THE INTERNATIONAL COUNCIL FOR SCIENCE AND CLIMATE CHANGE: **60 YEARS OF FACILITATING CLIMATE CHANGE RESEARCH AND INFORMING POLICY**

ICSU
International Council for Science

The International Council for Science and Climate Change:
60 years of facilitating climate change research and informing policy

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INTRODUCTION

Since the 1950s, the International Council for Science (ICSU) has played a pioneering role in the development of climate science at the international level, principally by generating mechanisms to orient and complement research undertaken at the national level. In recent decades, climate science has required international collaboration among researchers on an unprecedented scale, coupled with collaboration at the intergovernmental level. ICSU's contribution has been crucial to defining the scientific issues, facilitating consensus on research priorities and convening collaborations which have underpinned the research. In parallel, ICSU has also worked tirelessly to initiate and support mechanisms for ground-breaking climate research to reach policy-makers in some cases resulting in important shifts in policy development.

This document highlights the major contributions of ICSU and its scientific community to the development of climate science, and explains how ICSU's approach to facilitating research collaboration to inform policy development has evolved over time.

CATALYSING INTERNATIONAL RESEARCH COLLABORATION: HOW IT WORKS IN PRACTICE

A key part of ICSU's mission is to plan and coordinate research, especially on issues that require cooperation among scientists from different disciplines in different parts of the world. Typically, the first step in the development of a new ICSU programme is to bring leading international scientific experts together and secure the support of appropriate institutional partners. Depending on the issue, a scoping activity may be required as a prelude to a more focused programme planning exercise. In this way ICSU, in consultation with the international scientific community, is able to define the framework for an international research programme, set the scientific priorities and establish quality benchmarks, whilst taking on board the relevant policy issues. Once a scientific framework is approved – normally involving formal endorsement by the General Assembly of ICSU, a scientific steering committee is established with appropriate representation to oversee implementation of the programme. At this stage a separate secretariat or programme office is normally set up, to support the long-term coordination and planning. In effect, ICSU develops and incubates a programme until it is mature enough to stand on its own.

While ICSU will often fund some or all of the programme incubation costs from its own resources, the cost of the actual research will be met from other sources, national as well as international. ICSU may help scientists raise funds from such sources, for example by ensuring that funding agencies are fully briefed on the objectives of the overall programme. Most importantly, ICSU maintains a long-term responsibility for ensuring the quality and strategic direction of the programme.

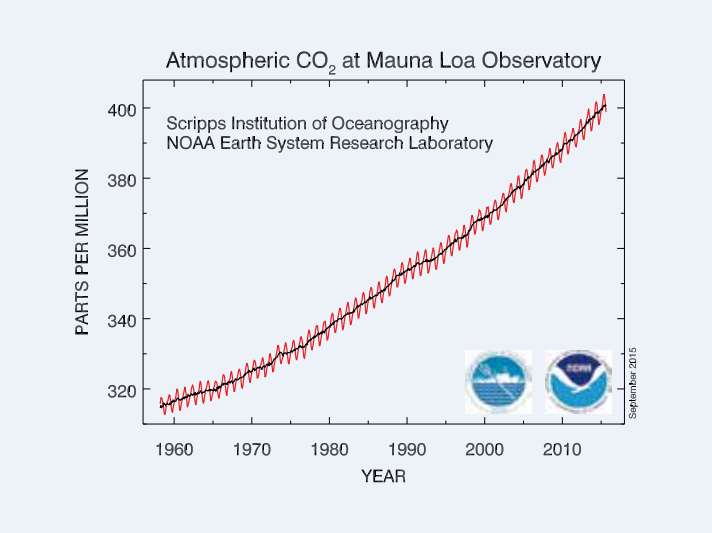
In the context of research collaboration, ICSU brings together the international scientific community, global governmental organizations and national funding agencies. Such a role is particularly valuable where a long-term scientific agenda has to be agreed. The link with intergovernmental organizations, which often takes the form of co-sponsorship of programmes, ensures that policy concerns are addressed in the research programmes and that the research outcomes are fed back into the policy-making process.

CATALYSING INTERNATIONAL CLIMATE RESEARCH TO INFORM POLICY DEVELOPMENT

Until the mid-1950s, international cooperation among scientists in diverse fields with an interest in climate was quite limited. An opportunity to scale up this cooperation emerged with the ICSU-initiated International Geophysical Year (IGY) in 1957–58, which brought together scientists from more than 60 countries to take part in a series of coordinated observations of geophysical phenomena.

While greenhouse gases were not its key priority, the IGY provided funding to initiate the systematic measurements of atmospheric carbon dioxide (CO_2). This work was carried out by Charles David Keeling at a base on Mauna Loa in Hawaii. In 1961, Keeling produced data showing that carbon dioxide levels were rising steadily on what became known as the "Keeling Curve".

Source: NOAA Earth System Research Laboratory



The International Geophysical Year was also marked by the launch of the first Earth- orbiting artificial satellite, Sputnik 1. During IGY, it became evident how important research in space, and from space, was going to be. Accordingly, to promote and coordinate space research at the international level, ICSU set up its interdisciplinary **Committee on Space Research (COSPAR)** in 1958.

Furthermore, IGY demonstrated that international scientific collaboration often does not take place in isolation from the political context. The work of the IGY led directly to the Antarctic Treaty, which called for the use of Antarctica for peaceful purposes and cooperative scientific research. The Antarctic Treaty was signed on 1 December 1959 by the twelve countries whose scientists had been active in and around Antarctica during the IGY. Since then, many other countries have signed the treaty. To maintain the momentum of Antarctic research, and ensure an advisory presence to the signatories of the Antarctic Treaty, ICSU established the **Scientific Committee on Antarctic Research (SCAR)** in 1958.

At the same time as IGY, ICSU was identifying other problems that needed a global perspective. Oceanic research was one of these, and in 1957 ICSU created the **Scientific Committee on Oceanic Research (SCOR),** focusing on the world's oceans.

All three scientific committees are still active today. While their activities go beyond climate change, their work contributes to the advancement of policy-relevant climate science.

SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH (SCOR)

SCOR was the first interdisciplinary committee formed by ICSU in 1957. Its mission is to tackle fundamental problems concerning how the ocean works. Through the coordination of international research, SCOR provides mechanisms for the global ocean science community to identify important gaps in knowledge of the ocean and to plan and implement large-scale international research projects in order to answer fundamental questions about the ocean. Such information is crucial for understanding the ocean sufficiently to transform the management of ocean systems towards sustainability of these systems. In addition to stimulating the creation of basic knowledge, SCOR-supported projects have produced summaries for policy-makers on the topics of ocean fertilization, ocean acidification, harmful algal blooms, and semi-enclosed coastal systems, all of which have proved useful in making information more accessible to policy-makers.

While SCOR's activities are broader than climate change, a number of SCOR large-scale projects and other activities have provided a major contribution to climate science, such as:

- **The Joint Global Ocean Flux Study (JGOFS), 1987–2003**: Co-sponsored by SCOR and the International Geosphere-Biosphere Programme (IGBP), JGOFS improved our understanding of the role of phytoplankton blooms and iron fertilization in the global carbon cycle. JGOFS established two long-term ocean sampling sites (still monitored regularly) that have helped document ocean acidification in the Atlantic and Pacific Oceans and major changes in phytoplankton populations in these oceans. JGOFS also carried out multinational process studies in the Atlantic, Pacific, Indian, and Southern Oceans to make it possible to compare carbon cycle processes among these basins. The improved understanding of the carbon cycle has helped climate modellers represent ocean systems better in their models that are also used in the assessments of the Intergovernmental Panel on Climate Change (IPCC).

- **The Global Ocean Ecosystem Dynamics (GLOBEC) project, 1999–2009**: Co-sponsored by SCOR, IGBP, and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), GLOBEC increased our understanding of how climate affects fish populations, useful for fisheries management worldwide.

