GLOBAL CLIMATE OBSERVING SYSTEM

ENSURING THE AVAILABILITY OF GLOBAL OBSERVATIONS FOR CLIMATE
OBSERVING THE GLOBAL CLIMATE SYSTEM FOR BETTER UNDERSTANDING AND BETTER DECISION-MAKING
The Global Climate Observing System (GCOS), established in 1992, is an internationally coordinated system of observing systems and networks for meeting national and international needs for climate observations. It consists of the climate-relevant components of all established environmental observing networks and systems, and it serves as the climate observation component of the Global Earth Observation System of Systems (GEOSS). It is co-sponsored by the

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

**Purpose and objectives**

The purpose of GCOS is to ensure that the observations required to meet the totality of national and international needs for climate and climate-related data and information are identified, obtained and made widely available. Its goal is to provide continuous, reliable, comprehensive data and information on the state and behaviour of the global climate system, including its physical, chemical and biological properties and its atmospheric, oceanic, hydrological, terrestrial and cryospheric processes.

The objectives of GCOS are to support all components of the World Climate Programme, the assessment role of the Intergovernmental Panel on Climate Change (IPCC) and the international policy development role of...
the United Nations Framework Convention on Climate Change (UNFCCC); and, in participation, to provide the comprehensive, continuous climate and climate-related observations needed for:

- Climate system monitoring;
- Climate change detection and attribution;
- Operational climate prediction on seasonal-to-interannual timescales;
- Research to improve understanding, modelling and prediction of the climate system;
- Applications and services for sustainable economic development;
- Assessment of the impacts of, and vulnerability and adaptation to, natural climate variability and human-induced climate change;
- Meeting the requirements of the UNFCCC and other international conventions and agreements.

GCOS Planning and Implementation

The four international sponsoring organizations (WMO, IOC, UNEP and ICSU) have appointed a GCOS Steering Committee (SC) to provide scientific and technical guidance to sponsoring and participating organizations and agencies for the planning, implementation and further development of GCOS.

For each domain (atmosphere, oceans, land surface), scientific advisory panels provide expert advice, for example, on the observing strategy, observation requirements, and the status of networks and systems. These panels work closely with the intergovernmental bodies (especially the WMO along with a substantial number of other global, regional and national observing systems based on both in situ and space-based remote sensing technologies (see figure below). A central aspect of the design and implementation of GCOS involves analysis of the extent to which the identified international and national needs for climate observations can be met through the aggregate of existing observing systems and their enhancement, strengthening and supplementation as necessary to ensure that those needs can be met.

The GCOS Foundation

The fundamental principle that shaped the original design and subsequent development of GCOS is that it should build, as far as possible, on existing operational and scientific observing, data management and information distribution systems, and further enhance these systems. GCOS is thus built fundamentally on:

- The WMO World Weather Watch Global Observing System (GOS) and Global Atmosphere Watch (GAW) for the atmosphere;
- The IOC-led Global Ocean Observing System (GOOS) and its components for the ocean; and
- The Global Terrestrial Observing System (GTOS), led by the Food and Agriculture Organization (FAO) and associated Global Terrestrial Networks (GTNs) for the land surface;
technical commissions such as the Commission for Basic Systems (CBS), Commission for Atmospheric Science (CAS), Commission for Climatology (CCI), the Commission for Hydrology (CHy) and the WMO-IOC Joint Commission for Oceanography and Marine Meteorology (JCOMM)) and other international bodies which are responsible for the coordinated implementation of the component systems of GCOS.

At the national level, the various National Meteorological Services (NMSs), the National Hydrological Services (NHSs), national ocean services, space agencies, research institutes and many other environmental and related organizations provide observing systems (ground-based, airborne, space-based) that provide a wealth of information required for the observation of the entire climate system.

The overall plan for GCOS was developed over the period 1992-95 and approved by the sponsoring organizations in 1995. A specific Implementation Plan (IP) for the Global Observing System for Climate in support of the UNFCCC was prepared at the request of the Conference of Parties (COP) to the Convention in 2004 (along with a 2006 Satellite Supplement) and a set of ten Regional Action Plans was developed over the period 2000-06.

