GLOBAL CLIMATE OBSERVING SYSTEM

WMO | of UNESCO | UNEP | ICSU

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC

Executive Summary

October 2004

GCOS – 92 (ES)

(WMO/TD No. 1244)

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL COUNCIL FOR SCIENCE

NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Editorial Note: This report has been produced without editorial revision by the WMO Secretariat. It is not an official WMO publication and its distribution in this form does not imply endorsement by the Organization of the ideas expressed.

Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC

Executive Summary

October 2004

GCOS - 92 (ES)

(WMO/TD No. 1244)

Table of Contents

Note:

GCOS is co-sponsored by WMO, IOC of UNESCO, UNEP and ICSU
GOOS is co-sponsored by WMO, IOC of UNESCO, UNEP and ICSU
GTOS is co-sponsored by FAO, WMO, UNESCO, UNEP and ICSU
WWW and GAW are sponsored by WMO

Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC

Executive Summary

1. Introduction

The Global Climate Observing System (GCOS), in consultation with its partners, has prepared an implementation plan that addresses the requirements identified in the Second Report[1] on the Adequacy of Global Observing Systems for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC) (hereafter called the 'Second Adequacy Report'). This plan specifically responds to the request of the Conference of the Parties (COP) to the UNFCCC in its decision 11/CP.9 to develop a 5- to 10-year implementation plan. As requested, the implementation plan (the Plan):

- Builds on the Second Adequacy Report and draws on the expressed views of Parties with respect to that report;
- Takes into consideration existing global, regional and national plans, programmes and initiatives, including those of the European Global Monitoring for Environment and Security programme and the Integrated Global Observing Strategy Partnership, as well as the plans of the Group on Earth Observations;
- Is based on extensive consultations with a broad and representative range of scientists and data users, including an open review of the Plan before its completion;
- Includes indicators for measuring its implementation;
- Identifies implementation priorities and resource requirements.

2. Meeting the Needs of the UNFCCC for Climate Information

This Plan, if fully implemented by the Parties both individually and collectively, will provide those global observations of the Essential Climate Variables and their associated products, to assist the Parties in meeting their responsibilities under Articles 4 and 5 of the UNFCCC. In addition, it will provide many of the essential observations required by the World Climate Research Programme and Intergovernmental Panel on Climate Change. Specifically the proposed system would provide information to:

- Characterize the state of the global climate system and its variability;
- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- Enable projection of global climate change information down to regional and local scales;
- Enable characterization of extreme events important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

As noted in the Second Adequacy Report, **"Without urgent action and clear commitment of additional resources by the Parties, the UNFCCC and intergovernmental and international agencies, the Parties will lack the information necessary to effectively plan for and manage their response to climate change"**.

[1] The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC, GCOS-82, April 2003 (WMO/TD No. 1143).

2.1. Essential Climate Variables

The Second Adequacy Report established a list of the Essential Climate Variables (ECVs) (see Table 1) that are both currently feasible for global implementation and have a high impact on the requirements of the UNFCCC. Clearly, there are additional climate variables that are important to a full understanding of the climate system. Many of these are the subjects of current on-going research, but are not currently ready for global implementation on a systematic basis. As our knowledge and capabilities develop, it is expected that some of these variables will be added to the list of ECVs.

Table 1. Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements.

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **Upper-air:** Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. **Composition:** Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[2], Aerosol properties.
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial[3]	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 (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance.

2.2. Implementation Actions and Associated Cost Implications

The Plan includes over a hundred specific actions to be undertaken over the next 10 years, across the three domains. Many of the proposed actions are already underway, at the least as part of research activities, and most of the required coordination mechanisms have been identified. The costs of undertaking these actions are summarized in Table 2 by cost and type of action. Priority should be given over the first 5 years to those actions that will address the critical issues identified within the Second Adequacy Report, specifically improving access to high-quality global climate data; generating integrated global analysis products; improving key satellite and *in situ* networks; and strengthening national and international infrastructure, including the enhancing of the full participation of least-developed countries and small island developing states.

[2] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs).

[3] Includes runoff ($m^3\ s^{-1}$), ground water extraction rates ($m^3\ yr^{-1}$) and location, snow cover extent (km^2) and duration, snow depth (cm), glacier/ice cap inventory and mass balance ($kg\ m^{-2}\ yr^{-1}$), glacier length (m), ice sheet mass balance ($kg\ m^{-2}\ yr^{-1}$) and extent (km^2), permafrost extent (km^2), temperature profiles and active layer thickness, above ground biomass (t/ha), burnt area (ha), date and location of active fire, burn efficiency (%vegetation burned/unit area).

The Plan is both technically feasible and cost-effective in light of the societal and economic importance of climate observations to the considerations of the UNFCCC. It involves global extension and improved operating practices for observing systems that are currently supported and functioning for other purposes. While its implementation is dependent on national efforts, success will be achieved only with international cooperation, coordination and in some cases, sustained technical and financial support for the key global reference observation sites in least-developed countries. While the Plan focuses on meeting global requirements, such global data and products are also relevant to regional and local needs. In the case of extreme events, which are usually of a small scale and/or short-lived, the Plan provides for global estimates of many such phenomena. Finally, the Plan will be updated over time as networks and systems become operational and as new knowledge and techniques become available.

Table 2. Summary of incremental annually recurring costs (in US-$).

