The GCOS at 20 years: the origin, achievement and future development of the Global Climate Observing System

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Introduction

Scientists concerned with climate variability and change have, from the very beginning, recognized the importance of observations to our understanding of the atmosphere and the application of atmospheric science to human affairs. Without accurate, high-quality observations on all time and space scales, climate science and services could make only limited progress. Systematic international coordination of weather and climate observations began around the middle of the nineteenth century, and advanced rapidly in the 1960s and 1970s as the advent of digital computers and Earth-observing satellites inspired the establishment of the operational World Weather Watch and the Global Atmospheric Research Programme. But the really great step forward came in the 1980s with the realization that understanding and predicting climate would require the involvement of a much wider set of scientific communities and comprehensive observation of the entire atmosphere-ocean-land climate system. This inspired the vision for an integrated Global Climate Observing System (GCOS).

The GCOS was formally established in 1992 as an international, interagency, interdisciplinary framework for meeting the full range of national and international needs for climate observations. Its goal 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. It is co-sponsored by three United Nations System organizations, under the leadership of the World Meteorological Organization (WMO), and the non-governmental International Council for Science (ICSU), and it consists mainly of the climate-relevant components of their established global observing systems for the atmosphere, ocean and land. It serves as the climate component of the Global Earth Observation System of Systems (GEOSS) and supports all components of the World Climate Programme (WCP), the Global Framework for Climate Services (GFCS), the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC).

The purpose, objectives, concept of operation, governance and financial arrangements for GCOS are set out in a Memorandum of Understanding (MOU) amongst its sponsors. The MOU originally provided for a Joint Scientific and Technical Committee (JSTC), which was replaced in 1998 by a Steering Committee (SC), to formulate the overall concept and scope of the GCOS and to provide scientific and technical guidance to sponsoring and participating organizations and agencies for its planning, implementation and further development. The initial GCOS Plan was completed in 1995 and its further planning and implementation have proceeded, under the guidance of expert domain-based observing-system panels for the atmosphere, ocean and land, through the sponsors' established observing system coordination mechanisms as well as through the various national operational and research observing agencies of their member countries. Following a comprehensive assessment of the observational needs of Parties to the UNFCCC, a specific Convention-focused 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC' was finalized in 2004 and updated in 2010, and a series of Regional Action Plans (RAPs) for GCOS implementation for ten separate groups of developing countries was prepared over the period 2001–2006. The 2009 Third World Climate Conference (WCC-3) identified the GCOS as an essential element of the new GFCS and its further development in support of climate services worldwide is an important focus of the GFCS Implementation Plan called for by the May 2011 World Meteorological Congress.

Much has been achieved, over the past 20 years, through the establishment of the GCOS and its support for the WCP, the IPCC and the UNFCCC. But the need for reliable climate observations has grown rapidly. Climate observing networks in most parts of the world remain inadequate for meeting important current needs for climate information and they fall far short of what will be required over the coming decades to support a scientifically-sound response to the adaptation and mitigation challenges of human-induced climate change.

As successive Chairs of the GCOS JSTC/SC over the past 20 years, we consider it timely to remind the international climate community of the origin and early planning of the GCOS, to identify a few of the highlights and lessons learned from its early years, and to offer some views on its future development.

In the available space, we can tell only a very brief version of the GCOS story and must therefore refer interested readers to the extensive series of GCOS publications for the full picture. We include a short glossary at the end to facilitate navigation through the sea of acronyms that link the GCOS with the wider worlds of Earth observation and climate.

Origin of the GCOS

The design of the WMO World Weather Watch (WWW) and the WMO-ICSU Global Atmospheric Research Programme (GARP) in the 1960s and 1970s had envisaged an operational- and research-based observing system that would meet the need for

observations for 'climate' as well as for 'weather' purposes. During the 1980s, though, it became clear that the emerging challenges of human-induced climate change would require a more climate-focused and better integrated observing system than could be provided solely by the WWW Global Observing System (GOS) for traditional atmospheric climate variables and the WMO Global Atmosphere Watch (GAW) for atmospheric chemistry (Davies, 1990). The early years of the World Climate Research Programme (WCRP) provided compelling evidence of the need for an integrated cross-domain (atmosphere-ocean-land) observing system as a basis for monitoring, understanding, and eventually predicting, both the natural variability of, and the human influence on, the global climate system. In the final chapter ('Narrowing the uncertainties') of the Working Group I (climate science) component of the IPCC's First Assessment Report, the Chairs of the Joint Scientific Committee (JSC) for the WCRP and the Scientific Committee for the International Geosphere-Biosphere Programme (IGBP) called for development of a comprehensive Global Earth Observing System and, in particular, for improvement of the global atmosphere and land surfaces observing system, and development of a global ocean- and ice-observing system (McBean and McCarthy, 1990).

The 1990 Second World Climate Conference (Figure 1) undertook a comprehensive review of the IPCC findings. The need for a greatly improved global observing system for climate featured strongly in both formal and informal discussions at the Conference. The Conference Statement (Jäger and Ferguson, 1991) concluded, *inter alia*, that *Present observational systems for monitoring the climate system are inadequate for operational and research purposes. They are deteriorating in both industrialized and developing regions*. It went on to assert that *There is an urgent need to create a Global Climate Observing System (GCOS) built upon the World Weather Watch Global Observing System and the Integrated Global Ocean Service System and including both space-based and surface-based observing components*… The Statement then elaborated the needs to be met through the proposed system and concluded that *The further development and implementation of the GCOS concept should be pursued, with urgency, by scientists, governments and international organizations.*

Figure 1. The origin of the GCOS. The Secretary General of the WMO, Professor G O P Obasi, addresses the opening of the Ministerial sessions of the Second World Climate Conference in the Palais des Nations in Geneva on 6 November 1990 following six days of scientific and technical sessions which prepared a Conference Statement calling, inter alia, for the establishment of a GCOS. Behind Professor Obasi are, from left to right: The Hon E Fenech-Adami, Prime Minister of Malta; the Hon M Thatcher, Prime Minister of the United Kingdom; HM King Hussein I of Jordan; Federal Councillor A Kőller, President of the Swiss Confederation; Mr M Rocard, Prime Minister of France, and the Rt Hon B Paeniu, Prime Minister of Tuvalu. (Source: WMO.)