- **The Working Group on the Role of the Agulhas Current in the Global Climate System**: a joint activity between SCOR, the International Association for the Physical Sciences of the Ocean (IAPSO) of the International Union of Geodesy and Geophysics (IUGG), and the World Climate Research Programme (WCRP) demonstrated that the Agulhas Current off the coast of South Africa has a significant influence in the global climate. The speed and volume of this circulation affects climate in various parts of the world, particularly in countries surrounding the North Atlantic Ocean.

- **The Working Group on Thermodynamics and Equation of State of Seawater** conducted jointly by SCOR and IAPSO, developed better equations on the relationships among temperature, salinity, and density of seawater, potentially reducing the variability in global climate models. The new equations have been adopted worldwide.

- **SCOR Working Group 143 on Dissolved N_2O and CH_4 Measurements** is improving the tracking of two greenhouse gases whose measurement and reporting worldwide is not standardized.

- The symposium series on the **Ocean in a High-CO_2 World** – conducted jointly with IGBP and IOC – identified ocean acidification as a major global change issue, stimulated research in this area of science, and provided an international forum for presentation and discussion of the latest research on ocean acidification and its effects on marine organisms. Two summaries for policy-makers were produced [1].

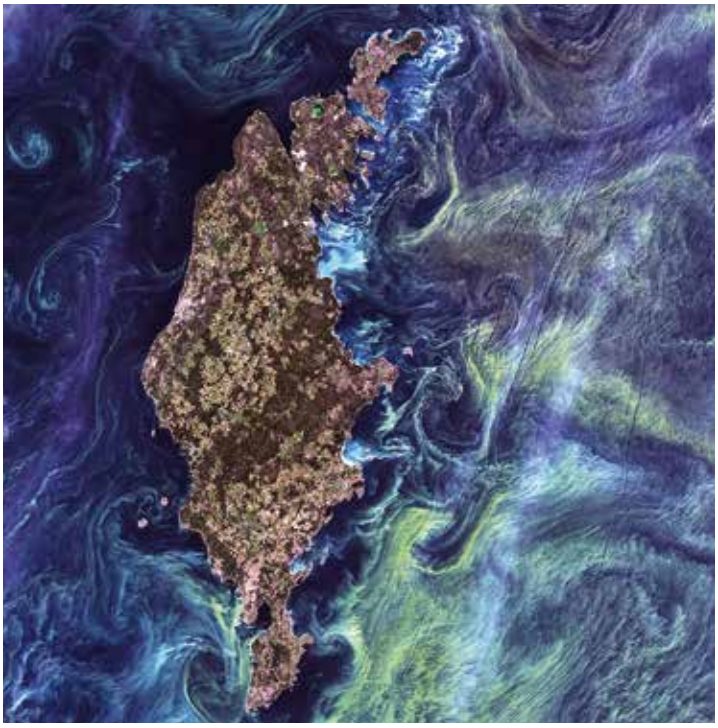
COMMITTEE ON SPACE RESEARCH (COSPAR)

COSPAR was established as an interdisciplinary scientific committee by ICSU in 1958, following the launch of Sputnik 1. From its inception COSPAR's primary goal was to *"provide the world scientific community with the means whereby it may exploit the possibilities of satellites and space probes of all kinds for scientific purposes, and exchange the resulting data on a cooperative basis."*

Over the years, COSPAR has developed various capabilities to serve the international space science community, along with either developed or developing space programmes. Among those capabilities, are the 'Roadmaps' produced in different domains with a view to exploring avenues of progress and identifying opportunities for international cooperation to develop future space programmes. Such roadmaps have been published on *"A stepwise strategy for global exploration"* (2012), *"The future of space-based astronomy"* (2013), and *"Understanding space weather to shield society"* (2014).

A new roadmap on *"Integrated Earth System Science (IESS) in the period 2015–2025"* was elaborated by the COSPAR Scientific Commission on 'Space Studies of the Earth's Surface, Meteorology and Climate', and is to be published soon.The IESS roadmap emphasizes the importance of space-based observation, together with ground-based and *in situ* observation, data assimilation and modelling, for an improved understanding of climate and climate change, and provides an assessment of the current space-based climate observing system. It identifies priorities for its continuity and innovation and encourages increased international cooperation in achieving a comprehensive climate observing system responding to society's goals in mitigating and adapting to climate change.

The IESS roadmap will be brought to the attention of all space agencies and research institutions and will also serve as an input to the US Decadal Survey on Earth Sciences, which is currently being initiated.



Congregations of greenish phytoplankton in the dark water around Gotland.
Credit: USGS/NASA/Landsat 7

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH (SCAR)

Created in 1958, SCAR is an interdisciplinary committee of ICSU charged with initiating, developing and coordinating high-quality international scientific research in the Antarctic region (including the Southern Ocean), and on the role of the Antarctic region in the Earth system. Through maintaining the impetus of Antarctic research, SCAR acts as adviser to the signatories of the Antarctic Treaty. In addition to the Antarctic Treaty Consultative Meetings, SCAR also provides independent scientific advice to other organizations such as the United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC).

SCAR's interest in climate change science has increased considerably in the last decade or so, in part as a consequence of growing concern that anthropogenic influence on the carbon cycle is becoming evident from the monitoring of the Antarctic region. In 2009, SCAR published the landmark Antarctic Climate Change and the Environment Report[2], which provides a comprehensive, up-to-date account of how the physical and biological environment of the Antarctic continent and Southern Ocean have changed from Deep Time until the present day. It also considers how the Antarctic environment may change over the next century in a world where greenhouse gas concentrations are much higher than those of the last few centuries. This report is updated yearly.

Currently, SCAR has a number of climate-related Scientific Research Programmes, among which are:

- **Antarctic Climate Change in the 21st Century (AntClim21)** aims to deliver improved regional predictions of key elements of the Antarctic atmosphere, ocean and cryosphere for the next 20 to 200 years and to understand the responses of the physical and biological systems to natural and anthropogenic forcing factors. The overarching question that the programme aims to answer is how the Antarctic environment will change over the 21st Century.
- **Past Antarctic Ice Sheet dynamics (PAIS)** aims to improve understanding of the sensitivity of East, West, and Antarctic Peninsula Ice Sheets to a broad range of climatic and oceanic conditions. The overarching goal of PAIS is to improve confidence in predictions of ice sheet and sea level response to future climate change and ocean warming.
- **Solid Earth Response and influence on Cryosphere Evolution (SERCE)** aims to advance understanding of the interactions between the solid earth and the cryosphere to better constrain ice mass balance, ice dynamics and sea-level change in a warming world. This objective will be accomplished through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment and ice sheet dynamics. The programme will contribute to IPCC Assessment Report (AR) 6.

To continue to monitor impacts of climate change, SCAR, together with SCOR, launched the Southern Ocean Observing System in 2011 with the mission to facilitate and enhance the collection and delivery of essential observations on dynamics and change of Southern Ocean systems to all international stakeholders. This is achieved through the design, advocacy and implementation of cost-effective observing and data delivery systems.

In 2014, SCAR conducted the 1st Antarctic and Southern Ocean Science Horizon Scan that identified the priorities for Antarctic research for the next 20 years – many of which tie directly to climate change and deal with the better prediction of the changing Antarctic.

Following the success of IGY, the United Nations General Assembly formally invited ICSU to work alongside the World Meteorological Organization (WMO) in developing a programme of research on atmospheric science. ICSU and WMO appointed a committee to plan a new research programme which became the **Global Atmospheric Research Programme (GARP)** in 1967. The goal was to understand the predictability of the atmosphere and extend the time range of daily weather forecasts to more than two weeks.

One of GARP's major achievements was its early recognition of the new science that could be done with satellites for continuous, global observation of the Earth and with computers for modelling global atmosphere circulation. In the 1970s, it produced several visionary collaborative experiments and results, notably the **GARP Atlantic Tropical Experiment (GATE)** in 1974. GATE delivered new insights into the ways in which tropical weather systems are organized and their links with overall tropical circulation and variations in surface temperature and other properties of the ocean. The Atlantic Tropical Experiment led to the highly successful Global Weather Experiment in 1979, involving over 140 countries, which laid the scientific foundation for redesign of WMO's operational World Weather Watch. GARP, together with several other initiatives, drove the development of the climate science agenda.