1 Plan for the Global Climate Observing System (GCOS) Version 1.0 (GCOS-14, May 1995)
2 Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (GCOS-92, October 2004)

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**GCOS Networks**

In developing the concept for GCOS, built as an integrated system of observing systems, the GCOS Steering Committee has identified the need for recognition of a hierarchy of climate relevant observing networks as follows:

- **Research observation networks.** These consist of experimental networks and observing systems specially established as part of time-limited research programmes and almost always funded from research budgets;

- **Reference networks.** These provide highly-detailed and accurate observations at a few locations for the production of stable long-time series and for satellite calibration/validation purposes;

- **Baseline global networks.** These consist of a limited number of selected locations that are globally distributed and provide long-term high-quality data records of key global climate variables as well as calibration for more comprehensive networks. They are usually funded from long-term operational budgets;

- **Comprehensive global networks.** These consist of the relatively dense global and regional (and, in some cases national) observing networks which are the basic building blocks of GCOS. The comprehensive networks provide observations at the detailed space and time scale required to fully describe the nature, variability and change of a specific climate variable. They are almost always funded from long-term operational budgets;

- **Complete national networks.** These consist of the totality of the national observing networks that contribute to meeting climate-related needs at the national level. They may be referred to as the ‘National GCOS Network’ or the ‘National Climate Network’. They are almost always funded by the long-term operational budgets of the National Meteorological and Hydrological Services (NMHSs) or sometimes, in developing countries, from targeted development assistance budgets.
Essential Climate Variables

The GCOS Steering Committee has identified a list of climate variables to support the work of the UNFCCC and the IPCC\(^3\). These Essential Climate Variables (ECVs) are technically and economically feasible and have high impact with respect to the scientific requirements for systematic climate observations. The following table lists the ECVs in the three domains of atmosphere, oceans and terrestrial observations:

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atmospheric</strong></td>
<td></td>
</tr>
<tr>
<td>(over land, sea and ice)</td>
<td>Surface: Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.</td>
</tr>
<tr>
<td></td>
<td>Upper-air: Earth radiation budget (including solar irradiance), Upper-air temperature, Wind speed and direction, Water vapour, Cloud properties.</td>
</tr>
<tr>
<td></td>
<td>Composition: Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties.</td>
</tr>
<tr>
<td><strong>Oceanic</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.</td>
</tr>
<tr>
<td></td>
<td>Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.</td>
</tr>
<tr>
<td><strong>Terrestrial</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation, Leaf area index, Biomass, Fire disturbance, Soil moisture.</td>
</tr>
</tbody>
</table>

While identified for purposes of the UNFCCC, these ECVs, if comprehensively observed according to established practices and schedules, can be expected to meet most of the other needs for GCOS observations.

Climate Monitoring Principles

The general standards and practices for climate observation have been well established for many decades under the auspices of the WMO Commission for Climatology (CCI). For GCOS purposes, it has been found useful to supplement these with a set of more general ‘GCOS Climate Monitoring Principles’ which were endorsed in their basic form (the first 10 principles) by the UNFCCC in 1999 and, after agreement by the world’s space agencies through the Committee on Earth Observation Satellites (CEOS) to a set of additional satellite monitoring principles, in complete form in 2003. They are intended to provide overall guidance for the design and implementation of GCOS observing systems.
Data Exchange

One of the most important roles of GCOS is to ensure the free and unrestricted availability of climate and climate-related data from all the observing networks and systems of which it is composed (in line with WMO Resolutions 25 and 40, and IOC and ICSU data policy). It is the expectation that all ‘essential’ GCOS observations will be made available for free and unrestricted international exchange. While some ‘additional’ GCOS data from national GCOS networks may not be required to be exchanged, all contributors to GCOS are urged to commit to free and unrestricted exchange of all GCOS data as a global public good.