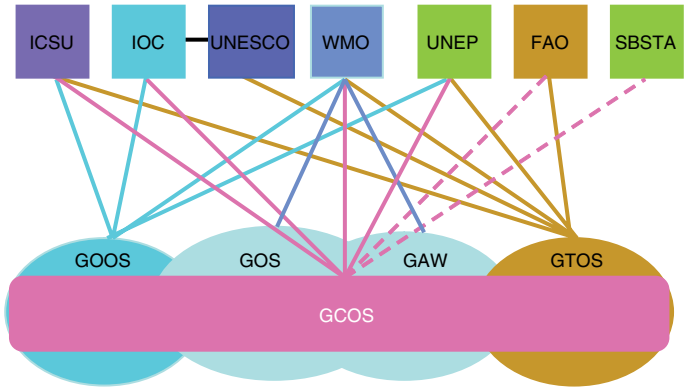

Figure 2. The co-sponsorship of the GCOS and the main domain-based observing systems (Global Ocean Observing System (GOOS) for the ocean, Global Observing System (GOS) and Global Atmosphere Watch (GAW) for the atmosphere, and Global Terrestrial Observing System (GTOS) for the land) on which it was built by the various UN System bodies (WMO, UNESCO and its IOC, UNEP and FAO (Food and Agriculture Organization of the United Nations)) and the non-governmental ICSU. The broken lines indicate GCOS' subsequent special relationship with the FAO (by virtue of FAO's lead sponsorship of the GTOS) and the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA).

In response to the exhortation of the Second World Climate Conference, the JSC Chairman (Dr Gordon McBean) convened, and the UK Meteorological Office hosted, a meeting of an *ad hoc* group of 27 observing system experts at Winchester in January 1991 to elaborate a specific proposal for establishment of the GCOS. The proposal (Winchester Group, 1991) built directly on the GCOS concept as spelled out in the Conference Statement, set out the objectives of the GCOS, reviewed and assessed the needs and building blocks, presented an early version of what was to become the GCOS logo, and suggested appropriate international arrangements for its implementation. The Winchester proposal was immediately submitted for approval by the 1991 sessions of the governing bodies of the proposed GCOS sponsors, *viz*

- the World Meteorological Organization (WMO);
- the Intergovernmental Oceanographic Commission (IOC) of UNESCO;
- the United Nations Environment Programme (UNEP) and
- the International Council for Science (ICSU).

Following approval of the concept by all four sponsors, the essential charter of the GCOS, including the governance and financial arrangements for its implementation, were incorporated in an inter-agency MOU. This established the JSTC and a Joint Planning Office (JPO) under a WMO-staffed position of Director. The GCOS thus formally came into existence as a global system of climate-relevant observing systems and as a joint WMO-IOC-UNEP-ICSU international programme (Figure 2), with a jointly-funded professional secretariat located in the WMO Headquarters in Geneva, on the day of the final signature of the MOU on 9 April 1992.

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Concept of the GCOS

The basic concept of the GCOS, as set down in the 1992 MOU in terms of its goal, objectives and design philosophy, and refined and elaborated over the years, can be summarized schematically as shown in Figure 3. The original MOU identified the objectives of the GCOS as support for all aspects of the World Climate Programme and relevant aspects of other climate-related global programmes (subsequently elaborated to include the IGBP and other Earth System Science Partnership (ESSP) programmes, the assessment role of the IPCC and the policy development role of the UNFCCC) and, specifically, as meeting the needs for:

- climate system monitoring, climate change detection, and monitoring the impacts of and the response to climate change, especially in terrestrial ecosystems and mean sea-level;
- data for application to national economic development, and
- research towards improved understanding, modelling and prediction of the climate system.

The GCOS plan

With the MOU signed, the initial membership of the JSTC appointed and the inaugural JPO Director (US oceanographer, Dr Tom Spence) in place, work began on preparation of a plan for the GCOS. The first session of the JSTC in April 1992 initiated the preparation of a skeleton plan for consideration at its second session through a series of task groups dealing with atmospheric processes, atmospheric chemistry and land-surface processes. For the ocean, it relied on the already existing IOC Ocean Observing System Development Panel (OOSDP). It also commissioned papers on cryospheric observation, space-based observation, the proposed GTOS and the World Weather Watch.

The first draft plan was reviewed at the second session of the JSTC in January 1993 and a revised draft submitted to the April 1993 Intergovernmental Meeting on the World Climate Programme, which established the international 'Climate Agenda' with 'Dedicated Observations of the Climate System' as one of its four thrusts (WMO, 1993). After further review and work by the JSTC's expert panels (below), the plan (GCOS, 1995) was issued in May 1995 as the 'Plan for the Global Climate Observing System (GCOS)' and soon became known as 'The GCOS Plan'. It was a comprehensive 12-chapter document centred around a 'GCOS strategy' built on nine 'guiding principles' and three 'specific strategic objectives'. It elaborated the concept of an 'Initial Operational System' (for the period 1995–2005) based mainly on enhancement of the established and proposed domain-based global observing systems to address the identified special needs for climate.

