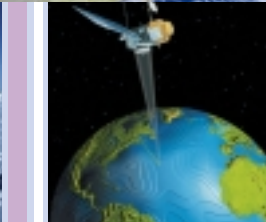


World Climate Research Programme: 25 years of science serving society



WCRP



ICSU

International Council for Science

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NOTE

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Foreword

Understanding climate and its change represents one of the most difficult challenges to modern science because of the complexity of physical, chemical and biological interactions occurring on the Earth — in its atmosphere, oceans and on land — at the widest range of space and timescales. Through the World Climate Research Programme (WCRP), the World Meteorological Organization (WMO), the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) have joined efforts to support and coordinate the activities of the global meteorological and oceanographic communities and the wider academic community to address this challenge.

The WCRP, in the 25 years since it was established, has made enormous contributions to advancing climate science. As a result of WCRP efforts, it is now possible for climate science to monitor, simulate and project global climate with unprecedented accuracy so that climate information can be used for governance, in decision-making and for support of a wide range of practical applications. At the same time, there are still many gaps in our knowledge, and much better and more detailed climate system observations, models, assessments and services are required. The Joint Scientific Committee for the WCRP, in collaboration with the WCRP projects and the larger scientific community, is developing a strategy for the next decade which will ensure that WCRP works efficiently and effectively towards strengthening our knowledge and increasing our capabilities with regard to climate variability and change and their prediction. This strategy, known as Coordinated Observation and Prediction of the Earth System (COPES), will facilitate the analysis and prediction of the Earth system variability and change for use in an increasing range of applications of direct relevance, benefit and value to society. I am confident that in this way the WCRP will continue to make a significant contribution to the understanding and governance of the Earth.



P. Lemke
Chairperson
Joint Scientific Committee for the WCRP



WCRP — at the forefront of climate science since 1980

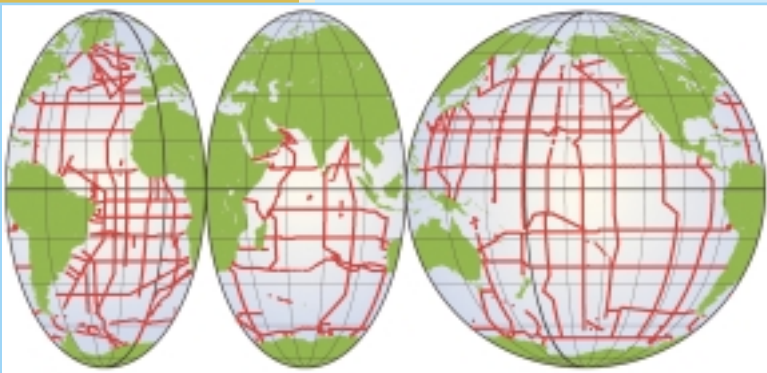
The main objectives, set for WCRP at its inception and still valid, are to determine the predictability of climate and to determine the effect of human activities on climate.

To achieve these objectives, WCRP adopts a multidisciplinary approach and organizes large-scale, observational and modelling projects, each of which focuses on aspects of climate too large and complex to be addressed by any one nation or individual scientific discipline.

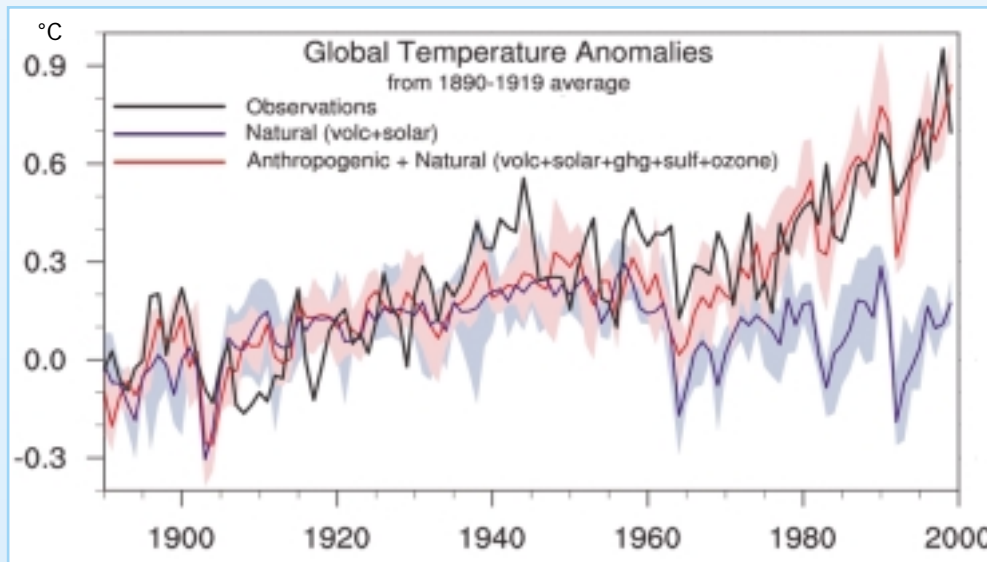
Three major WCRP projects have been successfully completed in the last decade. The Tropical Ocean and Global Atmosphere (TOGA) project (1985–1994) established the physical basis for the understanding and prediction of *El Niño* temperature signals and associated changes in global climate. This led to a major breakthrough in operational seasonal climate forecasting. The World Ocean Circulation Experiment (WOCE) (1982–2002), the biggest and most successful global ocean research programme to date, collected observations of the world's oceans of unprecedented quality and coverage and led to the development of important new ocean observing techniques and improved understanding of physical processes in the ocean. The Arctic Climate System Study (ACSYS) (1994–2003) examined the complex and interrelated pieces of the Arctic climate system to ascertain its role in the global climate system.

WCRP research over the years has greatly improved our understanding of key climate processes and a vigorous modelling programme has resulted in significantly improved climate models, as well as better operational weather and ocean forecasting models. Improved modelling of the climate system has provided increasingly accurate simulation and predictions of natural climate variations, giving more confidence in projections of human-induced climate change. WCRP research has provided the scientific underpinning for each of the assessments of the Intergovernmental Panel on Climate Change (IPCC) that, in turn, contribute to the political process related to climate change.

Ocean sections occupied during WOCE.



