GLOBAL CLIMATE OBSERVING SYSTEM

WMO · IOC of UNESCO · UNEP · ICSU

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

IMPLEMENTATION PLAN FOR THE GLOBAL OBSERVING SYSTEM FOR CLIMATE IN SUPPORT OF THE UNFCCC

October 2004

GCOS - 92

(WMO/TD No. 1219)

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

October 2004

GCOS - 92

(WMO/TD No. 1219)

(Intentionally blank)

Table of Contents

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 ($p\mathrm{CO_2}$) 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)

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

1. Background and Introduction

The Global Climate Observing System (GCOS), in consultation with its partners, has developed a plan that, if fully implemented by the Parties, will provide those global observations of the Essential Climate Variables[9] (ECVs) and their associated products that are required by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). This implementation 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 and to submit it to the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the COP at its 21st session in December 2004 (see Appendix 1). The plan draws on the views of the Parties on the Second Report on the Adequacy of Global Observing Systems for Climate in Support of the UNFCCC[10] (hereafter called the 'Second Adequacy Report') submitted by GCOS to SBSTA at its eighteenth session (June 2003). In preparing this implementation plan (the Plan), GCOS has:

- Considered existing global, regional and national plans, programmes and initiatives.
- Consulted extensively with a broad and representative range of scientists and data users, including an open review of the Plan.
- Collaborated closely with the *ad hoc* Group on Earth Observations (GEO) in developing their respective implementation plan.
- Identified implementation priorities, resource requirements and funding options.
- Included indicators for measuring progress in implementation.

The Second Adequacy Report provided a basic framework for an implementation plan through its overarching conclusions and its multiple findings (see Appendix 2). The Second Adequacy Report called for:

- Global coverage.
- Free and unrestricted exchange and availability of observations of the Essential Climate Variables (ECVs) required for global-scale climate monitoring in support of the UNFCCC (Table 6).
- Availability of integrated global climate-quality products.
- Improvements to and maintenance of the global networks and satellites required to sustain these products, including system improvements and capacity-building in developing countries, especially in the least-developed countries and small island developing states.
- Internationally-accepted standards for data and products, especially in the Terrestrial Domain, and adherence to the GCOS Climate Monitoring Principles (GCMPs) (see Appendix 3).

The goal of this Plan is to specify the actions[11] required to implement a comprehensive observing system for the ECVs that would address Articles 4 and 5 of the UNFCCC, and if fully implemented, 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.

---

[9] These are contained in Tables 1 and 6 and were fully described in the Second Adequacy Report and its Technical Annexes.

[10] 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). Appendix 2 herein provides background on the goals, findings and conclusions of the report as well as related activities with the UNFCCC Conference of the Parties (COP) and its Subsidiary Body on Scientific and Technological Advice (SBSTA).

[11] Cross-references to each proposed action are shown throughout the text by referring to the associated finding from the Second Adequacy Report.

- Support the prediction of global climate change.
- Enable projection of global climate change information down to regional and local scales.
- Enable the characterization of extreme events important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

The list of ECVs is expected to evolve slowly as scientific requirements change and as technological developments permit. Emerging ECVs, including soil moisture and isotopes in water among others, should be the focus of collaborative research initiatives. Future adequacy reports leading to revisions in the implementation planning will provide the opportunity for the research community and the UNFCCC to address the proposed changes to the list of ECVs, and will identify actions required to realize the emerging requirements.

Table 6. Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements (as Table 1).

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[12], 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[13]	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.	

The global observing system for climate requires observations from land-based and airborne *in situ* and remote-sensing platforms and also from satellites, 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 information, it will be composed of instruments at ground stations as well as on ships, buoys, floats, ocean profilers, balloons, samplers, aircraft and satellites. Information on where and how the observations are taken (meta-data) is absolutely essential, as are historical and palaeoclimatic records to set the context for the interpretation of trends and variability.

The Plan is both technically feasible and cost-effective. While its implementation is fully dependent on national efforts, success will be achieved only through internationally-coordinated action. The Plan initially focuses on the global nature of the requirements, but at the same time it recognizes that its data and products also are relevant to regional and local requirements. In the case of the monitoring of extreme events, which can be inherently of a small scale and/or high frequency, the Plan provides

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

[13] 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).

for global estimates of such phenomena. It will be updated over time as networks and systems become operational and as new knowledge and techniques become available.

Implementation depends upon close cooperation between many different organizations and agencies[14] with complementary responsibilities. These organizations, together with GCOS and other relevant bodies including the Space Agencies and the international research programmes, have formed the Integrated Global Observing Strategy Partnership (IGOS-P). The partnership provides a coordinated approach for the definition, development and implementation of global observing systems. Each of the observing system partners is interested in observation for a wide range of users, not only climate. Therefore GCOS works with them to ensure that they are fully aware of the climate requirements and to help ensure that those climate requirements are met.

The first Earth Observation Summit (Washington, DC, USA, July 2003) initiated actions to develop a conceptual framework for building a comprehensive, coordinated, and sustained Earth observation system of systems and established an *ad hoc* Group on Earth Observations (GEO). The second Earth Observation Summit (Tokyo, Japan, April 2004) adopted the framework document and initiated drafting of a ten-year implementation plan. The framework document identifies the understanding of climate variation and change (including assessment, prediction, mitigation and adaptation) as one of the principal societal areas of importance for the envisaged Global Earth Observation System of Systems (GEOSS). The document acknowledges the work undertaken by GCOS to address the global observing requirements for climate and the assessment of the adequacy of the present systems. GCOS will contribute directly to this comprehensive effort by providing the implementation requirements and mechanisms required to observe the global climate system – a major objective of the GEOSS.

Section 2 below provides the strategic approach to the development of the Plan. Section 3 addresses a number of actions relevant to all domains with Sections 4, 5, and 6 providing specific actions for the Atmospheric, Oceanic and Terrestrial Domains, respectively, and sorted with respect to the ECVs within each domain.

2. The Strategic Approach to Implementation

2.1. Basis Provided by Second Adequacy Report

This Plan translates the findings and priorities arising from the Second Adequacy Report into specific actions that can be taken by Parties, international and intergovernmental organizations and other regional and national entities. The approach proposes implementation actions on all the ECVs that are both currently feasible for global implementation and have a high impact on UNFCCC and the Intergovernmental Panel on Climate Change (IPCC) requirements for climate change detection, attribution, prediction, impact assessment, and adaptation. While many of the actions noted are directed at the international and intergovernmental organizations in their roles as programme coordinators, it should be stressed that actual progress is dependent on national actions.

The strategic approach adopted in the Plan is based on:

- Global coverage of surface-based *in situ* and remote sensing observing networks – this largely involves:
    - Improvements in existing networks to achieve the recommended technical, operational and maintenance standards, especially in developing countries, for the Atmospheric and Terrestrial Domains.
    - Expansion of existing networks and especially improving the density and frequency of observations for the Oceanic Domain and in remote data-sparse regions, including the high latitudes.
    - Improved data acquisition systems and data management programmes including adherence to the GCMPs.

[14] Including the international observing programmes such as the World Weather Watch Global Observing System (GOS) and the Global Atmosphere Watch (GAW) of the WMO; the Global Ocean Observing System (GOOS); and the Global Terrestrial Observing System (GTOS) and their sponsors.

- Effective utilization of satellite data through continuous and improved calibration and/or validation, effective data management, and continuity of current priority satellite observations.
- Routine availability of integrated global climate-quality products from international data and product centres and enhanced reanalysis activities.
- Management actions – changes or incremental enhancements to what Parties or international and intergovernmental organizations are currently doing, e.g., enhanced monitoring of data availability based on existing data systems.
- Continued generation of new capabilities through research, technical development and pilot-project demonstration.

The Plan designates three categories of networks that will provide observations. These are:

- Comprehensive global observing networks including regional and national networks as well as satellite data as appropriate/possible. The comprehensive networks provide observations at the detailed space and time scales required to fully describe the nature, variability and change of a specific climate variable.
- Baseline global observing networks, which involve a limited number selected locations that are globally distributed and provide long-term high-quality data records of key global climate variables, as well as calibration for the comprehensive networks.
- Reference networks, which provide highly-detailed and accurate observations at a few locations for the production of stable long time series and for satellite calibration/validation purposes.

Although an ultimate goal, it is presently unrealistic to attempt to establish and operate networks at all levels for all climate variables. Priority is currently given within the Plan to the establishment of key baseline and reference networks making *in situ* observations and selected comprehensive networks that include a substantial satellite observation component.

The GCMPs provide basic guidance regarding the planning, operation and management of observing networks and systems, including satellites, to ensure high-quality climate data that contributes 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 now been formally adopted or agreed by the UNFCCC, WMO, CEOS and other bodies (see Appendix 3).

2.2. Agents for Implementation

GCOS is a composite of contributions from observing systems and associated infrastructure from a broad range of existing programmes often with observing mandates different from the requirements of climate. The coordination and guidance provided by GCOS to these systems is designed to optimize the contribution of each one to the climate-observing mission.

Understanding climate requires observations in the Atmospheric, Oceanic and Terrestrial Domains and truly interdisciplinary analysis involving meteorologists, hydrologists, oceanographers, biologists, geologists, physicists, glaciologists, chemists, and others to mutually and collaboratively address the various issues and problems. It also requires open access to the full suite of observations and products.

The international observing systems contributing climate observations to GCOS include the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), the World Meteorological Organization (WMO) Global Observing System (GOS), the WMO Global Atmosphere Watch (GAW), the worldwide hydrological networks, and the full suite of operational and experimental Earth observing satellite systems. Appendix 4 lists the contributing systems, together with the associated international and intergovernmental organizations that currently set the standards and the technical regulations, under which they operate, and their various inter-relationships and coordination mechanisms.

The international scientific community is represented largely through the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP), which together with the IPCC have established the scientific basis for the observing system requirements. By virtue of their use of the observations, they are also uniquely placed to offer evaluations of the quality and coverage provided by the data sets – and to provide continuing guidance on the implementation process.

Although the international programmes provide a visible face for most global observing systems and networks, virtually all climate-related observations are actually taken and contributed by national agencies and/or institutions[15]. Thus, it is the Parties themselves and their agencies that bear the primary responsibility for implementing and operating observing activities for climate, for coordinating their activities through international programmes, and for providing support for research and technology development programmes. The functions of international data archiving and the provision of integrated global climate analysis and products are undertaken by national or multinational institutions, on behalf of the global community – these institutions should endeavour to provide the data and products openly and without restriction to all other nations as part of their commitment.

2.3. Criteria Used to Assign Priority

Criteria for placing items within the current or near-future implementation time-line of this Plan include:

- Clearly significant and citable benefits towards meeting the needs stemming from Articles 4 and 5 of the UNFCCC for specific climate observations in support of impact assessment, prediction and attribution of climate change, and the amelioration of and adaptation to projected future changes.
- Feasibility of an observation – determined by the current availability of an observation or by knowledge of how to make an observation with acceptable accuracy and resolution in both space and time.
- Ability to specify a tractable set of implementing actions ("Tractable" implies that the nature of the action can be clearly articulated, that the technology and systems exist to take the action, and that an Agent for Implementation, best positioned to either take the action or to ensure that it is taken, can be specified).
- Cost effectiveness – the proposed action is economically justified.

2.4. Phased Approach

The Plan identifies short-, medium- and long-term actions that focus on the high-priority elements. The ultimate goal of GCOS is to arrive at a climate-observing system that routinely provides observations for all ECVs, i.e., observations, which are long-term (sustained and continuous), reliable and robust, and with institutional commitment for their production (organizational home and sustained funding). Many observations in the current observing system are not provided routinely. The phased approach for some of these observations will initially involve an experimental or research phase that, if successful, will be followed by a pilot project stage where the technique or system is deployed, thoroughly tested and evaluated prior to making it a part of the operational or routine observing programme. This means that the Plan will evolve over time as new knowledge and technology becomes available. As GCOS implementation progresses, enhanced monitoring of implementation will be needed including the specification of targets for measuring progress over appropriate (e.g., five-year) intervals.

2.5. Global and Integrated Approach

In the future, the satellite remote sensing systems that provide global coverage and are well calibrated will become increasingly more important for global observations of climate. However, surface-based and airborne *in situ* and remote sensing systems will always remain important. When satellite remotely-sensed data are the primary source for observing an ECV, some *in situ* and/or remotely-sensed data are almost always needed to calibrate, validate and assess the long-term stability of the satellite data. If problems are detected in long-term stability, then high-quality *in situ* observations, with long station histories and appropriate adjustments in case of changes in instrumentation, can be used to vicariously adjust the satellite data. The synthesis of satellite and *in*

[15] Occasionally, nations form a multi-national agency or entity to undertake a particular activity (e.g. the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)).

situ data can take advantage of the unique characteristics of each data type to provide an integrated product with both high spatial resolution and long-term stability. Many of the current research satellite missions have demonstrated the potential of new instruments to better meet climate and other needs. Seeking effective means of maintaining long-term operation and continuity of these instruments will be critical to the achievement of this Plan.

From this global foundation, higher-resolution networks and analysis products enhance the observational resource and build functionality that allows for application on regional and national scales as appropriate.

As previously discussed, GCOS is being implemented primarily through the setting of climate standards and requirements for and the cooperation of its affiliated observing systems, e.g., World Weather Watch/Global Observing System (WWW/GOS) and WMO GAW, GOOS, GTOS, etc. Many of the potential contributing networks and systems have been designed and operated to address other applications; many of these can, however, become major contributors to GCOS often through some straightforward, operational changes such as providing adequate meta-data, ensuring that the instrument and observing platform or station operation follows the GCMPs and/or the systematic submission of data to the specified International Data Centres.

Thus, GCOS will require a composite of surface-based, sub-surface ocean, and airborne *in situ* and remotely-sensed data along with satellite data and products, yielding comprehensive information for all three domains (atmospheric, oceanic and terrestrial); with data acquisition procedures following the GCMPs, and data and information products available through internationally-designated data and analysis centres. This integration often occurs on a variable-by-variable basis and on two broad time-frames. The first time-frame is real time or near real time for monitoring and prediction purposes and for providing quality control and essential feedback to the observers and system operators. The second time-frame is delayed mode, where historical data are also incorporated, usually as part of an analysis or as part of ongoing research on climate variability and change.

Data assimilation is a technique that adds considerable value to global observing systems by combining heterogeneous sets of observations (e.g., *in situ* and remotely-sensed measurements) as well as using global numerical models to incorporate other ECVs into consistent analyses. Diagnostic data produced during the assimilation process provide information on the overall quality of the analyses, including information on model biases, and can be used to identify questionable data.

Information on many Atmospheric Domain ECVs could in principle be obtained by accumulating the analyses made each day to initiate numerical weather forecasts. However, the data assimilation systems used in routine numerical forecasting are subject to frequent change as the systems are continually improved. This introduces inhomogeneities in the analyses that limit their usefulness for studies of interannual and longer-term variations in climate. To overcome this situation, programmes of atmospheric reanalysis have been established in Europe, the USA and Japan, using modern stable data-assimilation systems to reprocess all the available observations taken over the past several decades. Such reanalysis products have found application in studies of climate, basic atmospheric processes, and ocean-model initialization and forcing. The extension of the reanalysis concept more fully to the Oceanic and Terrestrial Domains and to coupled atmosphere-ocean models will be major steps in global climate monitoring.

Another dimension of the integrated approach is the extension of the climate record through the blending of data from palaeo-data records from tree rings, sediment cores, ice cores, etc. with the instrumental records of the last two centuries. The production of an accurate record of the current global climate will assist enormously in the interpretation of the palaeo-data and provide opportunity to better compare and contrast the present climate with the past record.

2.6. Building Capacity

The need for Parties to improve the global observing system for climate in developing countries has been a common theme in the considerations by SBSTA on systematic observation. There are many ways that systems can be improved, including developed country agencies working with organizations and personnel from developing countries; the donation of equipment and the training of personnel etc. The Second Adequacy Report concluded, however, that there was a need to establish “a voluntary funding mechanism for undertaking priority climate-observing-system improvements and related capacity-building with least-developed countries and small-island developing states as well as with some of those countries with economies in transition".

Resulting from deliberation initiated at SBSTA-17 (New Delhi, 2002) the GCOS Cooperation Mechanism was 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 (baseline) elements of the global observing system for climate in support of the requirements of the UNFCCC, IPCC and other GCOS users, especially those needs of developing countries, taking into account the special needs and situations of least-developed countries and small island developing states. It consists of a:

- GCOS Cooperation Board as the primary means to facilitate cooperation amongst donor countries, recipient countries, and existing funding and implementation mechanisms, to address high-priority needs for improving climate observing systems in developing countries; and a
- GCOS Cooperation Fund as a means to aggregate commitments and voluntary contributions from multiple donors (both in-kind and financial) into a common trust fund.

The resulting mechanism will address priority improvements in atmospheric, oceanic, and terrestrial observing systems for climate, including addressing data rescue, analysis and archiving activities. It is intended to complement and work in cooperation with existing funding and implementation mechanisms (e.g., WMO Voluntary Cooperation Programme, the Global Environment Facility (GEF), the United Nations Development Programme, and the many national aid agencies), many of which deal with GCOS-related activities and, particularly, support capacity-building. The success of the mechanism will depend critically upon receiving adequate resources for both technical programme management and specific network needs.

Many Parties have expressed the need for better information on scientific priorities (e.g., through the GCOS Steering Committee) on current capacities in developing countries and on existing donor country activities (e.g., by developing an inventory) in order to facilitate cooperation in implementing system improvements through the cooperative and coordinated actions of multiple Parties. This work will require an active secretariat and project management function.

Capacity-building is a cross-cutting issue that supports operation and maintenance of observational networks, a range of data management activities such as data quality assurance, analysis and archiving, and a variety of applications to societal problems, while improving the underlying education and training. Building capacity also involves cooperation intra-nationally (among agencies within governments) and between nations regionally to address the multi-domain, multi-discipline objectives of GCOS. For example, the collocation of observing facilities, as appropriate, at stations or observatories in the various reference and baseline networks. Such synergy and collaboration will in principle be cost-effective and will encourage the collaboration among disciplines that climate science requires, particularly when orientated to vulnerability, impact and adaptation studies, as required in the UNFCCC.

2.7. Measuring Progress – Assessing Implementation

The following sections of the Plan outline the many and wide-ranging actions that will be required to attain a viable observing system that will address the stated requirements in the Second Adequacy Report.

For each proposed action a "Performance Indicator" is specified that defines the measures by which progress in implementation can be assessed, along with an indicated time-frame within which the action should be accomplished and reflect the concept of a "phased implementation".

The Performance Indicators used are either:

- Internal metrics that reflect the state and the degree of implementation of an observing system or network such as numbers and quality of available observations; the effectiveness of data exchange, archiving and quality control and the number of climate-quality analysis products.
- External metrics such as national reports to UNFCCC, regular assessments by the IPCC, evaluations from the scientific community (e.g., WCRP), inputs from the GCOS Monitoring

Centres and the internationally-designated data centres[16], as well as the GCOS archive centre for the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN) at the US National Climatic Data Center (NCDC).

The further development of techniques and processes to adequately monitor all observational data streams for time dependent biases and the detection of systematic error is necessary in measuring progress and assessing implementation. The Plan calls upon all observational network and system operators to ensure that appropriate data quality monitoring for application to climate is an integral part of all observing programmes.

2.8. Cost Definitions

The costs of taking the necessary actions are provided in broad but quantitative terms. Table 7 below indicates the range of costs associated with the terms used. Costs refer to the implementation of global networks and global cross-cutting issues and except where explicitly stated are incremental recurrent annual costs. Thus the network costs noted are usually spread across many nations. Costs associated with individual facilities are often borne by one nation or a group of nations with specified cost sharing.

Table 7. Implementation cost definitions.

Cost Category	Cost Implication (in US-$)
I	<100K
II	100K -1M
III	1M-10M
IV	10M-30M
V	30M-100M

The Plan includes 131 actions, 21 of which address GCOS-wide common over-arching and cross-cutting issues, 32 are actions specifically addressing the Atmospheric Domain, and 41 and 37 actions focus on the Oceanic and Terrestrial Domains, respectively. The costs for each action in this Plan will be estimated within one of the above cost categories.

3. Over-Arching/Cross-Cutting Actions

The Second Adequacy Report identified a number of issues that cut across all domains. The implementation actions to be taken arising from these issues are discussed in this section.

3.1. Planning, Reporting and Oversight

3.1.1. International Planning

The individual networks, systems and International Data Centres almost all operate within their own plans, procedures, standards and regulations coordinated by the Agents for Implementation (see Section 2.2 and Appendix 4). This Plan calls on all Agents for Implementation to adjust their activities to respond to the actions contained in this Plan.

Action C1

Action: Participating international and intergovernmental organizations are asked to respond to the actions in this Plan.
Who: International and intergovernmental organizations.
Time-Frame: Inclusion in plans by 2007 and continuing updates as appropriate.
Performance Indicator: Actions incorporated in plans
Cost Implications: Category I[17].

[16] See Tables 13, 16, and 18.
[17] See Section 2.8 Table 7 for cost definitions.

3.1.2. National and Regional Planning

The needs of the UNFCCC for global climate observations and products can be addressed only if plans are developed and then implemented in a coordinated manner by national and regional organizations. As noted in the Second Adequacy Report, with the exception of the main meteorological networks and the planning for specific projects, most climate-observing activities are rarely coordinated, planned and integrated at the national level. All Parties need national coordination mechanisms and plans for systematic observation of the climate system. Such mechanisms are usually best sustained when national coordinators or focal points[18] are designated and assigned responsibility to coordinate planning and implementation of systematic climate observing networks and associated activities across the many organizations and agencies involved with their provision.

GCOS will continue to emphasize with all relevant international and intergovernmental organizations the need for their Members to: (a) undertake national coordination and planning for systematic climate observations where this is not currently being undertaken; and (b) produce and update on a regular basis national plans for their contributions to the global observing system for climate taking into account the actions included in this Plan.

Action C2 (CF16, CF17)[19]

Action: Undertake national coordination and produce national plans for contributions to the global observing system for climate in the context of this Plan.
Who: Parties, in concert with the UNFCCC and international and intergovernmental organizations.
Time-Frame: Planning by 2007 with continuing updates as needed.
Performance Indicator: Number of national reports on climate observations submitted in national communications to the UNFCCC.
Cost Implications: Category II.

Efforts to enhance regional planning for the collection, processing and archiving of climate observations need to continue, as this shares the workload across many nations. Regional structures can also be an effective mechanism for building awareness, identifying needs, capacity-building, and capturing resources.

The GCOS regional workshop programme has established a framework for interested nations to work together to optimize their networks and 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. Even with the completion of the funded programme for these workshops in 2005, it is expected that regional initiatives will continue. GCOS, working with others, will seek support to maintain the momentum for Regional Action Plans with the provision of advice and other support to the planning groups. Utilizing the GCOS Cooperation Mechanism and other capacity-building programmes GCOS will work to match available funding with specific Regional Action Plan projects.

Action C3 (CF16, CF17)

Action: Complete development and alignment of Regional Action Plans for climate observations in the context of this Plan.
Who: Regional organizations and associations in cooperation with GCOS.
Time-Frame: 2005.
Performance Indicator: Availability of Regional Action Plans for climate observations.
Cost Implications: Category II.

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

[19] Actions in this document relate to 'Findings' of the Second Adequacy Report, as listed in Appendix 2 herein. These are identified as CF (Common Findings), AF, OF and TF (referring to Atmospheric, Oceanic, and Terrestrial Findings, respectively).

3.1.3. National Reporting

Reporting on systematic climate observation activities by the Parties[20] as part of their National Communications under the UNFCCC has been valuable in the planning and implementation of the global observing system for climate. The response by Parties to the Second Adequacy Report emphasized that in order to improve the understanding of climate and climate change, and for the UNFCCC to be implemented effectively, accurate and credible information relative to all aspects of climate observations must be exchanged according to the relevant guidelines (decision 4/CP.5). The following list of actions is pertinent for the Plan:

- The SBSTA/Subsidiary Body for Implementation (SBI) will be invited by GCOS to institutionalize the Supplementary Reporting Format (submitted to SBSTA-13), modified as necessary to be compatible with this Plan, and decision 11/CP.9, within revised guidelines.
- The Parties will be urged to report on measures aimed at adhering to climate monitoring principles and data rescue and preservation.
- The SBI will be encouraged to incorporate the GCMPs, as revised to address satellite observing systems, into the guidance for National Communications to the UNFCCC in accordance with decision 11/CP.9.
- All Parties will be encouraged to participate in the UNFCCC reporting process for systematic climate observations.

Action C4 (CF18)

Action: Report to the UNFCCC on systematic climate observations using an updated Supplementary Reporting Format and guidelines.
Who: Parties with the UNFCCC Secretariat.
Time-Frame: As soon as possible in conjunction with national communications.
Performance Indicator: Percentage of Parties reporting according to the required format.
Cost Implications: Category II.

3.1.4. National Implementation

Beyond planning and reporting, it is essential to make progress on the actual implementation of the plans. Sections 4, 5 and 6 make detailed suggestions for the implementation in the different domains. As noted earlier, almost all actions ultimately occur at the national level, therefore it is important to have regular reports to the UNFCCC on the actual status of implementation of the global observing system for climate and to keep up-to-date the actual Plan. The GCOS Secretariat will therefore provide a report to the UNFCCC on the status of implementation every two years together with information on any significant updates to the Plan. In addition, GCOS will undertake a Third Adequacy Report for 2010 in consultation with IPCC experts and subsequently consider a full update of the Plan.

Action C5 (CF18)

Action: Maintain oversight of implementation of national plans for systematic climate observations and products and report on progress.
Who: GCOS with its partners.
Time-Frame: Third Adequacy Report 2010.
Performance Indicator: Completion of Third Adequacy Report.
Cost Implications: Category II.

3.1.5. Executing the Implementation Plan

The Plan outlines a comprehensive programme that marshals contributions from virtually all countries and organizations dealing with Earth observations that will require continuing and strengthened coordination and performance monitoring. In addition, the GCOS Cooperation Mechanism is being developed to mobilize resources to ensure the effective operation of the overall global system. 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.

[20] Reports are available through the UNFCCC Secretariat.

Action C6

Action: Establish an International Project Office.
Who: GCOS Sponsors with advice from GCOS Steering Committee and with support from the Parties.
Time-Frame: Establish Office in 2005.
Performance Indicator: Establishment of an Office by GCOS Sponsors and resource support from Parties.
Cost Implications: Category II.

3.2. Toward Sustained Networks and Systems

Observations of several climate-system variables are made in the context of research programmes or by Space Agencies whose primary mission is research and development. This is particularly so in the Atmospheric Composition, the Oceanic, and the Terrestrial Domains. Once methods are sufficiently mature to guarantee a sustained set of observations to known and acceptable levels of accuracy to their users, they need to be sustained into the future as an operational observing system. The operational system includes the acquisition (measurement), transmission (reporting), analysis, and archiving of the data housed in an organization with an appropriate institutional mandate and sustained funding. Often the optimum arrangement is for the operation to be funded as part of a research laboratory's responsibility; in other cases it may involve the transfer of responsibility from one organization to another. This transfer of responsibility also implies sustained dialogue between the operational entities and the research community so that the operational arm may benefit from scientific advances. Although this transition into operation has been difficult to implement in national and organizational planning, recent progress involving the Space Agencies and some others has occurred and further improvements are encouraged. GCOS will, with the agreement of the involved research entities and at the appropriate time, work with the relevant international programmes and their Members to ensure the sustained operation of essential research networks and systems for the ECVs.

The Technical Commissions of WMO and the Intergovernmental Oceanographic Commission (IOC), and the proposed[21] technical commission dedicated to the Terrestrial Domain (see Action T1), provide overall guidance and coordination on the implementation of all operational networks. It is also vital for GCOS to liaise with these Technical Commissions in order to support and further strengthen the implementation of the GCMPs by all network operators, especially for the baseline networks. This may require additional resources and international coordination to be fully implemented.

Action C7 (CF19)

Action: Ensure an orderly process for sustained operation of research-based networks and systems for ECVs.
Who: System operators and research entities in cooperation with the GCOS Secretariat and the relevant international programmes (e.g., WCRP).
Time-Frame: Continuous.
Performance Indicator: Number of sustained networks and systems.
Cost Implications: Category I.

Action C8

Action: Ensure all climate observing activities adhere to the GCMPs.
Who: Parties and agencies operating observing programmes.
Time-Frame: Continuous, urgent.
Performance Indicator: Extent to which GCMPs are applied.
Cost Implications: Covered in domains. Sum of costs[22] Category IV. See Action C10 for satellite component.

[21] See Abridged Final Report with Resolutions of the Fourteenth World Meteorological Congress, General Summary paragraph 3.2.3.11.
[22] Sum of costs includes estimates from all domain actions as appropriate.

3.3. International Support for Critical Networks – Technical Cooperation

While most climate observations are currently carried out by national agencies on a "best-endeavours" approach, the full benefits of the global baseline networks will only be realized if the observations are global. Their sustainability therefore can be seen as an international responsibility. At this time, many developing countries and countries with economies in transition do not have the capabilities or the resources to provide the essential *in situ* observations or carry out associated analysis of climate data. The many multinational and bilateral technical assistance programmes together with the GCOS Cooperation Mechanism (see Section 2.6) can assist in addressing these difficulties especially in least-developed countries and some small island states. The support involves capacity-building, improving infrastructure and must, in some cases, sustain the required operating expenses associated with such things as upper-air operations and related expendables (e.g., radiosondes and balloons). GCOS will continue to draw the attention to the various international funding agencies of the needs and opportunities for monitoring the climate system in many countries.

Action C9 (CF20)

Action: Support the implementation of the global observing system for climate in developing countries and countries with economies in transition.
Who: Parties, through their participation in multinational and bilateral technical cooperation programmes, and the GCOS Cooperation Mechanism.
Time-Frame: Continuous.
Performance Indicator: Resources dedicated to climate observing system projects in developing countries and countries with economies in transition.
Cost Implications: Covered in the domains. Sum of costs Category IV.