Cost Category*	Number of Common Actions	Number of Atmospheric Actions	Number of Oceanic Actions	Number of Terrestrial Actions	Total
I – <100K	4	8	7	11	30
II – 100K-1M	8	4	11	13	34
III – 1M-10M	2	11	17	11	42
IV – 10M-30M	1	8	6	2	17
V – 30M-100M	0	1	0	0	1
Uncosted Actions[4]	6	-	-	-	6
Total Number	21	32	41	37	131
Estimated total cost profile[5]	**34.4M**	**282.8M**	**211.2M**	**102.6M**	**631.0M**

*K: 1000s of US-$, while M: 1 000 000s of US-$.

The estimated costs are incremental to the expected future support of the current observing systems and associated infrastructure. The cost estimates include both the costs of transition of current systems from research to operations as well as those wholly associated with new systems. The new observations and infrastructure for climate will serve many applications other than just the climate needs of the Parties. For example, as the climate component of the proposed Global Earth Observation System of Systems (GEOSS), they would meet the needs of many other GEOSS applications. Satellites, though a major cost item accounting for some 40% of the total cost profile, provide unique global coverage. In all cases the costs noted are simply indicative and would need to be refined by those charged with executing the actions.

Key Action 1: Parties need, both individually and collectively, to commit to the full implementation of the global observing system for climate, sustained on the basis of a mix of high-quality satellite measurements, ground-based and airborne *in situ* and remote-sensing measurements, dedicated analysis infrastructure, and targeted capacity-building.

3. Agents for Implementation

The global observing system for climate requires observations from all domains – terrestrial, oceanic, and atmospheric – which are then transformed into products and information through analysis and integration in both time and space. Since no single technology or source can provide all the needed observations, the ECVs will be provided by a composite system of *in situ* instruments on the ground, on ships, buoys, floats, ocean profilers, balloons, samplers, and aircraft, as well as from all forms of remote sensing including satellites. Meta-data (i.e., information on where and how the observations are taken) are absolutely essential, as are historical and palaeo-climatic records that set the context

[4] Costs covered in domain actions.

[5] Estimated total cost profile assumes average costs (in US-$) of 0.1M for Category I actions, 0.5M for Category II, 5.0M for Category III, 20.0M for Category IV, and 65.0M for Category V.

for the interpretation of current trends and variability. Although these individual activities are to be coordinated internationally through a variety of programmes, organizations and agencies, success will depend mainly on national and regional entities that will translate the Plan into reality. Collectively, all of these entities are referred to in the Plan as the 'Agents for Implementation'.

The Plan outlines a comprehensive programme that marshals contributions from virtually all countries and organizations dealing with Earth observations and requires continuing and strengthened coordination and performance monitoring. An International Project Office is needed to help coordinate the activities of the component elements of the system, to interact with regional bodies addressing aspects of the Plan, to monitor the performance of the system, to identify deficiencies in the system, and to coordinate measures to correct such deficiencies. It could also oversee the implementation of the GCOS Cooperation Mechanism (see Section 3.4 in the Executive Summary).

Key Action 2: Parties need to provide support for an International Project Office to provide overall coordination, to monitor performance, to report regularly on implementation, to initiate corrective actions, and to oversee the GCOS Cooperation Mechanism.

3.1. International Agents

The networks, systems, data centres and analysis centres identified within this Plan are almost all funded, managed and operated by national entities within their own requirements, plans, procedures, standards and regulations. This Plan calls on all contributing networks and systems to respond to the actions contained in it and, where appropriate, to adjust their plans, procedures and operations to address the specified climate observing requirements. GCOS will continue to emphasize with all relevant international and intergovernmental organizations the need for their Members to: (a) undertake coordination and planning for systematic climate observations where this is not currently being undertaken; and (b) produce and update on a regular basis plans for their contributions to the global observing system for climate, taking into account the actions included in this Plan. For this to be effective, it will also be essential for the Parties to ensure that their requirements for climate observations are communicated to these international and intergovernmental organizations.

Key Action 3: The international and intergovernmental organizations need to incorporate the relevant actions in this Plan within their own plans and actions.

3.2. Regional Agents

For some observations, regional planning and implementation of climate observing system components is particularly effective as a means of sharing workloads and addressing common issues. The GCOS Regional Workshop Programme has established a framework for interested nations to work together to optimize their networks and to identify both national and GCOS network needs in each region. Regional Action Plans, one of the outputs of these workshops, are being developed and some elements of them are finding support from member nations and/or donors for implementation.

Key Action 4: Parties need to complete development and alignment of Regional Action Plans for observations in the context of this Plan.

3.3. National Agents

The 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. As noted in the Second Adequacy Report, with the exception of the main meteorological networks and the planning for individual activities, most climate-observing system activities are poorly coordinated, planned and integrated at the national level. All Parties need national coordination mechanisms and national plans for the provision of systematic observation of the climate system. Such mechanisms are usually best sustained when national coordinators or focal points[6] are designated and assigned responsibility to coordinate planning and implementation of systematic climate observing systems across the many departments and agencies involved with their provision.

[6] The GCOS Steering Committee has developed guidelines for such functions.

Key Action 5: Parties are requested to undertake national coordination and planning and produce national plans on their climate observing, archiving and analysis activities that address this Plan.

Reporting by the Parties[7] on systematic climate observation activities as part of their National Communications under the UNFCCC is essential for planning and monitoring the implementation of the global observing system for climate. The response by Parties to the Second Adequacy Report emphasized that accurate and credible information relative to all aspects of climate observations must be exchanged, according to the relevant guidelines (decisions 4/CP.5 and 11/CP.9).