The Component Observing Systems

GCOS is built, to the extent possible, on existing observing, data management and information distribution systems, both operational and research, and on further enhancements of these systems. Many of these networks and systems have been recognized as contribution to the global observing system for climate. In order to ensure a long-term, homogeneous climate record, all systems should, to the extent possible, adhere to the GCOS Climate Monitoring Principles.

Each observational network and system provides measurements of one or more essential climate variables in the atmospheric, oceanic or terrestrial domains. These systems consist of in situ instruments on the ground, on ships, buoys, ocean profilers, balloons, and aircraft, for example. GCOS also makes use of all forms of climate-relevant remotely-sensed information from ground-based and airborne systems as well as satellites. The availability of information on where and how the observations are taken (metadata) is seen as absolutely essential. Historical and palaeo-climatic records that set the context for the interpretation of current climate trends and variability also play a major role in the GCOS context.

The WMO World Weather Watch Global Observing System (GOS) and Global Atmosphere Watch (GAW)

The WMO Global Observing System (GOS) provides the foundation for the atmospheric component of GCOS. It consists of both surface-based and space-based
components made up of the networks and systems provided by the NMSs and space agencies of the over 188 Members of WMO coordinated through the Commission for Basic Systems and other mechanisms such as the Coordination Group on Meteorological Satellites (CGMS).

The backbone of worldwide operational observation and processing of meteorological (including climatological) data is the WMO World Weather Watch (WWW) Global Observing System. It consists of in situ and satellite observing systems, telecommunication centres and systems (i.e., the Global Telecommunication System), and data processing and forecasting centres, which are operated by the WMO Member states. The Regional Basic Climatological Network (RBCN) is an approximately 2000-station subset of the full WWW network, which produces climate-relevant surface and upper-air observations of temperature, precipitation and many other variables.

The WMO Global Atmosphere Watch (GAW) is the atmospheric chemistry component of GCOS. GAW networks provide comprehensive observations of the chemical composition (e.g. greenhouse gases) and selected physical characteristics of the atmosphere on global and regional scales.

The Global Ocean Observing System (GOOS)

The IOC leads the planning and implementation of the Global Ocean Observing System with the

The Argo Network with 3006 free-drifting profiling floats that measure the temperature and salinity of the upper 2000 m of the ocean. Argo as one of the many observing systems of GOOS contributes to the ocean component of GCOS (Argo, 2007)
advice of the GOOS Scientific Steering Committee, and with implemented coordination through the Intergovernmental Committee for GOOS (IGOOS) and JCOMM. It has two main components with its open ocean component serving as the main ocean component of GCOS.

Lack of sustained observations of the oceans has hindered the development and validation of climate models. Deployment of Argo float instruments began to combat this lack of observations in 2000. By the end of 2007 the array is expected to be 100% complete. Today’s tally of floats in the global oceans is shown in the figure above. For the first time ever, the Argo Network allows continuous monitoring of temperature, salinity, and velocity of the upper ocean, with all data being relayed and made publicly available within hours after collection.

### The Global Terrestrial Observing Network (GTOS)

GTOS is being implemented under the leadership of the Food and Agriculture Organization (FAO) with the advice of the GTOS Scientific Steering Committee (GTOS). One of its principal foci is on terrestrial observations for climate through a series of Global Terrestrial Networks (GTN), including especially GTNs for rivers (GTN-R), glaciers (GTN-G), and permafrost (GTN-P).

**Global Terrestrial Network – Rivers (GTN-R).** River discharge serves as an indicator for climatic change and variability, as they reflect changes in precipitation and evapotranspiration. Additionally it has a role in driving the climate system, as the freshwater inflow to...
the oceans may influence thermohaline circulations. Based on the past demand for data, the Global Runoff Data Centre (GRDC) has identified 380 gauge stations near the downstream end of the largest rivers of the world, which build-up the evolving Global Terrestrial Network for Rivers (GTN-R). These stations collectively form a GCOS baseline network and capture 70% of the global freshwater flux to the oceans.