3.4. Earth Observation Satellites

Satellites now provide a vital and important means of obtaining observations of the climate system from a near-global perspective and comparing the behaviour of different parts of the globe (see Table 8). A detailed global climate record for the future critically depends upon a major satellite component. However, for satellite data to contribute fully and effectively to the determination of long-term records, the system must be implemented and operated in an appropriate manner to ensure that these data are climatically accurate and homogeneous. To assist the Space Agencies, the GCMPs have been extended specifically for satellite observations (see Appendix 3). Their implementation by the Space Agencies for operational spacecraft and systematic research spacecraft would greatly enhance the utility of satellite information and benefit the climate record. For "one time" research spacecraft, the principles of continuity obviously do not fully apply, but as many of the other principles as possible (e.g., those for rigorous pre-launch instrument characterization and calibration, on-board calibration, complementary surface-based observations, etc.) should be followed. Recently the Space Agencies, including both the operational systems and the experimental systems, have agreed to address climate-observing requirements. Continuing the attention being given by the Space Agencies to addressing the accuracy and homogeneity requirements for climate will significantly enhance the value of satellite observations to the global observing system for climate.

Table 8. Variables largely dependent upon satellite observations (cf. Tables 1 and 6).

Domain	Variables
Atmospheric (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction (especially over the oceans), Water vapour, Cloud properties, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity).
Terrestrial	Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), fAPAR, Fire disturbance.

As pointed out in the Second Adequacy Report, the GCMPs extended specifically for satellite operations address the following satellite specific key operational issues:

- Continuity and homogeneity and overlap.
- Orbit control.
- Calibration.
- Data interpretation, sustained data products and archiving.

Implementation will also involve collecting and archiving all satellite meta-data so that long-term sensor and platform performance is accessible. The creation of consistent data records from all relevant satellite systems (so that optimum use can be made of the satellite data in the integrated global analyses and reanalyses) requires the organization of data service systems that ensures an on-going accessibility to the data into the future. GCOS will work with the Integrated Global Observing Strategy (IGOS) and its information technology expert affiliates, its IGOS partner Committee on Earth Observation Satellites (CEOS) and other groups such as the Coordination Group for Meteorological Satellites (CGMS) and the WMO Space Programme to ensure the development of plans for the implementation of the GCMPs and data services systems by the Space Agencies, and to establish the appropriate mechanisms for the recording and archiving of satellite data and meta-data, perhaps through the establishment of a data archiving working group. This activity will contribute directly to the GEOSS information technology infrastructure.

Action C10 (CF1, CF2)

Action: Ensure continuity and over-lap of key satellite sensors; recording and archiving of all satellite meta-data; maintaining currently adopted data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses. **Who:** Parties operating satellite systems. **Time-Frame:** Urgent, continuing. **Performance Indicator:** Data and products conform to climate standards. **Cost Implications:** Covered in domains. Sum of costs Category V.

3.5. Integrated Climate Products

While observations of the climate variables are an essential pre-requisite, the users of the information generally require analyzed outputs and products. Thus developing analyzed products for all ECVs is vital. While the Parties are operating a number of analysis centres for some of the atmospheric variables, additional operational analyses are required. International coordination of these activities is highly desirable to take advantage of advances, avoid duplication, and promote efficiency, complementarity and cooperation rather than competition. It is also important to recognize that alternative analysis approaches are required to verify the accuracy of the various outputs for specific variables. At this point in time, there are few analysis centres that are integrating observations of a given variable using data from different networks. The integrated products should include estimates of the uncertainty inherent in the analysis.

Achieving the integrated analyses required for each ECV is a priority near-term objective. Actions on individual variables are noted below in Sections 4, 5, and 6. In accordance with the Second Adequacy Report, it is recommended that the IGOS-P continue to develop strategies for implementing these global products. GCOS in turn needs to extend the number of ECVs for which integrated products are being generated and improved by coordinating actions by national and regional centres and programmes, by the intergovernmental organizations, by the multiple agencies through the IGOS-P, and in the future, with GEOSS. Some ECVs will require active research programmes to develop the tools necessary to produce climate-quality integrated analyses (see Sections 3.8, 4.6, 5.5 and 6.4).

Real-time data assimilation and reanalysis is another method of generating integrated products and exploits the physical relationships among a number of the variables and thus uses many of the available types of observations. It is an increasingly powerful tool that has significant potential for providing a comprehensive picture of the climate system. Because an adequate observational record for reanalysis extends for only 40 years or so, the main focus and success of real-time data assimilation and reanalysis to date has been on the relatively short-term variability of the atmosphere rather than on long-term climate trends of the essential climate variables. The latter places particular demands on the reanalysis systems and on the observational data that are ingested. Ocean data assimilation and reanalysis is just now developing and terrestrial activities are in their infancy, owing to a lack of modelling infrastructure, historical data and limited institutional engagement.

Although the quality of reanalyses is at present insufficient for a number of climate applications, there are good reasons to be optimistic. The opportunity exists to develop improved procedures for climate reanalyses and thereby reveal long-term trends. As part of an internationally-coordinated effort, there is a need for a small number of reanalysis centres with adequate staff and data processing, to prepare integrated climate products. The international reanalysis programme should give initial priority to: (a) extending current atmospheric reanalysis activities to meet requirements for monitoring climate variability and trends; (b) building on and extending ocean data-assimilation research activities such as the Global Ocean Data Assimilation Experiment (GODAE) to establish ocean reanalyses for the recent satellite era, and for longer if practicable; and (c) developing products relating to the composition and forcing of the climate system. The outputs of the reanalysis programme will have wide use and should be easily available to the user community. Although reanalysis can enable value to be derived from a wide range of comprehensive data sources, a climate-quality reanalysis is only possible when the data sources include a significant fraction of data adhering to the GCMPs. The identified GCOS networks in the atmosphere and the proposed networks drifting buoys and sub-surface floats in the ocean are critical in this respect. The availability of national holdings of historical data to the International Data Centres is an essential requirement for the effective conduct of reanalysis.

Establishing continuing capabilities for reanalysis for each domain, recognizing the early stage of development of assimilation in the Oceanic and the Terrestrial Domains, is essential. GCOS will work with the respective technical commissions and international research programmes to develop a coordinated set of analysis and reanalysis centres. In addition, the GCOS/GTOS Terrestrial Observation Panel for Climate (TOPC) and the GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC) will continue to encourage continuation of pilot projects and associated research on ocean and terrestrial data assimilation. Finally, the International Data Centres, e.g., the World Data Centres (WDCs), should continue to work with the responsible technical commissions and research programmes to ensure the provision of historical data sets including meta-data to internationally-mandated archives for inclusion in reanalysis programmes.

Action C11 (CF5)

Action: Prepare the data sets and meta-data, including historic data records, for climate analyses and reanalyses.
Who: Parties with the International Data Centres (e.g., WDCs), working together with technical commissions and the scientific community.
Time-Frame: Now and ongoing.
Performance Indicator: New or improved data sets available for analysis or reanalysis.
Cost Implications: Covered in domains. Sum of costs Category III.

Action C12 (CF3)

Action: Establish sustainable systems for the routine and regular analysis of the ECVs, as appropriate and feasible, including measures of uncertainty.
Who: Parties sponsoring internationally-designated analysis centres with guidance from WCRP, IGBP and IPCC, with oversight by GCOS.
Time-Frame: Now and ongoing, with most ECVs addressed by 2009.
Performance Indicator: Quality and range of analyses of the ECVs.
Cost Implications: Covered in domains. Sum of costs Category IV.

Action C13 (CF4)

Action: Establish a sustained capacity for global climate reanalysis and ensure coordination and collaboration between reanalysis centres. **Who:** National and international agencies, with coordination and oversight by GCOS and WCRP. **Time-Frame:** Established programmes across all domains by 2009, ongoing activity thereafter. **Performance Indicator:** Reanalysis centres established and/or endowed with long-term and coordinated programmes; cyclical flow of products of improving quality and widening range. **Cost Implications:** Covered in domains. Sum of costs Category III.

3.6. Historical Data and Palaeo-reconstructions of Past Climates

The Plan focuses primarily on the need to improve ongoing monitoring of climate variables. However, there is a need to extend these records backwards in time, both for analysis and reanalysis purposes. Analysis of past variations and changes in climate is an essential part of interpreting current records of climate. The existence of long records allows:

- Documentation of the range of natural variability and the characterization of extreme events. Flood events, for example, are characterized by magnitude and return time. In many parts of the world, observations over the last 20-30 years are insufficient to characterize flood return times.
- Investigation of the relationships between atmospheric and oceanic modes of behaviour and extreme events, including possible changes in atmospheric teleconnections. In particular, some extratropical time and space scale variations, such as the Northern Annular Mode, typically operate on multidecadal timescales and thus can only be analyzed using relatively long records.
- Characterization of the climate system under a wider range of changes in external forcing than has occurred within the last 20-30 years of observation. Although the past does not provide direct analogues for anthropogenic changes in atmospheric composition or changes in land cover, the recent geological past has been characterized by large changes in climate forcing that provide insights into the mechanisms of climate change.

There are two types of data that can be used to extend observations back in time: historical data based on documentary evidence and palaeo-reconstructions based on biological, geophysical, geochemical or isotopic data.

There are documentary records for many ECVs, including direct observations of meteorological variables, ship-board and *in situ* observations of the occurrence of sea ice, measurements of the extent and mass balance of mountain glaciers and sub-polar ice caps, observations on the timing of lake freeze-up and break-up, gauge measurements on rivers and lakes, information on the occurrence and extent of floods, phenological data on the timing of bud-burst, flowering and harvests of specific crops, and information on changes in land use/cover. Quantitative observations may extend back for 100-300 years; discontinuous observations and more qualitative information is available on a regional basis in various forms of record for anything from several hundred to several thousand years.

Ice cores from polar regions provide a record of regional temperature change (isotope ratios of oxygen and hydrogen) as well as changes in atmospheric composition that are forcing factors of global (greenhouse gases) or regional (mineral aerosols) significance through multiple glacial-interglacial cycles. Existing records (e.g., Fuji, Vostok) cover the last 3-4 glacial cycles, and the new European Project for Ice Coring in Antarctica Dome C core has provided a record going back to at least 740 000 years before the present time. Ice cores have interannual to interdecadal resolution in the recent geological past but the resolution degrades to multidecadal to multicentennial in the oldest part of the record. Other palaeo-reconstructions fall into two broad categories: those designed to provide records of interannual to interdecadal variability (e.g., records based on tree rings, corals, laminated lake sediments) and those that provide records of multidecadal to millennial changes in climate or environmental conditions (e.g., pollen or plant macrofossil records of changes in vegetation, geomorphic or biostratigraphic records of changes in surface hydrology, biological/geochemical/ isotopic records of changes in sea-surface temperature and/or marine productivity). Much of the palaeo-data on interannual to interdecadal variability is confined to the relatively recent past (last few hundred years in the case of corals, last 2000 years in the case of tree rings). Longer records are available from some regions (e.g., tree-ring records covering *ca.* the last 6000 years are available from Europe) and isolated coral records are available from earlier time periods (including parts of the last glaciation and the last interglacial period). The availability of records of multidecadal to millennial changes decreases back through time: while there are sufficient sites to provide global reconstructions of key parameters during the last *ca.* 20 000 years, reconstructions for earlier time periods are based on a small number of sites which are assumed to be representative of a larger region.

3.6.1. Historical Data Sets

Improvement of historical records is dependent on adequate investment in data archaeology for the rehabilitation of data that are not presently accessible or are inadequately assessed due to random errors and time-dependent biases. At the present time, scientists are struggling to address all aspects of data archaeology. This includes retrieving data inaccessible because of outdated recording media, data previously unavailable for reasons of national security, restricted national data exchange, or inadequate resources to make them easily accessible. Three aspects of data archaeology are critical for putting new observations into a historical context or making effective use of past records. First, meta-data must be compiled about how, where and when observations were made. In the absence of adequate meta-data, exhaustive investigative research is required to find, compile, and integrate such information in order to effectively interpret the data. Second, it is essential to integrate present observations with historical data to obtain the most comprehensive spatial and long-term data sets. Third, once appropriate meta-data and comprehensive data sets are assembled, a demanding task remains; time-dependent biases within the data sets must be identified and corrected. When historical climate observations from GCOS baseline networks have been digitized, quality controlled and homogenized, the rehabilitated data and their associated meta-data should be available in International Data Centres.

There are a number of climate variables where specific efforts to collect and reprocess historical records could yield immediate benefits, including surface meteorological records, surface ocean records, sea-ice extent, river discharge, lake level/area, lake freeze-up and break-up records, glacier extent, and biomass derived from forest inventory data. In some cases, there are research networks that are involved in reprocessing and analyzing these data. In other cases, existing or planned data archives could provide an appropriate mechanism for archiving, homogenizing and analyzing the historical data. As a priority action, GCOS (working with the appropriate agencies) should request that national agencies retrieve archival data, including meta-data, and lodge them with the appropriate International Data Centre (see Table 9).

Table 9. ECVs targeted for special data archaeology efforts and the associated International Data Centres.

ECVs	Data archive
Surface atmospheric variables	WDC Asheville
Oceanic variables	World Ocean Data Centres
Sea-ice (extent)	National Snow and Ice Data Center (NSIDC)
River discharge	Global Runoff Data Centre (GRDC)
Lake level (including freeze and break-up records)	Proposed GCOS lake data centre
Extent and mass balance of mountain **glaciers** and sub-polar **ice caps**	World Glacier Monitoring Service (WGMS)
Biomass	FAO's Forest Resources Assessment Project (FRA)
Land cover (and use)	Existing research networks

A further area where historical data could be useful is in the creation of improved records of changes in natural land cover and land use. Existing historical land-cover data sets have a limited usefulness because of the coarseness of the classification schemes employed. Inventory data could be used to refine these classifications, providing there is sufficient documentation and the data are made available in spatially disaggregated form. GTOS, the Global Land Cover Network (GLCN) and GCOS (working with the appropriate national agencies) will request that national agencies retrieve archival data and make them available through appropriate International Data Centres.

Action C14 (CF7)

Action: Collect, digitize and analyze the historical atmospheric, oceanic and terrestrial data records from the beginning of instrumental observations in a region and submit to International Data Centres.
Who: Parties, working through the WMO Commission on Climatology (CCl), the WMO Commission for Hydrology (CHy), other appropriate coordinating bodies (e.g., GCOS and GTOS), the appropriate national agencies, and designated International Data Centres.
Time-Frame: Complete by 2009.
Performance Indicator: Data receipt at designated International Data Centres.
Cost Implications: Category II.

3.6.2. Palaeo-Data Sets

There is potential to extend the spatial and/or temporal cover of existing networks of records of annual to decadal variability. Recent research indicates that it is possible to derive tree-ring records from subtropical and tropical regions and to extend the temporal coverage of tree-ring records from extratropical regions back over at least the last *ca.* 6000 years. The number of ice cores and coral records has increased substantially in recent years, but again there is potential for further increasing the number of individual records, particularly for earlier intervals where information is currently only available from one or two sites. The potential for deriving information on annual to decadal variability from other types of records, specifically annually laminated lacustrine or marine sediments, has only been partially exploited. Continued support for research in these areas, and for new primary data collection initiatives, is required.

The strength of palaeo-data as a means of documenting climate variability and changes on multidecadal and millennial timescales lies in the existence of dense networks of observations. Despite the progress made in assembling such networks for individual types of record in recent years, there are still many parts of the world for which data coverage is sparse or existing chronologies are inadequate. In the terrestrial realm the need for more investigations is most marked for the tropical regions of South America and Africa, for mid-continental Eurasia, and for Asia and the Southern Hemisphere in general. In the oceanic realm, more investigations are needed in the Southern Ocean and Tropical Pacific. Reconstructions of palaeo-climate and palaeo-environmental conditions on multidecadal and millennial timescales are dependent on the collection of primary data at individual sites by the research community. Continued support for primary data collection, and for improvements to the dating of the biostratigraphic records, at a national level is a prerequisite. This support should be accompanied by efforts to ensure that the primary data are routinely lodged in archival International Data Centres (in particular the World Data Centre for Paleoclimatology).

Improvements in data coverage and data availability will facilitate analyses designed to document changes in climate variability through time. The integration of such analyses with analyses of more recent historical and/or observational data will require strengthening of the mechanisms for interdisciplinary communication.

Action C15 (AF9)

Action: Undertake research initiatives to acquire high-resolution palaeo-climate data by extending spatial coverage into new regions, extending temporal coverage back in time and exploiting new sources.
Who: Parties' national research programmes in cooperation with WCRP and IGBP.
Time-Frame: Continuing.
Performance Indicator: Reports in scientific literature.
Cost Implications: Category III.

Action C16 (AF9)

Action: Improve synthesis of palaeo-climate and palaeo-environmental data on multidecadal to millennial timescales, including better chronologies for existing records, particularly from the tropics, Asia, the Southern Hemisphere and the Southern Ocean. **Who:** Parties' national research programmes in cooperation with WCRP and IGBP. **Time-Frame:** Continuing. **Performance Indicator:** Reports in scientific literature. **Cost Implications:** Category III.

Action C17 (AF9)

Action: Preserve palaeo-climate and palaeo-environmental data in archival databases. **Who:** World Data Centre for Paleoclimatology in cooperation with national research programmes. **Time-Frame:** Continuing. **Performance Indicator:** Completeness of archival databases and availability of data to the research community through International Data Centres. **Cost Implications:** Category II.

3.7. Data Management and Stewardship

Data management and stewardship are some of the most important activities to be undertaken in order to ensure that high-quality climate data records are collected, retained and are accessible for analysis and/or reanalysis by current and future generations of scientists. It is noteworthy that data management has been a principal element in some programmes, e.g., the WMO WWW, but this activity needs to be extended throughout the full spectrum of systems contributing to the global climate observing system and existing efforts need to be strengthened to meet climate requirements. This essential but often overlooked activity is highlighted as a priority in this Plan.

First, it is clear from the detailed network reviews that the flow of real-time data to the user community and to the International Data Centres for the ECVs is inadequate. This is especially true for many terrestrial observing networks. Lack of engagement, data policies, lack of resources and inadequately integrated data-system infrastructures are the primary causes. The latter are especially problematic in developing countries and countries with economies in transition.

Second, access to very large data sets is becoming an increasing problem. Some satellite data sets and model simulations are becoming so large that it is difficult for many users to acquire them despite advances in technology. This is especially true in developing countries with inadequate information technology infrastructure or technical skills in using complex data. Access to these data must be made more effective through the development of derived products.

Third, the preservation of the data for future use requires facilities and infrastructure to ensure the long-term storage of the data. The rapidly-increasing volume of raw observations that must be saved and stored in an archive is such that without action the data will often be inaccessible to many users. Once data are in electronic format, the data must be continually migrated to newer storage devices, and data access software and consistent data formats must be maintained, in order to preserve the data for sustained future use. This practice of technological data stewardship is a requirement for the International Data Centres and the Space Agencies to ensure future data usage. At the present time, even large centres are barely keeping pace with the influx of new data. This is especially true when observing systems are put in place without adequate consideration of the technological data-stewardship requirements for data archive and access. It follows that nations sponsoring International Data Centres and Space Agencies need to give high priority to making use of modern information and communication technology to ensure effective access and long-term migration, and thus ultimate preservation, of the rapidly-growing volumes of climate-related data.

Fourth, a key component of data management includes adequate monitoring of the data stream. This includes timely quality control of the observations by the monitoring centres and notification to observing system operators and managers of both random and systematic errors, so that corrective action can occur. An operational system is needed that can track, identify, and notify network managers and operators of observational irregularities, especially time-dependent biases, as close to near real-time as possible. Such feedback systems are currently not routine practices at monitoring and analysis centres. Equally important is the follow-up required by operators and managers who are responsible for implementing timely corrective measures. This is especially problematic in developing countries with less-than-adequate resources for data stewardship. Without adequate scientific data stewardship, biases often become apparent only after substantial investment in research related to the rehabilitation of the data record. Scientific data stewardship, therefore, is a cost-effective measure that minimizes the need for uncertain corrections at a later date. When problems in the observations and reporting of the observations are not identified and corrected as soon as possible, errors and biases accumulate in the data and the climate records can be irreparably damaged.

Finally, many inconsistencies and apparent biases and inhomogeneities in the data can be addressed if adequate meta-data information is available to the analyst. International standards and procedures for the storage and exchange of meta-data need to be extended to all variables and implemented for many climate-observing systems. In 2004, the WMO CCI published guidelines for meta-data and homogeneity that begins to address this concern. International agencies, working with their technical commissions and the GCOS Secretariat, should address the inadequacies related to scientific data stewardship, including the introduction of adequate near real-time observing system performance monitoring and monitoring for time-dependent biases.

To help address the issues raised above there is a growing interest in adopting a uniform family of data representation standard for all Earth observations. Integration spanning all domains (terrestrial, oceanic and atmospheric) will be best served with common standards for as many of the data management activities as are possible, including geographical location, meta-data, archival strategies etc. The opportunity for standardization extends beyond climate and includes the whole geosphere observation mandate being covered in GEOSS. It is proposed to engage GEOSS to take the lead in organizing a major effort in conjunction with the International Organization for Standardization (ISO) and representatives from the various component systems of GEOSS including GCOS and its affiliated systems. Some progress has already been attained in the ISO 19100 series of standards (e.g., the ISO 19115 meta-data content standard for geographical information), which can serve as the starting point for extending the effort to the broadest possible application to a comprehensive family of interoperable geospheric data representation standards. A known family of compatible standards would then be harmonized and therefore anchored in a common base that would foster data and information integration so vital to the understanding of climate.

Action C18 (CF12)

Action: Develop standards and procedures for meta-data and its storage and exchange.
Who: International technical commissions with scientific advisory bodies.
Time-Frame: Guidance complete by 2006.
Performance Indicator: Number of ECVs with standards.
Cost Implications: Category I.

Action C19 (CF9)

Action: Ensure timely, efficient and quality-controlled flow of all ECV data to International Data Centres.
Who: Parties with coordination by appropriate technical commissions and international programmes.
Time-Frame: Urgent, continuing.
Performance Indicator: Data receipt at centres and archives.
Cost Implications: Category II.

Action C20 (CF9)

Action: Ensure that data policies facilitate the exchange and archiving of all ECV data.
Who: Parties and international agencies and appropriate technical commissions and international programmes.
Time-Frame: Urgent, continuing.
Performance Indicator: Data receipt at GCOS data centres.
Cost Implications: Category I.

Action C21 (CF10, CF13)

Action: Develop modern distributed data services that can handle the increasing volumes of data and which can allow feedback to observing network management. **Who:** Parties' national services committing to International Data Centre operation and high data volume providers such as Space Agencies through appropriate technical commissions and international programmes. **Time-Frame:** Long-term objective, 2014. **Performance Indicator:** Development of plans and initial steps at some centres. **Cost Implications:** Category IV.

3.8. Scientific and Technological Challenges

In the process of developing this Plan, the GCOS Steering Committee and the Observation Panels for Climate (AOPC, OOPC, and TOPC), as well as various levels of review by the broad scientific community, have identified areas where significant research and technology development will be necessary to completely realize the observational capability to adequately observe the global climate. Whilst these areas are discussed in the context of the specific domain and ECV in Sections 4, 5, and 6 below, the research topics are listed here in order to draw attention to the wide range of issues still requiring in-depth study and technological development.

Our ability to measure some key and a few emerging potential ECVs, by utilizing both *in situ* and remote sensing (both surface- and satellite-based), is limited by the lack of suitable techniques. The limitation can vary all the way from the fundamental underlying observing technique to those associated with instrumentation, algorithms, suitable calibration/validation techniques, spatial and/or temporal resolution, ease of operation, and cost. Expansion of the suite of observational techniques holds the possibility of enabling climate-quality global observations of some environmental parameters not yet possible, as well as improvement of the quality, coverage, and/or cost of measurements currently being made. The development, demonstration, and validation of these new techniques are a vital part of this research endeavour. As new global satellite-based observations of environmental parameters are made, it is critically important that the validation of both the measurements themselves (e.g., radiances) and the retrieval algorithms used be carried out under a sufficiently broad range of geophysical and/or biogeochemical conditions that they can be confidently applied to the creation of a global data set.

The development of integrated products (e.g., greenhouse gas emissions attributable to biomass burning) requires blending of different data sets and/or data sources. This applies to both "within-domain" products (e.g., those based on two or more primary products from the Atmospheric, Oceanic, or Terrestrial Domain), and "cross-domain" products, that involve observations or analyses normally associated with two or more of the domains considered here.

Further, it is recognized that many of the integrated products that will be of interest for climate studies are inferred or derived products, which are themselves products of the integration of data and models, such as the output of data assimilation systems. In validating these new global products, it will be important to compare the use of different data sets and/or models to establish confidence limits, and to carry out some focused experimental studies under selected conditions to provide confidence in these integrated quantities. As new types of data are assimilated, it will also be important to understand fully the error characteristics of the new data and the models used, and also to advance the state of assimilation to ensure that the new data are used in the most effective manner.

The development of new integrated data products, especially those produced through data assimilation, has the potential to provide information on climate forcing which may be useful both in driving climate models and for policy- and decision-makers (e.g., in assessing emissions which are regulated by statute and/or treaty). Assuring that such estimates are soundly based and validated under a sufficiently broad range of conditions will be critical if their use is to be accepted.

Given the large growth in global environmental data taking place and expected to continue, there is a need to develop more efficient tools for data analysis, dissemination, and validation that will allow both observational and model-created information to be extracted, combined, and used in an efficient way. This may include the development of enhanced subsetting techniques and automated analysis and pattern recognition routines, as well as accelerated models that can take advantage of advances (in both hardware and software) in computational technology.

4. ATMOSPHERIC CLIMATE OBSERVING SYSTEM

The atmospheric observing networks for climate are largely based on those of the WMO WWW for surface and upper-air observations, and the WMO GAW for atmospheric composition. The GCOS implementation strategy has placed an initial emphasis on the full implementation of baseline networks, including the GSN and the GUAN and the expansion of the GAW to provide a global distribution. These networks now need to be gradually augmented to encompass all the ECVs.

Satellite observations play a crucial role in attaining global coverage of virtually all atmospheric climate variables and through their incorporation in globally integrated analyses.

The careful management of data and their associated meta-data are vital aspects of the baseline and other climate networks, with real-time monitoring centres, delayed-mode analysis centres and reanalysis programmes complementing the work of the International Data Centres with their archives. For most atmospheric ECVs, such centres and programmes currently exist; however, as pointed out below, several gaps and weaknesses exist and need to be addressed.

Users of climate information require products that meet their requirements for quality, scope and coverage. These products are almost invariably generated through the integration of data from different sources. A key aspect of this integration is the process of reanalysis, which by incorporating historical data with consistent algorithms provides the potential to yield homogeneous, consistent, multivariate products with global coverage (see Section 3.5).

4.1. Atmospheric Domain – Surface

Observations at the surface of the Earth are vitally important as they characterize the climate of the layer of the atmosphere in which we live. The networks and systems required for collecting homogeneous measurements over the ocean are described in the sections covering the Oceanic Domain (Section 5).

The observational networks and satellite data required for implementation of the ECVs in the Atmospheric Surface Domain are shown in Table 10 together with the current status of each observing network and system (see next page).

Table 10. Observation networks and systems contributing to the surface component of the Atmospheric Domain.

ATMOSPHERIC DOMAIN – SURFACE				
ECV	**Contributing Network(s)**	**Status**	**Contributing Satellite Data**	**Status**
Temperature	Baseline GCOS Surface Network. Full WWW/GOS surface network. Ocean buoys and ships. Additional national net-works (see also Oceanic Section, Sea-surface Temperature ECV).	About 90 % of data being collected, but only 65% transmitted as CLIMAT. Need high-resolution data to be available for climate purposes; Networks inadequate in many countries.	Sea-surface temperature (IR, microwave). Land-surface temperature (IR).	Research topic for land-surface temperature.
Air Pressure	Baseline GCOS Surface Network. Full WWW/GOS surface network. Additional national networks. Ocean buoys and ships (see Ocean Surface Section).	About 90% of data being collected, but only 65% transmitted as CLIMAT. Some inconsistencies in pressure reduction methods to mean sea level. Some national networks inadequate for climate studies.		
Wind Speed/ Direction	Baseline GCOS Surface Network. WWW/GOS synoptic network. Additional national networks. Ocean buoys and ships (see Ocean Surface Section).	Wind is not yet included in GSN. Wind data over land are often not representative.	Scatterometer. Passive microwave.	Continuing operational uncertainty for scatterometry.
Precipitation	Baseline GCOS Surface Network. Full WWW/GOS surface network. Additional national networks; Island networks. Surface-based radar networks. National lidar networks. National meteorological and hydrological gauge networks.	About 90% of data being collected, but only 65% transmitted as CLIMAT. Quality of data is variable. Most countries operate national high-resolution precipitation networks, but data are largely not available. Radar data not globally exchanged; spatial and temporal sampling limitations.	Passive microwave, IR. Precipitation radar.	Uncertainty for continuity of precipitation radar; Uncertainty and bias in precipitation estimates; Research missions; Temporal sampling limitations.

Water Vapour	Baseline GCOS Surface Network.	Water vapour is not currently included in GSN data.		
	Full WWW/GOS synoptic network.			
	VOSClim fleet.	Climate analysis of data needs further work.		
Surface Radiation Budget	BSRN.	High-quality data, but coverage may need to be extended.	ERB missions (e.g., CERES, GERB).	Mainly for solar radiation; Operational products over ocean; Uncertainty in continuity.
	WWW/GOS synoptic network.	Quality of routine radiation data is inadequate for climate purposes.		
	Additional national networks.	Limited availability of high-quality data in national networks.		

The primary networks contributing to climate observations at the Earth's surface include:

- Over land, the WWW/GOS synoptic observing network (~10 000 stations) provides the major *in situ* observations of the following ECVs: Temperature, Air Pressure, Precipitation, Water Vapour, Surface Radiation (e.g., sunshine duration) and Wind Speed and Direction. Included in this network is the baseline GCOS Surface Network (GSN). The GSN comprises about 1000 stations that have been selected from the full available network based on past performance and their contribution towards a global representation of the climate system. The operators of GSN stations, in particular, are encouraged to fully meet the GCMPs for observation and for data exchange, where possible for all ECVs. The GSN data can be analyzed to yield basic indicators of the global climate system, and also provide benchmark locations for higher-density regional and national networks. The GSN is being implemented with cooperation among National Meteorological Services and the international community; through the Atmospheric Observation Panel for Climate (AOPC) working with the WMO Commission for Basic Systems (CBS) and WMO Regional Associations (RA); and through capacity-building initiatives such as those of the WMO Voluntary Cooperation Programme and the GCOS Cooperation Mechanism. The AOPC, in cooperation with the WMO CBS, will continue detailed analysis of the problems in the receipt of GSN observations and work with national services to resolve them. Figure 1 below shows the availability of GSN data at the NCDC World Data Centre for Meteorology, Asheville (WDC Asheville).