In its outline of 'The next steps' towards realization of the GCOS concept, the Plan stressed the vital role of individual countries in implementation action over the next few years. It assigned international implementation responsibilities for the atmospheric, oceanic and terrestrial domains, pointed out that space-based components of the GCOS would be implemented by national space agencies with international coordination by the informal Committee on Earth Observation Satellites (CEOS) and indicated that GCOS data management would be implemented primarily through existing programmes of the sponsoring agencies.

The GCOS Plan was endorsed by the sponsors and referred to their various specialized subsidiary mechanisms for implementation. Many international and national organizations took up the challenge of GCOS implementation, often in conjunction with implementation planning for the similarly co-sponsored GOOS and GTOS (cf Figure 2). For the atmospheric domain, the initial response to the GCOS Plan focused on identification of climate baseline subsets of the surface and upper air networks of the WMO GOS, which subsequently became known as the GCOS Surface Network (GSN) and GCOS Upper Air Network (GUAN) respectively. Work began on the preparation of an overall 'Implementation Plan' for GCOS to ensure a coordinated response to the 1995 GCOS Plan but, around that time (1996–1997), the GCOS, GOS, GAW, GOOS and GTOS sponsors became involved in efforts, led by the space community, to establish a broader international coordination framework for Earth observation. This eventually took shape as the IGOS (Integrated Global Observing Strategy) Partnership (IGOS-P) which served as the main inter-programme and inter-agency coordination mechanism (Chuvieco, 2008) until its integration into the GEO (Group on Earth Observations) process a decade later.

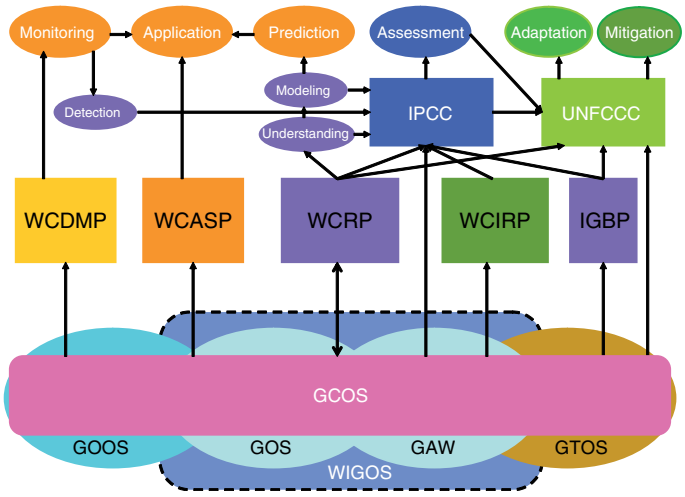

Figure 3. A schematic representation of the concept of the GCOS as a system of climate-relevant components of established and proposed global observing systems for the ocean (GOOS), atmosphere (GOS and GAW, recently brought together with other WMO observing systems as the WMO Integrated Global Observing System (WIGOS)) and land (GTOS) supporting all components of the World Climate Programme (shown in terms of its structure from 1991 to 2011 as consisting of the World Climate Data and Monitoring Programme (WCDMP), World Climate Applications and Services Programme (WCASP), World Climate Research Programme (WCRP) and World Climate Impacts and Response Strategies Programme (WCIRP)), the International Geosphere-Biosphere Programme (IGBP), the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC) in meeting the observational needs for climate monitoring and climate change detection, application to national economic development, climate prediction, climate change (including impacts) assessment and the adaptation and mitigation response to human-induced climate change.

Political support

Although the GCOS and UNFCCC were both formally products of the Second World Climate Conference response to the First Assessment Report of the IPCC, and Article 5 of the Convention included specific national obligations in respect of 'research and systematic observation', the early attention of the UNFCCC Conference of the Parties (COP) was directed almost entirely at emission reduction (mitigation) issues that eventually became the focus of the 1997 Kyoto Protocol to the Convention. There was little attention, in the early years, to Parties' commitments in respect of research and systematic observation.

Serious concern was, however, developing in the climate science community that the additional resources that were needed for GCOS implementation had not emerged from the 1993 Intergovernmental Meeting on the WCP or the 'Climate Agenda' which it had initiated. Indeed, as a result of economic restructuring programmes during the 1990s in both developed and developing countries, resources were being withdrawn from many former 'public good' functions of

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government. Even the long-established operational meteorological observing networks providing essential national climate records were in serious decline in many countries. The deterioration of established networks, and the resulting loss of momentum for GCOS implementation, so troubled participants at the 1997 International Conference on the WCRP that the Chairman of the IPCC (Professor Bert Bolin) agreed to raise the issue at the almost immediately following (Kyoto) session of the COP. This he did in forceful terms which triggered the first substantial involvement of UNFCCC bodies with GCOS issues, which had hitherto been regarded as the exclusive concern of the official GCOS sponsors and the relevant scientific agencies of their Members.

The COP called for an assessment of the adequacy of the existing global observing networks for climate for meeting the commitments and needs of the Parties to the Convention. This led to an increasingly close working relationship between the UNFCCC and GCOS Secretariats in the preparation of the First (1998) and Second (2003) Adequacy Reports, with the Second Adequacy Report (GCOS, 2003) triggering an explicit request from the 2003 (Milan) session of the COP for the GCOS Secretariat to submit an 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC'.

The preparation of the Adequacy Reports and the direct involvement of GCOS Secretariat and Steering Committee members in sessions of the UNFCCC bodies generated a level of political support for GCOS implementation that, notwithstanding the aspirations of the 1993 Intergovernmental Meeting, had been lacking up to that stage. It triggered a number of initiatives aimed at rebuilding the GCOS momentum including UNDP (United Nations Development Programme) and GEF (Global Environment Facility) funding for a six-year programme of GCOS Regional Workshops to prepare GCOS Regional Action Plans (RAPs) for all the main developing country regions of the world. The COP also threw its weight behind the 'GCOS Climate Monitoring Principles' (see below) and the sponsors' exhortations to countries for the establishment of national GCOS coordination mechanisms. And, as a further encouragement to Parties (governments) to give priority to a strengthening of their national observation networks, it called for regular reporting on progress on GCOS implementation. In many respects, the UNFCCC emerged over the period 1997–2004 as a *de facto* sponsor of the GCOS (cf the broken line to SBSTA in Figure 2).