Key Action 6: Parties are requested to submit information on their activities with respect to systematic observation of all ECVs as part of their national communications to the UNFCCC utilizing an updated Supplementary Reporting Format.

3.4. Participation by all Parties

Recognizing the common requirement for information on climate variability and change, the need for all Parties to improve global observing systems for climate in developing countries has been a consistent theme in the considerations by COP on systematic observation. There are many ways that systems can be improved, including for example through developed-country agencies working with organizations and personnel from developing countries, and the donation of equipment and the training of personnel. The GCOS Cooperation Mechanism has been established by a core set of countries to provide a coordinated, multigovernmental approach to address the high-priority needs for stable long-term funding for key elements of the global observing system for climate, especially in least-developed countries, small island developing states and some countries with economies in transition. It will complement and work in cooperation with existing funding and implementation mechanisms (e.g., the World Meteorological Organization (WMO) Voluntary Cooperation Programme, the United Nations Development Programme, and the many national aid agencies), many of which deal with climate-related activities and support capacity-building in particular.

Key Action 7: Parties are requested to address the needs of least-developed countries, small island developing states and some countries with economies in transition for taking systematic climate observations by encouraging multilateral and bilateral technical cooperation programmes to support global observing systems for climate and by participating in the GCOS Cooperation Mechanism.

4. Access to Climate Data

4.1. High-Quality Climate Data

Ensuring that high-quality climate data records are collected, retained and made accessible for use by current and future generations of scientists and decision-makers is a key objective of this Plan. As a result, investment in the data management and analysis components of the system is as important as the acquisition of the data. The Plan calls for strengthening the current International Data Centres[8] and seeking commitments for new Centres so that all ECVs have an appropriate infrastructure.

Key Action 8: Parties need to ensure that International Data Centres are established and/or strengthened for all ECVs.

The flow of data to the user community and to the International Data Centres is not adequate for many ECVs, especially for those of the terrestrial observing networks. Lack of national engagement and/or resources, restrictive data policies, and inadequate national and international data-system infrastructure are the main causes of the inadequacy.

[7] Reports are available through the UNFCCC Secretariat.

[8] International Data Centres are responsible for monitoring, product preparation and dissemination as well as archiving.

In decision 14/CP.4, the COP urged Parties to undertake free and unrestricted exchange of data to meet the needs of the Convention, recognizing the various policies on data exchange of relevant intergovernmental and international organizations. Yet, as the Second Adequacy Report points out repeatedly with respect to almost all of the variables, the record of many Parties in providing full access to their data is poor. This Plan is based on the free and unrestricted exchange of all data and products and incorporates actions to: develop standards and procedures for meta-data and its storage and exchange; to ensure timely, efficient and quality-controlled flow of all ECV data to climate monitoring and analysis centres and international archives, and to ensure that data policies facilitate the exchange and archiving of all ECV data and associated meta-data.

4.1.1. International Standards and Guidance

The international programmes and Technical Commissions of WMO and the Intergovernmental Oceanographic Commission (IOC) exist to provide the standards, regulatory material and guidelines for the collection of climate data in the Atmospheric and Oceanic Domains. There is at present no equivalent international body or technical commission for climate observations for the Terrestrial Domain. A key requirement for successful implementation of this Plan is the urgent establishment of such an international body by the relevant international organizations, including WMO, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU).

Key Action 9: The relevant intergovernmental organizations including WMO, FAO, UNEP, and ICSU need to create a mechanism for establishing standards, regulatory material and guidelines for terrestrial observing systems.

4.1.2. GCOS Climate Monitoring Principles

The GCOS Climate Monitoring Principles (GCMPs) provide basic guidance regarding the planning, operation and management of observing networks and systems, including satellites, to ensure that high-quality climate data are available and contribute to effective climate information. The GCMPs address issues such as the effective incorporation of new systems and networks; the importance of calibration, validation and data homogeneity; the uninterrupted operation of individual stations and systems; the importance of additional observations in data-poor regions and regions sensitive to change; and the crucial importance of data management systems that facilitate access, use and interpretation of the data. These principles have been adopted or agreed by the UNFCCC, WMO, Committee on Earth Observation Satellites (CEOS) and other bodies. The implementation actions now call on all data providers to adhere to the GCMPs and to initiate effective programmes of data quality control.

Key Action 10: Parties need to ensure that their climate-observing activities which contribute to GCOS adhere to the GCMPs.

4.1.3. Data Stewardship and Management

Climate observations that are well documented, and have good meta-data about the systems and networks used to make them, become more valuable with time. The creation of climate-quality data records is a fundamental objective of the global observing system for climate. International standards and procedures for the storage and exchange of meta-data need to be developed and implemented for many climate observing system components, including those of the operational satellite community. It is essential that all such data be properly archived and managed with the full expectation that they will be reused many times over in the future, often as a part of reprocessing or reanalysis activities. Good stewardship of the data also requires that data be migrated to new media as technology changes, be accessible to users, and be made available with minimal incremental costs.

Key Action 11: International standards for meta-data for all ECVs need to be established and adopted by the Parties in creation and archiving of climate data records.

4.2. Domain-Specific Observing Networks and Systems

The global observing system for climate is an integrated system comprised of complementary satellite and *in situ* components. With greater attention to climate monitoring issues, satellites are expected to become an increasingly more important means of obtaining observations globally for comparing climate variability and change over different parts of the Earth. Therefore, a system of satellites and satellite sensors implemented and operated in a manner that ensures the long-term accuracy and homogeneity of the data through the adoption of the GCMPs, is a high priority within the Plan. At the same time, some ECVs will remain dependent on *in situ* observations for long-term trend information, for calibration and validation of satellite records, and for measuring variables not amenable to direct satellite measurement (e.g., sub-surface oceanic ECVs). Consistent with the role of satellites, the Plan details the substantial effort required to ensure the operation and refinement of *in situ* networks.