- Over the oceans, the *in situ* surface meteorological observations are provided by the Voluntary Observing Ships (VOS), including the higher-quality VOS Climatology Programme (VOSClim) subset, drifting buoys, the Tropical Mooring Network and the Reference Buoy Network. The implementation of these observing systems is covered in detail under the Oceanic Domain. Some specific issues on observing the marine meteorological fields (temperature, pressure, wind speed and direction, and humidity) are addressed here. Satellite measurements are critical to the observing strategies addressing the global distribution of the essential atmospheric surface variables over the ocean. Combination of land and marine data is vital for the true assessment of climate change over the planet.

Action A1 (AF1)[23]

Action: Detailed analysis of causes of GSN faults, followed by full implementation of the GSN.
Who: National Meteorological Services, in coordination/cooperation with WMO CBS, with advice from the AOPC
Time-Frame: Complete operation of GSN by 2007 and receipt of all archival data by 2008.
Performance Indicator: Data archive statistics at WDC Asheville and National Communications to UNFCCC.
Cost Implications: Category III[24].

[23] Actions in this document relate to 'Findings' of the Second Adequacy Report, as listed in Appendix 2 herein. These are identified as CF (Common Findings), AF, OF and TF (referring to Atmospheric, Oceanic, and Terrestrial Findings, respectively).
[24] See Section 2.8 Table 7 for cost definitions.

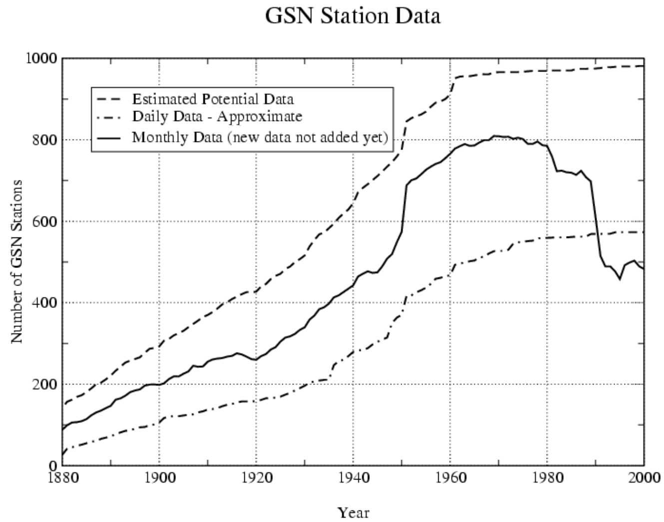

Figure 1. Availability of daily and monthly temperature data at WDC Asheville.

While the WWW/GOS synoptic observing networks have been developed primarily to support real-time weather prediction, their high spatial density and frequent sampling means that they are of increasing importance to the climate community. Initially GCOS, through the WMO CBS, WMO CCl and WMO RAs, and WMO WWW will focus on ensuring that the Regional Basic Synoptic Network (RBSN) of the WWW/GOS adopts and implements the GCMPs.

Action A2 (AF1, AF24)

Action: Obtain major progress in implementation and systematic operation of the full WWW/GOS RBSN in compliance with the GCMPs.
Who: National Meteorological Services, in cooperation/coordination with WMO CBS, WMO CCl, WMO RAs and WMO WWW.
Time-Frame: Continuous, with 10% improvement in receipt of RBSN data by 2009.
Performance Indicator: Data archive statistics at WDC Asheville.
Cost Implications: Category III.

National vulnerability to climate change, especially changes in extreme events, require national and regional climate observing networks at a much finer space scale than the GSN and WWW/GOS synoptic observing networks. To realize the full potential value of the networks for application to climate, network operators should follow the GCMPs. Focused action by the National Services in cooperation/coordination with WMO CBS, WMO CCl and their RAs will be needed to attain the goal of complete network implementation.

Action A3 (AF24)

Action: Apply the GCMPs to all surface climate networks.
Who: National Meteorological Services, in coordination with WMO CBS, WMO CCl, WMO RAs and GCOS Secretariat.
Time-Frame: Continuous.
Performance Indicator: Quality and homogeneity of data and meta-data submitted to International Data Centres.
Cost Implications: Category II.

Many observing facilities (over both land and ocean) are being changed from the traditional manual operation to automatic or quasi-automatic operation. These changes have been demonstrated to insert potential inconsistencies and inhomogeneities into the climate record, and are addressed as one element of the GCMPs. Additional guidance on the ways and means to ensure compatible transition is needed. The WMO Commission for Instruments and Methods of Observation (CIMO), in cooperation with WMO CCI and WMO CBS, through their appropriate expert teams, and the GCOS GSN Monitoring Centres should develop such guidance with urgency.

Action A4 (AF24)

Action: Develop guidelines and procedures for the transition from manual to automatic surface observing stations that incorporates the GCMPs. **Who:** WMO CIMO in cooperation with the WMO CCI, WMO CBS, and the GCOS GSN Monitoring Centres through the AOPC and the GCOS Secretariat. **Time-Frame:** Complete by 2006. **Performance Indicator:** Quality and homogeneity of data and meta-data submitted to International Data Centres; adoption noted in National Communication. **Cost Implications:** Category I.

4.1.1. Specific Issues – Surface ECVs

The following sections elaborate further on the issues and proposed actions related to each ECV in the Atmospheric Domain – Surface.

ECV – Surface Temperature

In addition to the land-based observations of temperature described above, the observation of sea-surface temperature, air temperature over the ocean (from VOS), and sea ice (from the Arctic and Antarctic buoy networks) is required, as described below in Section 5.

ECV – Air Pressure

In addition to the land-based observations of pressure, pressure data over the ocean are required from sensors mounted on drifting buoys (also in the sea-ice areas of the Arctic and Antarctic), VOS, including the higher-quality VOSClim subset, the Tropical Mooring Network, and the Reference Buoy Network. Many of these measurements have been operational over the last 25 years; the data are exchanged and inserted into the operational meteorological WWW system and are subject to quality-control procedures at the time of data acquisition and again at the analysis centres. Of particular concern is that surface pressure sensors are not included on all drifting buoys. Therefore the OOPC, working through the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), and the national agencies that deploy drifting buoys, will be asked to ensure that surface pressure sensors are included as a component of the suite of instruments on all buoys deployed (see Section 5.1.1).

Action A5[25] (AF3, AF6)

Action: Seek cooperation from organizations operating drifting buoy programmes to incorporate atmospheric pressure sensors. **Who:** Parties deploying drifting buoys and buoy-operating organizations, coordinated through JCOMM with OOPC and AOPC. **Time-Frame:** Continuous. **Performance Indicator:** Percentage of buoys with sea-level pressure (SLP) sensors. **Cost Implications:** Category III.

ECV – Precipitation

Since precipitation usually occurs on small space and time scales, the density of the networks used for surface temperature and air pressure is insufficient. Many nations have organized and operate special networks and systems devoted to the observation of precipitation amount, type (rain or snow) and distribution on fine space and time scales. Daily and if possible hourly data are required for studies of extremes and precipitation characteristics. The GCOS requirement for global and regional analyses of precipitation can be significantly improved by the incorporation of observations from these

[25] See also Action O10.

networks. Meeting this requirement means that all nations must routinely exchange their current precipitation gauge observations with the Global Precipitation Climatology Centre and the global archives at WDC Asheville. Continuing research is required to overcome some outstanding measurement problems such as undercatch of snow. There is potential for national radar networks to be combined to contribute to global estimates of precipitation.

Action A6 (AF5)

Action: Submit precipitation data from national networks to the International Data Centres.
Who: National Meteorological Services with coordination through the WMO CCl.
Time-Frame: Continuous with 20% improvement in receipt by 2009.
Performance Indicator: Percentage of nations providing all precipitation data to the International Data Centres.
Cost Implications: Category I.

Even with the efforts of many nations, precipitation observations are still not available with adequate density to define the distribution of precipitation in many parts of the globe, including the oceans and some land areas. Estimates of precipitation derived from satellite observing systems have been used to map the distribution of precipitation over some of these regions, and have proven essential for global analyses when combined with precipitation observations by the GPCP. Stable continuation and enhancement of the satellite systems contributing to precipitation observation will be required to ensure accurate global precipitation monitoring. The WMO Space Programme, in cooperation with the GCOS Secretariat, will continue to inform the Space Agencies through the CGMS and CEOS of the need to build this requirement into their medium and long-range planning.

Action A7 (AF5)

Action: Ensure stable operation and processing of relevant operational satellite instruments for precipitation and the continuity of associated products.[26]
Who: Space Agencies through CGMS and CEOS with WMO Space Programme and GCOS.
Time-Frame: Continuous.
Performance Indicator: Long-term homogeneous satellite-based global precipitation products.
Cost Implications: Category V.

Some observations of precipitation over the oceans are particularly important for the calibration of satellite observations. Therefore, the OOPC will work with the Ocean Reference Mooring Network (see Section 5.1) to ensure the required observations are obtained from key locations, including necessary technical developments.

Action A8 (AF5)

Action: Develop and deploy precipitation-measuring instruments on the Ocean Reference Mooring Network.
Who: Parties deploying moorings in cooperation with JCOMM and OOPC.
Time-Frame: Coordination finalized by 2005, implementation complete by 2009.
Performance Indicator: Number of instruments deployed and data submitted to International Data Centres.
Cost Implications: Category III.

The GPCP has devised and implemented an initial quasi-operational strategy, including *in situ* observations and estimates derived from satellite data, for providing global analyses of precipitation. This strategy must be periodically reviewed and enhanced to take advantage of improvements in technology and to accommodate the full suite of GCOS requirements. Estimates of precipitation in high latitudes remain a challenge.

[26] Specifically the Special Sensor Microwave/Imager (SSM/I) and the NOAA Advanced Microwave Sounding Unit (AMSU), as well as sustained and institutional support of critical research instruments including the Japan Aerospace Exploration Agency (JAXA) Advanced Microwave Scanning Radiometer (AMSR), the NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement Mission.

Action A9

Action: Develop and implement improved methods for observing precipitation that take into account advances in technology and fulfil GCOS requirements. **Who:** Parties' national research programmes through WCRP in cooperation with GCOS. **Time-Frame:** Continuous. **Performance Indicator:** Implemented methods; improved (in resolution, accuracy, time/space coverage) analyses of global precipitation. **Cost Implications:** Category II.

ECV – Wind Speed and Direction

Over land the observation of wind speed and direction is accomplished largely through the synoptic meteorological network. For many locations, however, measurements are only representative of the local area and there are often issues of homogeneity with the wind instruments. More representative and homogeneous wind speed and direction estimates can be derived from pressure data. Three-hourly pressure measurements can provide useful indicators of storminess.

Action A10 (AF7)

Action: Ensure availability of 3-hourly mean sea-level pressure and wind speed and direction data from GSN stations. **Who:** National Meteorological Services with coordination from the AOPC, WMO CBS. **Time-Frame:** Provide data by 2006. **Performance Indicator:** Data availability in International Data Centres. **Cost Implications:** Category II.

Over the oceans, the observations from VOS, including the higher-quality VOSClim, the Tropical Mooring Network, and the Reference Buoy Network (see Section 5) provide a sparse but vital data resource. However, there are continuing problems with the representativeness and quality of *in situ* wind measurements over both the land and ocean. WMO CBS should encourage national services to submit their data to the International Data Centres and consider advice on approaches to improving the value of the data.

Spaceborne scatterometer and passive microwave radiometer data have been demonstrated to be valuable sources for wind field information over the ocean when coupled with the *in situ* observations in an integrated analysis product. Systematic and sustained deployment of scatterometer or equivalent wind-measuring systems must be maintained. Scatterometers in particular provide large coverage and a spatial resolution of wind speed and direction that matches the scales of ocean variability.

Action A11[27] (AF7)

Action: Ensure continuous operation of AM and PM satellite scatterometer or equivalent observations. **Who:** Space Agencies through CGMS and CEOS with WMO Space Programme and GCOS. **Time-Frame:** Continuous. **Performance Indicator:** Long-term satellite observations of surface winds. **Cost Implications:** Category IV.

ECV – Water Vapour

Water vapour (humidity) measurements are obtained from the WWW/GOS synoptic observing networks over land. Over the oceans, the observations from VOS, including the higher-quality VOSClim, the Tropical Mooring Network, and the Reference Buoy Network provide a sparse but vital data resource. Homogeneous data are essential for assessment of the impact of changes of surface water vapour on natural and human systems. Unfortunately, poor observational practices hamper the usefulness of the data from most of these sources, an issue that needs to be addressed through research activity. Surface water vapour data have not been studied in a global climate context and

---

[27] See also Action O23.

efforts to provide historical data to the GCOS analysis and archive centres are needed. WMO CBS and the GCOS GSN Analysis and Monitoring Centres, with input from AOPC, should develop standards and protocols for the exchange of this information.

Action A12 (AF7)

Action: Submit water vapour data from national networks to the International Data Centres. **Who:** National Meteorological Services through WMO CBS and GCOS Analysis and Monitoring Centres with input from AOPC. **Time-Frame:** Complete analysis of global-scale data by 2006. **Performance Indicator:** Data availability in analysis centres and archive. **Cost Implications:** Category I.

ECV – Surface Radiation Budget

The surface radiation budget is a fundamental component of the surface energy budget that is crucial to nearly all aspects of climate, and needs to be monitored systematically. The Baseline Surface Radiation Network (BSRN) of the WCRP has established the relevant measurement techniques and is now recognized as the GCOS baseline network for surface radiation. The development of this global network is being done in concert with Earth Radiation Budget (ERB) observations from satellite (see below). The BSRN provides high-quality but spatially limited measurements of radiation at the surface, and should be expanded for global coverage and adequately supported. Expansion over the open ocean using research ships and buoys is a key element in attaining global radiation observations, since island stations are typically biased by island effect clouds. The AOPC, together with the climate research community (WCRP/Global Energy and Water Cycle Experiment (GEWEX) Radiation Panel), will develop plans for global coverage with the BSRN network and the establishment of analysis infrastructure. The existing extensive data sets of sunshine duration in most countries could also provide useful historic information for climate analysis, and their incorporation into GCOS analysis and archive centres is required The AOPC, in consultation with the WCRP, will develop a project for the utilization of existing long-term surface radiation budget data sets through the submission of sunshine data from national networks to International Data Centres.

Action A13 (AF8)

Action: Submit sunshine data from national networks to International Data Centres. **Who:** National Meteorological Services and others, in cooperation with the GCOS GSN Analysis Centres. **Time-Frame:** Submit national historical data by 2007. **Performance Indicator:** Data availability in International Data Centres. **Cost Implications:** Category I.

Action A14 (AF8)

Action: Expand the BSRN network to obtain global coverage and establish formal analysis infrastructure. **Who:** Parties' national services and research programmes operating BSRN sites in cooperation with AOPC and the WCRP/GEWEX Radiation Panel. **Time-Frame:** Plan completed 2004, BSRN fully operational by 2009. **Performance Indicator:** Published plan and the number of BSRN stations submitting data to International Data Centres. **Cost Implications:** Category III.

4.2. Atmospheric Domain – Upper-air

4.2.1. General

The observational networks and their current status, along with the satellite data required for each ECV in the Atmospheric Domain – Upper-air, are contained in Table 11. Because the main *in situ* observations are obtained from WWW/GOS radiosonde network, special issues related to this network affect several ECVs and are treated first.

Table 11. Observation networks and systems contributing to the upper-air component of the Atmospheric Domain.

ATMOSPHERIC DOMAIN – UPPER-AIR				
ECV	**Contributing Network(s)**	**Status**	**Contributing Satellite Data**	**Status**
Upper-air Temperature	GUAN. Reference network of high-quality and high- altitude radiosondes. Full WWW/GOS radiosonde network. Commercial aircraft.	About 75% of stations are providing CLIMAT TEMPS. International cooperation is needed to establish the reference network. Many stations do not provide two observations each day. Aircraft observations are valuable but limited to specific routes and levels.	Microwave (e.g., MSU, AMSU-A, ATMS). GPS radio occultation. Infrared sounders (e.g., HIRS, AIRS, IASI, CrIS).	Need to ensure continuity of MSU-like radiance bands. GPS is promising.
Upper-air Wind Speed and Direction	GUAN. Full WWW/GOS radiosonde network. Radar (profilers). Commercial aircraft.	About 75% of stations are providing CLIMAT TEMPS. Wind observations are often taken every 6 hours and provide useful information. Radar data are not globally distributed. Aircraft observations are valuable but limited to specific routes and levels.	Visible and infrared (atmospheric motion vectors). Lidar ESA Aeolus mission.	Continuity of polar winds at risk; Operational; NWP used for reanalysis. Awaiting Aeolus demonstration; no continuity planned.
Upper-air Water Vapour	GUAN. Reference network of high-altitude and high- quality radiosondes. Full WWW/GOS radiosonde network. Ground-based GPS receiver network. Commercial aircraft.	Water vapour is not accurately measured in the upper troposphere and lower stratosphere. Accurate reference sondes measuring upper-tropospheric and lower-stratospheric humidity are needed. International cooperation is needed to establish agreed protocols for the collection and exchange of GPS data. Aircraft data are potentially useful but limited to specific routes and levels.	Microwave (AMSU-B); Infrared sounders (e.g., HIRS, AIRS, IASI, CrIS); GPS radio occultation; Infrared and micro-wave limb sounders (e.g., HIRDLS, MLS); Solar occultation (e.g., HALOE).	Continuity assured for operational microwave and IR sounders; Continuity uncertain for research satellites.
Cloud Properties	Surface observations (GSN, WWW/GOS).	Surface observations of cloud cover provide an historical but uncertain record; Continuation and reprocessing of cloud climatology data is needed.	Visible and infrared radiances from geostationary and polar orbiting satellites; Cloud radar (research).	Cloud top temperature and coverage are operational; Emerging operational products on cloud microphysics.

Earth Radiation Budget		The historical record is not continuous nor homogeneous.	Broadband short- and longwave (e.g., from CERES).	CERES provides the next generation of accuracy, continuity uncertain past 2008; NPOESS provides a CERES-like record starting in 2011.
			GERB geostationary data provides first high time resolution broadband data.	GERB useful for process studies.

For temperature, wind speed and direction, and water vapour, the WWW/GOS radiosonde network provides the backbone of the *in situ* global observing system for climate as well as for weather forecasting applications. The full WWW/GOS plan for radiosondes, involving some 900 stations, has never been fully realized but remains a desirable goal for climate as well as weather forecasting. About 15 ships fitted with automated radiosonde systems operate largely in the North Atlantic and Pacific Oceans. Some problems are occurring in the performance of the radiosonde network either because observations are not being taken due to a lack of resources, or because data are not being exchanged. The resulting acquisition of data is unevenly distributed over the globe with relatively high-density coverage over most of the Northern Hemisphere, and with much poorer coverage over the tropics and the Southern Hemisphere. The advent of Global Positioning System (GPS) technology has helped improve the accuracy of radiosonde wind measurements; however, it has also created problems for some nations due to increased operating costs. In order to take advantage of the enhanced accuracy, it is essential to implement the reporting of position and time of each measurement. It is also highly desirable to have observations twice per day as this allows radiation biases to be partly assessed.

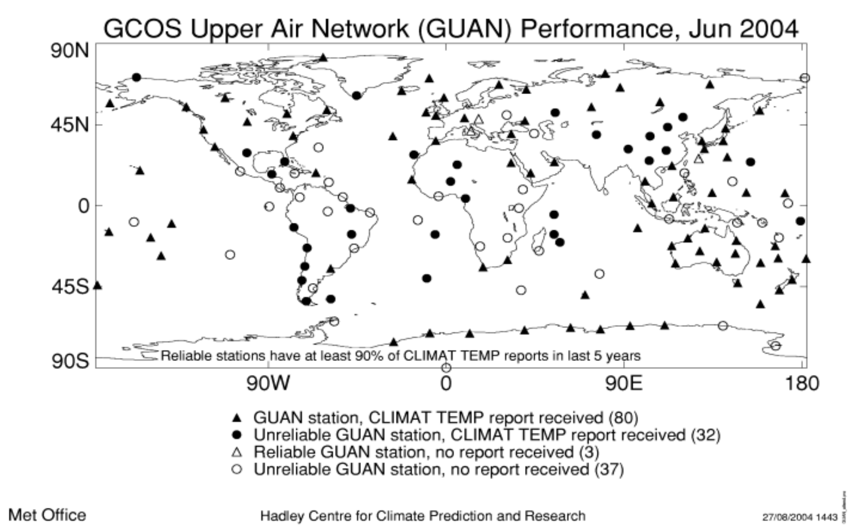

Figure 2. Performance of the GUAN upper-air temperature observations for June 2004 (Source: UK Met Office).

A continuing international effort is underway involving the WMO CBS, WMO CIMO and GCOS to help alleviate the negative impact of the high cost of radiosondes and obsolescent equipment on network performance. These groups are encouraged to continue to promote technology and policy actions to ensure that affordable high-quality sondes are readily available for global climate monitoring.

GCOS has designated a subset of the WWW/GOS radiosonde network as the baseline GUAN. GUAN consists of about 150 radiosonde stations fairly evenly distributed over the globe. The AOPC is working with the WMO CBS, the WMO RAs and the National Meteorological Services to implement a programme for the sustained operation of GUAN, together with its associated infrastructure. For some individual stations, technical cooperation is necessary from other nations or agencies and/or the GCOS Cooperation Mechanism, to equip the stations, provide training of operators and in some instances to support continuing operations (e.g., provision of expendables). The GCOS Secretariat, in consultation with the WMO CBS, will as a high priority seek complete implementation of the GUAN, including its infrastructure and data management.

Action A15 (AF10)

Action: Complete implementation of GUAN, including infrastructure and data management. **Who:** National Meteorological Services operating GUAN stations in cooperation with GCOS Secretariat and WMO CBS. **Time-Frame:** Complete 2006. **Performance Indicator:** Percentage of data archived in WDC Asheville. **Cost Implications:** Category IV.

Figure 2 above shows that in the 5 years up to June 2004, 83 stations were “reliable” in that at least 90% of their expected reports were received, while 69 stations were unreliable.

There remain outstanding issues concerning the quality of all radiosonde measurements for climate monitoring and climate change detection purposes. Radiation errors cause uncertainties in temperature, and standard radiosondes are not capable of measuring water vapour at low temperatures with sufficient accuracy. Prototype reference sondes have been developed to meet climate needs and routine observations from Boulder, Colorado (USA) currently provide the only reliable record of upper-tropospheric and stratospheric (up to 25 km altitude) temperature and water vapour. A reference network of about 30 such sites is proposed to permit systematic observations across all climate zones. This network will be extensively used to calibrate and validate various satellite observations including GPS occultation, as well as microwave and infrared sounding data on both temperature and water vapour. In addition to providing a network for climate purposes, the network will provide new information on water vapour in the upper troposphere and lower stratosphere that is vital for understanding the greenhouse effect.

The operational observing programme for such a reference radiosondes (frequency and instrumentation performance requirements) needs to be specified to align with the needs of all relevant users, including Space Agencies. The new network will be considered as a special component of the GUAN. Initiating and implementing this network on a five-year timetable is a very high priority. Where feasible, these reference sites should be collocated and consolidated with other climate monitoring instrumentation (e.g., GPS column water vapour measurements, ozonesonde and other GAW observatories). In addition to establishing the observation sites, it will be important to have mechanisms for quality control, archive and analysis of the data. The AOPC, in consultation with WMO CBS, will develop plans for the implementation of a reference network of high-altitude high-quality radiosondes, including data management, archiving and analysis.

Action A16 (AF14)

Action: Specify and implement a Reference Network of high-altitude, high-quality radiosondes, including operational requirements and data management, archiving and analysis. **Who:** Parties’ National Meteorological Services and research agencies, in cooperation with AOPC and WMO CBS. **Time-Frame:** Specification and plan by 2005. Implementation completed by 2009. **Performance Indicator:** Plan published. Data management system in place. Network functioning. Data availability. **Cost Implications:** Category IV.

The full implementation and operation of the WWW/GOS radiosonde network in compliance with the GCMPs is a desired long-term goal for both weather forecasting and climate monitoring. Additional data sources, such as vertically pointing radar systems (wind profilers) and data from aircraft (both at flight level and on ascent and descent), are becoming more important for weather analysis and forecasting and will contribute to climate applications, particularly as they pertain to atmospheric reanalysis. The AOPC will work with the WMO CBS and the RAs to ensure full implementation of the WWW/GOS radiosonde network in compliance with GCMPs, together with correct reporting. Lidar measurements of wind profile from space could form another important data source and it would be of great value to initiate a global vertical wind profiling satellite mission as a demonstration project.

Action A17 (AF11)

Action: Improve implementation of the WWW/GOS radiosonde network compatible with the GCMPs and in full compliance with coding conventions.
Who: National Meteorological Services in cooperation with WMO CBS and WMO RAs.
Time-Frame: Continuing.
Performance Indicator: Percentage of real-time upper-air data with no quality problems.
Cost Implications: Category IV.

The provision of meta-data concerning the instrumentation and data reduction and processing procedures is crucial to utilizing radiosonde data in climate applications. The historical record of radiosonde observations has innumerable problems relating to lack of inter-comparison information between types of sondes and sensor and exposure differences. Special efforts are required to obtain these meta-data records and to include them as important elements in the future observing strategy.

Action A18 (AF11)

Action: Submit meta-data records and inter-comparisons for radiosonde observations to International Data Centres.
Who: National Meteorological Services in cooperation with WMO CBS, WMO CIMO and AOPC.
Time-Frame: 2009.
Performance Indicator: Percentage of sites giving meta-data to WDC Asheville.
Cost Implications: Category I.

4.2.2. Specific Issues – Upper-air ECVs

The following sections elaborate further on the specific issues and proposed actions related to each ECV in the Atmospheric Domain – Upper-air.

ECV – Upper-air Temperature

Specific microwave radiance data from satellites (NOAA[28] Microwave Sounding Unit (MSU) and NOAA Advanced Microwave Sounding Unit A (AMSU-A)) have become key elements of the historical climate record and need to be continued into the future to sustain a long-term record. For climate applications, the satellite systems must be operated in adherence with the GCMPs. Failure of the on-board AMSU-A instrument should be regarded as sufficient cause to launch a new satellite in the series. It should be noted that new high-resolution infrared sounders such the NASA Atmospheric Infrared Sounder (AIRS), IASI and CrIS will improve the vertical resolution of satellite-derived temperature soundings by a factor of three, which will significantly improve the monitoring of temperature change. Other atmospheric temperature sounding data play an important role, along with many diverse data sources in reanalyses of all the upper-air variables.

Action A19 (AF12)

Action: Continue the system of satellites following the GCMPs to enable the continuation of MSU-like radiance data.
Who: Space Agencies.
Time-Frame: Continuing.
Performance Indicator: Quality and quantity of data; availability of data; monthly maps and products.
Cost Implications: Category III.

GPS radio occultation (RO) measurements provide high vertical resolution profiles of atmospheric refractive index that relate directly to temperatures above about 6 km altitude (where water vapour effects are small). They provide benchmark observations that can be used to calibrate all other data (sondes, IR and microwave soundings). Instruments are being flown on multiple low Earth orbiting

[28] National Oceanic and Atmospheric Administration (NOAA).

satellites (such as during the CHAMP and SAC-C projects) and further research missions are planned (such as the COSMIC fleet of 6 satellites due for launch in 2005). Data need to be developed for real-time use and exchanged and implemented into operational meteorological data streams. Plans also need to be made to ensure future RO instruments and platforms, including on operational meteorological satellites. Some such plans already exist (such as on METOP).

Action A20 (AF13)

Action: GPS RO measurements should be made available in real time, incorporated into operational data streams, and sustained over the long-term. Protocols need to be developed for exchange and distribution of data. **Who:** Space Agencies, in cooperation with CGMS, WMO CBS, the WMO Space Programme and AOPC. **Time-Frame:** Exchange standards and protocols by 2006. **Performance Indicator** Volume of data available and percentage of data exchanged. **Cost Implications:** Category III.

ECV – Upper-air Wind Speed and Direction

The WWW/GOS Upper-air Radiosonde Network is the backbone of the upper-air wind observation programme. Observations from commercial aircraft are also becoming more plentiful. A further source of wind information is the cloud motion vectors obtained by tracking cloud elements and assigning their height by estimating their temperature to provide “satellite winds” over the ocean. These data are part of the WWW/GOS designed for weather forecasting and will have application for climate through their incorporation in reanalysis.

ECV – Upper-air Water Vapour

Information on tropospheric water vapour is provided by the same operational passive microwave and infrared satellite instruments whose data are used to provide precipitation products. Requirements for stable operation and processing, as expressed in Action A7 for precipitation, apply for water vapour as well. Data assimilation can be used to improve the consistency of water vapour, cloud and precipitation estimates, and the combination of passive microwave and precipitation radar measurements from space (as in the Tropical Rainfall Measurement Mission and the proposed Global Precipitation Mission) has an important role to play in this regard. Water vapour also is an important product and reactant in the chemistry of the upper troposphere and stratosphere, influencing methane, ozone and halogenated greenhouse gases. Here it can be measured using the limb-sounding and occultation techniques employed for other trace constituents (Section 4.3). Calibration of the data from the various sensors is a very important issue, and for this the implementation of the proposed reference network of high-quality radiosondes (Action A16) would provide invaluable data.

Many nations are currently developing the capability to observe and analyze data from ground-based GPS receivers. These data provide continuous high-quality estimates of column water vapour, which is a key greenhouse gas. Through the WMO and other relevant international agencies, standards and protocols need to be developed for exchanging and archiving these data. The network of GPS receivers should then be extended across all land areas to provide global coverage, and the data should be freely exchanged for climate purposes. The feasibility of collocating GPS receivers at GSN and GUAN sites should be considered. The AOPC, in cooperation with WMO CIMO and WMO CBS, will develop an internationally-agreed plan for a network of ground-based GPS receivers and associated data processing, standards and protocols, and data management.

Action A21 (AF15)

Action: Develop standards and protocols for exchange of data from the networks of ground-based GPS receivers. **Who:** WMO CIMO and WMO CBS in cooperation with national agencies. **Time-Frame:** Exchange standards and protocols finished by 2005. Implementation continuing (part exists already). **Performance Indicator:** Number of sites providing data. **Cost Implications:** Category I.