Steering committee, panels and secretariat

From the outset, the implementation philosophy for the GCOS has been based on the 'system of systems' concept of coordination, strengthening and, where necessary, supplementation of the climate-relevant components of the established observing systems operated by its sponsors' Member countries and institutions. The role of the JSTC/SC has been to advise and guide the intergovernmental and other bodies responsible for implementation and operation of the various *in situ* and space-based observing systems on which the GCOS is built. Its members serve in their personal capacities and carry no individual or collective authority or responsibility for GCOS implementation or operation.

Also from the beginning, however, the JSTC/SC found it necessary to draw heavily on the expertise and connections of a wide range of individuals with direct involvement in *in situ* and space-based observation in the various contributing countries and organizations. Initially the JSTC carried out much of its work through three domain-based panels (for atmospheric, oceanic and terrestrial observing systems) and cross-cutting 'space' and 'data and information management' panels. Following approval of the 1995 GCOS Plan, it reverted to three domain-based panels, all co-sponsored by other research and observing system steering bodies although, in recent years, as a mechanism for reinforcement of coordination with the observing system needs and activities of the WCRP, it also joined in co-sponsorship of a 'WCRP Observations and Assimilation Panel' (WOAP). The three ongoing domain-based GCOS Panels are:

- The *Atmospheric Observation Panel for Climate (AOPC)* co-sponsored by the WCRP and chaired, in succession, by Lennart Bengtsson, Michael Manton and Adrian Simmons;
- The *Ocean Observations Panel for Climate (OOPC)* which evolved from the earlier OOSDP, co-sponsored by the WCRP and GOOS and chaired, in succession, by Worth Nowlin, Neville Smith, Ed Harrison and Eric Lindstrom, and
- The *Terrestrial Observation Panel for Climate (TOPC)* co-sponsored by the WCRP and GTOS and chaired, in succession, by David Norse, John Townshend, Joseph Cihlar, Alan Belward and Han Dolman.

The original MOU provided for the Joint Planning Office (JPO) to assist the JSTC in the overall planning and development of the GCOS and to undertake essential coordination, liaison and documentation functions on behalf of the JSTC and its sponsors. In the 1998 revision of the MOU, the JPO was replaced by the 'GCOS Secretariat' with essentially identical functions and responsibilities. The Secretariat consists of a Director, an Administrative Assistant and two or three additional staff. It is funded mainly by the WMO and a few individual countries and organizations. It carries out its work with a non-salary operating and programme budget of around half a million Swiss francs per annum along with a further half a million to a million Swiss francs per annum provided by donor countries to assist developing countries with specific system improvement projects through the GCOS Cooperation Mechanism established in 1999 (GCOS, 2008a). The Secretariat works closely with the Secretariats of other global observing systems, the WCRP, the IPCC and the UNFCCC to ensure effective coordination of the international climate observing effort in support of user needs (eg GCOS, 2008b).

Climate monitoring principles

Basic international standards and guidelines for climate observation have long been in place under the auspices of the WMO Technical Commissions for Instruments and Methods of Observation (CIMO) and for Climatology (CCl) and codified in successive editions of the WMO 'Guide to Climatological Practices' (WMO, 2010). It was considered important, however, early in the implementation of the GCOS, to put in place a relatively brief set of basic principles to serve as guidance, particularly for those outside the traditional climatological community, on the essential requirements for ensuring the quality of observations for GCOS purposes.

The initial ten principles emerged from the work of Karl (1996). These were subsequently supplemented by a further ten principles, focused on space-based observations for climate, endorsed by the CEOS. The resulting 20 'GCOS Climate Monitoring Principles' were formally endorsed by the 2003 World Meteorological Congress and the 2003 (Milan) session of the COP and have subsequently become widely accepted as a guide to good observing practice in climate circles.

Essential climate variables

While traditional climatological practice recognizes all the standard meteorological variables as 'climate variables' and the past half century has extended these to include a host of other oceanic, hydrological, cryospheric, terrestrial and socio-economic observations and indicators, it was found useful, for the purposes of the 2003 Second Adequacy Report to the UNFCCC, to introduce the concept of 'Essential Climate Variables' (ECVs).

The ECVs, as defined by the GCOS Steering Committee, are those climate variables 'that are both currently feasible for global implementation and have a high impact on UNFCCC requirements' (GCOS, 2003). The list is updated as new requirements emerge

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and new observational capabilities are developed. The current set of 48 ECVs, as set down in the latest version of the 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC' (see below), is shown in Figure 4. Different 'agents of implementation' have assumed responsibility for the actions needed to deliver the various ECVs.

GCOS systems and networks

The design and implementation challenges of the GCOS involve both the development, funding and ongoing operation of climate-focused networks and systems for the separate 'spheres' (atmosphere, hydrosphere, cryosphere, lithosphere, biosphere) and physical domains (atmosphere, ocean, land) of the climate system and the formidable task of integration across their distinct observing traditions and cultures, including those of the established *in situ* and space-based observation communities (Figure 5)

By virtue of its 'system of systems' architecture (Sommeria *et al*., 2007), the GCOS consists essentially of the aggregate of all the climate-related activities of the observing systems on which it is built, from global to local scale. It has been found useful, however, especially for purposes of recognition of individual domain-based networks as 'part of the GCOS' to identify a number of broad cross-cutting categories of GCOS networks including:

- *Global Reference observing networks* which provide highly-detailed and accurate observations at a few locations for the production of stable long-term series and for calibration/validation purposes;
- *Global Baseline observing networks* which involve a limited number of selected locations that are globally distributed and provide long-term high quality data records of key global climate variables and enable calibration for the comprehensive and designated networks, and
- *Comprehensive observing networks* which include regional and national networks and, where appropriate, satellite data.