Comprehensive field measurements and the provision of essential global and regional climatological data sets are major components of all WCRP projects. Some of these, such as the observing system in the Pacific established by TOGA and the global array of subsurface floats implemented during WOCE, have led to operational climate observing activities which are crucial to monitoring and predicting climate.



G.A. Meehl

Climate models with only “natural” forcings (volcanic and solar) do not reproduce observed late twentieth century warming. When increases in anthropogenic greenhouse gases and sulphate aerosols are included, models are able to reproduce the observed warming.

Today the WCRP consists of four major core projects:

- The Climate Variability and Predictability (CLIVAR) project;
 - The Global Energy and Water Cycle Experiment (GEWEX);
 - The Stratospheric Processes and their Role in Climate (SPARC) project;
 - The Climate and Cryosphere (CliC) project
- and the co-sponsored Surface Ocean-Lower Atmosphere Study (SOLAS).

WCRP — building awareness of climate change and related risks

It was the international community of physical climate scientists that alerted the world to the reality of global warming, the prospect of anthropogenic climate change and its consequences. It is this same community that has determined the most likely causes of the recent global climate change and which has the capability to provide increasingly reliable climate-change scenarios, which are crucial for many aspects related to planning for sustainable development. WCRP has helped bring such climate-related issues to centre-stage by carrying out policy-relevant science and by raising the level of scientific, governmental and public appreciation to the importance of climate issues. This has been done through fostering much greater cooperation between hitherto distinct scientific disciplines in understanding the whole climate system.

“Climate change ... may well be the greatest challenge that your generation will have to face. ... This is not some distant, worst-case scenario. It is tomorrow's forecast. Nor is this science fiction. It is sober prediction, based on the best available science.”

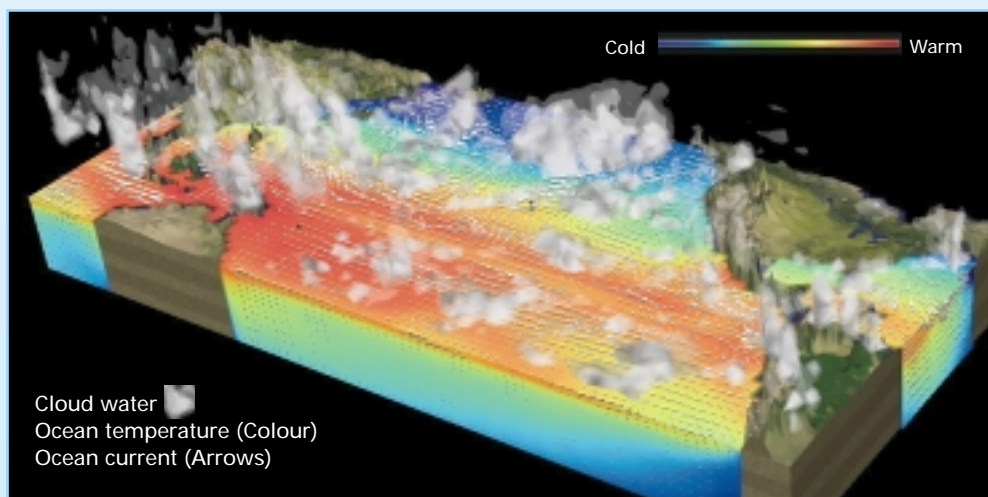
Kofi Annan,
Secretary-General of the
United Nations
Keynote address at Tufts
University Fletcher School
of Law and Diplomacy,
20 May 2001.

Enabling more useful climate predictions

Climate predictions seasons in advance — now a reality

The WCRP TOGA project established the physical basis for predicting *El Niño* temperature signals and associated changes in the global atmospheric circulation from a season up to a year in advance. This was a major breakthrough in the ability to make skilful forecasts of seasonal climate signals. The current WCRP activities are aimed at increasing the reliability of *El Niño*/Southern Oscillation (ENSO) event predictions and also extending predictive potential towards mid- and polar latitudes. The objective is to reveal all predictable features at the global and regional scales.

Three-dimensional output from a coupled atmosphere-ocean simulation of conditions over the equatorial Pacific region.



Monsoon rains — a source of life — can we predict them?

Over half of the world's population lives within the influence of the Asian monsoon and a further large fraction lives within the monsoon areas of Africa and the Americas. Forecasting monsoons, their onsets, breaks and duration, remains a very difficult scientific problem due to the complexities of the interactions involved. Advances in simulation of clouds and radiation, progress in assimilation of humidity and temperature data sets, better cloud-resolving schemes and several other factors have set the stage for WCRP to concentrate efforts on improving the monsoon prediction capabilities.

Long-term climate variability — can it be predicted?

In the North Atlantic, the changes to the patterns and intensity of the storm tracks associated with changes in the strength of the so-called North Atlantic Oscillation can result in periods of severe winter storminess with potential damage to property and loss of life. The changes in annual rainfall in the African Sahel on decadal and longer timescales and the dust bowl years of the 1930s in the United States are other examples of how longer term variations of climate affect the life support systems. On much longer timescales, the cycles of glacial (ice age) and interglacial periods (such as we are in now) demonstrate the very long-term variability of climate. Recent WCRP studies have indicated that there is some potential predictability on longer timescales; this avenue of research is being vigorously pursued.

Contributing to risk assessment

There are inherent limits to weather and climate predictability. Research will not always reduce the uncertainty associated with a forecast, but it can help to clarify the probability of a certain situation to occur. This information can be a very useful input to a broader risk management strategy. A recent major breakthrough has been the use of multimodel ensemble forecasting systems to give probabilistic risk forecasts of climate events and associated phenomena, such as occurrences of disease outbreak, heat waves, increased precipitation or drought conditions.



The Rio de la Plata basin in South America is the source of about 70 per cent of the gross national product of the five countries within the basin. A WCRP project is being developed to investigate the climatology and hydrology of the Plata basin with the aim to provide information and products that can help decision and policy makers manage better the regional resources.