ECV – Cloud Properties

Cloud feedback is considered to be one of the most uncertain aspects of future climate projections and is responsible for much of the wide range of estimates of climate sensitivity in climate models. The accurate measurement of cloud properties is exceedingly difficult. The WCRP International Satellite Cloud Climatology Project has developed a continuous record of infrared and visible radiances since 1983 utilizing both geostationary and polar orbiting satellite data, but the record suffers from inhomogeneities. Reprocessing the data to account for orbital drift and other issues has helped reduce uncertainties in the observations. Long-term data sets of the NOAA Advanced Very High Resolution Radiometer (AVHRR) should be reprocessed to obtain records of cloud microphysics. Because of the importance of the observation of cloud amount, microphysical characteristics and radiative properties, and their variation in time, continued research on improving the observational system is required, and an overall strategy needs to be devised to provide systematic cloud observations. Gaps in the future record should be avoided.

Action A22 (AF16)

Action: Ensure continuation of a climate data record of visible and infrared radiances, e.g., from the International Satellite Cloud Climatology Project, and include additional data streams as they become available.
Who: Space Agencies, for processing.
Time-Frame: Continuous.
Performance Indicator: Long-term availability of global homogeneous data at high frequency.
Cost Implications: Category III.

Action A23 (AF16)

Action: Research to improve cloud property observations in three dimensions.
Who: Parties' national research and Space Agencies in cooperation with the WCRP.
Time-Frame: Continuous.
Performance Indicator: New cloud products.
Cost Implications: Category III.

ECV – Earth Radiation Budget

The Earth Radiation Budget (ERB) measures the overall balance between the incoming energy from the sun and the outgoing thermal (longwave) and reflected (shortwave) energy from the Earth. It can only be measured from space, thus continuity of observations is an essential issue. The radiation balance at the top of the atmosphere is the basic radiative forcing of the climate system. Measuring its variability in space and time over the globe provides insight into the overall response of the system to this forcing. The satellite measurements include solar irradiance observations as well as the broadband measurements of reflected solar and outgoing longwave radiation. At least one dedicated satellite ERB mission should be operating at any one time. Satellite observations should be continued without interruption, and operational plans should provide for overlap so that accuracy and resolution issues are resolved to meet climate requirements. This should be a high priority for CEOS and CGMS in their planning process. The requirement for this overlap is demonstrated in Figure 3 below.

Action A24 (AF17)

Action: Ensure continuation of Earth Radiation Budget observations.
Who: Space Agencies, coordinated through WMO Space Programme, CEOS and CGMS.
Time-Frame: Present.
Performance Indicator: Long-term data availability at archives.
Cost Implications: Category IV.

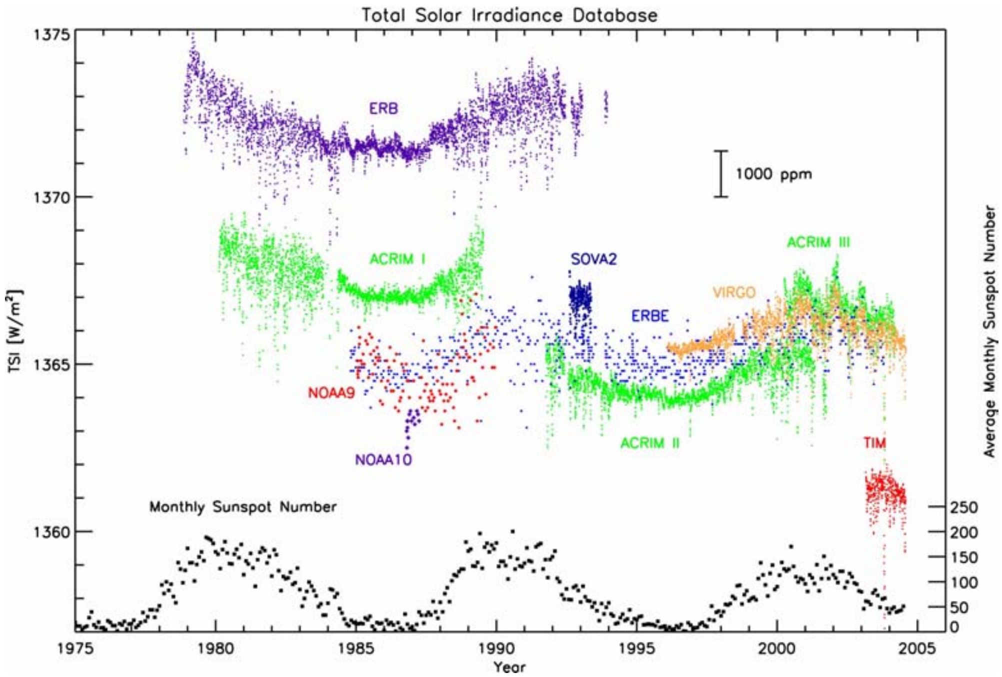

Figure 3. Observations of total solar irradiance (TSI) from a series of different instruments on satellites as indicated, along with monthly sunspot number. The vertical bar in the upper right corner shows a relative variation of 0.1% in TSI. Absolute values are uncertain and differ by as much as 9 Wm^{-2}, so that continuous time series are only made possible by overlapping measurements from different satellites. (Source: http://spot.colorado.edu/~koppg/TSI accessed 11 October 2004).

4.3. Atmospheric Domain – Composition

4.3.1. General

A number of atmospheric trace constituents, in addition to water vapour, must be monitored because of their important role in the forcing of climate. The atmospheric composition ECVs are listed in Table 12 together with the observational networks and satellites involved in global measurements. This is based on the detailed assessment of global atmospheric chemistry observational systems in the IGOS Theme Report on Integrated Global Atmospheric Chemistry Observations (IGACO), which outlines the data requirements based on four issues: climate, air quality, ozone depletion, and oxidizing efficiency. Here, the focus is on climate and the ECVs in Table 1. While gaseous precursors to methane, ozone and aerosols (e.g., CO, SO_2, NO_x and Volatile Organic Carbon Components) are not listed as GCOS ECVs, they are acknowledged to be important research variables that should be included in the global integrated air chemistry observation system as recommended in the IGACO theme report.

Table 12. Observational networks and systems contributing to the Atmospheric Domain – Composition.

ATMOSPHERIC DOMAIN – COMPOSITION				
ECV	**Contributing Network(s)**	**Status**	**Contributing Satellite Data**[29]	**Status**
Carbon Dioxide	GAW continuous surface monitoring network. GAW surface flask sampling network. Airborne sampling.	Operational; Partial network; Operational data management. Operational; Partial network; Operational data management. Limited operational aircraft vertical profiling initiated.	High-resolution IR (e.g., AIRS, OCO, GOSAT, SCIAMACHY).	Continuity in operational instruments but products are immature and limited; Dedicated research satellite missions are planned (e.g., OCO).
Methane and other greenhouse gases	GAW[30] surface continuous monitoring network. GAW surface flask sampling network. AGAGE, SOGE and University of California at Irvine, USA. Airborne sampling.	Operational; Partial network; Operational data management. Operational; Partial network; Operational data management. Operational; Partial network; Operational data management. Limited operational aircraft vertical profiling initiated.	IR nadir sounders (e.g., MOPITT, IASI). IR limb sounders (e.g., HIRDLS).	Continuity in operational instruments but products are immature and limited. Uncertain continuity of profiling sounders.
Ozone	GAW ozonesonde network, including NASA SHADOZ. GAW column ozone network (filter, Dobson and Brewer stations). NDSC.	Mature operational ground-based balloon sondes and total column network. Mature operational ground-based balloon sondes and total column network. NDSC network has limited spatial coverage.	UV (e.g., GOME, TOMS, SBUV/2); IR nadir (e.g., AIRS); IR limb (e.g., MIPAS); Occultation (e.g., SAGE).	Operational continuity for column ozone; Limited heritage for future operational profiling.
Aerosol Properties	BSRN; NASA AERONET; WMO GAW; Regional lidar networks.	Surface aerosol optical depth networks are operational, but not coordinated.	Solar occultation (e.g., SAGE); Visible/near-IR (e.g., AVHRR, MODIS, VIIRS); Lidar profiling (e.g., CALIPSO); UV nadir (e.g., OMI); Polarimetry (e.g., PARASOL); Multiangular viewing (e.g., MISR).	Planned operational continuity for column products; Research missions for profiling tropospheric aerosols; Uncertainty for continuity of stratospheric profiling.

A key objective of the GCOS baseline networks for atmospheric composition is determination of the sources and sinks of the main greenhouse gases. This matches one of the objectives of the WMO GAW. Thus, following the IGACO strategy, WMO GAW, in cooperation with GCOS, will develop a system to better quantify distribution of ECVs and their sources and sinks through integration of ground-based, aircraft and satellite measurements using modelling and data assimilation. GCOS will also promote the development of models that are key to this objective through a strengthening of ongoing programmes currently administered by WCRP and the WMO Atmospheric Research and Environment Programme.

[29] For complete listing and details of past, present and future satellite missions, see the IGOS IGACO Theme Report.
[30] GAW includes networks operated by NOAA/CMDL, CSIRO and many other WMO Members.

The WMO GAW programme will collaborate with AOPC to establish a global plan for *in situ* observational networks for the atmospheric composition ECVs that conform to the current data quality objectives set by GAW, and to ensure that freely-accessible data are archived in the WMO GAW World Data Centres.

Action A25 (AF18)

Action: Establish a plan for and implement a consistent surface- and satellite-based global observing system for the atmospheric composition ECVs, based on common standards and procedures, and encourage data submission to WDCs. **Who:** Parties' national services, research agencies and Space Agencies, under the guidance of WMO GAW in coordination with AOPC. **Time-Frame:** Plan ready by 2005, implementation 2006-2015. **Performance Indicator:** Published plan, availability of globally-consistent data. **Cost Implications:** Category IV[31].

The absence of information on the vertical-profile of some atmospheric composition ECVs (e.g., aerosols) is a major problem in the verification of climate model predictions. At the same time, the use of aircraft and similar techniques for airborne sampling has proven to be a powerful research tool. It is proposed that the WMO GAW, National Meteorological Services and research institutions work to develop a comprehensive plan to utilize commercial and research aircraft, pilotless aircraft, balloon-borne systems, kites, ground-based lidars and satellites in systematic observations of the vertical profiles of greenhouse gases (GHGs), ozone and aerosols.

Action A26 (AF20)

Action: Develop and implement a comprehensive plan to observe the vertical profiles of GHGs, ozone and aerosols utilizing commercial and research aircraft, pilotless aircraft, balloon systems, kites, ground-based lidars and satellites. **Who:** Parties' national services, research agencies and Space Agencies, under the guidance of WMO GAW in coordination with AOPC. **Time-Frame:** Plan by 2005, implementation 2006-2015. **Performance Indicator:** Published plan, availability of globally-consistent data. **Cost Implications:** Category IV.

4.3.2. Specific Issues – Composition ECVs

The following sections elaborate further on specific issues and implementation actions for each ECV in the Atmospheric Domain – Composition.

ECVs – Carbon Dioxide and Methane, and other GHGs

The present GAW comprehensive network (Figure 4) forms the basis of a GCOS/GAW CO_2 and CH_4 baseline network. There are major gaps to be filled in potential terrestrial sink regions as well as in the southern oceans. Sites that measure fluxes and concentrations from major regional research projects (e.g., North American Carbon Program, CarboEurope) could be added to fill some of these gaps. The CMDL of NOAA is a WMO GAW member and major partner in the comprehensive network (CMDL also hosts the WMO primary standards for CO_2, CH_4, and N_2O). Many other WMO GAW participants (e.g., Australia, Japan, France, Canada) contribute to the comprehensive network following WMO GAW measurement guidelines, data quality objectives, and submission of data to the World Data Centre for Greenhouse Gases (WDC-GG) in Japan. The analysis centres responsible for assembling a data set appropriate for inversion modelling to calculate carbon sources and sinks need to be formally recognized and supported. The baseline network will be specified and further developed by WMO GAW in cooperation with the AOPC.

[31] See Section 2.8 Table 7 for cost definitions.

Action A27 (AF18)

Action: Establish the GCOS/GAW baseline network for CO_2 and CH_4, and fill the gaps. **Who:** Parties' national services, research agencies and Space Agencies under the guidance of WMO GAW and its Scientific Advisory Group for Greenhouse Gases in cooperation with the AOPC. **Time-Frame:** Specification by 2005 and implementation by 2009. **Performance Indicator:** Plan. **Cost Implications:** Category III.

In addition to the baseline network a comprehensive network involving satellite and other *in situ* measurements will provide the observational resources to undertake regional analyses. Some of these data are already available for assimilation in real time and reanalysis systems. Furthermore, the assimilation techniques that are being developed for the determination of CO_2 distributions may be extended to some other greenhouse gases in the future. The utility of the comprehensive network will be enhanced as assimilation techniques improve and new types of satellite data become available.

Action A28 (AF18)

Action: Develop plans for an Integrated Data Analysis Centre (WIDAC) for CO_2 and CH_4. **Who:** WMO GAW and its WDC-GG in consultation with the AOPC. **Time-Frame:** 2007. **Performance Indicator:** Establishment of data analysis centre. **Cost Implications:** Category I.

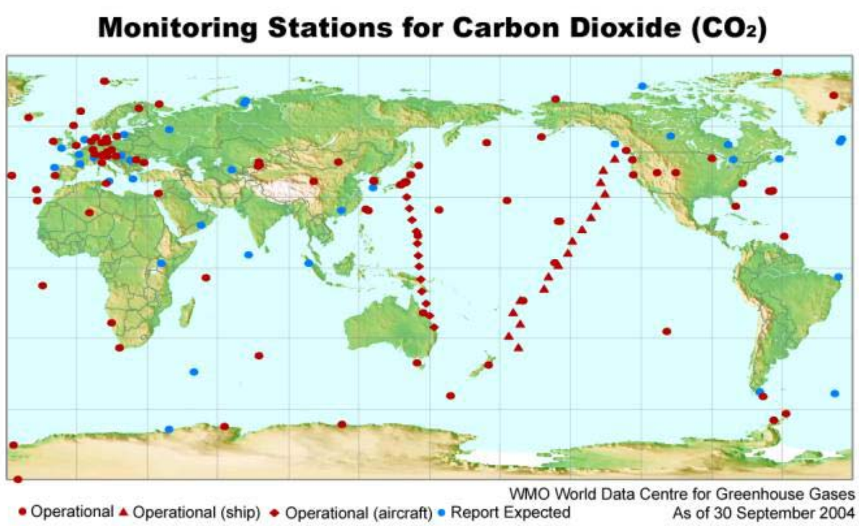

Figure 4. Current configuration of the comprehensive WMO GAW network for CO_2-based data contained at the WDC for Greenhouse Gases in Japan. The network for CH_4 is almost identical (Source: WDC-GG).

The N_2O and chlorofluorocarbon (CFC) networks are comprised of fewer stations than those for CO_2 and methane including approximately equal contributions from the Advanced Global Atmospheric Gases Experiment (AGAGE), and WMO GAW, with CMDL being a leading partner. Although there is an active inter-comparison programme among the partners, there is no primary standard laboratory for CFCs.

Action A29 (AF18)

Action: Complete an International Halocarbon Inter-comparison Study, linking measurement scales for CFCs of major networks as an initial step in an ongoing quality assurance programme.
Who: Parties' national research agencies and national services, through WMO GAW.
Time-Frame: Report in 2007; subsequent inter-comparisons 2007-2012.
Performance Indicator: Report of inter-comparison data.
Cost Implications: Category I.

ECV – Ozone

WMO has been coordinating global monitoring of ozone since the 1950's. The total column and vertical profile ozone networks are essential in the calibration and validation of satellite ozone measurements, to reliably detect trends needed for both climate studies and science assessments of ozone in support of the Vienna Convention on Protection of the Ozone Layer.

The WMO GAW total column ozone network of approximately 130 stations is an example of a network comprised largely of WMO Members making observations by using three different instruments (Dobson and Brewer spectrophotometers as well as less accurate (filter instruments). The challenge of WMO GAW is to assure the quality and comparability of these different observations. Regional calibration centres are operated for Dobson instruments at several locations and are being expanded. Brewer calibration is advancing rapidly and ozone assessments merge Dobson and Brewer data into a global picture of long-terms trends that is essential in early detection of ozone depletion recovery.

The WMO GAW global network consists of approximately 42 stations currently making vertical profile observations of ozone with balloon sondes. It is a good example of a global network in which a contributing partner, namely the NASA/Southern Hemisphere Additional Ozonesondes (SHADOZ) network of 9 stations, is collaborating with the WMO GAW network of 33 stations, utilizing similar measurement protocols and the WMO GAW World Ozone and UV Data Centre (WOUDC), to yield more comprehensive global observations of ozone in the troposphere and stratosphere.

There is a need for additional ground-based observations in certain regions (especially in the Southern Hemisphere and tropics) to support the use of satellite data for global monitoring of ozone. The WMO GAW, working in cooperation with the scientific community (WCRP and AOPC), will define the Baseline Ozone Observing Network and initiate implementation with national services and research institutions.

Action A30 (AF19)

Action: Define and implement the Baseline Ozone Observing Network for balloon vertical profiles and total column ozone and initiate implementation.
Who: Parties' national research agencies and national services through WMO GAW and partners, in consultation with AOPC.
Time-Frame: Agree on balloon sondes network by 2005, implementation thereafter.
Performance Indicator: Network specification. Percentage of data submitted to International Data Centres.
Cost Implications: Category III.

ECV – Aerosol Properties

Atmospheric aerosols are minor constituents of the atmosphere by mass, but a critical component in terms of impacts on climate and especially climate change. Aerosols influence the global radiation balance directly by scattering and absorbing radiation and indirectly through influencing cloud reflectivity, cloud cover and cloud lifetime. The IPCC has identified anthropogenic aerosols as the most uncertain climate forcing constituent. Aerosol measurements are currently included in the WMO GAW observing programme, where the intent has been to obtain measurements representative of the major geographical and exposure regimes. In addition, several limited regional networks of measurements directly related to aerosol properties are in place (e.g., sun photometer networks operated as part of research programmes) for addressing air quality and acidification issues, as well as for supporting satellite system calibration/validation activities. The directly-instrumented record for aerosols is limited to recent times, but there is an important source of long-term records on atmospheric aerosol abundance and composition in glacial ice (see also Actions C15 to C17).

WMO GAW has identified the ground-based aerosol monitoring needs for a global aerosol network aimed at climate and air quality. Five core parameters were recommended for measurement at all GAW sites around the world:

- Multi-wavelength aerosol optical depth.
- Mass in two size fractions.
- Major chemical components in two size fractions.
- Light absorption coefficient.
- Light scattering coefficient at various wavelengths.

In addition a comprehensive list of measurements was recommended for WMO GAW global stations. The WMO GAW programme is encouraging WMO Members to implement these as well as actively assisting stations in developing countries to upgrade their observations to the WMO GAW standard. WMO GAW, its partners (including the Space Agencies) and GCOS will encourage consolidation of baseline measurements and further develop a strategy for obtaining continuous homogeneous observations to characterize the nature and radiative properties of aerosols.

Comprehensive measurements of aerosols are available at a very limited number of sites, reflecting the difficulty in developing an effective and feasible observing strategy. The most extensive observation for aerosols is the optical depth measured by satellite and ground-based instruments. The latter are coordinated in part by WMO GAW and its partners, including BSRN and the NASA Aerosol Robotic Network (AERONET). In addition, routine vertical profiling of scattering from ground lidars is under development, as are more advanced satellite aerosol sensors. The coordination and consolidation of a global baseline network for aerosol optical depth should occur as soon as possible. Satellite measurements (e.g., AVHRR) have the potential to provide a long-term global record of aerosol optical depth over oceans. Production (reprocessing) of such a data set is recommended. More measurements from aircraft and ground stations are needed. A concerted effort to integrate the available satellite and ground-based measurements of aerosol optical properties and to expand the measurements has begun and is an important step in developing a system for global aerosol monitoring. The development and generation of consistent products combining the various sources of data are essential. Furthermore, the physical and chemical composition of aerosols needs to be routinely monitored at a selected number of globally-distributed surface sites. Finally, there should be a reprocessing of past satellite observations using better calibration, cloud screening and aerosol microphysics to obtain a historical record.

Action A31 (AF20)

Action: Develop and implement a coordinated strategy to monitor and analyze the distribution of aerosols and aerosol properties.
Who: Parties' national services, research agencies and Space Agencies, with guidance from AOPC in cooperation with WMO GAW, WCRP, IGBP.
Time-Frame: Define a baseline network for aerosol optical depth by 2006 with data archived at the WMO World Data Centre for Aerosols (Ispra, Italy), with proposal for implementation by 2009.
Performance Indicator: Strategy document, followed by implementation of strategy, availability of globally-consistent aerosol optical depth data.
Cost Implications: Category IV.

4.4. Atmospheric Domain – Data Management

Data management is a key consideration in the establishment of GCOS baseline networks (see Table 13). For GSN and GUAN, real-time monitoring centres have been set up, as well as delayed-mode archive and analysis centres. However, much remains to be done in these cases to obtain digital homogeneous historical records, and a greater focus is needed on the collection and archiving of digital meta-data associated with observing networks. In many countries, historical measurements have been archived only in paper records, and so a concerted international effort is needed to ensure that the global historical record is as comprehensive as possible. For other networks, real-time and delayed-mode analysis centres have yet to be established. Actions to establish improved data management for most of the greenhouse gases and other remaining atmospheric variables are in fact critical, and the actions noted in relation to the individual ECVs focus on the identification and establishment of networks so that data flow and data standards can be fully addressed by the International Data Centres. Timely delivery of ECV observations is recognized as a priority. The WWW Global Telecommunication System (GTS) and its successor, the Future WMO Information System (FWIS), should continue to be developed in this respect.

Table 13. International Data Centres and Archives – Atmospheric Domain.

Network or System	International Data Centres and Archives	Coordinating Body
Atmosphere Surface		
Baseline GCOS Surface Network	GCOS GSN Monitoring Centre (DWD, JMA) GCOS GSN Analysis Centre (NCDC, Hadley Centre) GCOS GSN Archive (WDC Asheville) WMO CBS GCOS Lead Centres (JMA, NCDC)	AOPC with WMO CBS
Full WWW/GOS synoptic network	Integrated Surface Hourly (WDC Asheville) Global Precipitation Climatology Centre (DWD)	WMO CBS
National surface networks	National responsibility; Submission to WDC Global Precipitation Climatology Centre (DWD)	WMO CCl, WMO CBS and WMO RAs
Baseline Surface Radiation Network	World Radiation Monitoring Centre (ETHZ)	WCRP
Atmosphere Upper-air		
Baseline GCOS Upper-air Network	GCOS GUAN Monitoring Centres (ECMWF, Hadley Centre) GCOS GUAN Analysis Centres (Hadley Centre, NCDC) GCOS GUAN Archive (WDC Asheville) WMO CBS GCOS Lead Centre (NCDC)	AOPC with WMO CBS
Full WWW/GOS Upper-air Network	WWW/GDPFS World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville	WMO CBS
Reference network high-altitude radiosondes	GUAN Centres (proposed)	AOPC with WCRP
Aircraft (ASDAR etc.)	WWW/GDPFS World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville	WMO CBS
Profiler (radar) network	WWW/GDPFS World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville	WMO CBS
Ground-based GPS receiver network		
Atmosphere Composition		
GAW CO_2 and GHG continuous monitoring network	WDC-GG (JMA) Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory)	WMO CAS
GAW CO_2 and GHG flask sampling network	WDC-GG (JMA)	WMO CAS
Ozonesonde network Ozone lidar network Column ozone network	WOUDC (MSC) Network for Detection of Stratospheric Change (NDSC) Archive Norwegian Institute for Air Research Southern Hemisphere Additional Ozonesondes (SHADOZ – NASA) Archive	WMO CAS
Aerosols: AERONET GAW baseline network Lidar network	World Data Centre for Aerosols (JRC Ispra)	WMO CAS

Open access to both *in situ* and satellite data is a key aspect of quality assurance, and further work is required to ensure that these data are available for analysis by all interested groups. Proper analysis of data requires access to relevant meta-data, so open data servers need to be established to support analysis activities.

The amount and diversity of satellite data concerning atmospheric composition variables are especially significant because of the large data volumes associated with some satellite projects, and the large number of projects associated with several Space Agencies. Currently, there are a number of independent data archives maintained for individual projects or specific scientific areas for individual agencies. The efficiency and effectiveness of the research community will be maximized by assuring that users can work simply with the widest possible set of data regardless of source. This can be facilitated through appropriate degrees of interoperability and establishment of common standards for data formats and comprehensive meta-data. Agencies that maintain these data archives should work together to make this goal a reality.

Action A32 (CF2, AF18)

Action: Develop and implement a strategy to enable use of satellite data on atmospheric composition for climate by scientific users, regardless of source.
Who: Space Agencies, in conjunction with CEOS and CGMS, IGOS-P, and WMO Space Programme.
Time-Frame: 2005 for strategy, 2007 for facilitated use of data regardless of source.
Performance Indicator: Written strategy by 2005; straightforward use of data regardless of source by broad range of scientific users.
Cost Implications: Category II.

4.5. Atmospheric Domain – Integrated Global Analysis Products

Although data from GCOS baseline networks can be used to estimate some indicators of the state of the global climate system, more comprehensive analyses depend upon combining data from different sources. In particular, satellite data providing global coverage integrated with *in situ* observations can remove biases and ensure consistency over land and ocean. An example is the difficulty in obtaining unbiased estimates of global precipitation due to the relative lack of *in situ* precipitation observations over the oceans.

Reanalysis provides a means to generate a range of integrated global products in the Atmospheric Domain, particularly for the upper atmosphere where a wide variety of diverse *in situ* and satellite data can be used to produce very detailed analyses. Establishing cooperative arrangements between the centres in Europe, USA and Japan that carry out global reanalyses would allow for each successive reanalysis to build on the data sets and results of the previous ones. While there has been progress, the state-of-the-art of the data inputs and reanalysis methods has not yet provided the homogeneity needed for most studies of climate change.

The Second Adequacy Report noted the importance of the links between the surface sources and sinks of greenhouse gases and aerosols and their influences on atmospheric concentrations. Previous actions have addressed the need to monitor the detailed regional and temporal distribution of the atmospheric concentrations of greenhouse gases and aerosols, especially over the continents. In addition, research on global data assimilation methods is also needed to achieve optimal global analyses, such as estimates of sources and sinks of carbon dioxide and methane. Actions C11, C12 and C13 in Section 3.5 on the preparation of data sets for reanalysis and on sustaining analysis systems must encompass atmospheric composition ECVs as well. For meteorological variables, considerable groundwork for this has been laid through the activities of reanalysis centres such as the European Centre for Medium-Range Weather Forecasts (ECMWF), the National Center for Environmental Prediction, and the Japan Meteorological Agency (JMA). Input data for reanalysis have been assembled by the reanalysis community with the assistance of the monitoring and research community. However, data assimilation of atmospheric composition variables has not occurred, until the recent initiation of the ECMWF Global Environmental Modelling System project. There is a need for all data for atmospheric composition ECVs to be assembled as input data for reanalysis and for evaluating climate models (see Actions C11 and C12).

4.6. Atmospheric Domain – Scientific and Technological Challenges

While there are well-established techniques for monitoring and analyzing most of the atmospheric ECVs, for some there remain outstanding issues requiring research, including:

- Representation of the 3D character of clouds.
- Global monitoring of the composition and distribution of aerosols.
- Global monitoring of water vapour especially at the surface and in the upper troposphere and lower stratosphere.
- Estimation of the spatial representation of surface wind speed and direction.
- Unbiased estimation of high temporal resolution precipitation amount and type, especially over the oceans and at high latitudes.
- Synthesis of quality-assured greenhouse gas and ozone data into a format suitable for reanalysis and inverse modelling.
- Development of consistent unbiased homogeneous reanalysis products for all ECVs.

In addition to the refinement of the treatment of current ECVs, further research is required to extend the range of ECVs to include other variables, such as soil moisture, and important reactive atmospheric constituents.

4.7. Atmospheric Domain – Synthesis and Consolidation of Actions

The main implementation activities have been outlined in the earlier sections. The strategy of establishing and consolidating baseline systems for each ECV has been initiated, but more international cooperation is required to ensure that these systems can be sustained. Through CEOS, CGMS, and the WMO Space Programme, the satellite community has adopted the application of the GCMPs, and there is optimism that future satellite missions will provide homogeneous data, archive all relevant meta-data, and support independent analyses of the basic data.

The recognition of the importance of all the ECVs in the Atmospheric Domain means that the scope of GSN measurements needs to be increased. 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.

A relatively small number of reference sites will be set up as a subset of the GUAN to enable, *inter alia,* high-quality measurement of water vapour in the upper troposphere and lower stratosphere. These sites could incorporate a range of research-quality instrumentation that measures both a comprehensive range of ECVs and that also provides alternative estimates of key variables like water vapour using both remote sensing and *in situ* data.

Specific five-year milestones include:

- Establish centres to monitor and analyze all ECV data.
- Attain a fully operational GSN, including all relevant surface ECVs.
- Complete the archive of GSN historical data in the WDC.
- Attain a fully operational GUAN.
- Establish a GUAN-based reference network of high-quality, high-altitude (5 hPa) radiosondes.
- Extend BSRN to global coverage and consolidate data monitoring and analysis functions.
- Ensure atmospheric surface pressure is reported from all drifting buoys.
- Establish a homogeneous record of active and passive microwave observations to support the monitoring of precipitation and water vapour.
- Establish a global ground-based GPS total-column water monitoring system.
- Ensure sustained homogeneous ERB satellite observations.
- Establish a baseline network for key greenhouse gases based on WMO GAW.
- Consolidate coordinated long-term programmes for reanalysis.

5. OCEANIC CLIMATE OBSERVING SYSTEM

The ocean is characterized by wide variation in both space and time, and the resolution of generally small climate change signals within this highly-variable ocean is a significant challenge. However, it has been demonstrated that we have the ability, if implemented, to effectively observe climate variability and climate changes in the ocean at global scales. At the same time, despite useful recent progress, ocean observing networks, their associated infrastructure and analysis systems are not adequate to meet the specific needs of the UNFCCC for most climate variables and in most regions of the planet, and particularly the Southern Hemisphere. There is a pressing need to obtain global coverage using proven observing technologies, to establish telecommunications and data management infrastructure, and to enhance ocean analysis and reanalysis capacity.