Some of the key domain-specific components merit highlighting.

4.2.1. Atmospheric Domain

Many atmospheric networks and systems, including some satellite components, are relatively mature, having been in existence for several decades, albeit generally for non-climate purposes. As a result, a key action for this domain is to ensure the full global implementation of these networks and systems for climate purposes. Other key actions respond to the need for additional baseline observations to enable full use of existing measurements, improvements relating to a few important but poorly-observed variables, and the use of reanalysis techniques to generate needed climate information products.

The GCOS Surface Network (GSN), together with the other surface atmospheric networks, provides the basic observations of the surface climate in which we live. The GCOS Upper-Air Network (GUAN), together with related satellite observations, provides a baseline for the upper atmosphere. Network and system improvements are proposed in many areas, including the extension of the GSN to include all relevant surface ECVs. Indeed, the advantages of collocated measurements imply that greater efforts should be made to establish sites where many of the ECVs for both the Atmospheric and Terrestrial Domains are observed. In the upper atmosphere, water vapour plays a critical role in climate feedback, and supplements to the current baseline observations are needed from reference networks and GPS-based techniques.

Key Action 12: Parties need to: (a) ensure the implementation and full operation of the baseline networks and systems contained in Table 3 in accordance with the GCMPs, in order to specifically resolve reported problems, to ensure the exchange of these data with the international community, and to recover and exchange historical records; (b) establish a high-quality reference network of about 30 precision radiosonde stations and other collocated observations; and (c) exploit emerging new technology including the use of radio-occultation techniques and ground-based Global Positioning System (GPS) sensing of the total water column.

Table 3. Existing atmospheric baseline networks and systems.

- GCOS Surface Network (GSN).
- The atmospheric component of the composite surface ocean observation system including sea-level pressure (see Key Actions 17 and 18).
- GCOS Upper-Air Network (GUAN).
- Global Atmosphere Watch (GAW) global CO_2 network.
- MSU-like radiance satellite observations.
- Total solar irradiance and Earth radiation budget satellite observations.

With the societal importance of precipitation, there is further urgent need for improved global analyses including unbiased estimation of precipitation over the oceans and at high latitudes and further development and understanding of the implications of automation on precipitation measurements.

Key Action 13: Parties are urged to: (a) establish a reference network of precipitation stations on key islands and moored buoys around the globe and at high latitudes; (b) submit national precipitation data (preferably hourly data) to the International Data Centres; and (c) support the further refinement of satellite precipitation measurement techniques.

The total solar irradiance and Earth radiation budget measurements provide overall monitoring of the solar radiation and the net greenhouse effect within the atmosphere. Clouds, as well as water vapour, strongly affect this Earth radiation budget and provide the most uncertain feedbacks in the climate system. It is vital to maintain long-term records concerning the overall radiation of the Earth. Cloud properties are of particular importance and research, some of which is in progress, is needed to improve the monitoring of clouds. Surface radiation measurements over land are an important complementary observation and the baseline surface radiation network needs to be extended to achieve global coverage.

Key Action 14: Parties need to: (a) ensure the continued operation of satellite measurements of the Earth radiation budget and solar irradiance (e.g., the NASA Earth Radiation Budget Experiment); and (b) support research to extend and improve current capabilities for monitoring clouds as a high priority.

Greenhouse gases and aerosols are the primary agents in forcing climate change; continuous observations that are spatially and temporally homogeneous are therefore required. For the greenhouse gases, elements of the needed networks are in place but extension and improved attention to calibration are needed. Aerosols are a complex variable and the Plan proposes a key action in the establishment of an improved reference network and a global network for the aerosol-related optical depth variable.

Key Action 15: Parties need to: (a) fully establish a baseline network for key greenhouse gases; (b) improve selected satellite observations of atmospheric constituents; and (c) extend existing networks to establish a global baseline network for atmospheric optical depth.

4.2.2. Oceanic Domain

New technology, developed and proven by the oceanic climate research programmes of the 1990's, has allowed the ocean community to design, and commence implementation of, an initial oceanic climate observing system. The first action of the initial system is the global implementation of the surface and sub-surface networks, including the establishment of data analysis systems. This will allow for a composite system of satellite and *in situ* observations collected by operational and research groups to be synthesized into information products. Sustaining this system will require national designation of and support for Agents for Implementation, and the establishment of effective collaboration between research and operational groups. This will also require the continuity of existing and predominantly research-based *in situ* and satellite activities.

Key Action 16: Parties need to: (a) complete and sustain the initial oceanic observing system for climate; (b) designate and support national Agents for Implementation for implementing this system; (c) establish effective partnerships between their ocean research and operational communities towards implementation; and (d) engage in timely, free and unrestricted data exchange.

The surface ocean network will provide information about the patterns of ocean surface temperature, pressure, winds, salinity, sea level, waves and sea ice that are important both to the global climate and its regional distribution and to marine resources and coastal societies. In particular, sea ice, which plays a key and complex role in climate feedback, requires continued research into improved *in situ* and satellite measurements.

The surface observing network depends critically on the continuity of satellite observations, most of which are in research rather than operational status (Table 4), and on the full implementation of the *in situ* activities identified in this Plan.