GARP ATLANTIC TROPICAL EXPERIMENT (GATE)

The Atlantic Tropical Experiment was the first major experiment of the Global Atmospheric Research programme. Its purpose was to understand the tropical atmosphere and its role in the global circulation of the atmosphere.

The experiment took place in the summer of 1974 in an experimental area that covered the tropical Atlantic Ocean from Africa to South America. The work was truly international in scope, and involved 40 research ships, 12 research aircraft, numerous buoys from 20 countries, all suitably equipped to obtain the observations specified in the scientific plan. The operations were directed by the International Project Office (IPO) located in Senegal. The IPO staff was seconded by the nations involved. The Scientific Director was from the United States and the Deputy Scientific Director from the USSR.

An operational plan was developed each day based on the meteorological situation and each ship and aircraft carried out the plan. The data collected were processed by nations participating in accordance with an overall plan and made available without restrictions to all scientists in the world. It is estimated that over a thousand scientific papers have been published based on the data collected during this short period in 1974.

The experiment involved the world's best scientists, engineers, technicians, pilots, ships' captains, logistics specialists and, computer scientists, as well as senior policy-makers from science agencies and foreign ministries in a large number of countries [3].

In 1978, ICSU, the WMO and the United Nations Environment Programme (UNEP) organized an International Workshop on Climate Issues in Laxenburg near Vienna, where the participants planned a pioneering World Climate Conference for 1979. Their mode of organization was crucial, setting a standard for many later efforts. Participation was by invitation, mostly scientists and some government officials. The conference organizers commissioned a set of review papers inspecting the state of climate science. These were circulated, discussed, and revised [4]. Then over 300 experts from more than 50 countries came to Geneva in 1979, examined the scientific evidence, confirmed the long-term significance of atmospheric CO_2 levels for global climate and called for the establishment of a climate programme in its own right.

Government representatives in WMO and the scientific leadership of ICSU heeded the advice and in 1979 launched a World Climate Programme (WCP) with various branches, including the **World Climate Research Programme** (WCRP), which was the successor to GARP. WCRP has the broad objectives of determining how far climate can be predicted and the extent of human influence on climate.

Over the decades, WCRP established a ground-breaking programme of international and interdisciplinary research that has produced some major advances in climate science. Notable achievements include establishing the physical basis for understanding and predicting El Niño events, improved climate models as the basis for research and international assessments, and comprehensive field measurements and the development of regional and global observational climatic data sets leading to improved understanding of key climate processes.

Credit: Danish Polar Centre

WORLD CLIMATE RESEARCH PROGRAMME (WCRP)

Jointly sponsored by WMO, IOC and ICSU, the WCRP serves as the international coordination centre for research on the sources, sinks and exchanges of heat, water and carbon within and across atmosphere, land, ocean and ice. WCRP researchers use a wide range of *in situ* and satellite-based observations integrated and extended through global and regional climate models. WCRP enables collaboration, organizes and facilitates observation and model intercomparisons, and stimulates collective progress, evaluation and the topical focus necessary to understand and predict our complex and changing climate. The working groups and panels of WCRP and its core projects: CliC (Climate and Cryosphere), CLIVAR (Climate and Ocean-Variability, Predictability, and Change), GEWEX (Global Energy and Water Cycle Exchanges) and SPARC (Stratosphere-troposphere Processes And their Role in Climate) provide connections, oversight and the planning necessary to sustain climate research.

WCRP, through its **Grand Challenges** – addressing sea-level rise, water availability, climate extremes, melting snow and ice, and clouds and circulation – guides and impacts the global climate research agenda. These Grand Challenges represent collective attention to urgent topics, mechanisms to engage new partners and recruit new leadership, and welcome challenges to cross disciplines and combine energy and skills.

Key WCRP achievements that advance our understanding of anthropogenic climate change include:

- **The WCRP Tropical Ocean Global Atmosphere (TOGA) programme, 1985–1994,** established cross-disciplinary approaches to climate processes, instigated a large successful multinational focused research effort in the equatorial Pacific (the Coupled Ocean-Atmosphere Response Experiment), produced the first long-term pan-Pacific ocean-atmosphere monitoring array, and stimulated scientific and public attention to the concepts of teleconnections and El Niño Southern Oscillation (ENSO).

- **Coupled Model Intercomparison Project (CMIP):** Since 1995, CMIPs have become the backbone of climate research. They have served as the basis for every IPCC Assessment Report. The open-access CMIP processes and products challenge and expand models and research, attract new partners, stimulate special efforts, issues and reports, and promote enduring institutional and international collaboration. The WCRP Coordinated Regional Climate Downscaling Experiment (CORDEX) provides similar services and benefits on regional scales.

- **The Permafrost Carbon Network** works to synthesize ongoing permafrost carbon research and data to quantify how permafrost carbon will respond to and drive climate change in the 21st Century and beyond. Since its creation, the network has produced and published the first Circum-Arctic atlas of permafrost carbon and has coordinated compilation and comparisons of permafrost carbon emission predictions up to the present day.

Furthermore, WCRP has stimulated persistent attention to climate extremes, including drought and heat waves, from early detection and description stages to reliable statistic evaluation of climate fingerprints. WCRP also maintains continuing attention to global sea level, increasingly with regional projections that integrate ocean, ice, atmosphere and coastal land processes and changes. WCRP has also compiled and shared comprehensive data sets of global water vapour, clouds, surface and top of the atmosphere radiation, and precipitation. These data sets enable a wide range of collaborative research and serve as important validation standards for satellite observations and climate models.

Hubbard Glacier 3
Credit: NPS Photo

In 1985, ICSU, together with WMO and UNEP, organized a major conference on the "Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts" in Villach (Austria). Scientists at this conference agreed that greenhouse gases could warm the earth by several degrees, with serious consequences. The group's scientific findings were summarized by the ICSU-initiated **Scientific Committee on Problems of the Environment (SCOPE)** in a seminal report "The greenhouse effect, climatic change and ecosystems". This was the first comprehensive international assessment of the environmental impact of atmospheric greenhouse gases. The SCOPE report, together with the Villach conference, was the first to state that "substantial warming" would occur as a result of a doubling of CO_2, to note that increases in CO_2 "were attributable to human activities", to recommend a variety of specific policy actions, and to urge more significant steps toward international cooperation on issues of climate change, calling for governments to recognize that future climate change could be stemmed by attention to policies concerning fossil fuel use, energy conservation and greenhouse gas emissions. The report called on governments to consider positive actions, even a "global convention" to prevent too much global warming. Climate science, in short, was no longer just a matter for scientists[5]. The SCOPE report also shaped the recommendations of the 1987 Brundtland Report "Our Common Future"[6] on action to protect the earth's climate.

The Villach conference called for ICSU, WMO, and UNEP to establish a task force on greenhouse gases and to ensure that periodic scientific assessment was undertaken. This led to creation of an **Advisory Group on Greenhouse Gases (AGGG),** appointed by ICSU/WMO/UNEP. This group organized international workshops and produced several reports on the policy implications of the emerging climate science.

AGGG can be viewed as an antecedent of the Intergovernmental Panel on Climate Change. Policy-makers were starting to understand the serious long-term implications of the scientific findings, and concluded that AGGG needed to be superseded by a new,

independent official group under the direct control of representatives appointed by each nation[7]. Responding to this request, WMO and UNEP jointly created the Intergovernmental Panel on Climate Change (IPCC) in 1988, tasked to regularly take stock of the science for government purposes and examine options for responding to human-induced climate change. Creation of the IPCC provided the institutional base for more focused, better-coordinated examination of needed science-policy interactions at the international level. Bert Bolin, who was a member of AGGG and an author of the SCOPE report, was appointed the first IPCC chairman.