The Second Adequacy Report and GCOS have endorsed the approach of the ocean community in adopting a composite and integrated system for observing the essential climate variables required by the UNFCCC. This composite global ocean observing system makes best use of a mix of proven remote and *in situ* technologies and optimizes the contributions from existing observing assets and deployment opportunities for both global surface and sub-surface variables. It also builds on the mechanisms established to foster more effective international collaboration, and the demonstration of capabilities to generate oceanic climate products as well as the development of new technologies. It is important to note that there has been significant progress toward implementation of the initial global ocean observing system for all of the essential climate variables required by the UNFCCC but additional commitments are required.

The global ocean observing system put in place for climate will also support global weather prediction, global and coastal ocean prediction, and marine environmental monitoring, among other things, and thus merits sponsorship from a range of sources. Many non-climate users will depend primarily on the baseline composite networks that collect data on primarily physical variables. Not all of the oceanic ECVs can yet be cost-effectively observed globally on the desired space and time scales with existing technology. This is true particularly for ocean biogeochemical variables. The reference network activities are key to the collection of these ECVs and a wider range of variables and also for the most accurate estimation and validation of trends for climate change attribution. The sampling strategy of the initial system will evolve as more is learned about the scales that need to be resolved, as technology is improved and as experience is gained from users working with ocean climate products. Ocean analysis and reanalysis activities, which may involve conventional analyses of integrated data sets (satellite and *in situ*) as well as ocean data assimilation techniques are critical to realize the value of these composite networks, and address the objectives of the global observing system for climate and the UNFCCC.

There are many different ways of developing capacity and functionality for the oceanic climate observing system. Unlike the Atmospheric Domain, there is not, at present, a system of national ocean centres or services dedicated to the implementation and maintenance of the observing system. Implementation ultimately falls to multiple agencies within nations, and these activities can be subject to formal, informal or minimal international coordination. Bodies such as the WMO/IOC JCOMM have a broad remit but they do not yet cover all aspects relevant to the UNFCCC. In some cases it is reasonable and appropriate to seek actions through such high-level bodies; in others, often involving research or pilot projects, it is more appropriate to activate regional and/or problem-specific pilot projects to undertake actions. In all cases where a body or group are named, it is understood that such groups mostly provide coordination and that the ultimate responsibility lies with nations and their agencies.

The global ocean provides an important context for the interpretation and prediction of regional and coastal ocean variability. There are particular challenges both in terms of monitoring and forecasting and in terms of testing and improving regional climate projections. Variability in the global ocean affects coastal regions in many different ways; without knowledge of the global ocean it can be impossible to interpret regional information properly or to select appropriate national responses. The fact that coastal regions are particularly vulnerable to changes in sea level and/or changes in wave climates also influences the actions called for here. The actions below provide selective enhancements and strategies to address these issues. The emergence of the GOOS Coastal Ocean Observing System programme provides a systematic pathway for both consideration of climate requirements and implementation in coastal waters, including issues relating to ecosystems and the marine environment in general. The coastal and global ocean observing systems must develop together for each to deliver value most effectively to the Parties.

Attaining and sustaining global coverage is the most significant challenge for the oceanic climate observing system. This challenge will only be met through national commitments to the global implementation and maintenance effort and with international coordination provided by JCOMM and other relevant bodies. The following general actions are proposed to address some of the issues raised in this section.

This Plan contains many actions to be undertaken by a variety of organizations. In addition, the UNFCCC has requested a report to the SBSTA at its twenty-second session, on progress made towards implementing the initial oceanic climate observing system. It is proposed therefore that GCOS and GOOS subsequently convene an early meeting of organizations and Parties interested in the implementation of the initial oceanic climate observing system to consider the contents of this Plan and to determine how best to proceed with its implementation.

Action O1 (OF13)[32]

Action: Continue to seek national and multinational participation in the implementation of the global ocean observing system for climate. **Who:** IOC in consultation with GCOS, GOOS, and JCOMM. **Time-Frame:** Continuous. **Performance Indicators:** Extent of national and multinational participation in the recommend-ations of this Plan. **Cost Implications:** Category II[33].

The multi-purpose nature of the global ocean and climate observing systems means that there is an on-going need to ensure balance and relevance. The OOPC and other relevant bodies of the IOC and JCOMM will provide oversight, and in collaboration with research programmes, provide monitoring and assessment of the evolving system and its products. The system must be responsive to the needs of the UNFCCC but at the same time exploit synergy and efficiencies with other sponsors of the observing system.

Action O2 (OF1)

Action: Review relevance and effect of Plan, and revise the Oceanic Section of the Plan every 5 years. **Who:** OOPC, in cooperation with participating partners. **Time-Frame:** Report by 2009. **Performance Indicator:** Report published. **Cost Implications:** Category I.

Ocean analysis, reanalysis and ocean data assimilation and forecasting systems are underway or planned in a number of nations, but enhancement and coordination of the suite of such efforts is needed to meet the specific needs of the UNFCCC. Key actions in this area are noted below in Section 5.4.

Research programmes are currently the primary source of funding for many elements of the present oceanic climate observing system and for developing new methods and technologies. Continued strong support is needed to develop and bring new technology into pilot project use and then into sustained use in the oceanic climate observing system.

[32] Actions in this document relate to 'Findings' of the Second Adequacy Report, as listed in Appendix 2 herein. These are identified as CF (Common Findings), AF, OF and TF (referring to Atmospheric, Oceanic, and Terrestrial Findings, respectively).

[33] See Section 2.8 Table 7 for cost definitions.

Action O3 (OF2)

Action: Promote and facilitate research and development (new improved technologies in particular), in support of the global ocean observing system for climate.
Who: Parties' national ocean research programmes and Space Agencies, in cooperation with GOOS, GCOS, and WCRP.
Time-Frame: Continuing.
Performance Indicator: More cost-effective and efficient methods and networks; strong research efforts related to the observing system; number of additional ECVs feasible for sustained observation; improved utility of ocean climate products.
Cost Implications: Category II.

The participation and collaboration of many groups beyond and in addition to the oceanic climate observing community is needed to effect the efficient implementation and maintenance of the agreed initial ocean observing system for climate. Effective partnership between operational and research programmes, such as the Partnership for Observations of the Global Oceans (POGO), science working teams such as Jason and SMOS, and specialized Space Agencies, will be required.

Action O4 (OF2)

Action: Promote and build partnerships with ocean research institutions and science teams.
Who: OOPC with WCRP and SCOR science programmes, and with POGO and other marine research institutions.
Time-Frame: Continuing.
Performance Indicator: Effective and productive partnerships, measured in terms of capacity delivered.
Cost Implications: Category II.

While each nation extracts benefit from the global climate observing system, actions at the regional and local level will ensure resolution of local ocean climate and help deliver the direct and tangible benefits. For the Oceanic Domain, this primarily means monitoring and analyses for shallow seas and coastal waters. Such extensions can satisfy region-specific objectives. National and regional participation in the GOOS Coastal Ocean Observing System provides one framework for coordinated development and operation of observing efforts in coastal waters. The OOPC and the Coastal Ocean Observations Panel, through the GOOS Steering Committee must ensure the requirements for coastal observations of certain ECVs, such as sea level and sea state, are fully taken into account in the implementation plan of the Coastal Ocean Observing System. It is equally important that the Intergovernmental-GOOS (I-GOOS) and the GOOS Regional Alliances (GRA) encourage and ensure that regional and coastal observing contributions and associated products are responsive to the needs of the UNFCCC. GOOS Regional Alliances have been established for most regional seas; effective planning and implementation in the Arctic Ocean would be facilitated by establishment of an Arctic GOOS Regional Alliance. This should occur as one of the International Polar Year actions.

Action O5 (OF16)

Action: Ensure the GOOS Coastal Ocean Observing System implementation plan is responsive to UNFCCC needs.
Who: GOOS Steering Committee with GOOS Regional Alliances and GOOS Panels.
Time-Frame: Continuing.
Performance Indicator: Regional and coastal needs met.
Cost Implications: Category I.

5.1. Oceanic Domain – Surface

5.1.1. General

Table 14 lists the components of the Oceanic Domain surface observing system together with their current implementation status. The absence of global coverage and the lack of sufficient high-quality observations remain the key weaknesses in the surface ocean network. For a few variables such as sea-surface temperature (SST) and mean sea-level pressure, cost-effective technologies are available to address this weakness. For other variables, further investment and additional research and development are required.

Table 14. Status (mid-2004) of the Implementation of the Oceanic Domain – Surface composite network components, their associated coordinating bodies and ECVs observed.

Component Network	ECVs	Implementation Status[34] with Long-term Sustained Commitments	Coordinating Body
Global surface drifting buoy array on 5x5 degree resolution (1250)	**SST, SLP**, position-change-based **Current**	~75% for SST, ~30% for SLP	JCOMM Data Buoy Cooperation Panel
Global tropical moored buoy network (~120)	Typically **SST** and **Surface vector wind**; Can include **SLP, Current**, Air-sea flux variables	~75%	JCOMM Tropical Moored Buoy Implementation Panel (TIP)
VOS fleet	All feasible surface ECVs	~90%	JCOMM Ship Observations Team (SOT)
VOSClim	All feasible surface ECVs plus extensive ship meta-data	~25%	JCOMM SOT
Global reference mooring network (29)	All feasible surface ECVs	~15%	WCRP and IGBP international time series group
GLOSS Core Sea-level Network, plus regional/national networks	**Sea level**	Core Network: ~50%; GCOS baseline network: ~50%	JCOMM GLOSS
Carbon VOS	***p*CO_2, SST, SSS**	~20%	IOCCP, OOPC pilot activity
Sea-ice buoys	**Sea ice**	~10%	International Arctic/Antarctic Buoy Programme
Satellite IR (polar orbit and geostationary)	**SST, Sea ice**	Polar orbit: 100%; Geostationary: ~50%	CEOS, IGOS, CGMS
AMSR-class microwave SST satellite	**SST, Wind speed, Sea ice**	~70%[35]	CEOS, IGOS, CGMS
Surface vector wind satellite (two wide-swath scatterometers are highly desired)	**Surface vector wind, Sea ice**	~50%	CEOS, IGOS, CGMS
Ocean colour satellite (SeaWiFS-class)	Chlorophyll concentration (biomass of **Phytoplankton**)	100%	CEOS, IGOS, IOCCG
High-precision satellite altimetry	**Sea-level** anomaly from steady state	~75%	CEOS, IGOS, CGMS
Low-precision satellite altimetry	**Sea level**	~75%	CEOS, IGOS, CGMS
Satellite SAR	**Sea ice, Sea state**	~50%	CEOS, IGOS, CGMS

A number of specific actions of a general nature and supplementary on-going actions are crucial to the realization of an effective system. Some component networks provide information on multiple ECVs. One of these is the VOS programme. These (typically commercial) vessels measure at least several important surface ECVs, and their data provides the great bulk of our historical knowledge of marine climate variability and change. They are the key link to the historical record at the marine surface.

[34] Most current implementation is based on short-term research funding, with few long-term commitments. Few nations have operational ocean services analogous to National Weather Services, with mandates for sustained observations.

[35] Uncertainty in commitments to routine and sustained data streams from experimental satellites.

Action O6 (OF3)

Action: Improve meta-data acquisition and management for a selected, expanding subset of VOS (VOSClim) together with improved measurement systems.
Who: Parties' national services and ocean research agencies through JCOMM VOSClim.
Time-Frame: VOSClim meta-database in place by 2006. Continuing improvement to data streams.
Performance Indicator: Greater use of VOS data in climate products. Successful completion of initial phase of VOSClim.
Cost Implications: Category II.

Satellites are an important element in the surface ocean observation system, and GCOS and the WMO Space Programme, through their participation in the WMO Consultative Meetings on High Level Policy on Satellite Matters, CGMS, CEOS, and IGOS-P, will continue to emphasize the need for the maintenance of a suite of proven satellite sensor systems that deliver global coverage of the essential surface oceanic climate variables such as SST, sea level and surface wind.

Action O7 (OF3)

Action: IGOS-P Ocean Theme Team to publish update of the Ocean Theme and, as appropriate, restating the satellite requirements and explicitly noting requirements for climate.
Who: IGOS-P through WMO Space Programme, CGMS, CEOS in consultation with OOPC and GCOS.
Time-Frame: Continuous.
Performance Indicators: Updated Ocean Theme document; Satellite agency commitments to oceanic climate measurements.
Cost Implications: Category I.

A sparse global suite of surface reference measurements (Surface Reference Mooring Network) can provide essential air-sea flux information for testing models and evaluating climate change projections. Such measurements should be characterized by high-quality, high-frequency temporal sampling; comprehensive sensor suites; comprehensive meta-data; and knowledge of the environment (ancillary measurements). The Working Group on Numerical Experimentation/OOPC SURFA project is aiming for around 29 surface moorings with global distribution representative of the different climate regimes and with real-time links to numerical weather prediction (NWP) centres so that surface flux estimates and other climate surface products can be continuously evaluated (see Figure 5). Where practical, the integration of the surface reference sites with other related initiatives that also require fixed-location time-series measurements, for example the Dedicated Data Sites of the GODAE High-Resolution SST Project and of the ocean satellite colour community (e.g., NASA Sea-viewing wide field-of-view sensor (SeaWiFS)) will contribute to other climate objectives.

Action O8 (OF4)

Action: Complete and maintain a globally-distributed network of ~29 surface moorings as part of a Surface Reference Mooring Network.
Who: Parties' national services and ocean research agencies responding to the OceanSITES plan.
Time-Frame: 15 moorings deployed by 2009, network complete by 2014.
Performance Indicator: Moorings operational and reporting to archives.
Cost Implications: Category IV.

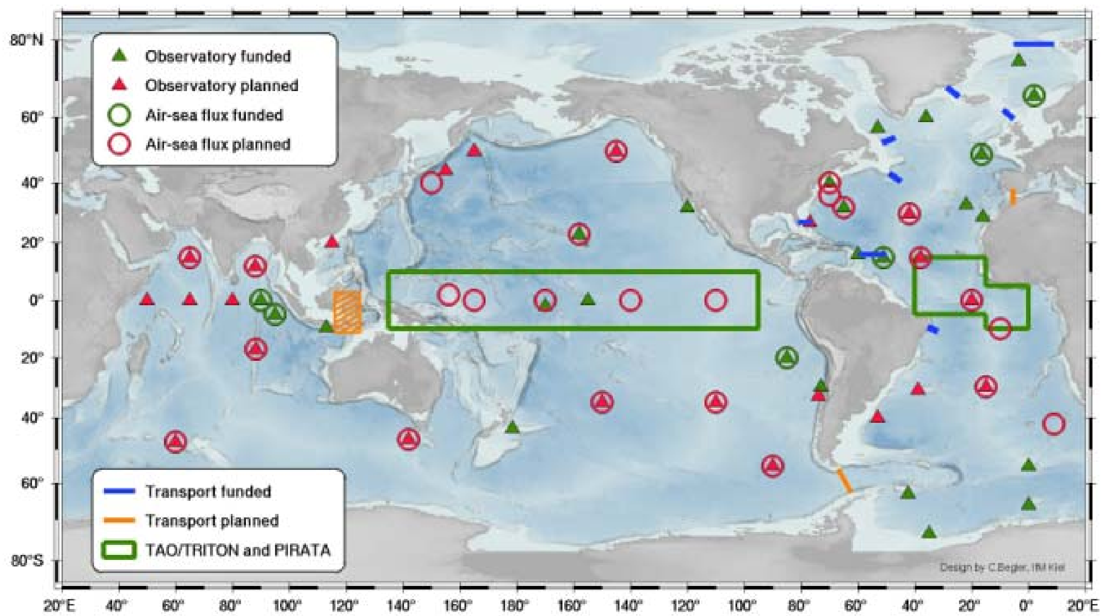

Figure 5. Map showing the planned distribution of the Ocean Reference Mooring Network (Source: http://www.oco.noaa.gov/page_status_reports_global.jsp accessed 11 October 2004).

5.1.2. Specific Issues – Oceanic Surface ECVs

ECV – Sea-surface Temperature

Global SST fields have been produced on a monthly basis for many years, but comparisons of different analyses reveal discrepancies that are unacceptable for many climate purposes including those of the UNFCCC. However, adequate global SST analysis is achievable through enhanced global deployment of existing technology and the improved operation of satellite sensors.

The networks and satellite systems that contribute to the observation of SST and are included in the development of global integrated products include:

- Surface drifters.
- Tropical moored buoy network.
- VOS.
- VOSClim.
- Reference mooring network.
- Satellite IR (polar orbiting and geostationary).
- Satellite microwave.

Relevant data is also available from the Argo global array of profiling floats and expendable bathythermographs (XBTs).

Figure 6 shows the distribution of drifting and moored buoys as of February 2004 coordinated through the Data Buoy Cooperation Panel.

Issues relative to the observation and analysis of SST include:

- Different sensors measure the temperature of different "surfaces". IR systems observe radiance from a very thin skin layer, while microwave systems observe radiance from a slightly thicker (sub-skin) layer and traditional *in situ* methods sample water from well below these skin layers (near-surface and mixed-layer "bulk" temperatures). Under almost all conditions skin temperatures are expected to differ from *in situ* temperatures; the difference can be several degrees under certain extremes but is typically a few tenths of a degree.

- Enhanced coverage and improved mechanisms for data exchange are needed for geostationary data.
- Atmospheric variability (e.g., cloud, water, aerosols, sea fog, spindrift) affects both coverage and accuracy from satellite systems. *In situ* systems are limited in their spatial resolution, collect data from different depths, make use of different sensors, etc.
- The ability to exploit historical and contemporary data sets is affected by the limited amount of meta-data typically available; this is especially true when dealing with the VOS data.
- For climate purposes integrated analysis products are needed that take advantage of the strengths of each data stream that make best use of our understanding of the limitations of each data stream, and that adjust for variations in the uncertainty from region to region.

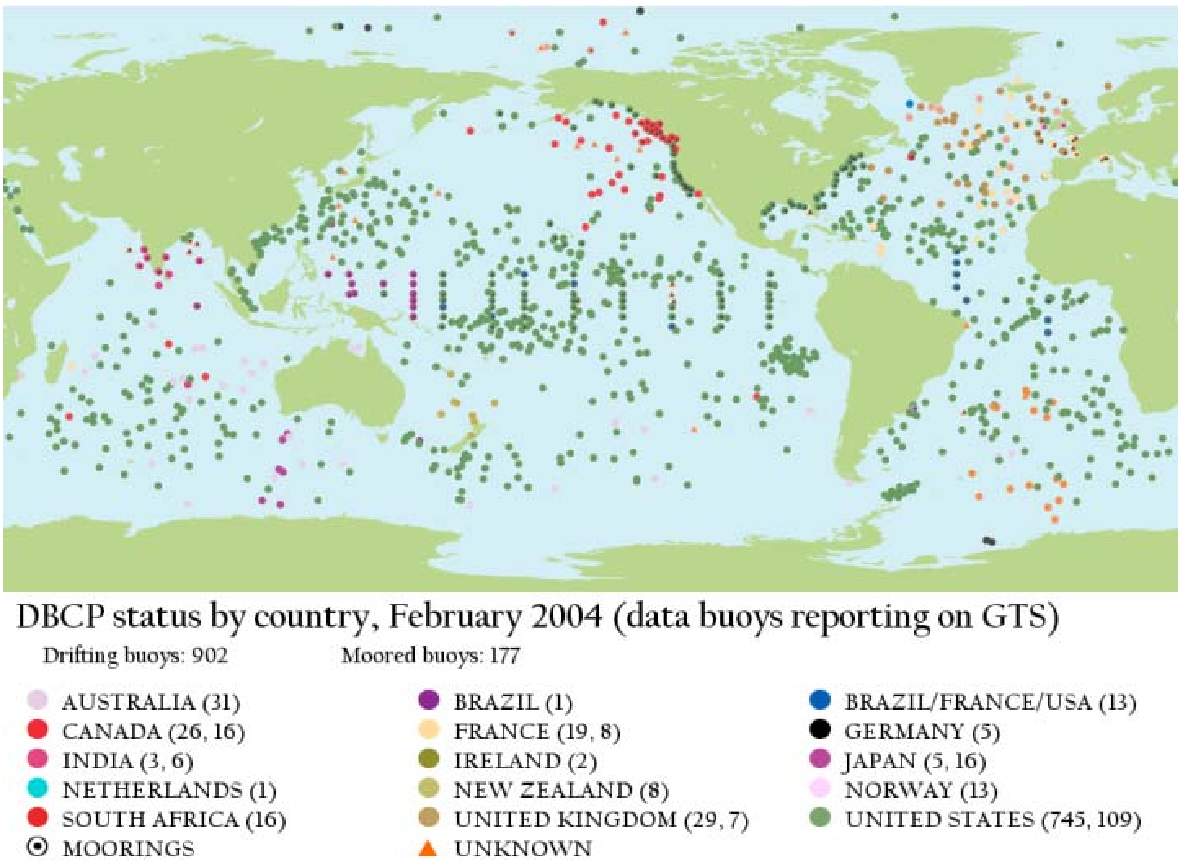

Figure 6. The distribution of drifting and moored buoys as of February 2004 (Source: http://www.oco.noaa.gov/page_status_reports_global.jsp accessed 11 October 2004).

To address the issues raised above, the following set of actions are proposed:

- Achieve ongoing support for an integrated and coordinated approach to satellite SST measurements (incorporating polar and geostationary IR, and microwave measurements). Sustained support is required for microwave instruments. Continuing support for efforts like the GODAE High-Resolution SST Project which attempts to make optimum use of satellite and *in situ* observations at the highest feasible space and time resolution.

Action O9 (OF5)

Action: Ensure a continuous mix of polar orbiting and geostationary IR measurements combined with passive microwave coverage. To link with the comprehensive *in situ* networks noted in O10. **Who:** Space Agencies coordinated through CGMS, CEOS, and WMO Space Programme. **Time-Frame:** Continuing. **Performance Indicator:** Satellite plans and performance. **Cost Implications:** Category III. See also Actions A7 and A19.

- The OOPC will work through JCOMM and its panels to achieve global coverage of the composite *in situ* programme. This includes: enhancement of the surface drifter component to maintain coverage in each 5x5 degree region outside the near-equatorial band (achieved with approximately 1250 drifters if optimally deployed); enhancement of the tropical moored buoy programme in the Indian and Atlantic Oceans (around 120 moorings in all); and the sparse global reference time series network (referred to in Action O8 above).

Action O10[36] (OF5)

Action: Obtain global coverage, via an enhanced drifting buoy array (total array of 1250 drifting buoys equipped with atmospheric pressure sensors as well as ocean temperature sensors), a complete Tropical Moored Buoy network (~120 moorings) and the improved VOSClim ship fleet. **Who:** Parties' national services and research programmes through JCOMM, Data Buoy Cooperation Panel, and Tropical Mooring Implementation Panel. **Time-Frame:** Complete by 2009. **Performance Indicator:** Data submitted to analysis centres and archives. **Cost Implications:** Category III.

- Continued research into the processes that determine the several surface and near-surface sea temperatures (skin, sub-skin, mixed-layer and "bulk" temperatures) and the relationship between these different forms of sea-surface temperature is needed. The OOPC will also encourage communication between the SST user community and those communities providing cloud and aerosol estimates in order to improve the quality of satellite IR SST retrievals. Finally, through the GODAE high-resolution SST project and the SST climate community, continued research into integrated, climate-quality products that overcome deficiencies in the current products that are based on subsets of the available data will take place.

ECV – Sea Level

Tide gauge sea-level data constitute one of the few long ocean climate time series but in general the sampling and global coverage is inadequate. Knowledge of global sea-level variability increased substantially in 1993 when the NASA/CNES TOPEX/POSEIDON ocean surface topography altimeter commenced operation. Monitoring of global sea level is technically feasible using complementary *in situ* networks and satellite measurements.

The Global Sea Level Observing System (GLOSS) Core Network of 290 gauges has been recommended as the desired *in situ* measurement network. Unfortunately, data are not available to the global community from many of these gauges. A subset of the Core Network gauges has a long-term record and is particularly useful for monitoring long-term trends. Another subset is suggested by this Plan for the purpose of calibration of satellite measurements. This GCOS subset of the GLOSS is proposed to be composed of about 170 gauges and includes the long-term trend sites and a global set of the geocentrically[37]-located gauges so as to enable climate-quality interpretation of sea level. Ideally, all gauges in this network should become geocentrically-located. Figure 7 shows the present tide gauge system, including information about which records are longer than 40 years, and which gauges are geocentrically-located at this time. Regional and national enhancements of the Core Network will be needed to address regional and local impacts. Continued operation of high-precision

[36] See also Action A5.
[37] So as to separate sea-level changes from land-level changes.

satellite altimetry and low-precision altimeter measurements complete the sea-level network. Together they represent an integrated strategy for monitoring of sea-level variability and change.

Effective and timely data exchange between nations is also required for global sea-level monitoring. Adequate characterization of regional sea level and extreme events requires that high-frequency sea-level observations be taken and exchanged and that historical data from tide gauges be recovered as appropriate and provided to the International Data Centres. Capacity-building efforts in developing countries for undertaking local sea-level change measurements can benefit the global system and foster needed regional enhancement.

Networks and systems contributing to the observation and global analysis of sea level include:

- GLOSS Core Network plus additional regional and national networks and specific enhancements for detecting trends and calibrating satellites.
- Satellite high-precision altimetry.
- Low-precision high-resolution altimeters.
- Sub-surface temperature and salinity network.

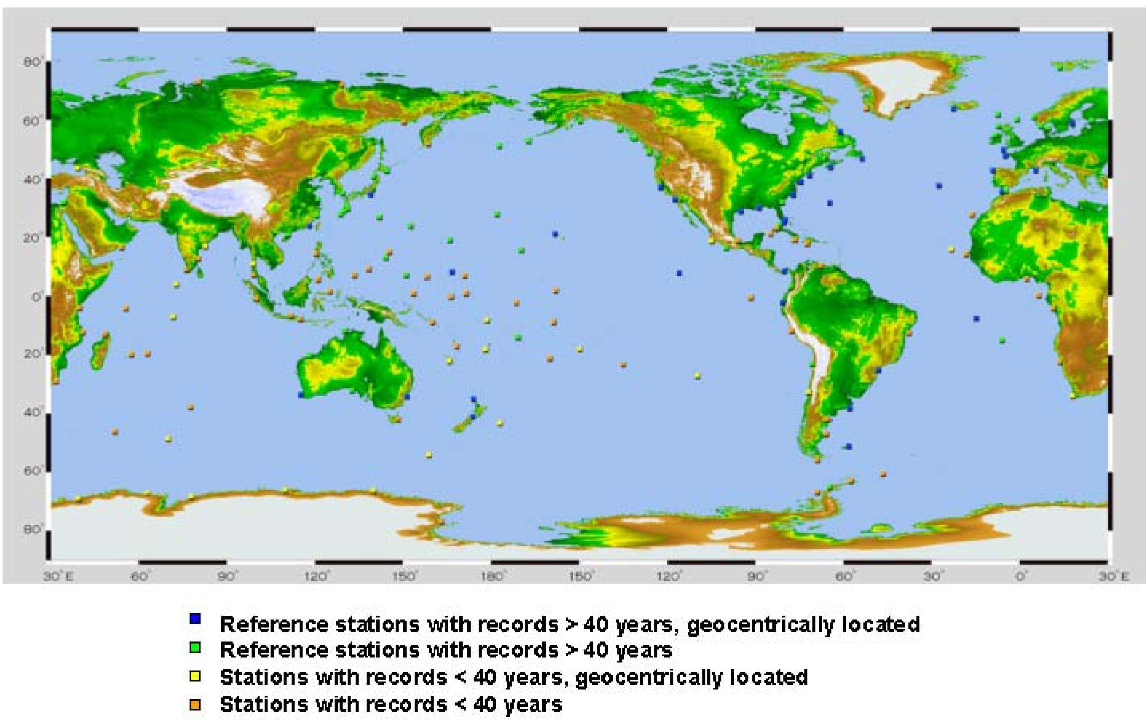

Figure 7. The global tide gauge network sorted by length of record. A subset of the stations has now been geocentrically-located (Source: Permanent Service for Mean Sea Level, http://www.oco.noaa.gov/page_status_reports_global.jsp accessed 11 October 2004).

Issues related to sea-level observing and integrated global analysis include:

- The spatially complex variability of the vertical motion of the surfaces upon which tide gauges are located. In addition to the ongoing larger-scale tectonic post-glacial adjustment there are often local vertical movements of consequence. These vertical movements are of the same magnitude as the anticipated sea-level change from global warming, and must be measured at each tide gauge in order to reveal water level changes relative to the centre of the Earth.
- The existence of large-scale low frequency variability of the oceanic density field which, if not appropriately and globally sampled, can introduce uncertainty in estimates of global sea-level change.
- The need to know variability and change in surface pressure, which affects water level.

- The technical challenges of making accurate high-frequency water level measurements over long periods.
- The present shortcomings of international data exchange.
- The need for significant regional and local network enhancements in order to support impact assessment and monitoring.
- The need for financial support for equipment purchase and maintenance, and technical assistance projects for capacity-building for small island developing states and least-developed nations.

The following set of actions are proposed to develop an adequate sea-level observing and analysis programme together with the capacity to apply the global products on regional and local scales:

- Through the GLOSS of JCOMM, implement at least the GCOS subset of the Core Network with geocentrically-located high-accuracy water level gauges with real-time data reporting. Since sea-level observations should now be reported to the International Data Centres in a timely fashion in accordance with IOC Resolution XXII-6 (IOC OCEANOGRAPHIC DATA EXCHANGE POLICY), the GLOSS will provide regular reports to the IOC on the extent to which the data are being exchanged.

Action O11 (OF8)

Action: Implement the GCOS subset of the GLOSS Core Network, with geocentrically-located high-accuracy gauges. Ensure real-time exchange and archiving of data. Ensure historical sea-level records are recovered and exchanged.
Who: Parties' national agencies coordinated through GLOSS of JCOMM.
Time-Frame: Complete by 2009.
Performance Indicator: Data availability at International Data Centres, global coverage.
Cost Implications: Category III.

- One high-precision altimeter is required at all times with planned extensive overlaps between successive missions, and two low precision but high-resolution altimeters to provide the needed sampling. GCOS, through its participation in the WMO Consultative Meetings on High Level Policy on Satellite Matters, CGMS, CEOS, and IGOS-P, will continue to emphasize the need for the continued operation of high-precision and low-precision satellite altimeters (in accordance with the GCMP).