Key Action 17: Parties need to ensure climate quality and continuity for essential ocean satellite observations (see Table 4).

Table 4. Essential ocean satellite systems.

• Sustained support for vector-wind (scatterometer), sea-ice, sea-surface temperature (microwave and infra-red) and ocean-colour measurements. • Continuous coverage from altimeters to provide high-precision and high-resolution sea-level measurements (1 high-precision and 2 lower-precision altimeters).

Key Action 18: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) the GCOS baseline network of tide gauges; (b) an enhanced drifting buoy array; (c) an enhanced Tropical Moored Buoy network; (d) an enhanced Voluntary Observing Ships Climatology (VOSClim) network; and (e) a globally-distributed reference mooring network.

The sub-surface ocean network will provide critical information on ocean climate variability and change. The network will provide a capacity for monitoring the regional oceanic uptake of heat, freshwater and carbon, and identification of abrupt climate change arising from changes in the planetary hydrological cycle processes. In association with the surface observations, they also provide the basis for seasonal-to-interannual predictions that can be critical in giving forecasts of the likelihood of extreme climatic events.

Key Action 19: Parties need to provide global coverage of the sub-surface network by implementing and sustaining: (a) the Argo profiling float array; (b) the systematic sampling of the global ocean full-depth water column; (c) the Ship-of-Opportunity Expendable Bathythermograph (XBT) trans-oceanic sections; and (d) the Tropical Moored Buoy and reference mooring networks referred to in Key Action 18 above, as well as the satellite altimetry system described in Table 4.

In recognition of the importance of potential changes to the ocean carbon cycle and marine ecosystems, the Plan contains a number of important research and implementation actions dealing with the establishment of an observing network for the partial pressure of carbon dioxide (pCO_2) and the measurement of the state and change of carbon sources and sinks in the oceans.

Finally, continuing climate research and technology programmes for the oceans are needed to enhance the efficiency and effectiveness of observing efforts, and to develop capabilities for important climate variables that cannot currently be observed globally. This need for enhanced capability is particularly acute for remote locations, for improved understanding of the ocean ecosystems, for improving the estimates of uncertainty, and for understanding the mechanisms of climate change.

4.2.3. Terrestrial Domain

The climate observing system in the Terrestrial Domain remains the least well-developed component of the global system, whilst at the same time there is increasing significance being placed on terrestrial data for climate forcing and understanding, as well as for impact and mitigation assessment.

The Plan proposes actions designed to achieve an initial coordinated and comprehensive observational programme for all terrestrial ECVs. The nature of the Terrestrial Domain is such that priority is being placed on obtaining global products for all ECVs from a range of research-level satellite sensors supported by an increasing number of reference and baseline *in situ* networks.

Key Action 20: Parties are urged to support the operational continuation of the satellite-based products given in Table 5.

Table 5. Priority terrestrial satellite products.

- Daily global albedo from geostationary and polar orbiting satellites.
- LAI and fAPAR products to be made available as gridded products.
- Gridded fire and burnt area products through a single International Data Centre.
- Snow cover of both hemispheres.
- Digital elevation maps of the ice sheet surfaces and full glacier inventory from current spaceborne cryosphere missions.
- Specification and production of land-cover characterization data sets.

A coordinated reference network is needed for: *in situ* observations of the fullest possible range of terrestrial ECVs and associated details relevant to their application in model validation; process studies; validation of observations derived from Earth observation satellites; and to address intrinsic limitations in some of these, such as the saturation of LAI measurements. Opportunities for collocation of Atmospheric and Terrestrial Domain reference network sites should be sought whenever possible.

Key Action 21: Parties are urged to develop a global network of at least 30 reference sites (collocated with atmospheric sites if possible) to monitor key biomes and to provide the observations required in the calibration and validation of satellite data.

The hydrological variables are of critical societal importance. Many are observed but not well exchanged for the purposes of assessing global climate change. The proposed international body (Key Action 9 above) is intended to establish standards for, and to facilitate the exchange of, terrestrial data for climate and other purposes. The Plan proposes specific actions to continue with the implementation of the Global Terrestrial Networks (GTNs) for hydrology (including specific lakes and rivers components), for glaciers and for permafrost.

Key Action 22: Parties are urged to: (a) fill the identified gaps in the global networks for permafrost, glaciers, rivers and lakes; (b) provide support for the designated International Data Centres; and (c) submit current and historical data to the International Data Centres.

5. Availability of Climate Products

Use of observations for policy and planning purposes depends on access to information beyond the basic observations. To meet the needs of all nations for climate information, the global observing system for climate must generate useful climate products. The preparation of climate products almost invariably involves the integration of data in time and space, as well as the blending of data from different sources. Some products, such as reanalysis to climate standards, involve extensive data set preparation and significant computing and data management resources, and implicitly require estimation of uncertainties. Providing access to climate information for all Parties will involve significant information technology infrastructure. The best use of available resources will come via international coordination of these activities. Therefore, a sustained and coordinated application of reanalysis is one of the key actions of this Plan for all domains.

Key Action 23: Parties are urged to adopt an internationally-coordinated approach to the development of integrated global climate products and to make them accessible to all Parties. As far as possible, these products should incorporate past data covering at least the last 30 years in order to serve as a reference for climate variability and change studies.

Key Action 24: Parties are urged to give high priority to establishing a sustained capacity for global climate reanalysis, to develop improved methods for such reanalysis, and to ensure coordination and collaboration among centres conducting reanalyses.

