ocean and atmosphere across the Pacific Ocean (Gill 1980). Thus the focus of TOGA is the El Niño-Southern Oscillation (ENSO) and the Walker Circulation, although the program also includes all the monsoon system. The objectives of TOGA are to determine the predictability of that coupled system, to develop models of the system, and to design an operational system to support such predictions (WMO 1985).

One component of the program is the development of a comprehensive observing system of the tropical atmosphere and upper ocean. The network builds on the existing operational systems, the World Weather Watch (WWW) for the atmosphere and the Integrated Global Ocean Services System (IGOSS) for the oceans. New measurements include the installation of continuous wind profilers on Christmas and Kanton Islands, and the deployment of an array of current-meter moorings across the Pacific Ocean. A particular project is the use of voluntary observing ships to deploy expendable bathythermographs (XBTs) across the tropical oceans in order to obtain sufficient data to analyse the upper-ocean thermal structure on a monthly or bimonthly basis (Smith 1991). These data are now being used in assimilation studies as a basis for research into long-range forecasting in the tropics.

The monitoring and modelling components of TOGA research are complemented by various field projects designed to focus on specific aspects of the TOGA problem. The Darwin region has been a centre for several process studies related to TOGA. The combined Australian Monsoon Experiment (AMEX) and the Equatorial Mesoscale Experiment (EMEX) in 1986–87 provided unique data on convection in a monsoon environment (McBride and Holland 1989), and continuing radar studies for the NASA Tropical Rainfall Measuring Mission (TRMM) have yielded new information on precipitating systems in the tropics (Keenan et al. 1988).

A major experiment, called the Coupled Ocean-Atmosphere Response Experiment (COARE), on the air-sea interaction of the western Pacific is planned for 1992–93. The scientific plan for COARE has been produced as an addendum to WMO (1985). The objective of the project is to clarify the mechanisms associated with the fluxes of heat, water and momentum across the air-sea interface in the 'warm pool' region of the western Pacific Ocean. The project will have significant Australian involvement in the design and implementation of the field study and in the analysis of the data.

The TOGA program has been a marked success in the World Climate Research Programme. It has involved collaboration between oceanographers and meteorologists, and has led to a rapid increase in our understanding of the physical processes affecting tropical weather and climate. The program has a definite ten-year duration from 1985, but it has laid a clear path for the WCRP to follow in future research on the interannual variability of seasonal weather and climate.

WOCE

The WOCE program is very ambitious: it plans to obtain comprehensive observations of the global ocean circulation and to use those data to develop global ocean models. Following detailed planning, the field program for WOCE covers the five-year period from 1990 (WMO 1988). The program has three core projects which will yield complementary data to support the modelling objectives of WOCE.

The first core project aims to provide a quantitative global description of the ocean circulation, including the transport of heat, fresh water and chemical constituents. Observations will be obtained on the full vertical structure, from the surface layer to the abyssal circulation, so that the measurements will be relevant to the range of dynamical time-scales from months to decades. The observations for WOCE come from conventional hydrographic surveys of the world oceans, moored arrays, drifting buoys and floats, expendable conductivity-temperature-depth probes, and satellite altimeters and scatterometers.

The other core projects focus on specific regions. The second project aims to improve our understanding of the Antarctic Circumpolar Current (ACC) and the main water-mass components of the Southern Ocean. The ACC is unique in its linking of the Pacific, Indian and Atlantic Oceans, and there is a primary region of formation of bottom water to the south, particularly in the Weddell Gyre.

The third core project of WOCE (Gyre Dynamics Experiment) is aimed at the physical processes that need to be better understood in order to model the global circulation on decadal time-scales. From measurements principally in the north Atlantic, further information will be obtained on the processes, such as surface fluxes and eddy dynamics, to which ocean models are found to have sensitivity.

The field program for WOCE started in 1990 in the Atlantic, as planned. There are firm commitments at present for at least fifty per cent of the requirements for the one-time global hydrographic survey, so that the primary objective of the field program should be met over the next five years.