Throughout the 1980s, evidence mounted that climate change was one part of a larger phenomenon - global change - requiring an even wider scientific view and building connections among geophysics, chemistry and biology. This awareness eventually led to the launch of the ICSU-sponsored **International Geosphere-Biosphere Programme (IGBP)** at the ICSU General Assembly in 1986. IGBP was created to address the Earth as a system of globally interacting phenomena, and to understand the physical, chemical and biological processes that regulate this system, changes occurring to these processes and the role of human activities in these changes.

In a sequel to the successful 1979 Conference that led to the creation of WCRP, ICSU and WMO sponsored a second World Climate Conference in Geneva in October 1990. That Conference was a further milestone in the recognition of the reality of climate change. It received the First Assessment Report from the IPCC. A key chapter on a scientific action plan for improved prediction of global climate change was co-authored by the Chairs of the WCRP and the IGBP.

The publication of the IPCC's First Assessment report in 1990 spurred governments to negotiate the United Nations Framework Convention on Climate Change (UNFCCC), which was ready for signature at the 1992 United Nations Conference on Environment and Development (UNCED) – also known as the "Earth Summit" – in Rio de Janeiro.

The IPCC Second Assessment Report of 1995 provided important material drawn on by negotiators in the run-up to the adoption of the Kyoto Protocol to the UNFCCC in 1997. WCRP and IGBP played a key role in coordinating the research that was assessed by the IPCC.

Prof. Chris Field
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Department of Global Ecology,
Member of the ICSU Committee on
Scientific Planning and Review (2012–2015)
– receiving the 2007 Nobel Peace Prize
Credit: IPCC

GLOBAL CHANGE
IGBP International Geosphere-Biosphere Programme

INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME (IGBP)

Established in 1986, IGBP addresses the interactive physical, chemical and biological processes that characterize the Earth system. The programme also seeks to understand the ways in which humans are affecting this system. IGBP contributes to new knowledge on climate change as well as many other global environmental change issues. During the past three decades IGBP, along with its international research projects, contributed to the advancement of climate science in various ways including the following:

- **Developed the concept of the Earth system.** IGBP research was critical to cementing the understanding of the Earth as an integrated system with physical, chemical and biological components. Humans were recognized explicitly as an integral component of this system – in other words, they both affect the system and are affected by changes in it. This understanding has underpinned subsequent research on human impacts on climate as well as measures to mitigate and adapt.

- Played a key role in the **development of the new approach to scenarios, the Representative Concentration Pathways (RCPs),** which became a foundation for IPCC AR5 future emissions, impacts and mitigation analysis.

- **Demonstrated that land cover can have implications for local climate extremes.** In the future, extreme heat events are expected to increase in many regions due to climate change. Understanding local and regional factors that exacerbate climate extremes is important for adaptation to and mitigation of these events. For instance, land cover was found to play a key role in the regional extent of extreme heating during the 2003–2006 European heat waves. Temperatures in grassland regions experienced higher maximum temperatures than those in forested areas, which were attributed to soil-moisture depletion in the grassland areas. Findings such as this can help in the development of appropriate local adaptation and mitigation actions to a changing climate.

- **Developed an understanding of the feedbacks between biogeophysical and societal forcings and responses.** For example, both environmental forcings and management responses were needed to understand the collapse of the cod fishery off Labrador and Newfoundland and why these stocks have not recovered while the Barents Sea cod stocks have prospered. Favourable environmental conditions combined with timely responses by fishery managers allowed the Barents Sea cod stock to recover and rebuild whereas the collapse of the cod stock off Newfoundland and Labrador was attributed to poor environmental conditions and the slow response to reduce fishing pressure.

- **Developed new knowledge of the interaction of air pollution and climate.** IGBP was strongly involved in assessing the contribution of black carbon to climate change, both globally and in specific cities such as Beijing and Shanghai. This assessment highlighted the importance of co-benefits of reducing air pollution and greenhouse gases; identified long-range transport of pollutants, such as tropospheric ozone, which is a greenhouse gas; revealed the limitations of purely national approaches to pollution control; and pointed to the need for an effective international regulatory framework for both climate and air pollution.

- **Developed the Global Carbon Budget** (as a result of the Global Carbon Project (GCP)) with annual updates that include new advances in understanding and constraining the human perturbation of the carbon cycle, the contemporary budget and past and future trends of its various emission and sink components. This includes global- and country-level emissions from the combustion of fossil fuels, land-use change, the evolution of the CO_2 sinks on land and oceans, and embedded carbon flows in international trade of products and services. The GCP annual carbon budget data is being used to inform climate policy and mitigation actions.

- **Evaluated the ecosystem impacts of geo-engineering to mitigate climate change.** This work has informed a report of the Convention on Biological Diversity (CBD).

THE GLOBAL COORDINATION OF EARTH OBSERVATIONS

In 1992, upon a recommendation by the 1990 Second World Climate Conference, the **Global Climate Observing System (GCOS)** was established by ICSU, WMO, UNEP and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

This was followed by the creation of analogous global observing systems focused on oceans (the **Global Ocean Observing System (GOOS),** 1993) and on land (the **Global Terrestrial Observing System (GTOS),** 1996), both co-sponsored by ICSU, WMO and other UN bodies.

Observations are fundamental to advancing the scientific understanding of climate and the delivery of timely, purposeful climate information to support decision-making in many sectors and the formulation of policy responses. They provide the initial data for climate models that predict seasonal and decadal phenomena, and are used to evaluate and improve the models used for long-term climate projections for different emission scenarios. Observations are also used to develop application models supporting societal needs. The outputs of these models are then used to determine and assess socio-economic impacts and inform decisions on policies for climate adaptation.

The observing systems stimulate and coordinate observations by national or international organizations; they do not perform the observations themselves. An example of this coordination is the Argo system, which is a global array of nationally deployed temperature/salinity ocean profiling floats. The observing systems also identify minimum needs for an effective international programme of measurements, and respond to requests on how to implement such programmes.

Since 2003, ICSU has been instrumental in representing the international science community in a new intergovernmental initiative to develop a **Global Earth Observation System of Systems (GEOSS).** Created by the **Group on Earth Observations (GEO),** GEOSS links Earth observation resources world-wide across multiple areas such as agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water and weather and make those resources available for better informed decision-making. ICSU's contribution to the development of GEOSS included, for example, taking the lead on identifying needs and exploring mechanisms for the collection of global socio-economic data, which are critical for research on the human dimensions of environmental change and sustainable development. ICSU interdisciplinary bodies such as the **Committee on Data for Science and Technology (CODATA)** and the **World Data System (WDS)** also contributed to GEOSS, through their involvement in the development of principles for data sharing and management for GEOSS.

GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)

Established in 1992 as an outcome of the Second World Climate Conference, the Global Climate Observing System (GCOS) is an internationally coordinated network of observing systems designed to meet evolving national and international requirements for climate observations. The goal of GCOS is to provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical, and biological properties and atmospheric, oceanic, hydrologic, cryospheric and terrestrial processes.

GCOS is sponsored by the WMO, ICSU, IOC-UNESCO and UNEP. Many observing systems, such as GOOS, the WMO Global Observing System (GOS) and Global Atmosphere Watch (GAW), and the GCOS/WCRP-sponsored Terrestrial Observation Panel for Climate, contribute to the GCOS network of global observing systems for climate. GCOS is both supported by and supports the international scientific community (e.g. WCRP), and constitutes the climate observing component of the Global Earth Observation System of Systems (GEOSS). GCOS also supports the assessment role of the IPCC and the policy development role of the UNFCCC, specifically in meeting the needs for climate system monitoring and climate change detection.

In the 1990s, to ensure the credibility of the climate record, GCOS developed the concept of **"essential climate variables" (ECVs),** which has since been broadly adopted in science and policy circles[8]. GCOS ECVs are the principal requirements for systematic observations of the climate system. They support work of its co-sponsoring organizations, of the UNFCCC, and of the IPCC. These variables are also essential to the observation and monitoring component of the Global Framework for Climate Services. GCOS also pioneered globally accepted norms in publishing a set of guidelines and principles for climate monitoring

GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

Sponsored by the IOC of UNESCO, WMO, UNEP and ICSU, the Global Ocean Observing System (GOOS) is a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions of the sea for as far ahead as possible, and the basis for forecasts of climate change. GOOS stimulates observations of the oceans from space, deep ocean, sea surface and from the coast. GOOS at the global level delivers strategic oversight, coordination, and evaluation of the sustained ocean observing system for the three themes: climate, services, and ocean health.