6. Improving the System

Our ability to measure some key and emerging ECVs from *in situ* and remote sensing systems (both surface- and satellite-based) is limited by the lack of suitable instruments and techniques. The limitation can vary all the way from difficulties with the fundamental observing technique to those associated with instrumentation, algorithms, suitable calibration/validation techniques, spatial and/or temporal resolution, ease of operation, and cost.

The development, demonstration, and validation of existing and new techniques are vital to the future success of the global observing system for climate. It is critically important that as new global satellite-based observations of environmental variables are made, the validation of both the measurements themselves (e.g., radiances) and the retrieval algorithms be carried out under a sufficiently broad range of conditions that they can be confidently applied in the creation of a global data sets.

Research is needed to improve the ability to blend different data sets and/or data sources into integrated products. As new types of data are assimilated into models, it will also be important to understand the error characteristics of the new data and the models used. Data assimilation for climate purposes is still in an early stage of development and requires continued research support. As these developments occur, reprocessing of data to take advantage of the new knowledge will be vital to sustained long-term records.

(Intentionally blank)

Agents for Implementation

Intergovernmental organizations sponsoring component observing systems or activities:

- UNESCO and IOC – geology, Earth surface and ocean observing systems.
- WMO – meteorological, hydrological and atmospheric constituent observing systems.
- UNEP – environmental observations.
- FAO – land-surface, land-cover, water-use observations.
- ICSU – research into most observing systems.

Regional and specialized intergovernmental organizations sponsoring and/or operating component observing or analysis systems:

- EUMETSAT – Operational meteorological geostationary satellite systems and (soon) polar orbiting systems.
- ESA – Research and development environmental satellite systems.
- ECMWF – Integrated global analysis systems.

National agencies sponsoring and operating global satellite observing systems:

- USA, NOAA/NESDIS – Operational meteorological polar orbiting and geostationary satellite systems.
- USA, NASA – Research and development environmental satellite systems.
- Japan, JMA – Operational meteorological geostationary satellite systems.
- Japan, JAXA – Research and development environmental satellite systems.
- Russian Federation, ROSHYDROMET – Operational meteorological polar orbiting and geostationary satellite systems.
- Russian Federation, FSA – Research and development environmental satellite systems.
- China – Operational meteorological polar orbiting and geostationary satellite systems.
- India, ISRO – Research and development environmental satellite systems.
- India, IMD – Operational meteorological geostationary satellite systems.
- France, CNES – Operational polar orbiting satellite systems.

Intergovernmental Technical Commissions dealing with climate observations:

- WMO/IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) – Comprehensive Global Ocean Observing System.
- WMO Commission for Basic Systems (WMO CBS) – Responsible for the World Weather Watch (WWW) and its components: the Global Observing System (GOS), Global Telecommunication System (GTS), Global Data Processing System (GDPS) as well as WMO Space Programme.
- WMO Commission for Atmospheric Science (WMO CAS) – Atmospheric chemistry. Lead Commission for the Global Atmosphere Watch (GAW).
- WMO Commission for Instruments and Methods of Observation (WMO CIMO) – Standardization and compatibility of instrumentation. Instrumentation inter-comparisons.
- WMO Commission for Hydrology (WMO CHy) – Operational hydrology including observing networks, collection, processing, archiving and retrieval of hydrological data. Standardization of methods, procedures and techniques.
- WMO Commission for Climatology (WMO CCl) – Lead Commission for the World Climate Data and Monitoring Programme. Data archaeology.

Scientific Programmes and Advisory/Steering committees to the intergovernmental bodies:

- World Climate Research Programme (WCRP) – sponsored by ICSU, WMO and IOC of UNESCO – comprehensive climate research programme.
- International Geosphere Biosphere Programme (IGBP) – sponsored by ICSU – programme to understand the interactive physical, chemical and biological processes regulating the total Earth system, the changes in this system, and influences from human actions.
- Intergovernmental Panel on Climate Change (IPCC) – sponsored by UNEP and WMO — assesses scientific, technical and socio-economic information for understanding climate change and its potential impacts.

- GCOS Steering Committee – sponsored by WMO, UNEP, UNESCO, and ICSU – provides scientific, technical and implementation guidance to the GCOS Sponsors and has established 3 domain-based scientific Panels:
    - Atmospheric Observation Panel for Climate (AOPC).
    - Ocean Observation Panel for Climate (OOPC).
    - Terrestrial Observation Panel for Climate (TOPC).

Climate observation systems; GCOS made up of contributions from:

- WMO World Weather Watch (WWW) Global Observing System (GOS) – comprehensive system for observing meteorological variable used in weather forecasting and other related applications.
- WMO Global Atmosphere Watch (GAW) – comprehensive observations of the chemical composition and selected physical characteristics of the atmosphere on global and regional scales.
- Global Ocean Observing System (GOOS) – permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide.
- Global Terrestrial Observing System (GTOS) – programme for observations, modelling, and analysis of terrestrial ecosystems, for facilitated access to terrestrial ecosystem information, and to support sustainable development.