Action O12 (OF8)

Action: Ensure continuous coverage from one high-precision altimeter and two lower-precision but higher-resolution altimeters.
Who: Space Agencies with coordination through CGMS, CEOS, and WMO Space Programme.
Time-Frame: Continuous.
Performance Indicator: Satellites operating, and provision of data to analysis centres.
Cost Implications: Category IV.

- GLOSS to report to JCOMM on the extent to which high-frequency sea-level observations, including regional and national enhancements, are being taken and exchanged together with historical data in accord with the recommendations of the implementation plan of the GOOS Coastal Ocean Observations Panel.

Action O13 (OF8, OF15)

Action: Ensure high-frequency sea-level observations are available for all coastal regions (including historical records) and submitted to the international archive.
Who: National agencies coordinated through GLOSS and the GOOS Coastal Ocean Observations Panel.
Time-Frame: Continuous.
Performance Indicator: Data availability at archives and national reports to UNFCCC.
Cost Implications: Category III.

- Through the coordinated capacity-building and training programmes of GOOS, WMO, JCOMM, other related bodies, and the system improvement programme of GCOS, encourage efforts in developing countries for undertaking local sea-level-change measurements, to support local and regional needs.

Action O14 (OF9)

Action: Include sea-level objectives in the capacity-building programmes of GOOS, JCOMM, WMO, other related bodies, and the system improvement programme of GCOS. **Who:** Parties providing capacity-building funds and programmes. **Time-Frame**: Continuous. **Performance Indicator:** Number of projects, global coverage. **Cost Implications:** Category III.

ECV – Sea-surface Salinity

At present, global knowledge of sea-surface salinity (SSS) is not adequate. Improvement in SSS analysis accuracy is limited by available technology. New satellite sensors hold promise of improved global coverage, although special *in situ* observing efforts will be needed to evaluate sustained sensor performance.

Networks contributing to global sea-surface salinity observations are:

- Subset of VOS under the Global Ocean Surface Underway Data Pilot Project (GOSUD).
- Global reference mooring network.
- Tropical moored buoy network.
- Research vessels carrying out repeat hydrographic sections.
- Argo (potentially).
- Ship of Opportunity Programme (SOOP) Expendable Conductivity, Temperature and Depth System (XCTD).
- Surface drifters (potentially).

Issues relative to the observation of sea-surface salinity include:

- At present there is no system capability to obtain appropriate space resolution and global coverage of high-quality SSS measurements.
- The need for long-term stability and accuracy of existing autonomous SSS sensors in surface waters.
- The uncertainty as to whether satellite systems are sufficiently sensitive to measure variability.
- Inadequate understanding and observation of the net air-sea freshwater flux, which limits SSS analysis skill.

To address these issues the following actions are proposed:

- Through the International Oceanographic Data and Information Exchange (IODE)/JCOMM pilot project GOSUD, and in collaboration with the International Ocean Carbon Coordination Project (IOCCP) and the WCRP Climate Variability and Predictability Project (CLIVAR), develop a sustained programme for sea-surface salinity measurements on selected VOS repeat lines, fixed-location buoys and, as appropriate, drifting and other autonomous platforms.

Action O15 (OF6)

Action: Develop a robust programme to observe sea-surface salinity to include VOS ships, research ships, reference moorings, and drifting buoys. **Who:** Parties' national services and ocean research programmes through IODE and JCOMM in collaboration with CLIVAR. **Time-Frame:** Programme plan by 2007. **Performance Indicator:** Plan published. **Cost Implications:** Category III.

- The OOPC through the WCRP endorses research efforts to demonstrate the feasibility of measuring salinity from space, in particular the current efforts through the Soil Moisture and Ocean Salinity project and Aquarius.

Action O16 (OF6)

Action: Research programmes to demonstrate feasibility of utilizing satellite data to help resolve global fields of SSS. **Who:** Space Agencies in collaboration with the ocean research community. **Time-Frame:** Feasibility studies complete by 2009. **Performance Indicator:** Reports in literature and to OOPC. **Cost Implications:** Category II.

ECV – Carbon Dioxide Partial Pressure

Knowledge of surface ocean pCO_2 is not adequate to quantify the spatial and temporal variability of air-sea fluxes of CO_2. An international network of surface pCO_2 observations is in the early stages of development. Network activities include:

- Approximately 20 operational programmes underway measuring pCO_2; approximately 12 of these programmes are doing full trans-basin sections.
- Automated drift buoys (number varies; typically 5-10 operating at any given time).
- Surface time series stations – approximately 10 stations.
- International planning and coordination provided by the IOCCP.

Issues relative to the development of an integrated and operational network to meet GCOS needs are:

- Improved technology/automation for on-board systems.
- Development of an internationally-agreed implementation strategy to identify priorities for the sustained system.
- Sustaining priority trans-basin programmes and development of new programmes according to implementation strategy priorities.
- Investigations of potential subjective sampling routines and interpolation techniques including remote-sensing and model-data assimilation.

To address these issues the following action is proposed:

- IOCCP in consultation with the OOPC will develop an internationally-agreed implementation strategy for a surface pCO_2 network VOS, drifter and time series observations from the Surface Reference Mooring Network and other platforms together with associated products.

Action O17 (OF6)

Action: Develop and implement an internationally-agreed strategy for measuring surface pCO_2. **Who:** IOCCP in consultation with OOPC, implementation through national services and research programmes. **Time-Frame:** Implementation strategy for mid-2005; initial pilot network to begin early 2006. **Performance Indicator:** Regular pCO_2 flux maps produced beginning in 2006. **Cost Implications:** Category III.

ECV – Ocean Colour

Knowledge of ocean ecosystem change is not adequate at present. Satellites provide global coverage of surface ocean colour, but the linkage between ocean colour and ecosystem variables, including chlorophyll-a, remains limited. In addition, enhanced *in situ* sampling of ocean colour and ecosystem variables is technically feasible.

Ocean colour as it relates to carbon and marine ecosystems and living marine resources is observed through the following network activities and satellite sensors:

- Satellite ocean colour (SeaWiFS class).

The issues related to the development of an ocean colour observing system are:

- On-going research to relate ocean colour to important climate variables of the carbon system and ecosystems.
- There are no international commitments to a coordinated, integrated, calibrated and sustained satellite ocean colour programme.
- Standards, sensor technology and best practices remain to be agreed for *in situ* observations.

To address the issues raised above, the following set of actions are proposed:

- GOOS support the plans being developed through the IGOS-P and its participating Space Agencies to implement a sustained and continuous series of ocean colour satellite sensors, with full and open exchange of data and products. The International Ocean Colour Coordinating Group (IOCCG), acting for GOOS and GCOS, will give oversight to ensure the measurements are implemented in accordance with GCMPs and the requirements outlined in the Second Adequacy Report as well as to promote associated research.

Action O18 (OF9)

Action: Implement plans for a sustained and continuous deployment of ocean colour satellite sensors together with research and analysis.
Who: Space Agencies through the IGOS-P and in consultation with the IOCCG.
Time-Frame: Satellite programme implemented by 2009.
Performance Indicator: Global coverage with consistent sensors operating according to the GCMPs.
Cost Implications: Category IV.

ECV – Sea State

Observations of sea state are particularly relevant to coastal and offshore impacts on human activities, but also affect climatically important air-sea exchanges and can also provide complementary information of relevance to monitoring changes in the marine environment, e.g., in winds, storms, air-sea fluxes and extreme events. There is no sustained global observing effort at present for sea state (variables relating to the height, direction, wavelength and time period of waves). Present best estimates of sea state are computed from model reanalysis and analysis systems.

Observing networks, satellites and analysis activities contributing various parameters to the knowledge of regional and global sea state include:

- Numerical weather prediction (indirect) estimates.
- Reference mooring network.
- Satellite altimetry.
- Satellite Synthetic Aperture Radar (SAR).
- VOS visual.

Issues relative to sea state observations and analysis include:

- The accuracy of NWP products is limited by validation and calibration data, and their utility is limited over the shallower coastal regions. Reliable surface wind data (observations and Reanalysis (RA)) are essential. For example, the ECMWF model RA40 makes use of sea state estimates within its assimilation system.
- The existing sea state reference buoys are limited in terms of global distribution and location (few open ocean sites and insufficient coastal measurements), and are not collocated with other ECV reference sites.

- Altimetry only provides significant wave height, and coverage is limited relative to synoptic scales of variability. SAR gives the most useful data but is rarely exchanged or available in a way that impacts estimates for climate.

To address the issues raised above, the following action is proposed:

- The JCOMM Expert Team on Waves and Surges will implement wave measurement systems as part of the Surface Reference Mooring Network.

Action O19 (OF13)

Action: Implement a wave measurement component as part of the Surface Reference Mooring Network.
Who: Parties operating moorings, coordinated through the JCOMM Expert Team on Waves and Surges.
Time-Frame: Deployed by 2009.
Performance Indicator: Sea state measurement in the International Data Centres.
Cost Implications: Category III.

ECV – Surface Current

The global surface current field is primarily relevant to climate through its role in the heat, freshwater and carbon transport, and the shallow overturning ocean circulation. Research also suggests a role in determining air-sea exchanges of momentum (wind stress). Derived analyses of the global surface current field, based primarily on dynamical models, surface wind and sea-level data, are feasible.

Contributing networks and satellite observations include:

- Drifting buoys.
- Argo floats.
- Global tropical moored buoy network.
- Ship drift.
- Satellite AVHRR (pattern tracking).
- Satellite altimetry (geostrophic).
- Analysis – blended estimates.
- Assimilation (indirect) as in GODAE.

Issues relative to surface current observation and analysis include:

- The *in situ* networks do not provide global coverage or sampling relative to the required space and time scales.
- Drifting buoys have uneven drift characteristics (drogues) and no agreed standard.
- There is no designated centre for current data exchange, product assembly, quality control and archiving, or other group performing these functions in research mode.
- Indirect estimates, including those with models (e.g., by GODAE), are data limited and subject to model biases. Lack of validation data limits ability to estimate uncertainties. However, such approaches provide the only long-term viable approach.

To address the issues raised above, the following action is proposed:

- OOPC will work with JCOMM and WCRP to identify a group of persons and/or organizations willing to establish a programme to collect surface drifting buoy motions, ship drift current estimates and to make global estimates of current based on wind stress and surface topography fields.

Action O20[38] (OF10, OF11)

Action: Establish an international group to assemble surface drifting buoy motion data, ship drift current estimates, current estimates based on wind stress and surface topography fields and to prepare an integrated analyses of the surface current field. **Who:** OOPC will work with JCOMM and WCRP. **Time-Frame:** 2008. **Performance Indicator:** Number of global current fields available routinely. **Cost Implications**: Category II.

ECV – Sea Ice

Sea-ice variability is a key indicator of climate variability and change. A sea-ice component[39] of the cryosphere research effort is ongoing, e.g., through the Climate and Cryosphere (CliC) project of the WCRP. Operational sea-ice products are being produced by JCOMM groups, such as the Expert Team on Sea Ice. However, at present the systematic coordination of sea-ice observations and improvement of products for climate monitoring and research requires considerable strengthening. The International Polar Year (2007-08) offers various opportunities to bring about the needed strengthening.

Action O21 (OF7)

Action: Establish improved interactions between existing sea-ice research programmes (e.g., WCRP/CliC) and operational sea-ice groups (e.g., JCOMM Expert Team on Sea Ice). **Who:** GCOS in consultation with JCOMM and WCRP. **Time-Frame:** By end of 2005. **Performance Indicators:** Preparation of a quantitative summary comparison of sea-ice products. **Cost Implications:** Category I.

Action O22 (OF7)

Action: Establish an Arctic GOOS Regional Alliance (GRA). **Who:** GOOS in cooperation with GCOS, WCRP (including CliC). **Time-Frame:** 2005, 2007-09. **Performance Indicators:** (a) development of an Arctic sustained observing and climate product plan (by end 2005); (b) implementation of the plan during the IPY. **Cost Implications:** Category I.

There are presently cryosphere-dedicated satellites in orbit, e.g., the NASA Ice, Cloud and Land Elevation Satellite (ICESat), and in development, e.g., the European Space Agency (ESA) Cryosphere Satellite (CryoSat). Many other satellites are also retrieving sea-ice parameters, e.g., the ESA European Remote Sensing Satellite (ERS-2), Envisat, and Radarsat. Most of the national sea-ice services base their operational output on satellite passive microwave, visual and IR data.

The sea-ice variable referred to in the Second Adequacy Report is complex and has been augmented in this Plan to include information on its extent, concentration, thickness and motion.

Sea-ice extent, concentration, thickness and drift can be derived from the following observations:

- Satellite passive microwave.
- Satellite visible.
- Satellite IR.
- Satellite SAR.
- Satellite altimetry.
- Satellite scatterometer.
- Sea-ice air-reconnaissance and ship observations.
- Ice Profiling Sonar ("upward looking sonar (ULS)", moored and submarine-based).

[38] See Action A11.

[39] Involving extent and concentration, thickness, and drift as elements; other elements which could be considered are: Sea-ice surface temperature; Sea-ice type (e.g., first year/multiyear (seasonal perennial), fast ice); Snow-layer thickness; Sea-ice albedo; Melt-pond fraction; Length of the melt season.

- Sea-ice *in situ* drilling.
- Sea-ice buoys.
- Observations of snow characteristics on sea ice.
- Observations by coastal stations.
- Other sensors under development, e.g., electromagnetic, laser, retrieval of ice thickness from sea-ice vibrations caused by waves, etc.

Improved information about sea-ice extent, concentration, thickness, and drift requires:

- Systematic efforts to improve the quality and coverage of sea-ice thickness observations.
- Validation of algorithms, both for passive and active microwave sensors, particularly for the melt period when wet ice-snow surfaces and melt ponds strongly affect the retrievals.
- Improved and validate multi-year ice concentration algorithms.
- Improved retrieval of sea-ice parameters from SAR (ice drift, shear and deformation, divergence, leads, ice ridging, etc.).
- Efficient use of SAR data, especially from the new wide-swath satellites (Envisat ASAR, Radarsat), requires a free-data policy from the Space Agencies and better coverage by SAR receiving stations for real-time use of the data.
- Exploiting ice motion fields from the Radarsat Geophysical Processor System, whose comparisons with other satellite-derived ice motion fields are promising.
- Effective use of Doppler sonar moored beneath the ice. This method may be especially attractive in marginal and seasonal sea-ice zones where the survival time of drifting buoys is very short.
- Improved techniques for assimilation of the whole range of sea-ice data into sea-ice/ocean models to provide consistent analyses of sea-ice concentration, thickness, motion and other parameters.

Issues preventing the effective observation of sea-ice thickness include:

- The validation of the spaceborne altimeter technique requires collocated observations such as upward-looking sonar (ULS) transects from autonomous underwater vehicles and/or submarines, moored ice profiling sonars, and airborne ice profiling sensors, and *in situ* snow on ice characteristics such as density and height. ULS from submarines have provided significant input to climate monitoring from historical observations to date. The future efficient use of submarine observations for the validation of altimetry depends on whether public release of data is granted and is prompt.
- Present ULS array is very sparse and inadequate. The problem, particularly for the Southern Hemisphere, is the destruction of instruments by icebergs – though less so if ULS themselves are deep. Deployment of sensors and data processing are difficult and labour-intensive.
- The Radarsat Geophysical Processor System at the Alaska SAR facility can provide some quantitative ice-thickness information at the thin end of the distribution, but precision is low. High-resolution radar images are costly and the data access is not assured.
- Better seasonal and regional analyses of snow depth and density for climate are needed for ice-thickness retrieval from altimetry.

Issues impacting the observation of sea-ice drift include:

- Arctic ocean ice buoys are located/deployed primarily on perennial ice so the seasonal ice pack is poorly sampled.
- The Antarctic buoy programme array is small with little engagement of operational agencies. The large seasonal variability of Antarctic sea ice is a strong limitation to lifetime on the ice.
- The use of the passive microwave record for deducing ice motion in both hemispheres, starting in the 1970’s, is under active development. However, it will be necessary to identify and correct the source of occasional significant disparity of ice speeds measured by buoys and computed satellite imagery.
- Availability of a large number of SAR images, in particular from the large-swath satellite.

To address the issues raised above, the following set of actions are proposed:

- The WMO Space Programme and GCOS through their participation in the WMO Consultative Meetings for High Level Policy on Satellite Matters, CGMS, CEOS, and IGOS-P will continue to emphasize the need for the sustained satellite (microwave, SAR, visible and IR) operations of sea ice. The OOPC will work with the JCOMM and CliC to improve the *in situ* observations from sea-ice buoys, visual surveys, and ULS.

Action O23 (OF7)

Action: Ensure sustained satellite (microwave, SAR, visible and IR) operations: improve the *in situ* observations from sea-ice buoys, visual surveys (SOOP and Aircraft), and ULS. Implement observations in the Arctic and Antarctic.
Who: Parties' national services, research programmes and Space Agencies, coordinated through the WMO Space Programme, IGOS-P Cryosphere Theme, CGMS, and CEOS; National services for *in situ* systems coordinated through JCOMM.
Time-Frame: Continuing.
Performance Indicator: Sea-ice data in International Data Centres.
Cost Implications: Category III. Partial costing assuming planned operations for other applications.

- The OOPC will work with the JCOMM and CliC to promote the development of integrated sea-ice analysis products and reanalysis projects using the historical data archive.

Action O24 (OF7)

Action: Promote development of integrated analysis products and reanalysis using historical data archives.
Who: JCOMM, WCRP/CliC, and IGOS-P Cryosphere Theme.
Time-Frame: Plan and commitment in place by 2007.
Performance Indicator: Improved sea-ice products.
Cost Implications: Category I.

5.2. Oceanic Domain – Sub-surface

Table 15 below provides a brief summary of the status of existing network contributions to observing the sub-surface ECVs contained in the Second Adequacy Report.

Table 15. Status (end 2003) of the Implementation of the Oceanic Domain – Sub-surface composite network components, their associated coordinating bodies and ECVs observed.

Component Network	ECVs	Implementation Status	Coordinating Body
41 repeat XBT line network	**Temperature**	~75%	JCOMM SOOP
119 tropical moorings	**Temperature; Salinity, Current**, other autonomously observable ECVs feasible	~75%	JCOMM TIP
29 reference moorings network	All autonomously observable ECVs	~15%	International reference station mooring programme
Sustained and repeated ship-based hydrography network	All feasible ECVs, including those that depend on obtaining water samples	~60%	IOCCP, CLIVAR, other national efforts
Argo network	**Temperature, Salinity, Current**	~40%	Argo Steering Team
Critical current & transport monitoring	**Temperature**, heat, freshwater, carbon transports, mass	Plan in development	CLIVAR, IOCCP
Regional and global synthesis programmes	Inferred **Currents**, transports	~30%	GODAE, CLIVAR, other national efforts

5.2.1. General

Systematic sampling of the global ocean is needed to fully characterize oceanic climate variability. Global implementation of upper-ocean measurements in ice-free regions is technically feasible, with proven techniques, but remains to be accomplished. This will be addressed initially through the implementation of the agreed upper-ocean network, the *in situ* component of which requires 3000 Argo profiling floats, 41 repeat XBT lines, 29 surface reference moorings network and ~120 tropical moorings, together with high-precision satellite altimetry. Similar to the surface, the Global Reference Network will provide essential reference-quality long-time records of sub-surface variables to identify climate trends and climate change. They also provide critical platforms for the testing and pilot project use of technology for autonomous measurement of biogeochemical and other ecosystem variables. The records from the Global Reference Mooring Network also will be key for testing climate models and their parameterizations. As new technologies are proven, as our understanding of the sampling requirements improves, and as our ocean analysis and reanalysis capabilities are exploited, the recommended global sub-surface observing system will evolve.

Climate variability is present at all depths in the ocean. Argo can document change in temperature and salinity in the upper 2000 m of the ice-free ocean. The only effective current approach to observing the full suite of ocean sub-surface ECVs involves repeat deep-ocean surveys. Accurate deep-ocean time series observations are essential for determining long-term trends. Ocean water column surveys from research vessels are also our only present means for determining the large-scale decadal evolution of the anthropogenic CO_2 inventory on a global and basin scale (see Figure 8).

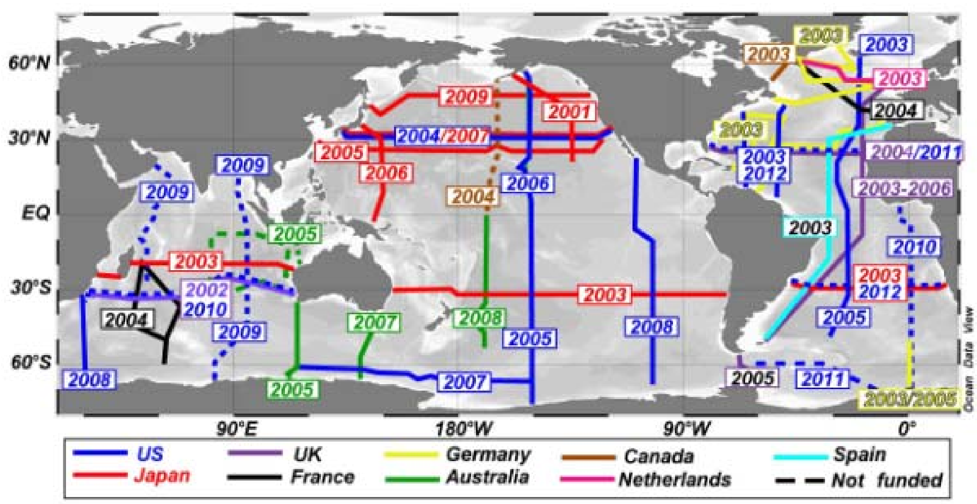

Figure 8. Recommended system of repeat hydrographic sections (31 lines funded, 7 funding pending) (Source: http://www.oco.noaa.gov/page_status_reports_global.jsp accessed 11 October 2004).

Several overarching actions are proposed that the international ocean community should take to ensure that a global sub-surface ocean observing system is implemented that will satisfy climate requirements.

- OOPC in conjunction with CLIVAR, JCOMM, POGO, and the International Ocean Carbon Coordination Project and through the national research institutions will implement the agreed programme of global repeat full-depth water column sections (~30 sections repeated on a ~10 year cycle, but more frequently where necessary because of known time scales of variability[40]).

[40] No long-term commitments are in place for repeat section surveys; continuation of existing research activities, with about a 40% enhancement, is needed.

Action O25 (OF10)

Action: Perform the systematic global full-depth water column sampling of 30 sections repeated every 10 years. **Who:** National research programmes in cooperation with OOPC and CLIVAR and the International Ocean Carbon Coordination Project. **Time-Frame:** Continuing. **Performance Indicator:** Data submitted to archives. Percentage coverage of the sections. **Cost Implications:** Category IV.

- The Ship Observations Panel of JCOMM will coordinate the agreed basin-spanning Ship-of-Opportunity XBT/XCTD Repeat Section Programme (a combination of 41 frequently-repeated sections and of high-density sections (about a 30% increase).

Action O26 (OF11)

Action: Perform the 41 Ship-of-Opportunity XBT/XCTD trans-oceanic sections. **Who:** Parties' national agencies coordinated through the Ship Observations Panel of JCOMM. **Time-Frame:** Continuing. **Performance Indicator:** Data submitted to archive. Percentage coverage of the sections. **Cost Implications:** Category III.

- The Argo Pilot Project through its Steering Team and in collaboration with the Observations Coordinating Group of JCOMM will implement to completion the initial 3000 float (3°x3° resolution) global array (1260 floats operating July 2004) and its long-term maintenance (estimated to require 800 float deployments per year).

Action O27 (OF11)

Action: Deploy the planned 3000 Argo float array, reseeding the array with replacement floats to fill gaps and maintain density (estimated 800 per year). **Who:** Parties participating in the Argo Pilot Project and in cooperation with the Observations Coordination Group of JCOMM. **Time-Frame:** Complete 3000 float array attained by 2007. **Performance Indicator:** Number of reporting floats. Percentage of network deployed. **Cost Implications:** Category IV.

- The Tropical Moored Buoy Implementation Panel of JCOMM, in cooperation with CLIVAR and the International Reference Time Series Mooring project, should maintain the tropical Pacific array, and develop plans for and develop an Indian Ocean tropical moored array pilot project and the needed evolution of the Atlantic Ocean tropical moored array pilot project. In all ~119 moorings (~30% increase) are needed, measuring temperature, salinity and currents as fully as possible over the upper 500m of the water column.

Action O28 (OF11)

Action: Maintain the current Tropical Moored Buoy arrays, expand the Atlantic array, and develop the Indian array – total array projected as ~120 moorings. **Who:** Parties national agencies coordinated through the Tropical Mooring Panel of JCOMM. **Time-Frame:** Array complete by 2009. **Performance Indicator:** Data acquisition at International Data Centres. **Cost Implications:** Category IV[41].

- OOPC, through GODAE and relevant climate research programmes, will develop a pilot project to coordinate the collection, quality control and assembly of ocean surface and sub-surface current data, from a variety of sources, including VOS acoustic Doppler current profilers, moorings, Argo and drifters, together with indirect estimates obtained from altimetry and surface pattern-tracking. They will also encourage other efforts to develop analyses and reliable data sets and products of climate variability and trends.

[41] See also Action O10.

Action O29 (OF11)

Action: Develop and implement a pilot project designed to assemble the *in situ* and satellite altimetry data into a composite data set and to assimilate the data into models and to create climate variability and trend analyses. **Who:** Parties' national ocean research programmes and space programmes through GODAE. **Time-Frame:** Pilot project complete by 2009. **Performance Indicator:** Plans and commitments. **Cost Implications:** Category III.

For the biogeochemical and ecological ECVs, the extension of systematic observations from the fixed moored buoy reference network needs to occur through first the development of new technology, and then through the deployment of this technology. There is an overarching requirement for research and development and testing of new autonomous technologies and approaches for biogeochemical and ecological ECVs that cannot currently be measured in that manner.

Action O30 (OF3)

Action: Work with research programmes to develop autonomous capability for biogeochemical and ecological ECVs. **Who:** Parties' national ocean research programmes in cooperation with the Integrated Marine Biogeochemistry and Ecosystem Research, Surface Ocean – Lower Atmosphere Study, and Land-Oceans Interactions in the Coastal Zone of IGBP. **Time-Frame:** Continuing. **Performance Indicators:** Systems available for the ECV pCO_2, nutrients, and phytoplankton with other ecosystem parameters available for use in reference network applications. **Cost Implications:** Category III.

OOPC, through collaboration with the IOCCG and relevant research programmes of the IGBP, will encourage the development of robust and cost-effective autonomous *in situ* instrument for biogeochemical and ecosystem variables. This will lead to the development of a "reference network" programme of around 25 VOS repeat lines for measuring a range of *in situ* parameters[42].

Action O31 (OF9, OF12)

Action: Develop and deploy in a reference network robust autonomous *in situ* instrumentation for biogeochemical and ecosystem variables. **Who:** Parties' national research programmes in coordination with the IGBP and with the IOCCG. **Time-Frame:** *In situ* observation capability developed as a matter of research priority and deployed by 2009. **Performance Indicator:** Progress to global coverage with consistent sensors to GCMP. **Cost Implications:** Category III.

5.2.2. Specific issues – Oceanic Sub-surface ECVs

ECV – Sub-surface Temperature

Knowledge of the global variability and change of ocean sub-surface temperature is essential for climate forecasting and for evaluation of climate change model performance. Satellite altimetry provides some information about vertically integrated variability, but *in situ* observations are essential for accuracy and vertical resolution. A composite system, using a variety of sensors and deployment platforms is the most cost-effective means for sampling variability and change on seasonal and longer time scales.

Networks contributing to the ocean sub-surface temperature observing system include:

---

[42] The IOCCG has identified chlorophyll-a, phytoplankton pigment composition, coloured dissolved organic matter, total suspended particulate material (in coastal regions), *in situ* photosynthetic rates and parameters, and fluorescence as important parameters, amongst others.

- XBT section network.
- Argo array.
- Full ocean depth survey network.
- Reference station network.
- Tropical moored buoy network.

The fundamental issue for the sub-surface temperature observing programme is that none of the existing observing networks have commitments to achieve and sustain the agreed global coverage and sampling density.

See Actions O25-O29.

ECV – Sub-surface Salinity

Knowledge of the sub-surface salinity variability and change is essential in improving seasonal and interannual prediction and understanding the impact of changes in the hydrological cycle on ocean circulation. It can be observed with existing technology, but this ECV is not adequately sampled globally at present. The agreed programme will dramatically increase our knowledge of this ECV. Repeating XCTD observations from ships of opportunity are also feasible.

The fundamental issue for the sub-surface salinity observing programme is that none of the existing observing networks have the agreed global coverage and sampling density. Sub-surface salinity observing networks and systems include the previously described elements of the sub-surface system (Argo array; Full-depth repeat survey network; Reference Time Series mooring network; Tropical Moored Array network). The long-term stability and accuracy of salinity sensors remains an issue.

See Actions O25-O29.

ECV – Sub-surface Carbon

The oceanic uptake of carbon from the land and the atmosphere is a significant element of the planetary carbon budget. Because the net ocean carbon uptake depends on biological as well as chemical activity, the uptake may change as oceanic conditions change (e.g., pH, currents, temperature, surface winds). At present, the community consensus is that the best strategy for monitoring ocean carbon uptake is via a global ocean carbon inventory network. The sub-surface ocean carbon variables and their change with time are not adequately sampled. With present technology, a major improvement in our knowledge can be achieved with the agreed full-depth repeat survey programme (see Figure 8).

Long-lived autonomous sensors for ocean carbon system components that can be deployed on moored or profiling observing elements are under development and will significantly increase our global observing capability. A more rapid repeat cycle for ocean survey sections will be needed for assessing the net carbon inventory change over intervals shorter than 10 years.

See Actions O17, O18, O25 and O31.

ECV – Sub-surface Nutrients (oxygen, phosphorus, nitrates, silicates)

Nutrient data are essential biogeochemical information, and provide essential links between physical climate variability and ecosystem variability, but are not adequately observed. They give an additional perspective on ocean mixing.

Networks and systems that contribute to the observation of sub-surface nutrients are:

- Repeat survey network.
- Reference station network.

These networks are research and/or pilot programmes and require technology development to attain reliable and accurate autonomous sensors and to deploy observing systems to sample better near-surface nutrient variability.

See Actions O8, O25 and O31.