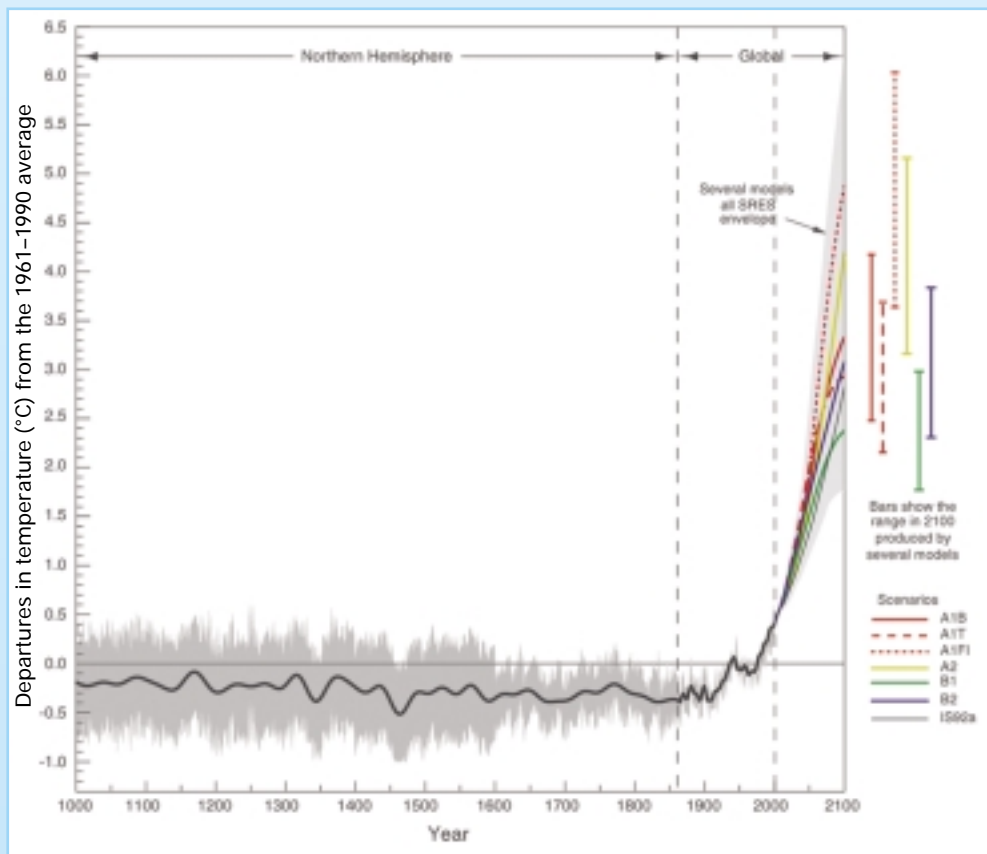
Narrowing the uncertainties regarding human-induced climate change

There is widespread concern and convincing evidence that human activities, through burning of fossil fuels and land use and cover changes such as large-scale deforestation, are affecting global and local climates, causing major environmental changes. Use of fossil fuels for energy generation and transport lies at the very foundation of our modern society and can be expected to increase substantially in the future. The need to form national and international policies on matters related to anthropogenic climate change has emphasized the need for a better understanding of, and ability to model, the climate system. It also calls for effective detection and attribution of climate change.

Making projections of future climate

Narrowing down the uncertainties of the future long-term climate projections as well as the overall spread of the predictions is of highest priority for WCRP. WCRP research is targeted at better understanding physical processes which characterize the biggest uncertainties.

Variations of the Earth's surface temperature for the past 1 000 years and various model projections for the next 100.



Contributing to the political process

WCRP results feed directly into major scientific assessments such as the reports of the WMO/United Nations Environment Programme (UNEP) IPCC. In turn, the IPCC assessments provide the authoritative, up-to-date scientific advice needed to contribute to the United Nations Framework Convention on Climate Change. They also reveal the gaps in our knowledge and serve as a stimulus for further development of the WCRP science.

Detection and attribution

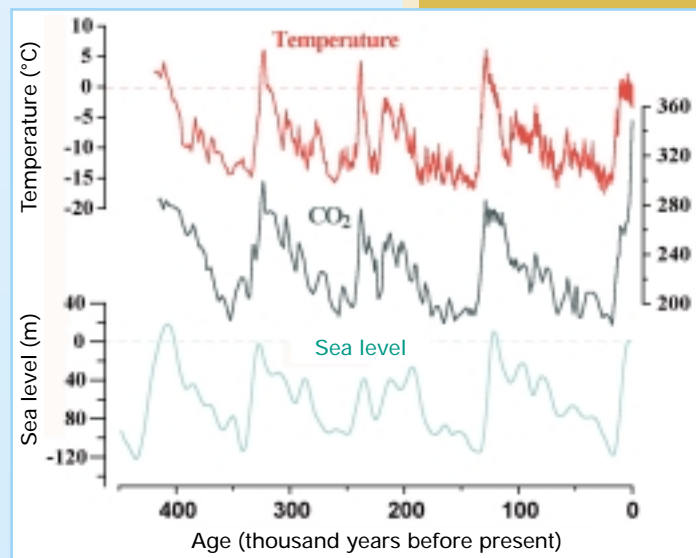
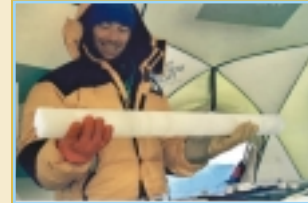
One of the crucial issues for climate science is understanding how much of the observed climate changes can be attributed to natural variability and how much to human activities. The approach of the WCRP is twofold. It includes support to climate observing systems — to determine quantitatively the changes that occurred in the past (“palaeo” observations) and are happening at present — and an extensive strategy for developing and using the models and analytical tools that can reproduce the observed changes and, where possible, reveal their causes.

Regional effects

Projected climate change is uneven around the globe. WCRP is developing techniques to downscale global model outputs to tell us what will happen to the climate at the regional level.

Climate extremes — are they increasing?

To many people it seems like extreme climate events like typhoons, heat waves and floods have been on the increase lately. WCRP is collaborating with WMO to produce worldwide analyses of indices that will give an objective measure of actual changes in climate extremes. The results from this work provide important input to the IPCC assessment reports.



Scientists reconstruct past temperature, CO₂ and sea level from ice cores.

J.R. Petit

How does WCRP work?

There are three fundamental ways in which WCRP approaches its aims, namely, through climate-related observations and their analysis, through fundamental research on climate/Earth system processes, and through the development, evaluation and use of climate/Earth system models. Scientific achievements in the areas of observation, modelling and prediction are systematically transitioned to operational monitoring and forecasting practices.