Coordination mechanisms and partnerships supporting observational objectives:

- Coordination Group for Meteorological Satellites (CGMS) – provides a forum in which the Space Agencies have studied jointly with the WMO technical operational aspects of the global network, so as to ensure maximum efficiency and usefulness through proper coordination in the design of the satellites and in the procedures for data acquisition and dissemination.
- Committee for Earth Observation Satellites (CEOS) – international coordinating mechanism charged with coordinating international civil spaceborne missions designed to observe and study planet Earth.
- Integrated Global Observing System-Partnership (IGOS-P) – provides a comprehensive framework to coordinate the common interests of the major space-based and *in situ* systems for global observation of the Earth into integrated observing strategies for a range of “themes” including: oceans, carbon cycle, water cycle, geohazards, coastal observations including coral reefs, atmospheric chemistry, land cover and cryosphere.

GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles[9]*:*

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.

2. A suitable period of overlap for new and old observing systems should be required.

3. The results of calibration, validation and data homogeneity assessments, and assessments of algorithm changes, should be treated with the same care as data.

4. A capacity to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information, should be ensured.

5. Consideration of environmental climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.

6. Uninterrupted station operations and observing systems should be maintained.

7. A high priority should be given to additional observations in data-poor regions and regions sensitive to change.

8. Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.

9. The carefully-planned conversion of research observing systems to long-term operations should be promoted.

10. Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.

Furthermore, satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.

12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.

13. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.

14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.

---

[9] *The ten basic principles were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. The complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.*

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.

16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.

17. Data systems needed to facilitate user access to climate products, meta-data and raw data, including key data for delayed-mode analysis, should be established and maintained.

18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.

19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.

20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

Contributors to the Implementation Plan

Preparation:

This Plan was prepared under the direction of:

Prof. Paul J. MASON
Chairman of the GCOS Steering Committee
Department of Meteorology
University of Reading
READING, United Kingdom

supported by the Chairmen of the GCOS Science Panels (Atmospheric, Ocean and Terrestrial) and the GCOS Secretariat:

Dr Michael MANTON
Chairman, AOPC
Bureau of Meteorology Research Centre
MELBOURNE, Vic., Australia

Dr D.E. HARRISON
Chairman, OOPC
Pacific Marine Environmental Laboratory, NOAA
SEATTLE, WA, USA

Dr Alan BELWARD
Chairman, TOPC
Institute for Environment and Sustainability
European Commission Joint Research Centre
ISPRA, Varese, Italy

Dr Alan R. THOMAS
Director, GCOS Secretariat, WMO
GENEVA, Switzerland

Dr Stephan BOJINSKI
GCOS Secretariat, WMO
GENEVA, Switzerland

Dr Hans TEUNISSEN
GCOS Secretariat, WMO
GENEVA, Switzerland

Integration of the Plan was undertaken by:

Dr James RASMUSSEN
Former Head of the WMO World Weather Watch Department
FREDERICK, MD, USA

supported by:

Dr D. Kirk DAWSON
Former Chairman, GCOS Steering Committee
OKANAGAN FALLS, B.C., Canada

Contributing Authors:

The following persons contributed directly to the preparation of this Plan:

Dr Len BARRIE
Atmospheric Research and Environment Programme, WMO
GENEVA, Switzerland

Prof. Roger G. BARRY
University of Colorado
BOULDER, CO, USA

Dr Osvaldo CANZIANI
IPCC
BUENOS AIRES, Argentina

Dr Howard CATTLE
International CLIVAR Project Office
Southampton Oceanography Centre
SOUTHAMPTON, United Kingdom

Dr Thomas CONWAY
Climate Monitoring & Diagnostics Laboratory, NOAA
BOULDER, CO, USA

Dr Albert FISCHER
Intergovernmental Oceanographic Commission, UNESCO
PARIS, France

Prof. Wilfried HAEBERLI
Dept. of Geography, University of Zurich-Irchel
ZURICH, Switzerland

Prof. Sandy HARRISON
School of Geographical Sciences, University of Bristol
BRISTOL, United Kingdom

Prof. Ola JOHANNESSEN
Nansen Environmental and Remote Sensing Centre
BERGEN, Norway

Prof. Philip JONES
Climatic Research Unit
University of East Anglia
NORWICH, United Kingdom

Dr Jack A. KAYE
NASA Office of Science
WASHINGTON, DC, USA

Dr Chet KOBLINSKY
NOAA Office of Global Programs
SILVER SPRING, MD, USA

Dr Rick LAWFORD
International GEWEX Project Office
SILVER SPRING, MD, USA

Dr Thomas MAURER
Global Runoff Data Centre, Federal Institute of Hydrology
KOBLENZ, Germany

Dr Paul W. MENZEL
NOAA/NESDIS
MADISON, WI, USA

Prof. Yunqi NI
Chinese Academy of Meteorological Sciences (CAMS)
BEIJING, China

Prof. Laban OGALLO
Drought Monitoring Centre – Nairobi
NAIROBI, Kenya

Prof. Shaun QUEGAN
Sheffield Centre for Earth Observation Science, University of Sheffield
SHEFFIELD, United Kingdom

Dr Vladimir RYABININ
World Climate Research Programme, WMO
GENEVA, Switzerland

Dr Adrian SIMMONS
European Centre for Medium-Range Weather Forecasts
READING, United Kingdom

Dr Neville SMITH
Bureau of Meteorology Research Centre
MELBOURNE, Australia

Dr Gilles SOMMERIA
World Climate Research Programme, WMO
GENEVA, Switzerland

Dr Makoto SUZUKI
EORC
Japan Aerospace Exploration Agency
TOKYO, Japan

Dr Kevin TRENBERTH
National Center for Atmospheric Research
BOULDER, CO, USA

Prof. Michel VERSTRAETE
Institute for Environment and Sustainability
European Commission Joint Research Centre
ISPRA, Italy