ECV – Sub-surface Tracers

Ocean tracers are essential for identifying the anthropogenic carbon uptake, storage and transport in the ocean, as well as for understanding multi-year ocean ventilation, long-term mixing and ocean circulation and, thereby, providing essential validation information for climate change models. Ocean tracers are not adequately sampled at present. Present technology for most important tracers requires water samples and subsequent processing of these samples.

The primary network contributing to sub-surface tracers is the Repeat Section Programme Network. With technology development, some tracers are expected to be observable from the time series reference moorings within the decade; pilot project use, as development proceeds, should be a priority.

To attain adequate sampling, the following technical challenges must be overcome:

- Improved technology for small water volume measurements needed.
- Technology development needed for autonomous sensors.

See Actions O8, O18 and O25.

ECV – Sub-surface Currents

Ocean sub-surface current information is needed in order to estimate oceanic transports, as well as to identify ocean circulation changes, including the onset of abrupt ocean overturning changes.

Observing networks and systems contributing to the observation of sub-surface currents are:

- Argo float displacements.
- Reference mooring network.
- Tropical moored buoy network.

Issues facing the ocean observing community in the effort to observe the ocean circulation parameters adequately for climate objectives are the following:

- Argo array needs global completion.
- Agreed plan for key regional monitoring efforts (e.g., choke points, sill overflows, boundary currents) needed.
- Tropical and reference station currents seriously under-sample for change detection.

See Actions O22 and O27-O31.

ECV – Phytoplankton

Phytoplankton records from analyses of the continuous phytoplankton recorder data provide the only basin-scale multidecadal records of ocean ecosystem variables. These records have been obtained by many different vessels and organizations. The historical record of intercomparable records should be made as complete as possible and a plan for sustained repeat continuous plankton recorder sections should be developed and implemented.

See Actions O30 and O31.

5.3. Oceanic Domain – Data Management

Section 3.7 of this Plan introduced the data management needs and some general issues together with associated actions. There are additional issues within the Oceanic Domain however that also require specific actions. The coordination of ocean data management activities is principally carried out through the IODE of IOC and the International Council for Science (ICSU), and the Data Management Coordination Group of JCOMM that in turn works closely with the data management programmes of WMO. At this time, WMO is examining the adoption of meta-data standards and the potential of a Future Information System that would introduce new internet-based technology into the GTS and rationalize the system of International Data Centres. Any actions taken for ocean data management will inevitably be linked to, or included within, these activities of WMO.

A data policy has been agreed by the Member States of the Intergovernmental Oceanographic Commission, Resolution XXII-6, with the intent of facilitating the free and open exchange of essential ocean data. Within the IOC and JCOMM, a review is underway to examine potential future arrangements for their data management needs. The review envisages "A comprehensive and integrated ocean data and information system, serving the broad and diverse needs of IOC Member States, for both routine and scientific use". Figure 9 below shows schematically a possible arrangement with a hierarchal system of global, regional and national activities/centres. There are also important activities underway at the regional and national level.

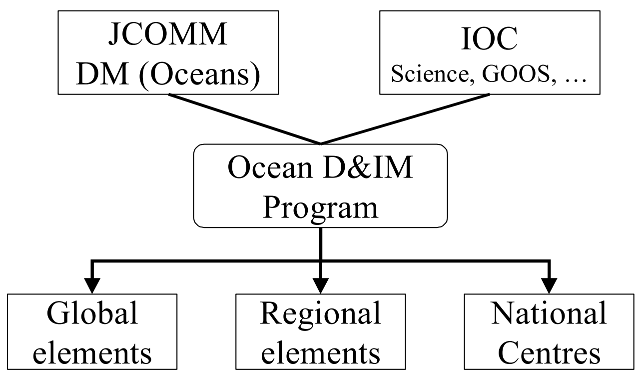

Figure 9. A possible structure for JCOMM and IOC/IODE data management.

Three data management functions within the Oceanic Domain are particularly important: Firstly, the ability to efficiently and effectively communicate data (and meta-data) from platforms that are often remotely located and/or autonomous. While most products required by GCOS do not demand real-time acquisition, experience has shown that a policy of immediate acquisition is the most effective for assuring that data are available, exchanged and submitted in at least preliminary form to International Data Centres.

Telecommunication from platforms such as moorings, drifters and floats is limited, and in some cases this means measurements are lost. Various groups currently do provide data telecommunication services to the ocean community (e.g., Argos) and these services will continue to be a critical contribution. However, to implement the networks and systems being proposed, the community requires at least an order of magnitude increase in telecommunications capacity and, for some systems, an increase of 100 times is necessary.

Secondly, there is the function of data transport between the various components of the networks. The ocean community has to-date made extensive use of the WMO WWW/GTS for exchange of data in real time and near real time. Other data sets, particularly from hydrographic cruises, are exchanged via other means. At the OCEANOBS99 conference, the community reached a consensus that, wherever practical, ocean data should be exchanged freely in real time. This policy has been followed with Argo and, increasingly, in other endeavours contributing to the oceanic climate observing system. The definitions adopted by OOPC and JCOMM for “operational” status in effect demand such arrangements. Recently, increasing use has been made of Internet systems to exchange data and, in particular, using the OPeNDAP (formerly DODS) protocol. Yet other systems are being considered by WMO to enhance the capability of the GTS.

Thirdly, the function of data assembly and quality control are critical for ensuring that the global ocean data meet the climate-quality standards and are accessible to users. The Tropical Atmosphere-Ocean Array (TAO) and initiatives such as those of the Global Temperature-Salinity Profile Project have ushered in an era of greatly improved access to data, greater reliability of delivery and access and improved quality, and have facilitated and made more efficient data assembly procedures. In concert with the Data Assembly Centre activities of the World Ocean Circulation Experiment (in part continued through IODE and CLIVAR), the community is now better able to produce high-quality data sets, in time-frames that account for the immediacy of some climate issues. Through JCOMM and IODE, these initiatives continue to provide significant benefit to the community. Other initiatives such as the World Ocean Database of the US National Oceanographic Data Center, the International Comprehensive Ocean-Atmosphere Data Set Project, and the Global Oceanographic Data Archaeology and Rescue (GODAR) project also provide significant capability for developing oceanic climate data sets and analyses. The World Data Centre for Glaciology and the National Snow and Ice Data Center (NSIDC), among others, provide similar functionality for aspects of the sea-ice data.

Table 16 documents the International Data Centres (or activities) that provide functionality for particular variables and/or platform types, or for specific regions.

Table 16. International Data Centres and Activities – Oceanic Domain.

ECVs	Contributing Activity	Classification	Implementation Status
Delayed-mode monthly and annual mean **Sea level**	Permanent Service for Mean Sea Level	Operational	Fully adequate, but inadequate national participation in data exchange
Real-time **Sea level**	University of Hawaii Sea Level Centre	Pre-operational	Satisfactory
Surface	VOSClim Real/Time Monitoring Centre and VOSClim Data Centre	Pre-operational	Marginal (early days)
Sub-surface Temperature and **Salinity**	GTSPP	Operational	Satisfactory
Surface	GOSUD	Pre-operational	Marginal (early days)
Surface	The International Comprehensive Ocean-Atmosphere Data Set	Operational	Satisfactory, but long time intervals between updates
Sub-surface **Temperature**, **Salinity** and **Currents**	Argo Global Data Assembly Centres	Pre-operational	Real-time satisfactory; Delayed-mode at initial stage
Surface and sub-surface	World and Responsible Data Centres of IODE	Operational	Variable
Surface and sub-surface	Specialized and regional centres	Varying	Marginal (early days)
All **sea-ice** ECVs	US National Snow and Ice Data Center	Operational	Satisfactory
Sea-ice extent, concentration	JCOMM Global Digital Sea Ice Data Bank	Operational	Marginal for climate

The following actions will be undertaken to develop and implement the data management component of the Oceanic Domain of GCOS:

- The IOC should monitor the implementation of the IOC Data Policy using among other means the national reports on systematic observations to the UNFCCC.

Action O32

Action: Monitoring the implementation of the IOC Data Policy.
Who: IOC.
Time-Frame: Continuous.
Performance Indicator: Reports by the Executive Secretary (IOC) on the implementation of the IOC Data Policy.
Cost Implications: Category I.

- The IODE and JCOMM are developing a Pilot Project on data assembly, quality and orderly archiving of ocean data, data sets and products. The Project will develop a system for ensuring the integrity of data sets is sustained and that value-adding is recognized and maintained through an agreed system of versions and classifications, in particular for scientifically quality controlled data sets and associated products. The Pilot Project will build on the (pre-operational) data management arrangements initiated by Argo, including its system of data centres, and the Global Temperature-Salinity Profile Program of JCOMM and IODE.

Action O33 (CF13)

Action: Develop and implement comprehensive data management procedures.
Who: IODE and JCOMM.
Time-Frame: Project plan by 2007.
Performance Indicator: Plan published.
Cost Implications: Category II.

- The IODE and JCOMM, in collaboration with the ocean community generally, the WMO and other standard setting bodies, such as ISO and the World Wide Web Consortium, should develop an international standard for ocean meta-data including syntactic and semantic (description, search) meta-data.

Action O34 (CF6)

Action: Undertake a project to develop an international standard for ocean meta-data.
Who: IODE and JCOMM in collaboration with WMO CBS and ISO.
Time-Frame: Standard developed by 2009.
Performance Indicator: Publication of standard for an agreed initial set of the ECVs. Plan to progress to further ECV.
Cost Implications: Category II.

- The IODE and JCOMM, in collaboration with the FWIS initiative, and building on innovations and emerging protocols for data transport such as OPeNDAP, should develop an ocean data transport system for data exchange between centres using ocean data, and for open use by the ocean community generally (subject to agreed standards).

Action O35 (CF15)

Action: Undertake a project to apply the innovations emerging from the Future WMO Information System initiative, and innovations such as OPeNDAP to develop an ocean data transport system for data exchange between centres and for open use by the ocean community generally.
Who: JCOMM.
Time-Frame: Report by 2009.
Performance Indicator: Report published.
Cost Implications: Category II.

- Following the review of data management arrangements being conducted internally by IODE and JCOMM, and recognizing the capabilities and potential of existing centres and arrangements, IODE and JCOMM should continue to encourage the implementation of a system of regional, specialized and International Data Centres that will: (a) handle data in accordance with GCMPs; (b) be able to provide advanced ocean data services; (c) be capable of bringing expert analysis and interpretation in their region/area of specialization; (d) undertake exchange of data and associated products with other relevant centres of IODE and JCOMM; and (e) ensure the safe-keeping and archiving of ocean climate data. Further, with specific regard to the needs of GCOS, several Centres should be established that specialize in the provision of oceanic climate data services.

Action O36 (CF3, CF4, CF19)

Action: Plan and implement a system of regional, specialized and global data and analysis centres. **Who:** Parties' national services under guidance from IODE and JCOMM. **Time-Frame:** Plan finished by 2007, implementation following. **Performance Indicator:** Plan published. **Cost Implications:** Category III.

- The IODE through its GODAR project should promote the rescue and assembly of historical ocean data, including data in non-digital forms.

Action O37 (CF5)

Action: Support data rescue projects. **Who:** Parties' national services with coordination by IODE through its GODAR project. **Time-Frame:** Continuing. **Performance Indicator:** Data sets in archive. **Cost Implications:** Category II.

- The IODE and JCOMM should support projects that enhance the flow, quality control and overall management of ocean data in real time and, specifically the Global Temperature-Salinity Profile Program (GTSPP) and GOSUD.

See Action O31.

- The IODE and JCOMM, in collaboration with specific national groups, should develop enhanced and more cost-effective telecommunication capabilities including, as feasible, two-way communications for dynamic control of instruments.

Action O38 (CF3)

Action: Develop enhanced and more cost-effective telecommunication capabilities, including two-way communications for dynamic control of systems, instruments and sensors. **Who:** Parties, coordinated through JCOMM. **Time-Frame:** 2007. **Performance Indicator:** Capacity to communicate data from ocean instrumentation to ocean data centres. **Cost Implications:** Category III.

5.4. Oceanic Domain – Integrated Global Analysis Products

The purpose of the observing system described is to provide the information necessary to meet the needs of the UNFCCC. A fundamental set of products have been identified and developed by research and operation communities to meet these requirements. In addition, high-value products and services to stakeholders, decision-makers, and policy-makers are emerging from an ongoing dialogue with the science community. This exchange will provide the guidance for the further development of the system.

Ocean data analyses are important for supporting the testing of climate change models and evaluation of the ocean state/structure of predictions of future changes of the climate system. The comprehensive global networks, together with baseline and reference networks described previously, can provide the needed information, with particular emphasis on three-dimensional analyses, climatologies and time series.

Ocean analysis, reanalysis and ocean data assimilation and forecasting systems are underway or planned in some nations, but enhancement and coordination of the suite of such efforts is needed to meet the specific needs of the UNFCCC. Several groups are testing the capacity of ocean data assimilation systems to contribute to climate assessment, climate forecasting and climate analysis. There are two types of global reanalysis efforts: 1) high-resolution, but focused on the most recent satellite altimeter period; and 2) lower-resolution, mostly covering the atmospheric reanalysis period. A number of existing efforts participate in GODAE, a pilot project to demonstrate the impact and feasibility of operational oceanography and prediction, with several partners having specific interests in climate. Other research and pilot projects are also underway. Such efforts are essential to developing on-going systems capable of making products that address the needs of the UNFCCC.

Several specific actions are proposed to ensure the production of integrated ocean analysis products to address climate user requirements including those of the UNFCCC:

- JCOMM, in collaboration with CLIVAR and other research activities, should develop plans for the construction of climate-quality historical data sets for the oceanic ECVs, including estimates of variance and covariance statistics.

Action O39 (CF3)

Action: Develop plans for and coordinate work on data assembly and analyses.
Who: JCOMM, in collaboration with CLIVAR, CliC, GODAE, and other relevant research and data management activities.
Time-Frame: Plan available by 2006.
Performance Indicator: Number of ocean climatologies and integrated data sets available.
Cost Implications: Category II.

- JCOMM should develop pilot projects for the generation of operational oceanography product suites of the oceanic ECVs (e.g., national GODAE activities). Systematic evaluation of the skill of these products is needed, so each group will be encouraged to participate in the various GODAE regional comparison projects. The utility of these operational products as the basis for the development of oceanic climate information products will be investigated. Feedback on the performance of the initial oceanic climate observing system will thus be provided to observing system management, including recommendations for enhancement and/or evolution of the initial system networks.

Action O40 (CF4)

Action: Develop plans and pilot projects for the production of global products based on data assimilation into models. All possible ECVs.
Who: Parties' national services and ocean research agencies through CLIVAR, the CLIVAR Global Synthesis and Observations Panel, and GODAE.
Time-Frame: 2008.
Performance Indicator: Number of global oceanic climate analysis centres.
Cost Implications: Category III.

- OOPC, in coordination with CLIVAR and other relevant research programmes, will develop plans for pilot projects for ocean reanalysis, including the comparison of the results of different reanalysis results.

Action O41 (CF5)

Action: Undertake pilot projects of reanalysis of ocean data.
Who: Parties' national research programmes coordinated through OOPC and WCRP.
Time-Frame: 2010.
Performance Indicator: Number of global ocean reanalyses available.
Cost Implications: Category III.

5.5. Oceanic Domain – Scientific and Technological Challenges

A number of new or improved sensors and platforms will become available for sustained observations within the next 5 to 10 years. Ocean technology is making rapid progress in observing ocean variables that could be accurately measured only in the laboratory until a few years ago, or could not be measured at all. Some of the new sensors are already in research use on moorings and other autonomous deployments. Further technology development and research are necessary for some variables of long-standing importance but limited present feasibility, even if payoff may not be achieved in the desired time. In addition, advances are needed in telecommunications and are likely to become widely available in the near future.

Ocean climate product development will advance rapidly if adequately supported. Collaboration with ongoing global research programmes (e.g., WCRP, IGBP) and fishery/ecosystem programmes must be fostered. The following list is meant to be illustrative of areas requiring research and technology development:

- Satellite observations with higher resolution and accuracy and more spectral bands from geostationary satellites; improved capability for ocean colour observations in coastal and turbid waters; improved interpretation of sea-ice data from satellites; satellite measurement of salinity.
- Observing system evaluation and design, including improvements in air-sea flux parameterizations.
- Improvements in ocean platforms, including increased capabilities for Argo floats; improved 'Gliders' technology[43] and mooring technology.
- New development in ocean sensors and systems, including improved bio-fouling protection, autonomous water sampling systems, optical and acoustic systems, airborne variable sensors, and two-way, low-cost, low-power telecommunications.
- New and improved capability to measure biogeochemical variables, nutrients, and dissolved oxygen and carbon dioxide, as well as to identify organisms.
- Improved instruments, including near-surface current meters, in-water radiometers, sensors for air-sea interface variables and turbulent fluxes, and VOS sensor systems.

5.6. Oceanic Domain – Synthesis and Consolidation of Actions

The agreement on a design and an implementation strategy by the ocean climate community (GCOS, GOOS, WCRP) have led to the Plan recommended here. If implemented, a global perspective on variability and change within the ocean will be achieved. The strategy depends on composite surface and sub-surface networks, making best use of all existing observing activities. The Plan depends on continuation of critical satellite observations and on establishment of a sparse global array of reference time series mooring sites measuring all oceanic ECVs. It also has benefited from technology proven over the previous decade in international research programmes, together with establishment of the JCOMM.

The routine generation of ocean climate products will provide necessary ocean data for global climate and weather models, and lead to the decision-support information needed by the Parties. All actions are technologically feasible and can be accomplished with established coordination mechanisms and agreements.

The composite approach, with carefully-balanced contributing systems and networks and broad coordination and cooperation, is essential for meeting the requirements. The major weaknesses of the present observing system are the lack of global coverage of the ocean, the need for efficient autonomous and remote instruments for the entire oceanic ECV list, the need for expanded and more effective data and product systems, and the need for long-term continuity of national efforts in conjunction with international coordination.

At present, there are few national and regional agencies tasked to implement and sustain the ocean component networks and systems or to deliver ocean data products and services. The present global effort depends heavily on the efforts and funds of the research community. National and regional

[43] Profiling floats with a positioning capability achieved by directional gliding.

agents of implementation with clear tasking and adequate resources are needed. Efficient and cost-effective implementation will depend on partnerships – between Space Agencies and agencies responsible for *in situ* observations, between operational and research agencies and between providers and users.

Linkages between the Oceanic Domain Plan and the emerging plans of the Coastal Ocean Observing System must be fostered and encouraged so that benefits from the systems are mutually realized.

Continued research is required to improve and develop observing capabilities for some ECVs and to make systems more robust and cost-effective. The research and operational communities must work together with stakeholders/users to evaluate the effectiveness of the present system, to guide its evolution and to ensure that information products serve the needs of the Parties.

Pathways to improved ocean data management and access are enumerated. Progress can be made in ocean data transport, data quality and observing standards, meta-data standards, and access to data in archives. The infrastructure for real-time operational oceanography is also needed for ocean climate objectives; development should be coordinated and resources shared.

Specific five-year milestones include:

- Completion of the initial oceanic climate observing system, including the composite surface networks and satellite systems (Table 14) and the composite sub-surface networks (Table 15).
- The designation and/or establishment of national and regional agents of implementation with responsibility to sustain the surface and sub-surface networks and satellite systems.
- Develop and implement an ocean data management and information system with agreed meta-data standards, effective quality control and data set assembly and maintenance, and efficient data transport systems.
- Obtain timely, free and unrestricted data exchange between Parties and International Data Centres for oceanic ECVs, including historical data.
- Complete a first set of global ocean climate reanalyses with uncertainty estimates and including the preparation of needed input data sets.
- Establish partnerships between the ocean and climate research and operational communities to provide scientific oversight and to recommend evolution needs of the observing system.
- Support development of new and/or more efficient technologies and observing methods for oceanic ECVs, including ecosystem and biogeochemical variables.
- Designation and/or establishment of Agents of Implementation to generate routinely ocean climate information products.
- Establish an Arctic GOOS Regional Alliance to plan, coordinate, implement and evaluate Arctic Ocean and sea-ice observing networks and systems.

6. TERRESTRIAL CLIMATE OBSERVING SYSTEM

6.1. General

Many organizations make terrestrial observations, for a wide range of purposes. The same variable may be measured by different organizations using different measurement protocols. The resulting lack of homogeneous observations hinders many terrestrial applications and limits the scientific capacity to monitor the changes relevant to climate and to determine causes of land-surface changes. The Second Adequacy Report noted that these difficulties could be resolved by the creation of an intergovernmental technical commission for terrestrial observations similar to those that exist for the Atmospheric and Oceanic Domains. Such a body would *inter alia:*

- Prepare and issue regulatory and guidance material for making terrestrial observations.
- Establish common standards for networks, data management, as well as associated products and services.
- Ensure compatibility with standards and initiatives.
- Seek hosts for designated International Data Centres addressing the full range of Terrestrial Domain ECVs.

As requested by the WMO Congress in May 2003, the WMO, in partnership with the Food and Agriculture Organization of the United Nations (FAO), ICSU, United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), and in consultation with other agencies as appropriate, will explore the benefits of and procedures for establishing an intergovernmental mechanism for terrestrial observations.

As a first step, it is proposed to establish an *ad hoc* inter-agency working group to examine the respective roles and responsibilities of the relevant international agencies involved with terrestrial observations and to suggest the possible mandate and reporting relationships of such a body, or mechanisms to effect the needed identification and adoption of observing, reporting and archiving standards for terrestrial variables. The inter-agency working group should be convened in 2005 and deliver its findings concerning the appropriate mandate and reporting relationship of such a technical commission by 2006.

Action T1 (TF1)[44]

Action: Create of an intergovernmental mechanism for terrestrial observations.
Who: WMO, in consultation with FAO, ICSU, UNEP and UNESCO will form an inter-agency working group and explore options and propose a mechanism (e.g., an intergovernmental technical commission for terrestrial observations).
Time-Frame: Develop proposal by 2006.
Performance Indicator: Presentation of plan to governing bodies of participating organizations.
Cost Implications: Category I[45] increasing to II.

With regard to the hydrological variables, the WMO CHy should take a lead role in enabling programmes for the monitoring of rivers, lakes, and in conjunction with the proposed Terrestrial Commission (see Action T1) for ground water and water use among others. The monitoring programmes are envisaged to involve the establishment of GCOS baseline networks for river runoff and lake level and area. The National Hydrological Services are generally responsible for making the observations required by the different baseline networks. Coordination within the hydrological domain is therefore clearly needed. GCOS, in consultation with other involved organizations, has begun the establishment of an informal body, the Global Terrestrial Network for Hydrology (GTN-H), as a partnership of relevant involved programmes and International Data Centres with the objective of designing and implementing the associated baseline networks. For this reason, the GTN-H or an

[44] Actions in this document relate to 'Findings' of the Second Adequacy Report, as listed in Appendix 2 herein. These are identified as CF (Common Findings), AF, OF and TF (referring to Atmospheric, Oceanic, and Terrestrial Findings, respectively).
[45] See Section 2.8 Table 7 for cost definitions.

equivalent organizational entity under the auspices of CHy should be formally established and appropriate secretariat functions initiated.

Action T2 (TF2)

Action: Find sponsors and a host for the GTN-H. **Who:** TOPC, in cooperation with WMO CHy and National Hydrological Services. **Time-Frame:** 2006. **Performance Indicator:** Contact names and location for the GTN-H secretariat. **Cost Implications:** Category I increasing to II.

A number of the variables noted below, e.g., fAPAR, LAI, biomass, and albedo, are related to land cover and are both hard to measure and too heterogeneous to make global *in situ* measurement practical. They are typically measured at research sites. There are two key needs for such measurements in the context of long-term global climate measurements. One is to ensure that a representative set of biomes have measurements, which monitor these variables in a consistent fashion. This will allow the details of natural vegetation changes and carbon stocks to be carefully monitored in key locations. A second need for such measurements is to provide a set of reference sites providing essential ground data for validation of satellite-based measurements that enable the calculation of global coverage for these variables. Appropriate funding support will be needed to realize this reference network objective. Opportunities may exist to collocate some of these sites with atmospheric reference sites.

Action T3[46] (TF12, TF15)

Action: Develop a global network of some 30 sites based on a progressive evolution of existing reference sites to monitor key biomes and provide the observations required for the calibration and validation of satellite data. **Who:** Parties' national services and research agencies, in cooperation with the IGBP, WCRP and in association with TOPC and GTOS. **Time-frame:** Plan prepared by 2007 with progressive establishment of sites thereafter. **Performance Indicator:** Preparation of a plan and the establishment of sites. **Cost Implications:** Category I increasing to IV.

Despite the lack of a technical commission, some progress is being made on the provision of the terrestrial observations required by the UNFCCC as shown in Table 17. International Data Centres for some variables are functioning at a basic level (see Table 18, Section 6.3), infrastructure to coordinate the collection of data for key *in situ* variables is being developed, Space Agencies now provide observations for some variables on an increasingly routine basis and improved mechanisms exist for international consensus (e.g., new GTOS science panels and a Land Product Validation Group within the CEOS Working Group on Calibration and Validation (WGCV)).

[46] See also Actions A16, A27, A30.

Table 17. Observation networks and systems contributing to the Terrestrial Domain ECVs.

ECV	Contributing Network(s)	Status	Contributing Satellite Data	Status
River Discharge	Proposed GCOS Baseline River Discharge Network based on the GRDC priority list.	Stations selected, but GTN-R not formally established.	Research concerning laser/radar altimetry for river levels and flow rates.	Operational laser altimeters not scheduled; Earth Observation (EO)-based network only research.
Lake Level/Area	Proposed GCOS Baseline Lake Level/ Area Network based on TOPC priority list. To include freeze-up/break-up.	Stations selected, but GTN-L not formally established.	Proposed altimetry, high-resolution. Optical and radar and reprocessing of archived data.	Operational laser altimeters not scheduled. Question mark over high-resolution systems continuity. EO-based network only research.
Ground Water (Levels and Use)	None, but many national archives of ground-water level do exist.			
Water Use (Area of Irrigated Land)	No network, but a single geo-referenced database exists.		Any high-/medium-resolution optical/ radar systems.	Lack of high-resolution optical continuity.
Snow Cover	WWW/GOS synoptic network (depth). National Networks (depth and snow water equivalent).	Synoptic and national networks have significant gaps and are ALL contracting. Southern Hemisphere not monitored operationally for extent and duration.	Moderate resolution optical for extent/duration. Passive microwave for snow water equivalent.	Moderate resolution optical system follow-on is programmed.
Glaciers and Ice Caps	GTN-G coordinates national monitoring networks. Radarsat Antarctic Mapping Project; Program for Arctic Regional Climate Assessment; International Trans-Antarctic Scientific Expedition.	Major geographic gaps must be closed; especially concerning glacier mass balance measurements inadequate. One-off research projects.	Visible and infrared high-resolution; Along track stereo optical imagery; Synthetic Aperture Radar. Satellite altimetry.	Lack of high-resolution optical satellite continuity. Satellite altimetry research missions will help; Lack of laser altimetry mission continuity.
Permafrost and seasonally-frozen ground	GTN-P coordinates National Monitoring Networks.	Major geographical gaps.	Satellite-derived variables (e.g., vegetation type and snow cover, water) are essential, plus skin temperature measurements.	
Albedo	CGMS; CEOS/WGCV; MODLAND; Atmospheric Radiation Measurement sites.	No designated baseline network.	Geostationary Polar orbiters. GCMPs applied to measurements.	Use of operational meteorological satellites and moderate-resolution optical polar orbiters.
Land Cover	FAO's Global Land Cover Network; GOFC-GOLD.	First generation products available.	Any high-/medium-resolution optical/ radar systems.	Moderate resolution good; Question mark over high-resolution optical system continuity.

fAPAR and LAI	CEOS/WGCV; FLUXNET; GTOS Net Primary Productivity.	No designated baseline network exists.	Optical, multispectral and multiangular.	Moderate spatial resolution multi-spectral good; Question mark over multiangular measurements.
Biomass	FAO's FRA.	No designated baseline network exists; FRA data not currently applicable for high-resolution spatial analysis.	Low-frequency radar and laser altimetry.	No appropriate laser/radar missions currently planned.
Fire Disturbance	GOFC Regional Networks.	Some geographical gaps exist.	Optical.	Geostationary and moderate-resolution optical systems should be adequate.

6.2. Specific Issues – Terrestrial Domain ECVs

ECV – River Discharge

River discharge has a role in driving the climate system, as the freshwater inflow to the oceans may influence thermohaline circulations. The statistical properties of river discharge are an indicator for climatic change and variability as they reflect changes in precipitation and evapotranspiration. They are also required for the calibration of global models, trend analysis and socio-economic investigations. Monthly observations of river discharge are generally sufficient, though daily data are needed to calculate the statistical parameters of river discharge.

Most countries monitor river discharge, yet many are reluctant to release their data, in spite of WMO resolutions requesting free and unrestricted exchange. Additional difficulties arise because data are organized in a scattered and fragmented way, i.e., data are managed at sub-national levels, in different sectors, and using different archival systems. Even for those data providers that release their data, delays of a number of years can occur before data are delivered to International Data Centres such as the Global Runoff Data Centre (GRDC).

Though methods for monitoring water levels and surface water velocities from satellites are being developed, e.g., by SAR Along Track Interferometry, they are still at an early stage. Research into interferometric and altimetry-based approaches to river discharge monitoring by the Space Agencies will be encouraged by GCOS, TOPC and IGWCO.

With current technology *in situ* systems offer the most complete basis for river discharge monitoring. The GRDC has a mandate, through resolution 21 (WMO Cg-XII), to collect river discharge data on behalf of all Members and in a free and unrestricted manner, in accordance with resolution 25 (WMO Cg-XIII). However, there are major gaps in the data received by the GRDC; gaps both in terms of the number of rivers monitored and the time it takes for the GRDC to receive the data. To address this problem, GCOS proposes two phases of implementation action.

Phase 1: Based on past demands for data, the GRDC has identified 380 stations near the downstream end of the largest rivers of the world – as ranked by their long-term average annual volume These stations would be given priority and collectively form a new GCOS baseline network; the Global Terrestrial Network – Rivers (GTN-R). Data from these stations will capture about 70% of the global freshwater flux to the oceans (see Figure 10). All these stations have reported at some time in the past, and most are operating today.