In 2012, to improve communications and data-sharing across the ocean observing community, the Framework for Ocean Observing was developed by a Task Team, which included GOOS representatives[9]. The Framework is organized around **"essential ocean variables" (EOVs)** of GOOS, which are fundamental measurements needed to address the current scientific and societal ocean/climate-related issues. The Framework is expected to lead to faster and better-coordinated information to support both research and societal needs; contribute to capacity building and enhancement of ocean observations in developing countries; and foster innovation and scientific discovery. Since the publication of the Framework, a growing community has been working using the same interoperable language of developing observing requirements for societal benefit.

For climate, the EOVs are coordinated with the Essential Climate Variables (ECVs) of GCOS. The adoption and use of EOVs and ECVs allows monitoring of the physics and some of the key climate-related biogeochemical cycles of the global ocean from satellite and *in situ* platforms.

Shrinking Aral Sea
Credit: NASA Earth Observatory

GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

Established in 1996, GTOS is a programme for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. Co-sponsored by FAO, ICSU, UNESCO, UNEP and WMO, GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy-makers can detect and manage global and regional environmental change. Climate change, and terrestrial carbon stocks and fluxes are among key focus areas on which GTOS concentrates.

GTOS implements its activities through technical panels and in partnership with the other observing systems (GCOS and GOOS). At least three panels are climate-related:

- **The Terrestrial Observation Panel on Climate (TOPC),** sponsored by GCOS and by WCRP, identifies measurable terrestrial properties that control the physical, biological and chemical processes affecting climate, which are themselves affected by climate change, or serve as indicators of climate change. TOPC has played an important role in establishing standards for the **terrestrial Essential Climate Variables** (ECVs) within its overall mandate of improving the understanding of the terrestrial components of the climate system, the causes of change to this system and consequences in terms of impact and adaptation. TOPC has also contributed to the definition of new ECVs for Ice Sheets, Soil Moisture and redefinition of several existing ones.

- **The Terrestrial Carbon Observation (TCO) panel** was set up to provide support for better understanding the terrestrial carbon budget and for supporting decision-makers in adopting mitigation and adaptation strategies. TCO provides information on the spatial and temporal distribution of terrestrial carbon sources and sinks through three broad categories of information (*in situ,* satellite, and terrestrial ecosystem data) from the local to the regional and global scales.

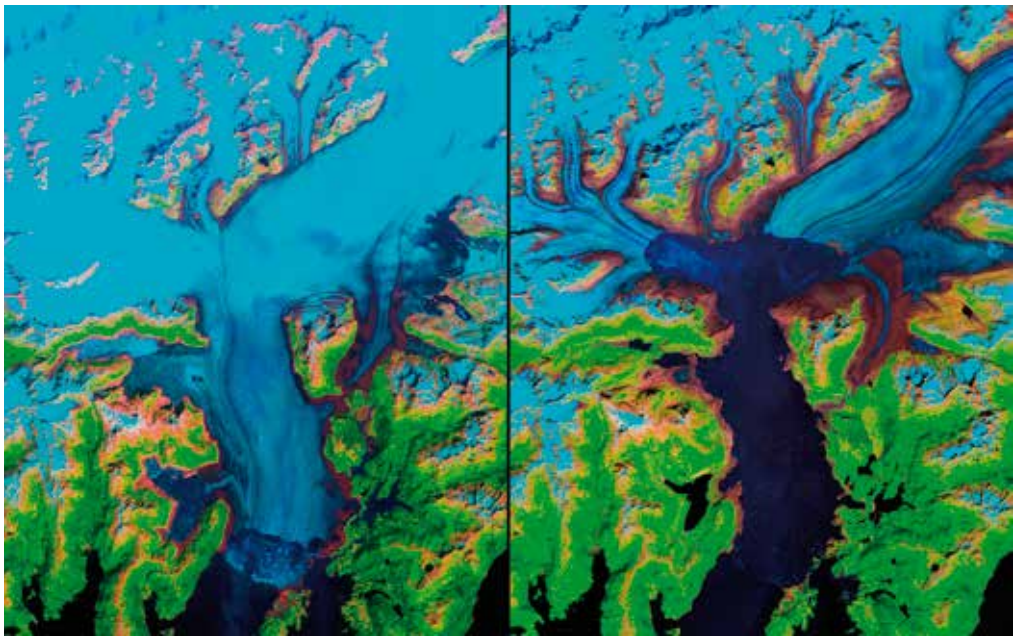
- **The Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD)** panel, was created to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. One of the key contributions of GOFC-GOLD is the development of a **technical sourcebook** on procedures for monitoring, measuring and reducing greenhouse gas (GHG) emissions from deforestation and degradation in developing countries (REDD) in support of the UNFCCC process[10].

GROUP ON EARTH OBSERVATIONS (GEO)

Established in 2005, the intergovernmental Group on Earth Observations (GEO) is a global partnership of 99 governments and 87 international, scientific and technical organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations." The GEO community is creating a Global Earth Observation System of Systems (GEOSS) that will link Earth observation resources world-wide across multiple Societal Benefit Areas - agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water and weather - and make those resources available for better informed decision-making. GEO is urging its Members to coordinate their Earth observation efforts through National GEO Offices, which would create closer collaboration among the various space, scientific and observational organisations and agencies within government.

Climate is one of nine societal benefit areas that have framed GEO's work during its first decade, with the strategic target of achieving effective and sustained global climate observations and reliable delivery of quality climate information needed to predict, mitigate and adapt to climate variability and change. The Global Climate Observing System (GCOS) described above constitutes the climate-observing component of GEOSS. Another major objective of GEO's climate work is to improve understanding of the global carbon cycle, a crucial element in identifying any solutions relating to climate change.

The next GEO Strategic Plan (2016-2025) recognizes that climate will be a cross-cutting issue of crucial importance affecting most, if not all, future societal benefit areas in GEO, such as food security and sustainable agriculture, disaster resilience, health surveillance and water management. GEO will increasingly focus on the integration of climate products and services into adaptation processes and encourage the use of this information by policy and decision-makers at all levels, thereby addressing the entire end-to-end value chain of turning observations into decisions.



Retreat of the Columbia Glacier
Credit: NASA Earth Observatory

DATA AND SCIENTIFIC INFORMATION

Increasingly scientific breakthroughs depend on an international, collective ability to create and analyse vast quantities of data. Likewise, understanding and responding to environmental and societal challenges, including climate change, depends on the ability to gather data, identify appropriate indicators, interpret them correctly and design intelligent responses.

Working with its members, ICSU is committed to ensuring the long-term stewardship, quality, integrity, availability and usefulness of scientific data and information. A number of interdisciplinary bodies and committees have evolved over time to enable ICSU to ensure this commitment. Key amongst these are the **Committee on Data for Science and Technology (CODATA),** the **World Data System (WDS),** and the **International Network for the Availability of Scientific Publications (INASP).**

COMMITTEE ON DATA FOR SCIENCE AND TECHNOLOGY (CODATA)

CODATA, is an interdisciplinary body of ICSU established in 1966. CODATA's membership includes national science and data institutions, international scientific unions and other commercial and not-for-profit, data-oriented organizations. The mission of CODATA is to strengthen international science for the benefit of society by improving the quality, reliability, management and accessibility of data of importance to all fields of science and technology. It does so by creating both a culture and a framework of standards, agreements and protocols that enable data to be shared and reused. To this end, CODATA's strategy defines three principal priorities:

- **Data Policy & Practice:** options for the national policies and actions required to support and incentivise best practice for research data.
- **Data Science:** addressing the frontiers of data science
- **Capacity building** in data science (particularly in low and middle income countries).