Observations

Comprehensive in situ and remotely-sensed measurements are a major element of all WCRP projects. The maximum possible value of observations

is obtained by putting them together with other observations in the context of models. WCRP projects, such as the Continental Scale Experiments and the Coordinated Enhanced Observing Period (CEOP), represent a new era in integration of models and satellite and in situ observational data. Through various means including support to the Ocean Observations Panel for Climate (OOPC) and the Atmospheric Observation Panel for Climate (AOPC), WCRP contributes to the design and implementation of the Global Climate, Ocean and Terrestrial Observing Systems. To assist further in the design and coordination of observing systems, WCRP is also a member of the international Integrated Global Observing Strategy Partnership and an associated member of the Committee on Earth Observation Satellites.

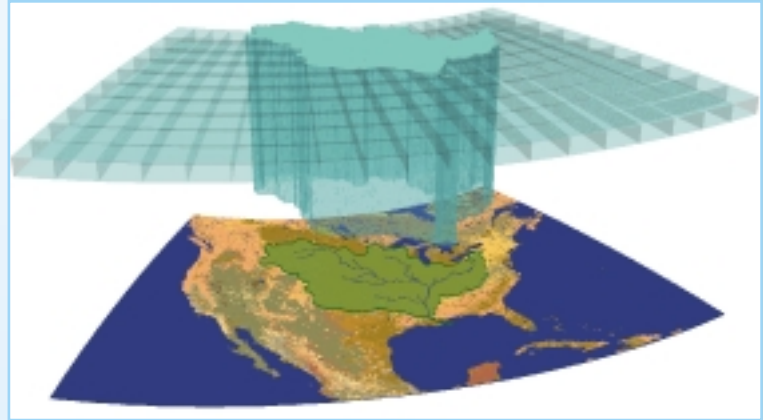
WCRP provides an international framework that:

- Generates major international scientific initiatives in the area of climate science and observation;
- Enables priority setting through an internationally-agreed agenda;
- Facilitates efficient and effective sharing of, and access to, resources, including computer resources and data;
- Stimulates and supports scientific networking;
- Develops common methodologies and experimental protocols for observations and modelling;
- Synthesizes and integrates individual research project results;
- Acts as a knowledge-base and think-tank for climate and global change assessments;
- Organizes relevant data and information management, and model intercomparisons.

Data sets

WCRP has assembled and made available to scientists an unprecedented collection of global and regional data sets for radiative fluxes, clouds, water vapour, hydrological cycle parameters, cryosphere parameters, etc., from the bottom of the oceans to the stratosphere. WCRP has encouraged several reanalysis projects that, through the assembly and extensive quality control of data and its assimilation in models, allow leading meteorological centres

in the world to produce dynamically-consistent data sets that have revolutionized diagnostic studies in meteorology. The scope of reanalysis activities is being extended by WCRP now to include the full climate system.



Coupled land-atmosphere models are used to study hydrology of the Mississippi River basin.

Modelling

WCRP analyses of data sets, process studies, and support to, and coordination of, model development have helped global climate models reach a new level of sophistication and accuracy. While in the 1970s climate models mostly represented only physical and dynamical processes, modern models include representations of biological and chemical processes as well, and will soon include socio-economic factors. We are now at the dawn of a new era of comprehensive Earth system modelling.

The Working Group on Numerical Experimentation, jointly sponsored by WCRP and the WMO Commission for Atmospheric Sciences (CAS), has acquired widest recognition for its contribution to advancing numerical weather prediction and various aspects of atmospheric modelling. The WCRP Working Group on Coupled Modelling is the core group organizing model experiments for the WMO/UNEP IPCC assessments.

Capacity-building

The global change system for analysis, research and training (START), established by WCRP, the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) attempts to enhance the scientific capacity of developing countries in addressing the complex processes of environmental change and degradation. START provides training and career development and supports infrastructure for environmental change research. The network of scientists supported by START conduct research on regional aspects of environmental change; assess impacts and vulnerabilities to such changes; and provide information to decision makers.

Participants preparing climate indices at a WCRP/WMO workshop in Turkey in 2004.



The WCRP strategic framework 2005–2015: Coordinated Observation and Prediction of the Earth System (COPES)

After 25 years of huge advances in climate science, there are many new opportunities and challenges for international climate research. Among these are the realization that there is a seamless prediction problem from weather through to climate timescales, the necessity to address the broader climate/Earth system and the increasing ability to do this, new technology for observations and computing, and the numerous possibilities for the application of WCRP research to societal needs.

In response, WCRP is launching a new strategic framework, COPES, for its activities in 2005–2015 with the aim to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

COPES will provide the unifying context and agenda for the wide range of climate science coordinated by, and performed through, WCRP core projects and other activities, and for demonstrating their relevance to society. Specific, time-limited objectives will be identified and set annually by the Joint Scientific Committee for the WCRP. An initial list of topics includes: seasonal prediction; monsoons; and sea-level rise. The necessary activity to achieve these objectives will, in general, be performed through the continuing WCRP projects; summary reports will be published.

Strong research collaborations will be sought, in particular:

- (a) On the broader Earth system aspects with IGBP, IHDP and the International Programme on Biodiversity Science (DIVERSITAS), which with WCRP comprise the Earth System Science Partnership (ESSP);
- (b) With THORPEX: A World Weather Research Programme, on weather aspects;
- (c) Within the new Global Earth Observation System of Systems (GEOSS) of which WCRP is a member along with 40 nations and 30 international organizations;
- (d) With satellite agencies and numerical weather and climate prediction centres;
- (e) Through START for the involvement of scientists from developing countries.

Collaborations will also be actively pursued in areas of applications, for example with those involved with seasonal prediction, with the monitoring and service-oriented components of WMO's World Climate Programme, the Hydrology and Water Resources Programme, and the new WMO Natural Disaster Prevention and Mitigation Programme.



Earth Simulator Center/JAMSTEC

Powerful new computers such as the Earth Simulator in Japan will make possible major advances in climate modelling.

Direct input will continue to be provided for international assessments, such as those of IPCC, that contribute to the United Nations Framework Convention on Climate Change and the Vienna Convention for the Protection of the Ozone Layer.

How fast will the sea level rise?