The evolving network structure of the GCOS also involves networks of ecosystem monitoring sites where long-term observations of ecosystem properties, including biodiversity and habitat properties, are made in order to study climate impacts. It also includes an increasing range of ecosystem measurements in the oceans.

The most advanced of the Reference networks is the GCOS Reference Upper Air Network (GRUAN) comprising, in its initial implementation, 14 globally distributed high-quality, high-altitude upper air measurement stations with a Lead Centre at Lindenberg in Germany (Seidel *et al*., 2009).

Baseline networks exist for all domains with varying coverage and maturity. The best known are the GSN and GUAN (Figure 6), the high quality sub-set of the WMO GOS Surface and Upper Air Networks. Special efforts have been made through the GCOS Cooperation Mechanism to restore and support GSN and GUAN stations in those developing countries whose National Meteorological Services have been unable to maintain their continuing operation.

One of the most significant contributions to the GCOS so far has been the successful implementation of the Argo array of profiling floats (Figure 7) as a major component of the GOOS. More than 3000 Argo drifters now provide continuous sampling of the temperature and salinity structure of the global ocean to a depth of 2000 metres (GCOS, 2007).

The best established of the terrestrial observation networks that contribute to the GTOS and GCOS include the various global, regional and national hydrological networks that have been built up under a range of WMO, UNESCO, FAO and other programmes. Figure 8 shows the 2012 status of the GTOS/GCOS Baseline River Discharge Network (GTN-R).

OCEANIC	ATMOSPHERIC	TERRESTRIAL
Surface (10)	**Composition (3)**	**Biological/Ecological (6)**
Sea-surface temperature	Carbon dioxide	Land cover
Sea-surface salinity	Methane and other long-lived greenhouse gases	FAPAR
Sea level	Ozone and Aerosol supported by their precursors	Leaf area index
Sea state		Above ground biomass
Sea ice	**Upper-air (5)**	Soil carbon
Surface current	Temperature	Fire disturbance
Ocean colour	Wind speed and direction	
Carbon dioxide partial pressure	Water vapour	**Hydrological (5)**
Ocean acidity	Cloud properties	River discharge
Phytoplankton	Earth radiation budget (including solar irradiance)	Water use
		Ground water
Sub-surface (8)	**Surface (6)**	Lakes
Temperature	Air temperature	Soil moisture
Salinity	Wind speed and direction	**Cryospheric (4)**
Current	Water vapour	Snow cover
Nutrients	Pressure	Glaciers and ice caps
Carbon dioxide partial pressure	Precipitation	Ice sheets
Ocean acidity	Surface radiation budget	Permafrost
Oxygen		**Other (1)**
Tracers		Albedo

Figure 4. Essential climate variables for the three domains of the global climate system (GCOS, 2010).

Figure 5. An artist's impression of the integrated (atmosphere-ocean-land and in situ-space based) architecture of the GCOS (GCOS, 2007).

Support for the UNFCCC

The major shift in emphasis in GCOS planning and implementation since adoption of the original GCOS Plan in 1995 followed from the Steering Committee and Secretariat response to the 2003 (Milan) session of the COP through preparation of the 2004 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC' (GCOS, 2004) and, in collaboration with CEOS, its 2006 Satellite Supplement (GCOS, 2006).

The 2004 'Implementation Plan', which was extensively updated in 2010 (GCOS, 2010), identifies the specific needs and commitments of Parties for climate observations under Articles 4 and 5 of the UNFCCC. The 2010 Update, elaborates some 138 specific actions (34 atmospheric, 41 oceanic, 40 terrestrial and 23 cross-cutting) required for effective implementation of the GCOS in support of the Convention. The cost of implementation of these actions is estimated at US$2.5B per year in addition to the approximate US$5-7B per year which nations already invest in climate-related

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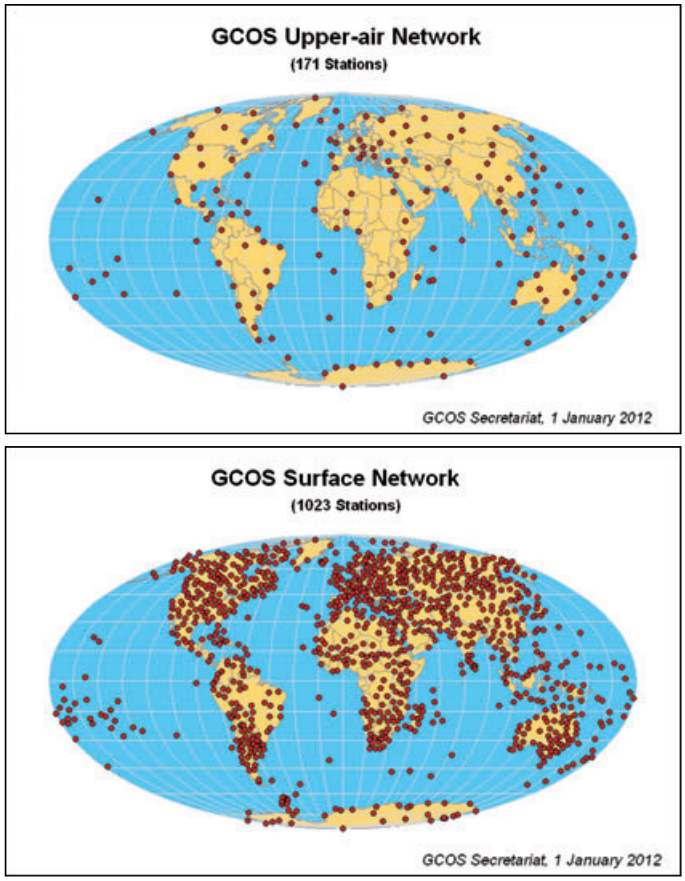

Figure 6. The GCOS Surface Network (GSN) (lower) and GCOS Upper Air Network (GUAN) (upper). (Source: GCOS Secretariat.)