The availability of quality data is a *sine qua non* for transformational research that can provide a sound basis for policy. CODATA's work is driven by the conviction that the most significant research challenges - and in particular, the pressing and transdisciplinary issues relating to global sustainability - cannot be properly addressed without paying attention to issues relating to data: including policy frameworks, quality and interoperability, long-term stewardship, and the research skills, technologies, infrastructures required by increasingly data-intensive science. Three related issues are fundamental to the credibility of data analyses that purport to create reliable information:

- Ensuring analytical rigour in drawing valid inferences from data, particularly those that are integrated from widely divergent sources.
- Ensuring the replication of results: apart from the importance of detecting fraud, high standards of release of data and meta-data are vital in ways that permit scrutiny and re-use of the software code used in analysis.
- Data, meta-data and code should be intelligently open (discoverable, accessible, intelligible, assessable, re-usable) both to maximise re-use and re-combination of data and to provide the transparency that is vital if public confidence (and scrutiny) in the reliability of conclusions is to be achieved.

CODATA helps to create a framework to achieve these capabilities and an important part of that framework consists of policies for Open Data to which CODATA has made a major contribution. CODATA played a leadership role in the development of the influential *OECD Principles and Guidance for Access to Research Data from Public Funding* and in the Group on Earth Observation's *Data Sharing Principles*[11]. In turn, promoting the sharing of Earth Observation data – essential to climate change research – is regarded as one of GEO's major achievements and will be emphasized as such at the next Ministerial and Plenary in Mexico City, November 2016.

CODATA's Data Policy Committee advances this agenda by promoting effective data policy and practice. Through the Data Science Journal, a biennial conference (organized with ICSU-WDS) and the work of its Task Groups and Working Groups, CODATA addresses the frontier issues of data science, including the profound challenges and opportunities generated by 'Big Data'. CODATA's Data Science Capacity Building Initiative will help develop the skills that will help researchers, decision-makers and practitioners globally take advantage of the 'Data Revolution' to address the challenges of climate change and of global sustainability.

ICSU
WORLD DATA SYSTEM

WORLD DATA SYSTEM (WDS)

The World Data System was created by ICSU in 2008, building on a strong and proven 50+ year legacy of predecessor bodies established to ensure long-term stewardship, curation, archiving, and dissemination of data generated by the International Geophysical Year (1957–1958).

The mission of WDS is to promote long-term stewardship of, and universal and equitable access to, quality-assured scientific data and data services, products, and information and to respond efficiently to the needs of new scientific research endeavours across natural and social sciences.

As of April 2015, WDS had accredited 69 Members as trusted scientific data services using internationally recognized standards. WDS Members – holders and providers of data or data products – cover wide-ranging scientific domains and regions. They provide full and open access to their holdings and commit to support international research collaboration under the ICSU umbrella. They also form the building blocks for a common distributed, searchable and interoperable infrastructure.

Climate-related WDS Members provide direct support to and improve trustworthiness of climate research, which ultimately strengthens the policies based on it. For example, the long-standing World Data Centre for Climate collects and disseminates climate research data and is one of the Core Data Nodes archiving and disseminating the Coupled Model Intercomparison Project CMIP5 data used by the IPCC.

Similarly, Environment Climate Data Sweden was recently established to facilitate seamless sharing of scientific data and information in the fields of environment and climate. In addition, WDS Members provide many data services to the research community supporting scientific domains that are essential to enable climate research or to assess the physical, social and economic impacts of climate change.

By 2018, WDS is aiming to become the premium global multidisciplinary network for quality-assessed scientific research data and to expand to new domains such as health. It will continue to support appropriate acquisition, handling, sharing, exploitation and dissemination of scientific research data, with a particular focus on enabling global sustainability research.

Credit: Jose Xavier/ IPY IPO

THE INTERNATIONAL NETWORK FOR THE AVAILABILITY OF SCIENTIFIC PUBLICATIONS (INASP)

Established by ICSU in 1992, INASP is an international development charity working with a global network of partners to improve access, production and use of research information and knowledge in developing countries. To this end, INASP leads a number of initiatives and programmes:

- **Strengthening Research and Knowledge Systems (SRKS)** aims to increase sustainable access to and production of research literature
- **AuthorAID programme** supports early-career researchers in writing and communications skills
- **VakaYiko programme** supports the use of research and evidence in informing policy decisions
- **Discounted or free access to scientific books and journals** is provided to 67 countries across Africa, Asia and Latin America
- **Journals Online platforms** provide a global online presence for 319 journals published in seven countries in Asia and Latin America

INASP supports climate-science research across its programme areas. For instance, as part of VakaYiko programme, in 2015 INASP organized a round-table meeting about climate change science and technology and its impact on policy in Kenya. Furthermore, through publisher resources INASP provides access to more than 200 journals, conference proceedings, books and monographs on environmental issues. The AuthorAID community includes researchers working in environmental science and related disciplines.

OTHER PROGRAMMES/INITIATIVES OF ICSU AND ITS SCIENTIFIC COMMUNITY RELATED TO CLIMATE SCIENCE

In addition to the research programmes and scientific committees described above, ICSU has developed a number of other interdisciplinary bodies and committees that have contributed or contribute to the advancement of climate science and development of solutions. Among them are the Global Environmental Change (GEC) Programmes, their scientific partnership, the Earth System Science Partnership (ESSP), and Future Earth.

GLOBAL ENVIRONMENTAL CHANGE PROGRAMMES

In addition to WCRP and IGBP, ICSU co-sponsored two other major interdisciplinary programmes on global environmental change (GEC), **DIVERSITAS** and the **International Human Dimensions Programme** on Global Environmental Change **(IHDP).**

DIVERSITAS was an international research programme on biodiversity, established in 1991 by UNESCO and ICSU's Scientific Committee on Problems of the Environment (SCOPE) and the International Union of Biological Sciences (IUBS) to address the complex scientific questions posed by the loss in biodiversity and ecosystem services. While its scientific scope was broader than climate change, DIVERSITAS generated scientific knowledge on issues such as climate change impacts on biodiversity and ecosystem services, biodiversity "tipping-points" and adaptive management strategies for biodiversity in the face of climate change.

IHDP was established in 1996 by the International Social Science Council (ISSC) and ICSU to provide a better understanding of human interactions with and within their natural environments. Six out of ten IHDP research projects focused on how humans affect and are affected by climate change, with specific topics including human security, urbanization, industrial transformation and environmental governance.

As with WCRP and IGBP, DIVERSITAS and IHDP contributed to the IPCC. For instance, DIVERSITAS contributed to the work of IPCC Working Group II on "Climate Change Impacts, Adaptation and Vulnerability" and Working Group III on "Mitigation of Climate Change". In 2010, concepts and perspectives on human security of the IHDP-project Global Environmental Change and Human Security (GECHS) were integrated into the IPCC assessment report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).

To build scientific capacity on global environmental change in Africa and Asia-Pacific, the **System for Analysis, Research and Training (START)** was launched in 1992, under the aegis of ICSU and its four GEC programmes (WCRP, IGBP, IHDP and DIVERSITAS). Over the last two decades, START has advanced the understanding of climate change and other drivers of global change at local, national and regional scales in Africa and Asia-Pacific.

In 2001, the four GEC programmes issued the Amsterdam Declaration on Global Change[12] calling for a new system of global environmental science that would draw upon the disciplinary base of global change science and integrate across disciplines, environment and development, natural and social sciences, and international bounda-

ries. The declaration stressed the need for a new partnership to further advance and integrate Earth system knowledge, and as a consequence, in 2001 the **Earth System Science Partnership (ESSP)** was born.

The ESSP facilitated a number of joint research projects on food, water, carbon and health between GEC programmes and other partners. One of the ESSP projects, the Global Carbon Project, for example has done pioneering work on the global carbon cycle and the global carbon budget. The annual release of the budget and accompanying Global Carbon Atlas are now an integral and much anticipated part of the policy and media communities looking at climate change.