The IPCC Third Assessment Report projects the sea level rise in the twenty-first century in the range of 9-88 cm. WCRP aims to reduce this range of uncertainty and to substantiate significantly the future estimates by making better estimates of all changes in mean sea level rise sources, more accurate account of water balance on land, and improved models for ocean heat expansion.



ESA

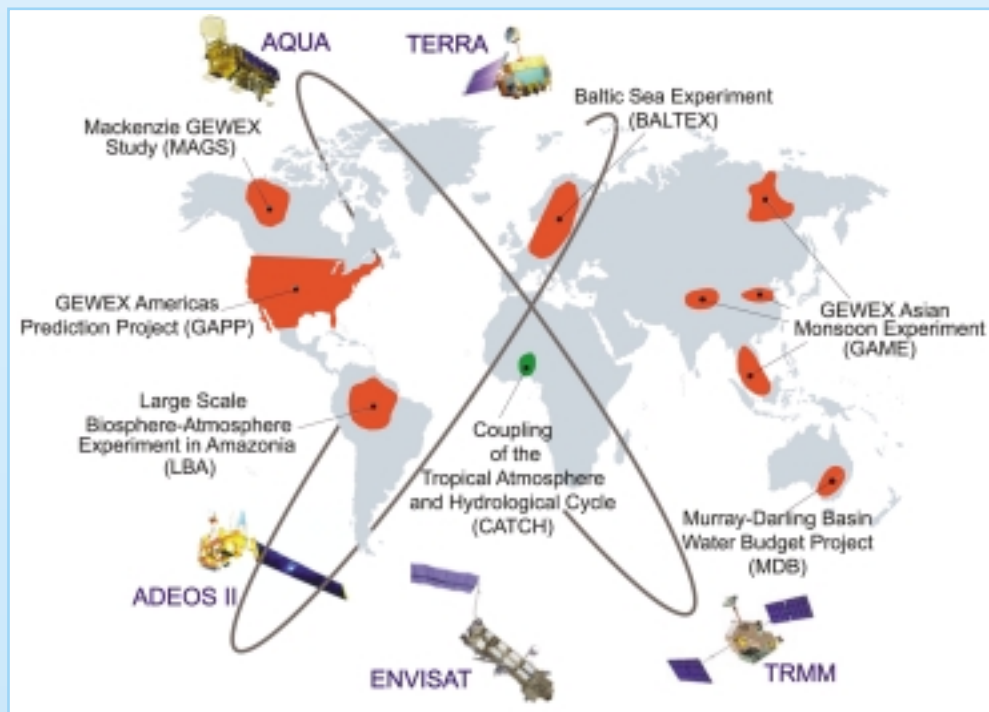
CryoSat is a radar altimetry mission, scheduled for launch in 2005, to determine variations in the thickness of the Earth's continental ice sheets and sea-ice cover. Its primary objective is to test the prediction of thinning Arctic ice due to global warming.

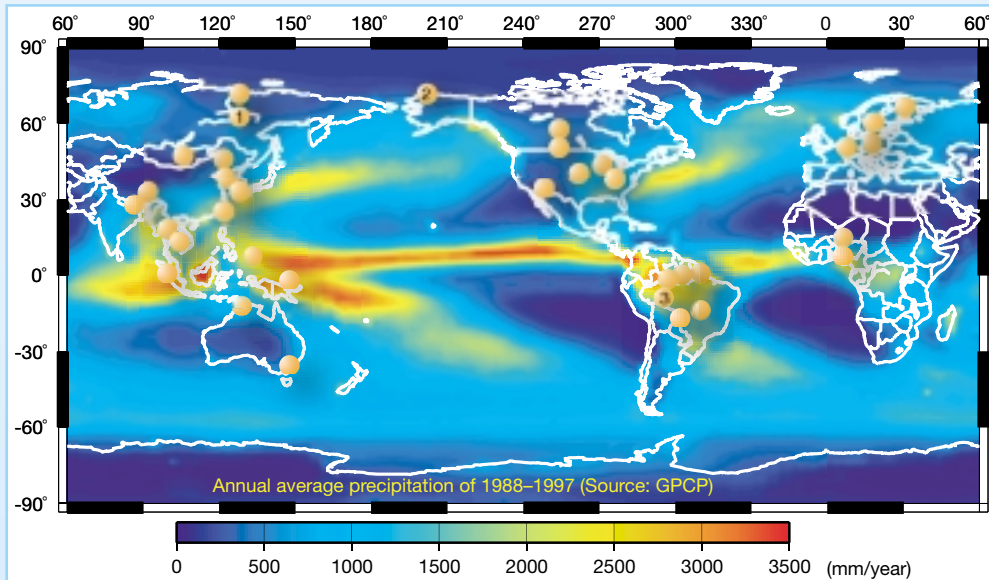
Global Energy and Water Cycle Experiment (GEWEX): ongoing core project since 1990

Water in the atmosphere and at the surface of the Earth is the most influential factor regulating our environment, not only because water is essential for life but also because it is the main energy source that controls clouds and radiation and drives the global circulation of the atmosphere. Over the past 15 years, GEWEX has made significant advances in our understanding of the atmosphere, the associated global water cycle and the overall atmospheric energy budget, and how they might adjust to global changes such as the increase in greenhouse gases.

These advances have been obtained through the cooperation of research communities in hydrology, land-surface and atmospheric science. GEWEX has coordinated field experiments over continental areas representative of the major climate types and has developed models of relevant physical processes and global data sets that enable the monitoring of the various components of the water cycle and energy budget for the past 20 years. It has also initiated projects that apply its scientific findings to the management of water resources.

The GEWEX observing strategy includes continental- and basin-scale experiments as well as global observations from satellites.





The goals of GEWEX have recently been revised as part of the overall WCRP strategy. These include:

- (a) To produce consistent descriptions of the Earth's energy budget and water cycle, its variability and trends, and data sets for the validation of models;
- (b) To enhance the understanding of how the energy and water cycle processes contribute to climate feedbacks;
- (c) To develop improved parameterizations encapsulating these processes and feedbacks for atmospheric circulation models;
- (d) To interact with the wider WCRP community in determining the predictability of energy and water cycles; and
- (e) To interact with the water resources community to ensure the usefulness of GEWEX results.