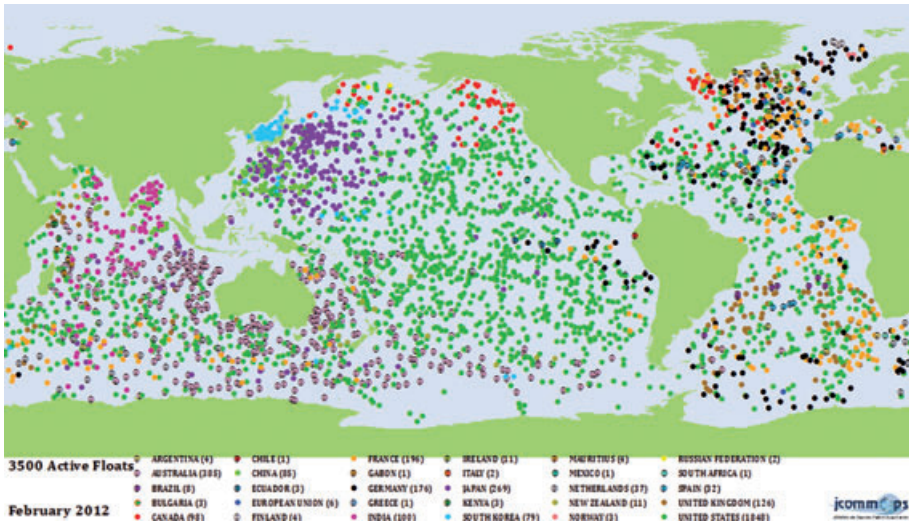

Figure 7. The GOOS/GCOS array of ARGO floats (in 2012). (Source: GOOS, Argo Information Centre (AIC), JCOMMOPS, 2012.)

observations and infrastructure, mainly for weather forecasting and environmental management purposes. The largest components of the incremental costs are for satellite missions, for data sets and products for the benefit of all countries and for enhancement of national observing systems in developing countries.

For each individual implementation action, the Plan identifies the responsible agents for implementation, time-frame and performance indicators. The 2004 edition of the Implementation Plan (GCOS-92) served as the basis for regular reporting to the Convention bodies over the period 2005–2009, including a comprehensive 2009 Progress Report (GCOS, 2009) which provided the foundation for COP guidance on the content of the updated Plan. The 180-page 2010 Update (GCOS-138), which was subsequently endorsed by the COP, provides the most detailed and up-to-date elaboration of implementation plans for the GCOS as well as an explicit statement of expectations on the various satellite operators and other national and international agents for implementation. It particularly emphasizes the importance of establishment of national coordination mechanisms for the GCOS and the need for greatly increased support for the GCOS Cooperation Mechanism to coordinate donor support for GCOS implementation in developing countries (GCOS, 2008a).

It is important to recognize that GCOS-92 and GCOS-138 and their Satellite Supplements, although widely referred to as the 'GCOS Implementation Plan', are focused primarily on meeting the needs of the UNFCCC and the commitments of Parties under Article 5 of the Convention. These needs are broad in scope and the 138 specific actions listed in GCOS-138, if fully implemented, would also meet many of the observational needs for climate research under the WCRP, for climate-change assessment through the IPCC and for climate information in support of adaptation to climate change (GCOS, 2008b). They also largely cover, but do not explicitly address, the additional requirements for observations in support of climate service provision at the sectoral and national levels envisaged under the implementation plans for the GEOSS (see below) and GFCS.

Climate component of the GEOSS

In the early stages of GCOS planning, it was initially envisaged by some in the broader Earth system science community (eg Malone, 1993) that the GCOS should be expanded into a comprehensive global Earth-observation system and, through the late 1990s and early 2000s, various proposals for a more integrated global weather, climate and environmental observing system were canvassed on the international scene within the overall framework of the IGOS (Chuvieco, 2008).

Eventually, following the US-hosted 2003 Earth Observation Summit, a group of national governments and 'participating organizations' joined together as the Group on Earth Observations (GEO) to implement a '10-year Implementation Plan' for a 'Global Earth Observation System of Systems (GEOSS)' with 'Climate' as one of its nine Societal Benefit Areas (SBAs) (Group on Earth Observations, 2005).

This immediately raised the question of the appropriate relationship of the WMO-IOC-UNEP-ICSU GCOS to the Climate SBA of the GEOSS with the initial presumption in the GCOS community being that they would be identical (Sommeria *et al*., 2007). It emerged, however, that some of the GEO community envisaged a different 'system of

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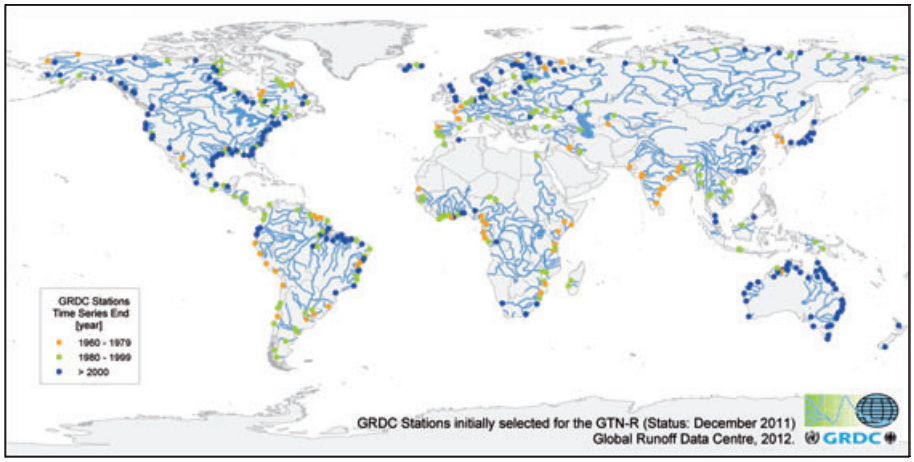

Figure 8. The 2012 composition of the GCOS Baseline River Discharge Network (GTN-R) based on the GRDC (Global Runoff Data Centre) priority stations. (Source: GTOS, GRDC, 2012.)