Another legacy of ESSP was the creation, in partnership with the CGIAR (a Global Agricultural Research Partnership), of a 10-year programme on Climate Change, Agriculture and Food Security (CCAFS). CCAFS research focuses on agriculture and food security in a changing climate and exploring new ways of helping vulnerable rural communities adjust to global changes in climate. CCAFS research was widely cited by the IPCC 5th Assessment Report on Impacts, Adaptation and Vulnerability, in particular in the chapter on 'Food security and food production systems'.

Furthermore, the ESSP and its sponsor programmes (DIVERSITAS, IGBP, IHDP and WCRP) contributed to annual "Research Dialogues" with the Parties at the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA). These dialogues provided the research community with an opportunity to provide regular science updates to major science-policy processes on climate change.

TRANSITION INTO "FUTURE EARTH"

A 2008 review of the ESSP recommended stronger engagement with policy and development, greater scientific focus and more resources, a greater commitment to an integrated approach to global environmental change and governance options that included a consolidated secretariat or a fusion of the GEC programmes [13]. Subsequent reviews of individual GEC programmes confirmed the need for change. To explore options for a holistic strategy for earth system research, ICSU and ISSC initiated an Earth System Visioning process in 2009. This process called for both disciplinary and interdisciplinary research, and new partnerships between researchers, research funders and users to coordinate and co-design research [14]. The need for a coordinated scientific and societal response to global environmental change was highlighted at the 2012 "Planet under Pressure" conference organized by the GEC programmes. The conference declaration called for a new approach to research that would be more integrative, international and solutions-oriented; reaching across existing research programmes and disciplines, north and south, and with input from governments, civil society, local knowledge, research funders and the private sector. This call was echoed in the Rio+20 declaration and the United Nations Secretary-General's High-Level Panel on Global Sustainability report, with the latter calling for a major global scientific initiative to strengthen the interface between policy and science [15].

As a response to these calls, ICSU together with other partners (the International Social Science Council (ISSC), the Belmont Forum of funding agencies, UNESCO, UNEP, the United Nations University (UNU), and WMO as an observer) established a new 10-year research programme on global sustainability – **Future Earth.** Other organizations have joined the international partnership since the launch of Future Earth, including the Sustainable Development Solutions Network (SDSN).

Launched in 2012, Future Earth provides the critical knowledge required for societies to face the challenges posed by global environmental change and to identify opportunities for a transition to global sustainability. Bringing together IGBP, IHDP, DIVERSITAS,

Irrawaddy Delta, Burma. Credit: NASA

ESSP* and in partnership with WCRP, Future Earth is an international initiative to coordinate new, interdisciplinary approaches to research on three themes: Dynamic Planet, Global Sustainable Development and Transformations towards Sustainability. It aims to be a platform for international engagement to ensure that knowledge is generated in partnership with society and users of science.

In its 2025 Vision [16] and the Strategic Research Agenda 2014 [17], Future Earth identifies climate change as one of the key global sustainability challenges and related research priorities that it intends to address in the coming years.

Programme on Ecosystem Change and Society

Among Future Earth's projects is the **Programme on Ecosystem Change and Society (PECS)** which was established in 2008 by ICSU and UNESCO to foster coordinated research on the dynamics of social-ecological systems. PECS aims to integrate research on the stewardship of social-ecological systems, the services they generate, and relationships among natural capital, human wellbeing, livelihoods, inequality and poverty. PECS research is explicitly transdisciplinary. The near-unique contribution of PECS to the global change research community is its strong emphasis on transformation: on futures quite unlike the present, and how they might be reached.

* IHDP, DIVERSITAS and ESSP with their projects have already transitioned into Future Earth. IGBP will transition into the new programme by the end of 2015.

OTHER ICSU CO-SPONSORED RESEARCH PROGRAMMES AND INITIATIVES INCLUDE:

The **Integrated Research on Disaster Risk (IRDR)** programme was established in 2008 by ICSU, with the ISSC and the United Nations Office for Disaster Risk Reduction (UNISDR) joining ICSU as co-sponsors in 2008 and 2009 respectively. IRDR is a decade-long global, transdisciplinary and cross-sectoral research programme on disaster risk reduction and resilience building. Research and capacity building activities under IRDR address major challenges of natural and human-induced environmental hazards and seek to curb disaster losses through better use of science. IRDR scientists were involved in the development of the IPCC assessment report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).

In the lead-up to the third World Conference on Disaster Risk Reduction in 2015, the IRDR programme, together with ICSU and other partners, worked to ensure a strong role for science in the Sendai Framework for Action 2015–2030. The new framework calls for science to support the understanding of disaster risk and promote risk-informed decisions and risk sensitive planning from the local to the global levels. The Sendai Framework also calls for an enhancement of the Scientific and Technical Advisory Group (STAG) as a mechanism to scale up the mobilisation of science for disaster risk reduction. ICSU and IRDR are co-organizers of the UNISDR Science and Technology Conference on the implementation of the Sendai Framework, which will take place in January 2016, in Geneva, Switzerland.

The International Polar Year (IPY) 2007–2008, sponsored by ICSU and WMO, was an unprecedented two-year programme of international science, education, and outreach focused on the Arctic and the Antarctic. It was the largest coordinated research project ever undertaken on the Arctic and Antarctic regions, bringing some 50 000 participants from more than 60 countries in the 228 international IPY projects. It yielded large amounts of information which will shape our understanding of the polar regions, global oceans and climate change for decades to come, and is a perfect example of ICSU's role in planning and promoting international science programmes.

It created critical momentum in the form of new funding for polar research and monitoring programmes, new observational and forecast technologies. It helped consolidate a trans-disciplinary approach that includes biology, human health, social sciences and the humanities, in addition to meteorology, glaciology, oceanography, geophysics, geology, and other traditional polar research fields. Hundreds of publications, a long list of special issues, and at least two monograph series provide access to a broad range of still-emerging IPY science. Several activities as varied as the international sea ice prediction network and the Earth System Science Data journal extend the impact of the IPY.

The IPY represented one of the largest coordinated efforts in science outreach and communication in the modern days. The IPY education and outreach effort catalysed global attention to polar issues from journalists, artists, teachers, students and the general public. ICSU sponsored the development of a systematic and thorough report, on-line data base, and summary assessment of many of these activities as inspiration and guide for future programmes [18].

The IPY also stimulated and supported the development of an early career scientist network, the Association of Polar Early Career Scientists (APECS), which during and since the IPY set and achieved high standards for interdisciplinary and international inclusivity, for novel administrative and leadership practices suited to early career scientists, and for support of scientists in their multiple roles as researchers and communicators.

All the findings and achievements of the IPY are summarized in the report, "Understanding Earth's Polar Challenges"[19], which was compiled by some 300 authors and reviewers.

ICSU was also a co-organizer of the international IPY conference "From Knowledge to Action" in Montreal in 2012 that advanced polar science for policy. This conference was one of the largest and most important scientific conferences for polar science and climate change, impacts and adaptation. At this meeting Yuan Tseh Lee, ICSU President at that time, declared IPY a "triumph of global science".

Prof. Lee, ICSU President (2011–2014), at the "From Knowledge to Action" conference
Credit: IPY

Health and Wellbeing in the Changing Urban Environment: a Systems Analysis Approach was established by ICSU in 2011, with the United Nations University (UNU) and the InterAcademy Medical Panel (IAMP) joining as co-sponsors in 2014. The programme seeks to inform city planning, policies and design with science-based strategies to improve the health of billions of people living in fast-growing urban areas. Using systems analysis modelling methodology, it will identify and help manage the unintended health consequences of urban policy and the connections between cities and global change. Climate-related challenges that the programme is tackling include health problems in low coastal zones and small islands affected by rising sea level; risks of mortality and diseases due to heat waves; malnutrition due to crop failure; impacts of life style changes in the urban environment on health; and effects of El Niño and ENSO on infectious diseases epidemics.

FUTURE DIRECTIONS OF CLIMATE SCIENCE: PERSPECTIVES OF THE ICSU SCIENTIFIC COMMUNITY

The leadership of ICSU's co-sponsored programmes* and leading figures from the international science/policy community and the French government met in 2015 on the sidelines of the "Our Common Future Under Climate Change" conference in Paris to discuss opportunities for the scientific community to play a role in the transition to a low-carbon future.