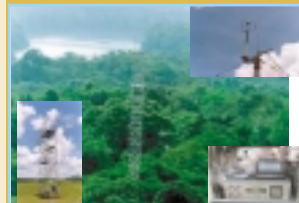
1. Eastern Siberian Tundra (Yakutsk site)



2. North Slope of Alaska



3. Rhondonia



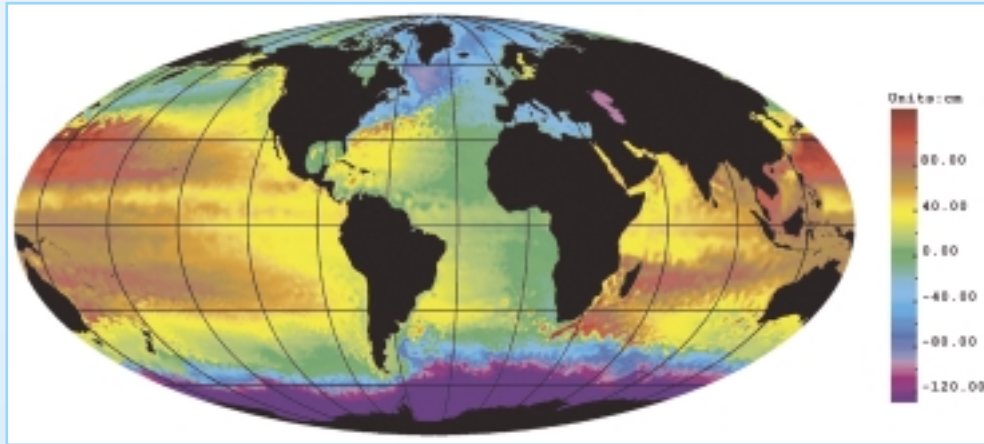
The Coordinated Enhanced Observing Period (CEOP), is a WCRP project initiated by GEWEX which aims at developing a global network of pilot joint meteorological-hydrological stations. This is associated with a unique effort to make use of the huge amounts of Earth observing satellite data available today.

Climate Variability and Predictability (CLIVAR): ongoing core project since 1995

CLIVAR is the WCRP programme that addresses climate variability and predictability with a particular focus on the role of ocean-atmosphere interactions in climate. The oceans' great heat capacity both exerts a moderating influence on seasonal and longer climate changes, and provides a mechanism for sustained oceanic influence on the atmosphere. CLIVAR builds on the successfully concluded WCRP TOGA programme that advanced our understanding of the ENSO phenomenon and laid the foundation of today's operational monitoring and predictions of seasonal climate variability. It also builds on the WCRP WOCE that collected an unprecedented comprehensive data set of the world ocean circulation, heat storage and sea level.

The African Monsoon Multidisciplinary Analysis (AMMA) project, sponsored by GEWEX and CLIVAR, is being implemented in western Africa to understand better African climate variability, its impact on water resources, food sustainability and health. The approach includes an in situ observing system built on the existing operational network, modelling activities, satellite measurements and a training programme. A multidisciplinary team of scientists as well as operational meteorologists and hydrologists from the region and from other countries are involved.





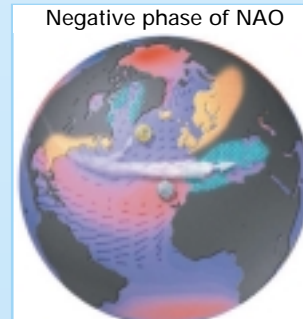
A. Coward

High-resolution models can represent most of the key features of the large-scale ocean circulation.

CLIVAR research is aimed at developing more useful predictions of climate variability and change through the use of improved climate models and observations. Its objectives are:

- (a) To describe and understand the physical processes responsible for climate variability and predictability on season, interannual, decadal and centennial timescales;
- (b) To extend the range and accuracy of seasonal to interannual climate predictions;
- (c) To build the record of climate variability through the use of instrumental and palaeoclimate data sets;
- (d) To determine the human influence on natural climate variability.

CLIVAR investigations address large-scale characteristics of the coupled climate system such as the ENSO phenomenon, monsoonal circulations in Asia, the Americas and Africa, the North Atlantic Oscillation and its link to climate in the region, and the Pacific Decadal Oscillation and its influence on climate.



L. Doherty Earth Laboratory; NOAA

An important source of climate variability over the North Atlantic region is known as the North Atlantic Oscillation (NAO). The positive phase of NAO (*left*) can lead to milder and wetter winters over northern Europe and dry conditions over the Mediterranean; opposite conditions may prevail during the negative phase (*right*).

Climate and Cryosphere (CliC): ongoing core project since 2000

The frozen water in the Earth's climate system — sea-, lake- and river-ice, snow cover, ice caps and ice sheets, glaciers, frozen ground and permafrost — significantly influences climate locally and globally. The role of ice and snow in climate are studied by CliC. This global project builds on the previous WCRP ACSYS. The principal goal of CliC is to assess and quantify the impacts that climatic variability and change have on components of the cryosphere and the consequences of these impacts for the climate system.

CliC will:

- (a) Enhance the observation and monitoring of the cryosphere and the climate of cold regions in support of process studies, model evaluation and change detection;
- (b) Improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system;
- (c) Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate change;
- (d) Facilitate assessment of changes in the cryosphere and their impact, and to use this information to aid the detection of climate change.

The project studies:

- (a) The magnitudes, patterns and rates of change in the terrestrial cryosphere on seasonal-to-century timescales and the associated changes in the water cycle;
- (b) The contribution of glaciers, ice caps and ice sheets to changes in global sea level;
- (c) The nature of changes in sea-ice distribution and mass balance in both polar regions in response to climate change and variability;
- (d) The impact of changes in the cryosphere on atmospheric and oceanic circulation and the likelihood of abrupt or critical climate and/or Earth system changes resulting from processes involving the cryosphere.

Future of sea-ice cover in the Arctic Ocean

Through innovative methods of observations in the Arctic, advances in models and creation of previously unavailable historical data sets, the foundation is being built for substantiated projections of future sea-ice cover in the Arctic. The future scenarios foresee considerably reduced multi-year ice, changes in the freshwater balance of the Arctic Ocean due to increased river run-off and accelerated melting of the Greenland ice sheet. Implications of these changes will be of global character.