Dr David WILLIAMS
EUMETSAT
DARMSTADT, Germany

Contributors:

Dr Philip ARKIN
Earth System Science Interdisciplinary Centre
University of Maryland
SILVER SPRING, MD, USA

Dr Jerry BROWN
International Permafrost Association
WOODS HOLE, MA, USA

Prof. Edmo J.D. CAMPOS
Universidade de São Paulo
SAO PAULO, Brazil

Mr Kok Kee CHOW
Malaysian Meteorological Service
PETALING JAYA, Malaysia

Prof. Tommy D. DICKY
University of California
SANTA BARBARA, CA, USA

Dr Yoji FURUHAMA
JAXA
TOKYO, Japan

Prof. Johann GOLDAMMER
Global Fire Monitoring Center
FREIBURG IM BREISGAU, Germany

Mr Mitchell D. GOLDBERG
NOAA/NESDIS
CAMP SPRINGS, MD, USA

Dr Raino HEINO
Finnish Meteorological Institute
HELSINKI, Finland

Dr Anthony HOLLINGSWORTH
ECMWF
READING, United Kingdom

Dr Maria HOOD
Intergovernmental Oceanographic Commission, UNESCO
PARIS, France

Dr Johnny A. JOHANNESSEN
Nansen Environmental and Remote Sensing Centre
BERGEN, Norway

Mr Robert KEELEY
Department of Fisheries and Oceans
OTTAWA, Ontario, Canada

Dr Hal KIBBY
US Environmental Protection Agency
CORVALLIS, OR, USA

Dr Jurate Maciunas LANDWEHR
US Geological Survey
RESTON, VA, USA

Mr John LATHAM
Food and Agricultural Organization
ROME, Italy

Dr Valentin MELESHKO
Voekov Main Geophysical Observatory
ST PETERSBURG, Russian Federation

Dr Yukata MICHIDA
University of Tokyo
TOKYO, Japan

Dr David NORSE
University College London
LONDON, United Kingdom

Dr Raphael OKOOLA
University of Nairobi
NAIROBI, Kenya

Mr Kazutoshi ONOGI
Japan Meteorological Agency
TOKYO, Japan

Mr David PARKER
Met Office
Exeter, United Kingdom

Dr Thomas C. PETERSON
NOAA/NESDIS/NCDC
ASHEVILLE, NC, USA

Dr Richard REYNOLDS
NOAA/NESDIS/NCDC
ASHEVILLE, NC, USA

Dr Bruno RUDOLF
Deutscher Wetterdienst
OFFENBACH AM MAIN, Germany

Dr Steve RUNNING
University of Montana
MISSOULA, MT, USA

Dr Johannes SCHMETZ
EUMETSAT
DARMSTADT, Germany

Dr Allen M. SOLOMON
US Environmental Protection Agency
CORVALLIS, OR, USA

Dr Peter K. TAYLOR
Southampton Oceanography Centre
SOUTHAMPTON, United Kingdom

Prof. John TOWNSHEND
University of Maryland
COLLEGE PARK, MD, USA

Dr Robert A. WELLER
Woods Hole Oceanographic Institution
WOODS HOLE, MA, USA

Mr Gregory W. WITHEE
NOAA/NESDIS
SILVER SPRING, MD, USA

Mr Ted YUZYK
Meteorological Service of Canada
OTTAWA, Canada

Endorsement:

The GCOS Steering Committee endorsed the Plan for submission to the UNFCCC. The Steering Committee members are:

Prof. Paul J. MASON (Chairman)
Department of Meteorology, University of Reading
READING, United Kingdom

Mr Kok Kee CHOW
Malaysian Meteorological Service
PETALING JAYA, Malaysia

Dr Yoji FURUHAMA
Office of Satellite Technology, Research and Applications, NASDA
TOKYO, Japan

Dr Anthony HOLLINGSWORTH
ECMWF
READING, United Kingdom

Prof. Ola M. JOHANNESSEN
Nansen Environmental and Remote Sensing Center
BERGEN, Norway

Dr Jack KAYE
NASA Office of Science
WASHINGTON, DC, USA

Dr Valentin MELESHKO
Voeikov Main Geophysical Observatory
ST PETERSBURG, Russian Federation

Prof. Yunqi NI
Chinese Academy of Meteorological Sciences (CAMS)
BEIJING, China

Prof. Laban A. OGALLO
Drought Monitoring Centre – Nairobi
NAIROBI, Kenya

Dr Ilana WAINER
Universidade de São Paulo
SAO PAULO, Brazil

Dr David WILLIAMS
EUMETSAT
DARMSTADT, Germany

Mr Gregory W. WITHEE
NOAA/NESDIS
SILVER SPRING, MD, USA

Mr Ted YUZYK
Meteorological Service of Canada
OTTAWA, Canada

Members Ex-Officio:

Dr Michael MANTON
Chairman, AOPC
Bureau of Meteorology Research Centre
MELBOURNE, Vic., Australia

Dr D.E. HARRISON
Chairman, OOPC
Pacific Marine Environmental Laboratory, NOAA
SEATTLE, WA, USA

Dr Alan BELWARD
Chairman, TOPC
Institute for Environment and Sustainability
European Commission Joint Research Centre
ISPRA, Varese, Italy

(Intentionally blank)

GCOS Secretariat
Global Climate Observing System
c/o World Meteorological Organization
7 *bis,* Avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland
Tel: +41 22 730 8275/8067
Fax: +41 22 730 8052
Email: gcosjpo@wmo.int