GCM

The Global Climate Modelling (GCM) program is the core of WCRP because it is axiomatic in the WCRP that physically based models are the basic tool for understanding and predicting the climate system (WMO 1984). The objective of the program is to develop and apply models of the climate system and its components in order to simulate and predict climate variations on all time-scales.

Modelling is an integral part of all the WCRP programs, and there are several specific numerical experimentation working groups supporting programs, such as WOCE and TOGA. The Working Group on Atmospheric Transport and Chemistry is concentrating on the development of three-dimensional chemical-dynamical models that can accurately represent the transport of chemical tracers on global scales. The WGNE originated with GARP about twenty-five years ago, and it has remained the primary focus for the development of the basic modelling tools for weather and climate.

The JSC decided in 1990 to establish the Steering Group on Global Climate Modelling which aims to promote the development of comprehensive models of the climate system, including the global oceans and the hydrological processes. The steering group is first reviewing the current status of global coupled ocean-atmosphere models. It is found that all the coupled models have significant systematic errors, associated directly with the coupling at the air-sea interface. The determination of the cause and consequent elimination of these errors is seen to be a priority.

Future directions

The general direction for each of the main programs of the WCRP can be estimated (subjectively) for the next few years on the basis of current knowledge. The major activity of GEWEX will be the execution of GCIP, and this work should provide a focus on the role of vegetation in the land-surface hydrological and biochemical systems. Continuing research on the understanding of the fluxes of heat, moisture and momentum across the land and sea surfaces should lead to progress on the reduction of the present uncertainties on the fluxes of greenhouse gases across the earth's surface (Tans et al. 1990).

In Australia there should be further work relevant to GEWEX in both the tropics and Antarctica. The GMCSS and TRMM will stimulate more effort on the parametrisation of deep tropical convection, and that research should continue beyond the successful completion of TOGA COARE in 1993. The sea-ice of the Antarctic region has not been fully studied, although it is a significant source of error in climate models. International research is expected to increase on the sea-ice problem of Antarctica over the next few years. (This research will be complementary to a specific Arctic Climate System Study, which is now being considered by the JSC to focus efforts in the Arctic on the problem of the fresh-water budget as it affects the global thermohaline circulation.)

Over the next five years the WOCE observational program should be carried out, leading to a unique data set for the development and validation of ocean models. However, it is likely that there will be an increasing emphasis on the elucidation of specific processes associated with the low-frequency variability of climate. For example, a principal component analysis of global sea-surface temperatures (SSTs) shows that the third component has a dominant characteristic of a north-south oscillation in the Atlantic Ocean, with a time-scale of decades (Folland et al. 1991). Such processes must be understood before reliable estimates of future climate states can be made.

The major achievement of TOGA is the continuing clarification of the ENSO process, which appears as the second principal component of the global SST analysis (Folland et al. 1991). (The first component corresponds to the mean trend in global SST.) The growing recognition of structure in the low-frequency variability of climate provides a basis for some optimism about the prospects of climate prediction. The JSC is therefore considering a proposal for a program, following and building on the success of TOGA and WOCE, to concentrate on the problem of predicting variations in the coupled atmosphere-ocean-land climate system on time-scales from months to several years.

The new program on climate variability should provide a focus for research across WCRP, especially for the modelling activities. The GCM program should concentrate on the coupled ocean-atmosphere models, with the objective of reducing systematic errors. The models will then be most effective in the assimilation of both the oceanic and atmospheric data that will become increasingly available with the introduction of the Global Climate Observing System.

Conclusion

The main programs of WCRP are well established and have well-specified activities for at least the next five years. Australian scientists have made significant contributions to these programs in the past, and such involvement is expected to continue. Although there is public concern for improvements in our ability to predict climate change on decadal time-scales, the major advances over the next few years in understanding and predicting climate are most likely to be on the seasonal and interannual time-scales. These advances will not only provide great support for agricultural and other community activities but also improve the foundation for the prediction of longer-term climate change.

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