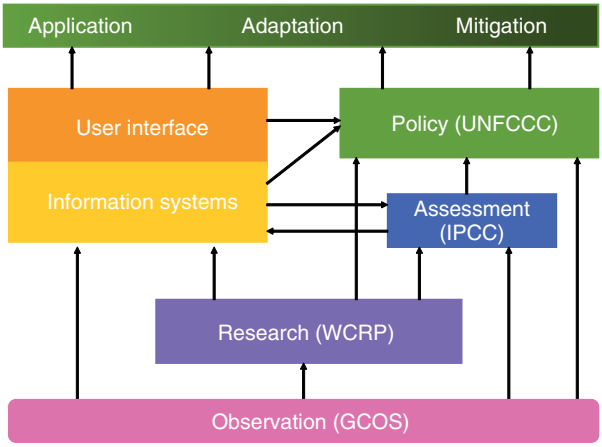

Figure 9. The underpinning role of the GCOS for the WCRP, the IPCC, the UNFCCC, and the information systems and user interface and application elements of the proposed new global framework for climate services (WMO, 2009a).

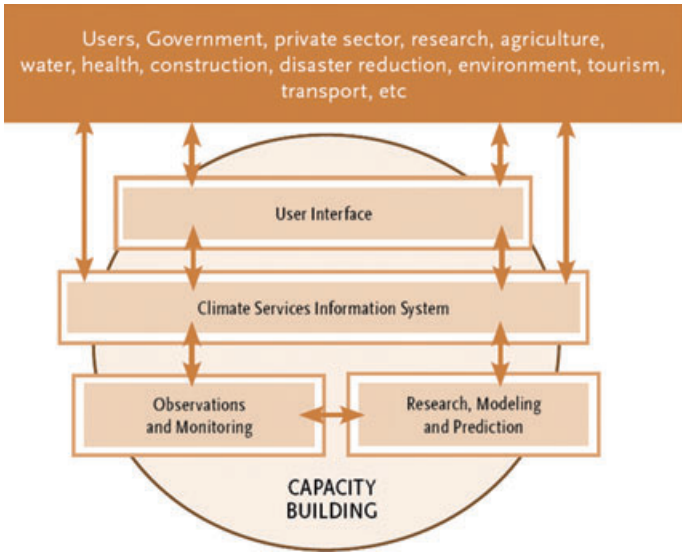

Figure 10. The overall structure of the Global Framework for Climate Services envisaged by the High-level Task Force (WMO, 2011b).

systems' concept for the Climate SBA with emphasis on individual, voluntary, bottom-up contributions in lieu of the more structured WMO-IOC-UNEP-ICSU design concept of the GCOS. Eventually, following an extensive review of the GEOSS targets and consultation at Secretariat and other levels, agreement was reached on recognition of the GCOS as the climate (observing) component of the GEOSS with subsequent increased alignment of GCOS 'Actions' and GEO 'Tasks'. There are grounds for optimism that full alignment will eventually be achieved between the GCOS and GEOSS and that both 'systems of systems' will benefit from their common foundation in the global observing systems operated by the Member States of the United Nations System (WMO, 2011a).

Observing component of the GFCS

With the GCOS, WCRP, IPCC and UNFCCC all in place, the 2009 Third World Climate Conference (WCC-3) was designed to achieve what the 1993 Intergovernmental Meeting on the World Climate Programme and the Climate Agenda had been unable to deliver – a robust and adequately-resourced global framework for the provision of the full range of climate services needed to support the worldwide response to the challenges of natural climate variability and human-induced climate change. Early in the planning for the WCC-3, it was recognized that one of the key requirements for a successful global framework for climate services would be a greatly strengthened foundation of climate observations, particularly in developing countries (WMO, 2009a). It was agreed that, as an already existing example of the 'UN System delivering as one on climate knowledge' (UN Chief Executives Board for Coordination, 2008), the GCOS provided the appropriate observational foundation on which to build the new System-wide Global Framework for Climate Services (GFCS). Conference White Papers were prepared elaborating both provider and user views on what needed to be done (Karl *et al*., 2010; Manton *et al*., 2010).

The WCC-3 preparations envisaged a greatly strengthened GCOS, underpinning information systems and user interface and applications elements of a new world climate services programme which would replace the former WCDMP and WCASP (Figure 3) and would complement and support the role of the WCRP, the IPCC and UNFCCC in applying climate information in all the various climate sensitive sectors of society and addressing the adaptation and mitigation challenges of human-induced climate change (Figure 9).

The WCC-3 Conference Declaration of 3 September 2009 announced the decision to establish the Global Framework for Climate Services (GFCS). The Conference Statement (WMO, 2009b) identified the GCOS and all its components and associated activities as one of the five essential elements of the GFCS and set out six specific recommendations for its strengthening in support of the provision of climate services

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around the world. The subsequent GFCS High–level Task Force Report (World Meteorological Organization, 2011b) further elaborated the contribution of the GCOS systems (especially WIGOS, GOOS and GTOS) to the overall implementation of the observations and monitoring component of the comprehensive GFCS (Figure 10) in support of the GFCS Implementation Plan which will be submitted for approval by an extra-ordinary World Meteorological Congress in October 2012.