Participants acknowledged that the next frontier is to work across scientific disciplines, including in the social and economic sciences, in order to ensure that broader climate and development goals are met. The science system alone cannot be the driver of the transformation to a low-carbon future. Large-scale collaboration and co-design and co-production of knowledge with non-science actors such as the private sector, governments and civil society are required. Within those partnerships, science has a valuable role to play by identifying potential sustainable futures and innovations at different spatial and time scales, by designing and assessing relevant and coherent solutions, policies and measures.

Looking ahead, participants highlighted areas for future focus. These include:

- translating the goal of limiting global warming to 2°C to clear and tangible objectives;
- exploring a range of pathways combining climate change mitigation and adaptation;
- assessing the potential for evidence-based solutions;
- understanding effective ways of using the remaining carbon budget to ensure well-being;
- improving understanding of the cost of inaction; and
- public engagement to frame climate change as an opportunity rather than a burden.

Furthermore, understanding the implications of the data revolution is key, as is sustaining the capability to observe changes across the Earth system to discover unknown relationships. It is clear that long-term space observations, ground-based monitoring and information-processing and data management capabilities need to be expanded to provide better global coverage. Observing networks, high-performance computing, Earth-system models, theoretical frameworks, data-management systems and research infrastructure need to be enhanced to track human dimensions and societal changes. New approaches to observation such as use of smaller satellites, constellations, small unmanned aerial vehicles, drones, balloons, and even smart phones should also be explored. Bringing together large volumes of diverse data will require data sharing policies.

The leadership of the ICSU co-sponsored initiatives expressed its commitment to address the future challenges, emphasizing the need for enhanced international cooperation across the programmes to improve our capacity to deal with future climate and environmental changes.

* These include: WCRP, Future Earth, IGBP, GCOS, GOOS, GEO, COSPAR, SCOR, IRDR, Urban Health and Well-being Programme, CODATA, WDS, and INASP

SCIENCE/POLICY INTERFACE

Since the 1980s, ICSU has been engaged in ground-breaking work at the science/policy interface, ensuring that the emerging understanding of the effects of greenhouse gases had an impact on national and international policymaking, eventually via the creation of the IPCC and adoption of the UNFCCC. ICSU, its interdisciplinary bodies and associated scientific networks have provided major scientific contributions to all the IPCC assessments and informed the UNFCCC policy processes from the outset.

In 2015, Paris will host the 21st Conference of the Parties to the UNFCCC (COP21), at which governments are expected to adopt a global agreement to curb greenhouse gas emissions beyond 2020. Climate change is also a cross-cutting issue of two other major UN processes of 2015 – the Sendai Framework for Disaster Risk Reduction and the Post-2015 Development Agenda with the Sustainable Development Goals (SDGs). ICSU has made sustained efforts to integrate science into these policy processes. For instance, ICSU, together with its programmes, has worked since 2012 to ensure that scientific advice and expertise were available to the Open Working Group tasked with developing the SDGs. This has been a long and complicated process of consultation with civil society, whereby ICSU led the Science and Technology Major Group throughout. ICSU provided its input through expert group meetings, papers on the SDGs and via an important report which provided an independent scientific analysis of the targets under the 17 goals [20].

ICSU President Gordon McBean speaking at the conference "Our Common Future Under Climate Change"

On 7–10 July 2015, ICSU was a co-organizer of a major international science conference "Our Common Future Under Climate Change" in Paris. The conference explored all dimensions of the climate change challenge and the range of mitigation and adaptation options that can lead to sustainable, equitable solutions across nations and regions. More than 2,000 scientists from almost 100 countries took part, making it the biggest forum for the scientific community ahead of COP21.

The conference issued an outcome statement [21] in which science offers robust foundations for ambitious outcomes at COP21 and beyond:

> *"Solving the challenge of climate change requires ambition, dedication and leadership from governments, the private sector, and civil society, in addition to the scientific community. We in the scientific community are thoroughly committed to understanding all dimensions of the challenge, aligning the research agenda with options for solutions, informing the public, and supporting the policy process."*

Climate science has, in recent decades, required international collaboration among researchers on an unprecedented scale, coupled with collaboration at the intergovernmental level. ICSU's contribution has been crucial to defining the scientific issues that need to be addressed, achieving consensus on research priorities and facilitating the various collaborations that have underpinned the research.

Now more than ever, international research collaboration around these issues remains crucial to solving the challenges ahead. The International Council for Science will continue to play its role to support and convene the scientific community to work together in creating the structures necessary to advance climate research in the 21st Century.

LIST OF ACRONYMS

AGGG – Advisory Group on Greenhouse Gases
ANTCLIM21 – Antarctic Climate Change in the 21st Century
AR – Assessment Report
CBD – Convention on Biological Diversity
CCAFS – Climate Change, Agriculture and Food Security
CGIAR – A Global Agricultural Research Partnership
CMIP – Coupled Model Intercomparison Project
CODATA – Committee on Data for Science and Technology
COP – Conference of the Parties
COSPAR – Committee on Space Research
ECVS – Essential climate variables
ENSO – El Niño Southern Oscillation
EOVS – Essential ocean variables
ESSP – Earth Systems Science Partnership
GARP – Global Atmospheric Research Programme
GATE – GARP Atlantic Tropical Experiment
GAW – Global Atmosphere Watch
GCOS – Global Climate Observing System
GCP – Global Carbon Project
GECHS – Global Environmental Change and Human Security
GEO – Group on Earth Observations
GEOSS – Global Earth Observation System of Systems
GHG – Greenhouse gas
GLOBEC – Global Ocean Ecosystem Dynamics project
GOFC-GOLD – Global Observation of Forest and Land Cover Dynamics panel
GOOS – Global Ocean Observing System
GOS – Global Observing System
GTOS – Global Terrestrial Observing System
IAMP – InterAcademy Medical Panel
IAPSO – International Association for the Physical Sciences of the Ocean (of the International Union of Geodesy and Geophysics, IUGG)
ICSU – International Council for Science
IESS – Integrated Earth System Science
IGBP – International Geosphere-Biosphere Programme
IGY – International Geophysical Year
IHDP – International Human Dimensions Programme on Global Environmental Change
INASP – International Network for the Availability of Scientific Publications
IOC – Intergovernmental Oceanographic Commission (of UNESCO)
IPCC – Intergovernmental Panel on Climate Change
IPY – International Polar Year
IRDR – Integrated Research on Disaster Risk

ISSC – International Social Science Council
IUBS – International Union of Biological Sciences
JGOFS – Joint Global Ocean Flux Study
PAIS – Past Antarctic Ice Sheet dynamics
PECS – Programme on Ecosystem Change and Society
REDD – Reducing GHG emissions from deforestation and degradation in developing countries
RCPS – Representative Concentration Pathways
SBSTA – Subsidiary Body for Scientific and Technological Advice
SCAR – Scientific Committee on Antarctic Research
SCOPE – Scientific Committee on Problems of the Environment
SCOR – Scientific Committee on Oceanic Research
SDGS – Sustainable Development Goals
SDSN – Sustainable Development Solutions Network
SRKS – Strengthening Research and Knowledge Systems
START – System for Analysis, Research and Training
TCO – Terrestrial Carbon Observation panel
TOGA – Tropical Ocean Global Atmosphere programme
TOPC – Terrestrial Observation Panel on Climate
UN – United Nations
UNCCD – UN Convention to Combat Desertification
UNCED – United Nations Conference on Environment and Development
UNEP – United Nations Environment Programme
UNESCO – United Nations Educational, Scientific and Cultural Organization
UNFCCC – United Nations Framework Convention on Climate Change
UNISDR – United Nations International Strategy for Disaster Reduction
UNU – United Nations University
WCP – World Climate Programme
WCRP – World Climate Research Programme
WDS – World Data System
WMO – World Meteorological Organization

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