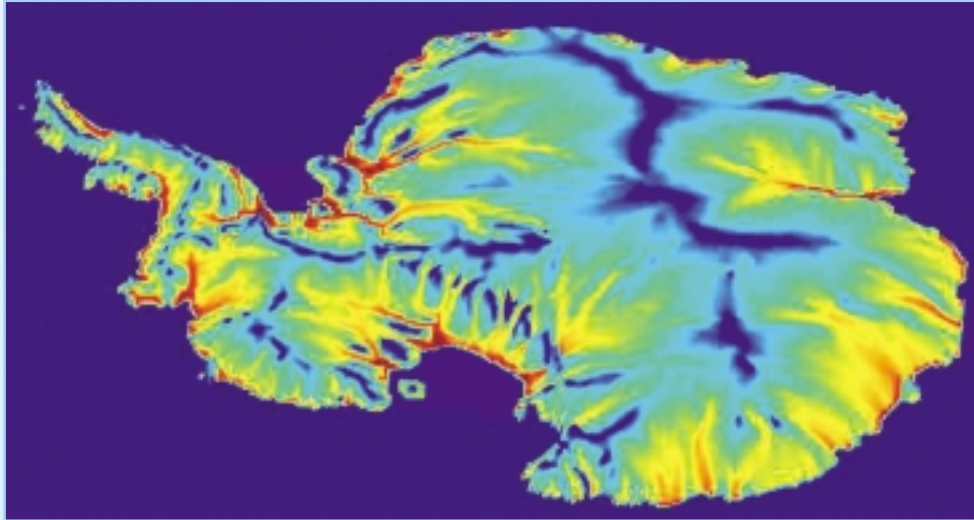
Present day



2080

Hadley Centre

A model projection of multi-year sea-ice area.



R. Warner

Complex models of ice sheet elevation are used to calculate their mass balance and contribution to mean sea level change. The image depicts simulated ice motion needed to maintain mass balance of the Antarctic ice sheet.

CLIC implementation is planned around the following areas of climate and cryosphere science:

- (a) The terrestrial cryosphere and hydrometeorology of cold regions;
- (b) Glaciers, ice caps and ice sheets, and their relation to sea level;
- (c) The marine cryosphere and its interactions with high-latitude oceans and atmosphere;
- (d) Links between the cryosphere and global climate.

Stratospheric Processes and their Role in Climate (SPARC): ongoing core project since 1992

In the stratosphere, a complex chain of interacting dynamical, radiative and chemical processes controls the atmospheric circulation and composition. Studies of the stratosphere hold the key to the understanding of formation of polar stratospheric clouds and ozone depletion, penetration of ultraviolet radiation into the troposphere, sudden stratospheric warmings, weather predictability beyond one week, etc. Some trends of atmospheric parameters in this region are yet unexplained. The SPARC project, in collaboration with the IGBP International Global Atmospheric Chemistry project, addresses these issues.

SPARC research addresses, inter alia, the following themes and associated questions:

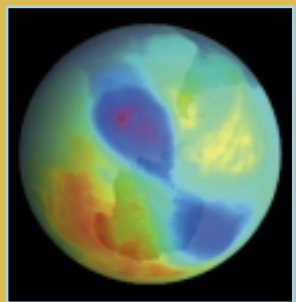
- (a) Stratosphere-troposphere coupling:
 - (i) What is the role of the stratosphere in tropospheric weather and long-term climate?
- (b) Detection, attribution and prediction of stratospheric changes:
 - (i) What are the past changes and variations in the stratosphere and what do we expect for the future?
 - (ii) How well can we explain past changes in terms of natural and anthropogenic effects?
- (c) Stratospheric chemistry and climate:
 - (i) How will stratospheric ozone and other constituents evolve and how will they affect climate?
 - (ii) What are the links between changes in stratospheric ozone, ultraviolet radiation and tropospheric chemistry?

The role of chemistry in climate change and the future of the ozone layer

In collaboration with IGBP, WCRP scientists are developing sophisticated and extensively verified climate-chemistry models. Early results demonstrate the ability to reproduce in simulations the observed changes in the ozone layer. Measurements and experiments indicate the possibility of ozone layer recovery.



Super-pressure balloons carry instruments up to the stratosphere to measure temperature and water vapour.



NASA

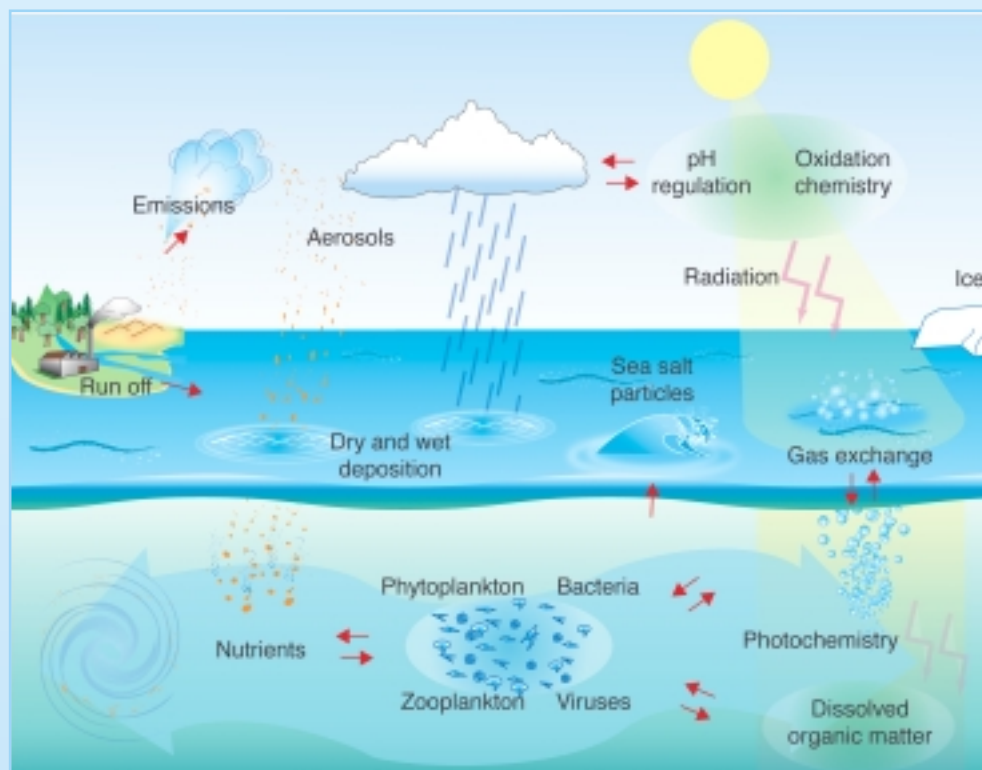
On 24 September 2002, the Antarctic ozone hole split into two holes for the first time since satellite measurements have been taken. Dark blue indicates the hole, an area with at least 20 per cent less ozone than normal.