**Global Terrestrial Network – Glaciers (GTN-G).** Glaciers are very sensitive to temperature fluctuations accompanying climate change. Since the early twentieth century, with a few exceptions, glaciers around the world have been retreating at unprecedented rates. The Global Terrestrial Network for Glaciers (GTN-G) monitors the extent and volume of glaciers worldwide.

The Vernagtferner glacier in the southern parts of the Oetztal Alps in Austria is one of the glaciers monitored in the GTN-G. The Vernagtferner glacier (see photographs above) has been monitored since 1600 and volumetrically since 1889. The change in volume is illustrated by the photographs: the glacier tongue, which once reached deep into the valley, completely vanished during the 20th century.

**Space-based observing systems**

Satellite systems provide a major – in some cases the only – contribution to systematic and continuous observation of essential climate variables on a global scale. The space-based sub-system of the WMO Global Observing System (GOS) includes three components:

- Geostationary satellites
- Low-Earth Orbit satellites
- Environmental Research and Development satellites

The world’s space agencies coordinated through the Coordination Group on Meteorological Satellites (CGMS), the Committee on Earth Observation Satellites (CEOS) and the WMO Space Programme, are comprehensively addressing GCOS needs for satellite based observation of the climate system.
The early planning of GCOS focused particularly on the identification, as part of the Initial Operational Systems, of the GCOS Surface Network (GSN) and GCOS Upper Air Network (GUAN) as priority subsets of the WMO Global Observing System (GOS).

The GCOS Surface Network (GSN) consists of 1016 stations of the World Weather Watch RBCN that measure surface-air temperature, rainfall and other meteorological parameters (GCOS Secretariat, 2007).

The GCOS Upper Air Network (GUAN) consists of 164 stations of the World Weather Watch RBCN that measure upper-air temperature, upper-air wind speed and direction, and upper-air water vapour (GCOS Secretariat, 2007).
extremes, of surface air temperature over land at global hemispheric and continental scales. Likewise, for upper air temperature and relative humidity measurements, the GCOS Upper Air Network (GUAN) represents a baseline network of about 160 stations using balloon based instruments.

In 2006 the GCOS Steering Committee endorsed the establishment of a GCOS Reference Upper Air Network (GRUAN), consisting of 30 to 40 reference sites measuring atmospheric profiles and other atmospheric variables of highest quality.

The surface radiation budget is a fundamental component of the surface energy budget that is crucial to nearly all aspects of climate, and therefore needs to be monitored systematically. The Baseline Surface Radiation Network (BSRN) of the World Climate Research Programme (WCRP) serves as the GCOS baseline network for surface radiation. The BSRN provides high-quality measurements of short and longwave surface radiation fluxes from a small number of selected stations in contrasting climate zones.

**GCOS Serving Users’ Needs**

The objectives of GCOS as agreed by its sponsors are to meet seven broad categories of climate-related needs which may be summarized as follows:

- (a) Monitoring
- (b) Detection and attribution
- (c) Research
- (d) Operational prediction
- (e) Impacts, vulnerability and adaptation
- (f) Applications and services
- (g) The UNFCCC

In the same way, however, that GCOS is built on the various established observing systems (rather than being constituted as a new and separate system), so too it meets these important societal needs not through its own new structures but by underpinning the various components of the World Climate Programme, the IPCC, the UNFCCC and other international climate programmes.

**(a) Climate System Monitoring**

GCOS observations provide the basis for routine monitoring of the state of the global climate system (e.g., annual precipitation anomalies, see figure) by the global network of climate monitoring and analyses centres operated by national meteorological services and other organizations.

**(b) Climate Change Detection and Attribution**

The Intergovernmental Panel on Climate Change (IPCC) periodic assessment reports focus particularly on the detection and description of observed climate change and the scientific basis for its attribution to greenhouse warming or other natural or human causes. GCOS observations play a fundamental role in the work of the IPCC.
Continuous, comprehensive, high quality climate observations are essential for almost every aspect of climate research. The observational data record both enables and emerges from research-based process studies aimed at providing an eventual robust scientific basis for modelling and prediction of the climate system. Many of the immediate and longer-term benefits from climate observations are apparent from the published findings of research carried out under the auspices of the World Climate Research Programme, the International Geosphere-Biosphere Programme and other international climate research programmes.