Conclusions

We believe that the concept of the GCOS as an integrated global system of climate-relevant observing systems co-sponsored by United Nations organizations and the ICSU, and aimed at meeting the full range of needs for climate observations, has proved extremely successful through its first 20 years. Though not resourced to the level originally envisaged, and now urgently needed, the 'system' is widely accepted in the international community as the overarching global framework for climate observations and the GCOS 'programme' enjoys very strong political support through the UNFCCC COP and its Subsidiary Bodies. Through the work of its sponsors and their individual and co-sponsored observing systems, the GCOS has become a vital source of observational support for climate-change research and assessment, a highly valued advisory mechanism for climate-change negotiations, a successful prototype for other GEOSS Societal Benefit Areas, and the pre-eminent example of the UN System already 'delivering as one on climate knowledge'.

We strongly endorse the further development of the GCOS as the essential observational foundation for climate services world-wide envisaged in the Conference Statement of WCC-3. We encourage WMO, IOC, UNEP, FAO and ICSU, with the support of the SBSTA, GEO, CEOS and other climate and observation organizations and communities, to renew and increase their commitment to implement the GCOS over the next decade. We especially encourage the establishment of stronger GCOS coordination and implementation mechanisms at the national level in sponsor Member countries and increased support for climate observing systems in developing countries through enhancement of the GCOS Cooperation Mechanism and renewed commitment to the basic national meteorological, oceanographic and terrestrial observing systems on which the GCOS is built. And we urge the international satellite community to continue their strong support for climate observation within the framework of the GCOS. We applaud the achievements of the past 20 years and wish the GCOS and its sponsors great success in its further development and ongoing operation.

Acknowledgements

We wish to acknowledge the efforts of all who have helped turn the GCOS vision of the Second World Climate Conference into an effective global system. We are particularly grateful to all the members of the JSTC/SC and its panels who have provided the intellectual framework and the expert advice that enabled the GCOS sponsors and their various observing systems to work together towards achievement of the vision. And we extend our special thanks to the successive Directors of the JPO/Secretariat, and their staff, who have played such a central role in overall GCOS planning and coordination: Tom Spence (1992–1998), Mike Coughlan (1998–1999), Alan Thomas (2000–2004), Dave Goodrich (2005–2007), Alex Karpov (2008) and Carolin Richter (2009 onwards).

Glossary of acronyms

AOPC	Atmospheric Observation Panel for Climate
CCl	Commission for Climatology
CEOS	Committee on Earth Observation Satellites
CIMO	Commission for Instruments and Methods of Observation
COP	Conference of the Parties (to the UNFCCC)
ECV	Essential Climate Variable
FAO	Food and Agriculture Organization of the United Nations
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GEF	Global Environment Facility
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GOOS	Global Ocean Observing System
GOS	Global Observing System (of WMO)
GRUAN	GCOS Reference Upper Air Network
GSN	GCOS Surface Network
GTN-R	Global Terrestrial Network-River Discharge
GTOS	Global Terrestrial Observing System
GUAN	GCOS Upper-Air Network
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
IGOS-P	Integrated Global Observing Strategy Partnership
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
JPO	Joint Planning Office
JSTC	Joint Scientific and Technical Committee
OOPC	Ocean Observations Panel for Climate
OOSDP	Ocean Observing System Development Panel
RAP	Regional Action Plan
SBA	Societal Benefit Areas (of GEOSS)
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC/COP)
SC	Steering Committee (of GCOS)
TOPC	Terrestrial Observation Panel for Climate
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WCC-3	World Climate Conference-3 (Third World Climate Conference)
WCASP	World Climate Applications and Services Programme
WCDMP	World Climate Data and Monitoring Programme
WCIRP	World Climate Impacts and Response Strategies Programme
WCP	World Climate Programme
WCRP	World Climate Research Programme
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WOAP	WCRP Observations and Assimilation Panel
WWW	World Weather Watch (of WMO).

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DOI: 10.1002/wea.1964

Meteorologist's profile – Charles Ernest Pelham Brooks I.S.O., D.Sc. (1888–1957)

Joan M. Kenworthy
Formerly of the Department of Geography, Durham University

> *By nature he was a brilliant mathematician and poet; by choice a geologist; but like so many of our versatile and talented scientists he was drawn into meteorology by accident and stayed with us for a lifetime because of the many challenging problems which remained (many still remain) unsolved. (Rigby, 1958)*

Charles Ernest Pelham Brooks was probably the most prolific climatologist of his generation. The range of his publications is evident in the memorial issue of *Meteorological abstracts and bibliography* (Rigby and Rigby, 1959), in holdings of the National Meteorological Library and in citations found in a Google search. Rigby (1959) refers to *thousands of publications by other scientists where his works are cited, or where his ideas have been appropriated or extended without being credited to the rightful author*.

Brooks was born on 10 November 1888 and lived with his parents and older sisters at 6 Francis Street, St Pancras (north London). His father, Charles Thomas Brooks, shown as a printing compositor in the 1881 census and draper in the 1891 census, died in 1894. The 1901 census shows Brooks living with his mother at 11 St. Peter's Road, Islington (London).[1] He attended Dame Alice Owen's School in Islington[2] and, in 1903, won a scholarship to University College School, where he studied economics and won the mathematics prize. He joined the Meteorological Office as a probationer on 4 October 1907; his first task was the compilation of monthly and annual summaries of pressure, temperature and precipitation

[1]I am grateful for census information from Peter Marsh and details from Meteorological Office minutes from Malcolm Walker.

[2]Founded by Dame Alice Owen in 1613, the school is now located in Potters Bar (Hertfordshire).

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