Surface Ocean-Lower Atmosphere Study (SOLAS): a co-sponsored project since 2001

The goal of this joint project with IGBP, the Scientific Committee on Oceanic Research (SCOR), and the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Sciences (IAMAS) is to advance quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and the atmosphere and how this coupled system affects and is affected by climate and environmental change.

The aims of SOLAS are to determine:

- Biogeochemical interactions and feedbacks between the ocean and the atmosphere;
- Exchange processes at the air-sea interface and the role of transport and transformation in the atmospheric and oceanic boundary layers; and
- Air-sea flux of carbon dioxide and other long-lived radiatively-active gases.



The SOLAS domain.

WCRP: working with partners towards global sustainability

The physical climate system is inextricably linked to the biogeochemical system and to human activities. To achieve fully our goals of understanding and predicting climate variability and change, and their effect on mankind, we must study the fully integrated Earth system. To this end, WCRP is working increasingly close with IGBP, IHDP and DIVERSITAS to provide the international framework for coordination and cooperation for Earth system science and global environmental change. The four programmes have formed the Earth System Science Partnership.

Joint projects for global sustainability

Four topics of immediate social and economic relevance have been selected for the initial joint projects — global carbon, food systems, human health and water resources.

Global carbon

The global carbon joint research project is providing an integrated framework across disciplines as well as national boundaries to determine:

- (a) What are the current spatial and temporal patterns of the major sources, sinks and fluxes of global carbon?
- (b) What are the control and feedback mechanisms — both anthropogenic and natural — that determine the dynamics of the carbon cycle?
- (c) What are the dynamics of the carbon-climate-human system into the future, and what points of intervention and windows of opportunity exist for societies to manage this system?

Global environmental change and food systems

This project aims to determine strategies to cope with the impacts of global environmental change on food systems and to assess the environmental and socio-economic consequences of adaptive responses aimed at improving food security. The project will:

- (a) Investigate how global change will affect food security in different regions and among different socio-economic groups;



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- (b) Determine how different societies might adapt their food systems to cope with both global change and food demand;
- (c) Assess the environmental and socio-economic consequences of potential adaptations to food systems;
- (d) Provide information and research findings to assist policy makers decide on food systems in the context of global change.



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Global water system

This project seeks to answer the fundamental and multi-faceted question of how humans are changing the global water cycle, the associated biogeochemical cycles and the biological components of the global water system, and what are the social feedbacks arising from these changes.

Major research themes include:

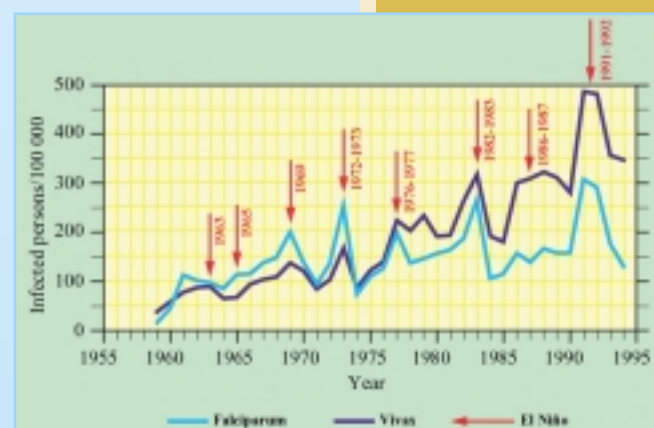
- (a) What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?
- (b) What are the main linkages and feedbacks within the Earth system arising from changes in the global water system?
- (c) How resilient and adaptable is the global water system to change, and what are sustainable water management strategies?

Human health

The goals of this project are to identify and reduce the risks to human health posed by global change and to collect systematically evidence of these health risks to minimize or avoid their impact. The project will:

- (a) Assess health impacts of global change and examine their relationship;
- (b) Develop adaptation measures and early warning systems for human health;
- (c) Develop strategies and policies to facilitate mitigation (hazard reduction or elimination) and increase the adaptive capacity of local populations;
- (d) Satisfy interdisciplinary data and modelling needs to generate a better understanding of the tradeoffs between economic development, global environmental change and human health.

Graph showing the link between malaria outbreaks in Colombia and *El Niño* events.



M. Latif

The World Climate Research Programme is supported by a small Secretariat, known as the Joint Planning Staff, hosted by the World Meteorological Organization in Geneva, Switzerland.



World Climate Research Programme (WCRP)
World Meteorological Organization
7bis, avenue de la Paix
P.O. Box 2300
1211 Geneva 2, Switzerland
Tel.: + 41 (0) 22 730 8111
Fax: + 41 (0) 22 730 8036
E-mail: dwcrp@wmo.int
Web: <http://www.wmo.ch/web/wcrp>

Additionally, each of the major WCRP projects have international offices which assist in implementing and coordinating the various WCRP research elements.



CLIC International Project Office
Tromsø, Norway
E-mail: clic@npolar.no
Web: <http://ipo.npolar.no/org/address.php>



International CLIVAR Project Office
Southampton, United Kingdom
E-mail: icpo@soc.soton.ac.uk
Web: <http://www.clivar.org>



International GEWEX Project Office
Silver Spring, Maryland, United States
E-mail: gewex@gewex.org
Web: <http://www.gewex.org/igpo.html>



SPARC Office
Toronto, Ontario, Canada
E-mail: sparc@atmosph.physics.utoronto.ca
Web: <http://www.atmosph.physics.utoronto.ca/SPARC/office.html>



SOLAS International Project Office
Norwich, Norfolk, United Kingdom
E-mail: SOLAS@uea.ac.uk
Web: <http://www.uea.ac.uk/env/solas/contact.html>