For example, blending observational data into climate models, e.g. through data assimilation, helps provide us with a more consistent climate data record. In order to continuously improve confidence in climate model predictions on all temporal and spatial scales, historical data records are required since models are able to ‘learn’ from past data. With improving capability to realistically simulate the climate system by models comes the interest for using models in combination...
with observed data to create consistent climate records, the so-called “reanalyses”.

(f) Climate Applications and Services

Through a hierarchy of national, regional and global climate monitoring centres, governments and businesses world-wide now keep track, on an almost daily basis, of the state of the climate and its impact

(d) Operational Climate Prediction

Increasingly, following the highly successful TOGA (Tropical Ocean Global Atmosphere) programme of the WCRP, operational centers in several countries are providing routine climate predictions up to a year ahead. GCOS observations provide the essential starting point for prediction of phenomena like the El Niño Southern Oscillation (ENSO) (see figure below). Observations of the atmosphere and the ocean surface and sub-surface (e.g., ocean heat content, ocean salinity) are at the basis of such predictions.

(a) Impacts, Vulnerability and Adaptation

Increasing demands are being placed on climate and climate-related observational records and analysis techniques, since governments and society are in urgent need to be better informed of the nature of any systematic long-term changes in climate, to be able to comprehensively and reliably assess the risks incurred by the impact of climate change, e.g. droughts, and to decide on adaptive measures to mitigate these risks. The community expectation as to what can be learned from the observational climate record has never been greater.

Drought destroyed the corn crop of this farmer in Lisutu, Zambia (Photo: Richard Lord, 2002)

on commodity prices and financial markets generally. For this purpose, many sophisticated climate monitoring products are becoming available for widespread use. The routine prediction of, e.g., the ENSO being observed, modelled and predicted on a routine basis, is critical for societies, e.g. in the areas of agriculture, health and water resource management, given their sometimes dramatic impacts. The Climate Information and Prediction Services (CLIPS) programme of the WMO World Climate Programme coordinates worldwide activities in this area, in collaboration with National Meteorological Services.

**UN Framework Convention on Climate Change**

The achievement of the objectives of the UNFCCC is almost entirely dependent on comprehensive understanding, monitoring, modelling and prediction of the behaviour of the climate system and the impacts of climate on humans and the natural environment. None of this would be possible without comprehensive world-wide networks of climate observations and a properly functioning GCOS.

Although the obligations of Parties (signatory states) in respect of climate observations were set down in Articles 4 and 5 of the Convention, it was not until the late 1990s that the contribution of GCOS to the working of the Convention began to be actively pursued within the policy agencies of the Parties. Through mandatory national communications to the Convention, Parties now regularly provide updates on their activities in support of the Convention, and, in the area of systematic observation, in support of GCOS.

Climate observations are of as great importance, and value, to the adaptation thrust as they are to the mitigation thrust of the UNFCCC and GCOS observations will provide an essential input to **UNFCCC Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change**. Climate observations are equally central to the ultimate purpose of other environmental conventions such as that on desertification. Without good observations, little can be understood or done. With good observations underpinning scientific understanding, a great deal is possible and much is already being achieved.

**GCOS as the Climate Observation Component of GEOSS**

GCOS is the climate observation component of the **Global Earth Observation System of Systems (GEOSS)**. Established following a series of ministerial-level summits, GEOSS is an intergovernmental initiative building upon existing national, regional, and international systems, with the aim to provide comprehensive, coordinated Earth observations from all platforms for the benefit of societies worldwide. GEOSS is organized around nine key societal areas: agriculture, ecosystems, biodiversity, weather, climate, water, disasters, energy, and health. Since almost all of these societal benefit areas are also ultimately the strong beneficiaries of climate observations, GEOSS provides the overall framework for further implementation of GCOS networks and systems, by fostering enhanced integration and interoperability among and between its component observing systems (e.g., through the WMO Integrated Global Observing System).
GCOS at the National Level

Almost all climate observing networks, systems, data centres and analysis centres are funded, managed and operated by national entities within their own requirements, plans, procedures, standards and regulations. Needs of the UNFCCC and other users for global climate observations and products can be addressed only if plans are developed and implemented in a coordinated manner by national organizations.

Such mechanisms are usually best sustained when national coordinators or focal points are designated. Their assigned responsibility includes coordinated planning and implementation of systematic climate observing systems across the many national departments and agencies involved with their provision.

In several countries, **National GCOS Coordinators** and **National GCOS Committees** provide effective coordination of national and local institutions on GCOS matters, e.g. through regular workshops, meetings, and public campaigns. In addition, **National Focal Points** for GCOS and related Climatological Data in more than 130 countries liaise within the National Meteorological Services, on GSN and GUAN issues related to data availability and quality.

Regional Activities

Regional Workshop Programme

One of the major thrusts of Global Climate Observing System Secretariat has been the realization of its Regional Workshop Programme. This Programme, launched in 2000 following an invitation from the Conference of the Parties to the UNFCCC in November 1999, comprised workshops and follow-up meetings in ten developing regions. The central goal of the GCOS Regional Workshop Programme was to initiate processes in developing regions that would lead to real, substantial, and lasting improvements in global climate observing systems. The specific objectives for each workshop were:

- to assess the contribution of each region to GCOS baseline networks;
- to help participants understand guidelines for reporting on systematic observations to the UNFCCC;
- to identify national and regional needs and deficiencies for climate data, including needs for assessing climate impacts, conducting vulnerability analyses, and undertaking adaptation studies; and
- to initiate the development of a Regional Action Plan for improving climate observing systems.

GCOS has now completed all ten regional workshops in the Programme and all associated Regional Plans.

Climate for Development in Africa

Follow-up actions to the Regional Workshop Programme include the evolving Climate for Development in Africa Programme (ClimDev Africa), an integrated, multi-partner programme addressing:

- climate observations,
- climate services,
- climate risk management, and
- climate policy needs in Africa.

The user-driven programme will support efforts to achieve the Millennium Development Goals. In addition to GCOS, principal partners are the UN Economic Commission for Africa, the African Union, the African Development Bank, the World Meteorological Organization, and potential donors including the UK Department for International Development.

**Improving the System**

In order to bring GCOS to its operational-design level, and provide support needed from the scientific, donor, and host communities to implement selected improvements to GCOS, especially in developing countries, the GCOS System Improvement Programme has been one...
of the leaders in the global effort to maintain systematic climate observations. The program provides assistance through global, regional, and bi-lateral efforts primarily through the support of atmospheric observing stations, but also via support for the GCOS Lead Data Center at the US National Climatic Data Center, the operation of the Global Observing Systems Information Center, as well as support to selected improvements in the Global Atmosphere Watch. On the regional level, the programme supports bi-lateral climate agreements between partners for the Pacific Islands regional GCOS programme. With the Pacific being of critical importance to climate (e.g., the source of El Niño) and given the general sparseness of data from this critical climate region, a strong regional program in support of GCOS is a benefit to the global climate observing effort.

The purpose of the GCOS Cooperation Mechanism is to identify and make the most effective use of resources available for improving climate observing systems in developing countries, to enable them to collect, exchange, and utilize data on a continuing basis in support of the UNFCCC. In particular, the GCOS Cooperation Board is established to facilitate cooperation amongst donor countries, between donor and recipient countries and amongst countries and existing funding and implementation mechanisms, in addressing high-priority needs for the improvement of global observing systems for climate in developing countries. It aims to ensure the most effective use of voluntary contributions for meeting such needs.
OBSERVING THE GLOBAL CLIMATE SYSTEM FOR BETTER UNDERSTANDING AND BETTER DECISION-MAKING
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