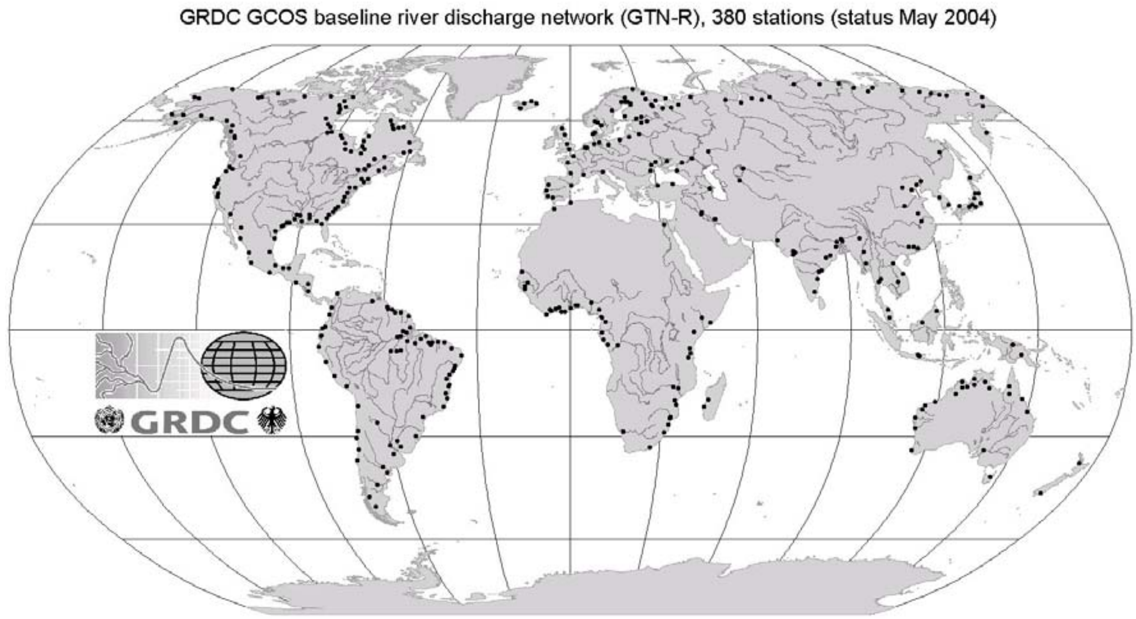

Figure 10. Baseline River Discharge Network based on the GRDC priority stations (Source: GRDC).

The WMO through CHy will request that the National Hydrological Services responsible for these 380 stations: (a) evaluate the identified gauging stations, determine their operational status and provide the GRDC with this information, i.e., all existing data and meta-data, including the measurement and data transmission technology used; and (b) ensure that daily discharge data be submitted to the GRDC within one year of their observation.

Action T4 (TF2)

Action: Confirm locations of GTN-R sites, determine operational status of gauges at all GTN-R sites, ensure that the GRDC receive daily river discharge data from all 380 sites within one year of their observation (including measurement and data transmission technology used).
Who: National Hydrological Services, through WMO CHy in cooperation with TOPC, GTOS and the GRDC.
Time-Frame: 2006 for finalization of network and reporting of any historical records, complete compliance, i.e., one-year time lag by 2009.
Performance Indicator: Reports to WMO CHy on the completeness of the GTN-R record held in the GRDC including the number of stations and nations submitting data to the GRDC, National Communication to UNFCCC.
Cost Implications: Category II increasing to III.

Phase 2: Whilst the emphasis will be initially on the 380 priority stations and a reporting delay of no more than one year, it is a limited but important step towards the ultimate goal of near real-time receipt from as many stations as possible on all significant rivers. Some stations are able to transmit near real-time data; others need to be upgraded (average cost per station ~15,000 US-$ per station). The GTN-R, in cooperation with WMO CHy, will develop standards for the near real-time transmission of river discharge observations taken by the National Hydrological Services to the GRDC. When these standards have been developed, they will be presented to WMO CHy for its approval, and then promulgated by WMO. Implementation will be assessed by the number of priority stations reporting annually with a maximum one-year delay, by the number of near real-time stations established, by the amount of data transferred or made accessible, and by the number of countries submitting timely data to the GRDC.

ECV – Lake Level/Area

Information on changes in lake level and area (which are surrogates for lake volume) is required on a monthly basis for climate assessment purposes. Approximately 95% of the volume of water held globally in the ~4 000 000 lakes is held in the 150 largest lakes. However, most of these large lakes are hydrologically open. Closed-basin lakes are more sensitive to changes in regional water balance and therefore better sensors of changes in regional climate.

Large open lakes cannot be neglected in designing the monitoring programme because they are important sources of water for consumption, and because large expanses of water can have a regional impact on climate through albedo feedback and evaporation. Furthermore, in some regions (e.g., the semi-arid interior of Australia or the Great Basin of the USA) highly ephemeral lakes (which contain water only every few years) provide a record of extreme events and also have potential feedback effect on regional climate.

The TOPC approach is to focus on the largest lakes, primarily closed-basin lakes but including major ephemeral lakes and a selection of the largest open lakes. Measurements at these lakes would form a new GCOS baseline network, the Global Terrestrial Network – Lakes (GTN-L). Lake level and area need to be measured weekly (ideally) or at least monthly with a horizontal resolution of 10m and a vertical resolution of at least 5cm. These measurements would be made by National Hydrological Services and then provided to the designated International Data Centre. Unlike the GTN-R, no operational data management centre for lake level/area exists, although several institutes[47] have expressed willingness to extend their current activities to take on this role, subject to obtaining adequate financial support. Currently, TOPC is defining the GTN-L, but once established the lake information data centre would host the GTN-L. The creation of an operational lake data management function is imperative, but funding for the support of an International Data Centre is required.

Phase 1. TOPC will, after consultation with interested parties, seek through the WMO CHy to identify one or more International Data Centres willing to assume responsibility for the archiving of lake level/area data.

Action T5 (TF2)

Action: Create a lake information data centre.
Who: TOPC in consultation with WMO CHy and National Hydrological Services.
Time-Frame: Operational by 2006.
Performance Indicator: Commitment by host country.
Cost Implications: Category II.

Phase 2. TOPC, working with WMO CHy, will refine the list of GTN-L sites and then request that the WMO invite National Hydrological Services to continue, or where necessary initiate, monitoring of these priority lakes and provide data to the International Data Centre. As satellite altimeter measurements can provide additional data, particularly in more remote areas, those Parties with space observing capacities will be asked to contribute to monitoring the 150 initial GTN-L lakes and provide the measurements to the designated International Data Centre.

Action T6 (TF2)

Action: Submit weekly/monthly lake level/area data for the 150 GTN-L lakes to the International Data Centre; submission of weekly/monthly altimeter-derived lake levels by Space Agencies to the International Data Centre.
Who: National Hydrological Services, through WMO CHy; Space Agencies; the new global lake information data centre.
Time-Frame: Continuous.
Performance Indicator: Completeness of database: National Communications to UNFCCC.
Cost Implications: Category II.

Phase 3. The existence of measurement time series for the 19th and 20th centuries would considerably enhance the value of ongoing monitoring by allowing baseline measurements to be

[47] This includes the Mullard Space Science Laboratory (UK), the State Hydrological Institute of St. Petersburg (Russian Federation), the International Lake Environment Committee (Japan), and the new GLCN facility at FAO, in conjunction with the GTOS Secretariat.

extended to cover most of the post-industrial period. There are only isolated measurements for the period prior to the 19th century, and it is therefore not appropriate to place any priority in obtaining earlier measurements.

TOPC, working with other interested parties including WMO CHy, will request that WMO invite National Hydrological Services to retrieve archival data for the 150 GTN-L lakes and provide the data to the designated International Data Centre.

Action T7 (TF2)

Action: Submit weekly/monthly lake level and area data measured during the19th and 20th centuries for the 150 GTN-L lakes to International Data Centre.
Who: National Hydrological Services, in cooperation with WMO CHy and the new global lake information data centre.
Time-Frame: Completion of archive by 2009.
Performance Indicator: Completeness of database, National Communications to UNFCCC.
Cost Implications: Category I.

There are a number of other lake-specific variables that are needed by the climate modelling community (e.g., surface water temperature) or for climate monitoring purposes (e.g., surface and sub-surface water temperature, timing of freezing, timing of break-up). In any case possible, these variables should be measured by National Hydrological Services in association with measurements of lake level/area. TOPC will request that the WMO invite National Hydrological Services to monitor lake surface temperature and freeze/break-up dates of the 150 GTN-L lakes, based on both *in situ* or satellite measurements as appropriate, and report these measurements to the designated International Data Centre.

Action T8 (TF2)

Action: Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of 150 priority lakes in GTN-L.
Who: National Hydrological Services; Space Agencies in response to request from TOPC through the WMO.
Time-frame: Continuous.
Performance Indicator: Completeness of database, reporting to UNFCCC.
Cost Implications: Category I.

Phase 4. The initial target of 150 GTN-L lakes worldwide will be of immediate benefit to climate modellers. However, it will be important in the future to extend monitoring to as many of the further estimated 500 larger lakes as possible to ensure adequate regional coverage and sufficient sites to ensure that the derived records can be replicated.

ECVs – Ground Water and Water Use

(a) Ground Water
An appreciable amount – at least 20% – of the world's total freshwater (i.e., including snow/ice) is estimated to be stored as ground water. The TOPC recognizes that ground-water discharge and recharge are critical aspects of climate change. From a practical perspective, progress on adequately monitoring ground water is not likely to occur within a 10-year time horizon, though the research efforts of the Integrated Global Water Cycle Observations (IGWCO) theme and UNESCO's International Hydrological Programme for a ground-water inventory may in the longer term lead to more reliable monitoring of this previously expected ECV. These research themes require further development.

National Hydrological Services, in cooperation with WMO CHy are encouraged to continue and expand where possible the existing programmes of ground-water and aquifer monitoring, including expansion of the International Groundwater Resources Assessment Centre.

(b) Water Use
The availability of freshwater plays a crucial role in food production and food security. Irrigated land covers about 20% of the cropland, but contributes about 40% of total food production. Irrigated

agriculture accounts for about 70% of all freshwater consumption worldwide and more than 80% in developing countries. Future food needs will require intensified production including increased irrigation of agricultural crops that is expected to raise water consumption from present 2128 km^3 to 2420 km^3 annually by 2030, and hence will become more sensitive to climate change. Thus, in order to obtain improved quantitative and qualitative information on irrigated land and available water resources, data on their spatial distribution and change over time are essential.

Changes in the area of irrigated land and the amount of water used for irrigation do not, by themselves, provide a way of monitoring climate change or of vulnerability to climate change. However, information on these two variables is necessary in order to be able to diagnose how far changes in other terrestrial ECVs (e.g., land cover, melting of glaciers, river discharge, lake level/area) are caused by climate changes as distinct from land-use and water-use changes.

The FAO will define requirements for information on irrigation water use by international, regional, national and local communities and has plans to archive and disseminate information related to irrigation water use through its on-line AQUASTAT database.

Currently, the only spatially-referenced global information on the area of irrigated land is the map prepared by the University of Kassel, Germany, in collaboration with FAO. This raster map has a 5' resolution (about 5km at the Equator) but is compiled from different sources of variable information content Higher-resolution mapping could be achieved using satellite data, e.g., NASA Moderate Resolution Imaging Spectroradiometer (MODIS) and ESA Medium Resolution Imaging Spectrometer (MERIS), which could be exploited to produce maps at a 250 – 300m resolution. Whereas satellite data analysis is fairly simple for semi-arid/arid areas, more complex analysis of seasonal data sets is needed to identify irrigated areas for temperate and tropical zones. The main priority at this time is production of gridded global data sets of irrigated area at 250m resolution on a decadal basis. Attention should be paid to this in future land-cover databases (see ECV Land Cover).

However, the *in situ* information required to complement the satellite data, e.g., on the source of irrigation water (surface, lake, river, ground water, local, extra-local), type of irrigation (surface, sprinkler, micro-irrigation), the timing and frequency of irrigation, and the volume of irrigation water used is unlikely to be available in the next 10 years. There are, however, a number of research projects that can be proposed that will support the eventual integration of satellite and *in situ* measurements such as improvements in the land-cover characterization.

Action T9 (TF2)

Action: Archive and disseminate information related to irrigation and water resources through FAO's on-line AQUASTAT database and other means.
Who: FAO.
Time-Frame: By 2010.
Performance Indicator: Availability of AQUASTAT database.
Cost Implications: Category II.

ECV – Snow Cover

Snowfall and snow cover play a key role with respect to feedback mechanisms within the climate system (albedo, runoff, soil moisture and vegetation) and are important variables in monitoring climate change. About one third of the Earth's land surface is seasonally snow-covered and seasonal snow melt is a key factor in runoff regimes in middle and high latitudes. Snow thickness and snow-cover duration affect the permafrost thermal state, the depth and timing of seasonal soil freeze/break-up, and melt on land ice and sea ice.

Many problems arise because: (a) snow-cover data are collected, even within one country, by several agencies with differing goals; (b) funding support for snow research is fragmentary and not well coordinated; (c) the cost of surface networks is leading to their contraction, or automated measurement using different instrumentation whose compatibility is not yet determined and (d) many existing data are not readily accessible.

Station networks are generally contracting – especially in the Russian Federation – and more generally, automation is changing the nature of snow-depth measurements (e.g., across Canada). An associated problem is the contraction in snowfall measurements – increasingly automated precipitation gauge measurements do not discriminate between liquid and solid precipitation. Research concerning monitoring of precipitation at high latitudes is addressed in Section 4. Accessible documentation is needed on where and when these changes have occurred. National Meteorological and Hydrological Services need to document the contraction of *in situ* observation networks and ensure that adequate coverage of representative measurements are maintained to meet GCOS requirements.

Action T10 (TF2)

Action: Strengthen and maintain existing snow-cover, snowfall observing sites and recover historical data.
Who: National Meteorological and Hydrological Services and research agencies, in cooperation with WMO CHy, WMO CBS and WCRP, with oversight by TOPC and AOPC.
Time-Frame: Continuing.
Performance Indicator: Data submission to national centres such as the National Snow and Ice Data Center (USA).
Cost Implications: Category II.

To assist in providing global coverage of snow extent and snow water equivalent, optimal procedures to generate blended products of surface observations of snow cover with visible and microwave satellite data and related airborne measurements need to be agreed and implemented by national services and research groups involved in snow mapping. The Climate and Cryosphere Project (CliC) of the WCRP should take the lead in organizing this with GEWEX and other involved working groups.

Snow-cover extent is mapped daily by operational satellites, but sensor channels change and continuing research and surface observations are needed to calibrate and verify algorithms and satellite products for snow depth and snow water equivalent. The National Environmental Satellite Data and Information Service (NESDIS) of NOAA began producing daily Northern Hemisphere snow extent maps in May 1999, with weekly maps available since 1966. Comparable Southern Hemisphere data are not generated, but are needed. Agencies currently generating Northern Hemisphere snow-cover products (particularly NASA groups and NOAA/NESDIS) should also routinely generate and archive Southern Hemisphere products. TOPC in cooperation with the AOPC should approach the Space Agencies through CGMS, CEOS, and the WMO Space Programme to seek commitment to provide snow-cover products for both hemispheres.

Action T11 (TF2)

Action: Obtain integrated analyses of snow cover over both hemispheres.
Who: Space Agencies through CliC and IGOS–P Cryosphere, with advice from TOPC and AOPC.
Time-Frame: Continuous.
Performance Indicator: Availability of snow-cover products for both hemispheres.
Cost Implications: Category III.

The Canadian Meteorological Centre has produced global daily snow-depth analyses, and daily snow-depth data from the WMO WWW/GOS Synoptic Reports are available through NCDC. In addition, snow water equivalent is observed in many countries by national, state, provincial and private networks on a 10-30 day basis. However, no central archive of snow information exists and many national databases are not readily accessible. Finally, no standard global snow water equivalent (SWE) product exists.

An experimental mission to measure hydrological properties of the cryosphere is being proposed in 2004 to NASA's Earth System Science Pathfinder programme for a Cold Land Processes Pathfinder for snow water equivalent measurements in mountain regions using dual-frequency SAR.

Maintenance of adequate, representative surface networks of snow observations must begin with documentation and analysis of required network densities in different environments. Resolution of the problem of data inaccessibility requires: promoting political commitment to data sharing; removing practical barriers by enhancing electronic inter-connectivity and meta-data; and data rescue and digitization. The provision of necessary resources to improve and make available existing archives of snow data will require national efforts. Development of snow products that blend multiple data sources and are globally applicable needs urgent focused attention. The research community through WCRP-CliC could help lead such an effort. The TOPC in consultation with the AOPC, WCRP-CliC and WMO CBS will establish standards and protocols, design an optimum network, and recommend International Data Centre and analysis centre responsibilities. TOPC's current cryosphere activities can provide a starting point, but the required activity would require dedicated funding for meetings/workshops to agree on standards and protocols, funding for report preparation, and funding for filling gaps in networks.

Action T12 (TF3)

Action: For snow cover and snow water equivalent, establish standards and protocols, design an optimum procedure and designate International Data Centre responsibilities.
Who: TOPC/AOPC, with WCRP, WMO and IGOS-P Cryosphere.
Time-Frame: Planning complete by 2007.
Performance Indicator: The completed SWE network and a functioning inclusion of remote sensing measurements will be the main indication of successful implementation.
Cost Implications: Category I.

ECV – Glaciers and Ice Caps

(a) Glaciers

Changes in mountain glaciers and ice caps provide some of the clearest evidence of climate change, constitute key variables for early-detection strategies in global climate-related observations and cause serious impacts on the terrestrial water cycle and societies dependent on glacial melt water. The Global Terrestrial Network for Glaciers (GTN-G), based on century-long worldwide observations, has developed an integrated, multi-level strategy for global observations. Extensive glacier mass balance and flow studies within major climatic zones form the basis for improved process understanding and calibration of numerical models.

GTN-G is overseen and maintained by the World Glacier Monitoring Service (WGMS) of the International Commission on Snow and Ice, the Federation of Astronomical and Geophysical Data Analysis Services (FAGS), ICSU, UNESCO and UNEP on behalf of GCOS. The WGMS is in charge of collecting and disseminating standardized data worldwide through a network of national correspondents and principal investigators.

Measurements of glacier and ice cap area and mass balance must be made by national services, governmental and research groups to determine regional volume changes using cost-saving methodologies (index stakes, laser altimetry, repeated mapping, long-term observations of glacier length). It is important that there are sufficient reference sites within each region selected with respect to climate and size/dynamics of ice body. GTN-G, together with national correspondents, must identify these reference sites. Mass balance measurements of glaciers and ice caps need to be re-initiated in equatorial Africa, Patagonia and New Zealand so that patterns of glacier changes can be monitored globally. Data should be provided to the International Data Centre. The GTN-G gaps should be communicated to IGOS-P Cryosphere as a means of engaging Earth observations for completing glacier inventories.

Glacier inventories (area and topography for flow direction) using satellite remote sensing with special application of digital terrain information in Geographic Information Systems for automated procedures of image analysis, data processing and modelling/interpretation are needed at time intervals of 10 years in areas of rapid change and/or strong impact, at horizontal resolutions of 10m to 20m. The 10-year inventory will be performed by a network of experts in different regions working in close cooperation with those Space Agencies operating high-resolution sensors with stereographic image acquisition capabilities. The GTN-G will coordinate the production of the next 10-year inventory.

Continental-scale transects of observations exist in the American Cordilleras (N-S), in Africa-Pyrenees-Alps-Scandinavia-Svalbard (N-S) and through central Eurasia (E-W). GTN-G, through contact with institutions making measurements in the Southern Hemisphere (especially Patagonia and New Zealand), will start to implement a web-based data management and data dissemination system of existing historical records and archived high-resolution satellite data. Complementary mass balance measurements also need to be re-initiated in these regions.

Close cooperation with the Global Land Ice Measurements from Space (GLIMS) project based at the US Geological Survey (USGS) and the NSIDC helps provide systematic satellite observations from ASTER and NASA Landsat and the introduction of advanced/automated image analysis techniques. National and international efforts have assured the continuation of these fundamentally important activities for reaching coverage of a significant fraction of the most important glacier-covered regions globally over the next 3-5 years.

Action T13 (TF4)

Action: Maintain current glacier observing sites and add additional sites and infrastructure in South America, Africa, the Himalayas and New Zealand; ensure continued functioning of WGMS. **Who:** Parties' national services and agencies coordinated by GTN-G, WGMS, USGS and IGOS-P Cryosphere. **Time-Frame:** Continuing, new sites by 2009. **Performance Indicator:** Completeness of database held at WGMS. **Cost Implications:** Category III.

(b) Ice Caps

The Greenland and Antarctic ice sheets hold the major part of the world's freshwater and almost 70m of sea-level equivalent. Iceberg calving, especially from ice shelves, and ice sheet basal and marginal melt contribute large quantities of freshwater to the world's oceans. This freshwater addition to the oceans affects the salinity and density of the upper ocean and thus is a major contributor to ocean deep-water formation and the global thermohaline circulation. Ice sheet geometry and mass balance need to be monitored. The former involves airborne or satellite altimetry, and the latter *in situ* measurements.

Digital elevation maps of the ice surface with 5km resolution based on ERS-1 and Geosat for Greenland and Antarctica are available. For Antarctica, there are also 200m, 400m and 1km resolution maps from the Radarsat Antarctic Mapping Project. Satellite and airborne remote sensing data, Automatic Weather Station meteorological data, snow pits and shallow cores from the Program for Arctic Regional Climate Assessment exist for Greenland. Snow melt extent on the ice sheet has been mapped from passive microwave data, continuously from 1979-present. All these data are held by the NSIDC.

The recently-launched Gravity Recovery and Climate Experiment satellite (combined with ICESat data) will enable mass balance estimates for Antarctica equivalent to a sea-level change of 0.2 mm/yr. The International Trans-Antarctic Scientific Expedition is collecting shallow cores along transects across Antarctica to study the climate of the last 200 years. However, the satellite missions and the field programmes are one-time research projects without plans for repeat surveys at this time. The ICESat research satellite mission and the forthcoming CryoSat will provide the initial data set of the polar ice sheets. However, long-term monitoring of ice sheets using the same sensor types is essential for change detection and cannot be resolved with a 3-year mission. GCOS, TOPC and WCRP/CliC will draw the attention of the Space Agencies to the requirement for continuity of ice sheet monitoring missions, and the archival and dissemination of the data products, as for ICESat, at the appropriate fora. The satellite and airborne surface elevation and ice velocity data need to be supported by field campaigns to measure changes occurring below floating ice tongues and within the ice sheets. The IPCC recognizes that land ice contributions to sea-level rise are of increasing international concern in the 21st century.

Action T14 (TF5)

Action: Ensure continuity of current spaceborne cryosphere missions. **Who:** Space agencies, in cooperation with IGOS-P Cryosphere. **Time-Frame:** New sensors to be launched following demise of ICESat and CryoSat in next 3-5 years. **Performance Indicator:** Appropriate follow-on missions agreed. **Cost Implications**: Category IV.

ECV – Permafrost and seasonally-frozen ground

Decadal changes in permafrost temperatures and depth of seasonal freezing/thawing are reliable indicators of climate change in high latitude and mountain regions. Warming may result in a reduction in the extent of permafrost and can have an impact on terrain stability (e.g., thaw settlement and slope instability) and moisture and gas fluxes. Like glaciers, mountain permafrost and seasonally-frozen ground can also provide a significant contribution to summer water availability. Standardized *in situ* measurements are essential, both to calibrate and to verify regional and global climate models.

The Global Terrestrial Network for Permafrost (GTN-P), coordinated by the International Permafrost Association (IPA) forms a GCOS baseline network for these variables. The Geological Survey of Canada (Ottawa) maintains borehole meta-data files and coordinates thermal data management and dissemination. Every five years, the NSIDC prepares and distributes a Circumpolar Active Layer Permafrost System compact disc containing information and data acquired in the previous 5 years.

GTN-P currently involves 16 participating countries, with 125 active sites in the Circumpolar Active Layer Monitoring (CALM) network and 287 identified boreholes for monitoring permafrost thermal state, though some of these need to reactivate their measurement campaigns. GTN-P has also identified sites for approximately 150 new borehole and active layer sites needed to obtain representative coverage in the Europe/Nordic region, Russian Federation and Central Asia (Mongolia, Kazakhstan, China), in the Southern Hemisphere (South America, Antarctica), and in the North American mountain ranges and lowlands. A measurement campaign of all boreholes is planned by IPA during the International Polar Year (IPY, 2007-2008). This will establish a baseline network of Thermal State of Permafrost and should leave a legacy for sustained observations post-IPY.

Presently, GTN-P *in situ* data acquisition operates on a largely voluntary basis, through individual national and regionally-sponsored programmes. Regional projects support local networks and observatories such as the US Geological Survey Alaskan deep borehole network and the US National Science Foundation-supported CALM sites, Canadian transects, and Permafrost and Climate in Europe activities, GEF in Mongolia, among others. Measurement and reporting standards are emerging through the coordination of the IPA, but further work is needed to prepare and publish definitive reporting standards; the IPA through its working groups presently addresses these issues.

Action T15 (TF5)

Action: Define, publish and apply international observing standards and practices for borehole measurements.
Who: GTN-P and International Permafrost Association.
Time-Frame: Complete by 2005.
Performance Indicator: Published guidelines.
Cost Implications: Category I.

Action T16 (TF5)

Action: Maintain the current 125 CALM boreholes, ensure that all the other 287 sites in the GTN-P are active and reporting; add 150 additional sites as identified by GTN-P in the high mountains of Asia, Europe, Southern Hemisphere and North American alpine and lowlands, ensure that all use standards as defined by the IPA and provide data to the NSIDC.
Who: Parties' national services/research institutions, with coordination through GTN-P and International Permafrost Association, data holding by Geological Survey of Canada and NSIDC. IGOS-P cryosphere to ensure continuity and associated Earth observation derived variables.
Time-Frame: Continuing. Addition of new sites during the IPY by 2008 with subsequent follow-on.
Performance Indicator: Completeness of database. Initiation of new sites.
Cost Implications: Category III.

GTN-P is also involved in identifying additional borehole sites to monitor seasonally-frozen ground at locations without permafrost. This will require similar coordination and measurement funding to the permafrost sites.

Action T17 (TF5)

Action: Implement operational mapping of seasonal soil freeze / thaw. **Who:** Parties' national services, with guidance from GTN-P and International Permafrost Association with IGOS-P Cryosphere. **Time-Frame:** Complete by 2016. **Performance Indicator**: Published guidelines. **Cost Implications:** Category I.

ECV – Albedo

Surface albedo is both a forcing variable controlling the climate and a sensitive indicator of environmental degradation. Albedo varies in space and time as a result of both natural processes (e.g., changes in solar position, snowfall and vegetation growth) and human activities (e.g., clearing and planting forests, sewing and harvesting crops, burning rangeland, etc.).

Some nationally-driven networks making *in situ* albedo observations exist, but coordinated global networks are missing. Daily-average surface albedo values have been derived experimentally from a single geostationary satellite, but could be obtained from all the current geostationary platforms to give near-global coverage. The CGMS is promoting such an activity. Archived data from these instruments could also be used to document the evolution of albedo during the last two decades. Mono-angular multispectral sensors on polar-orbiting platforms usefully complement this potential monitoring system by providing better coverage of polar regions (especially important during summer). The accuracy of the estimates needs to be assessed, as they often rely on the accumulation of data over 2 weeks or more, during which atmospheric conditions may vary considerably. The technical definition of albedo requires gridded measurements of the directional hemispherical reflectance factor, bi-hemispherical reflectance factor, fraction of direct radiation and fraction of diffuse radiation. These variables need to be generated from the data holdings at the Space Agencies at spatial scales of 1-3 km on a daily basis. These should be generated from current, future and archived satellite observations. Some research groups running land surface process models have already begun to assimilate these new satellite derived albedo products into their schemes and have noted improvements in the models' performance, but not all land surface process schemes have tried this, and not all may benefit from all satellite derived products. Thus, in addition to product generation, benchmarking and validation action should also be taken to ensure that the climate modelling community are able to access the most appropriate albedo product for each model.

Three actions are proposed: firstly, through the coordination of the CGMS, a global directional hemispherical reflectance factor (or black sky albedo) product should be generated. Testing of prototype algorithms will be performed by EUMETSAT, and then applied by the other CGMS members. Secondly, the CEOS/WGCV will coordinate an international benchmarking activity comparing the global black sky albedo with other currently available albedo products. Thirdly, CEOS/WGCV will interact with the GEWEX Project for Intercomparison of Land-surface Parameterization Schemes to ensure that the climate modelling community are able to access the most appropriate albedo product for each model.

Action T18 (TF7)

Action: Test prototype algorithms to retrieve the directional hemispherical reflectance factor (or black sky albedo) from geostationary satellites on a daily and global basis. **Who:** Space Agencies, especially EUMETSAT, in cooperation with the algorithm developers and the CEOS WGCV. **Time-Frame:** Complete algorithm testing by 2005. **Performance Indicator:** Availability of full suite of algorithms and associated processing chains that apply these algorithms. **Cost Implications:** Category II.

Action T19 (TF6)

Action: Obtain *in situ* calibration/validation measurements and collocated albedo products from all Space Agencies generating such products. **Who:** Space Agencies in cooperation with CEOS/WGCV. **Time-Frame:** Full benchmarking/intercomparison by 2007. **Performance Indicator:** Publication of inter-comparison/validation reports. **Cost Implications**: Category II.

Action T20 (TF6)

Action: Identify the most appropriate satellite derived albedo for specific climate models. **Who:** CEOS WGCV, in cooperation with GEWEX and the Project for Intercomparison of Land-surface Parameterization Schemes. **Time-Frame**: Testing by 2007/8. **Performance Indicator:** Data available to analysis centres. **Cost Implications:** Category I.

Action T21 (TF7)

Action: Implement globally coordinated and linked data processing to retrieve the directional hemispherical reflectance factor (or black sky albedo) from geostationary satellites on a daily and global basis from archived (and current) satellite data. **Who:** Space Agencies, through the CGMS and WMO Space Programme. **Time-Frame:** Back-process archived data by 2009, then continuous. **Performance Indicator:** Completeness of archive. **Cost Implications:** Category III.

ECV – Land Cover

Land cover and the change of land cover affect the services provided to human society (e.g., provision of food, fibre, recreational opportunities, etc.), force climate by modifying water and energy exchanges with the atmosphere, and change greenhouse gas and aerosol sources and sinks. Land-cover distribution is partly determined by regional climate, so changes in cover may indicate climate change.

Although land-cover change can be observed using data from Earth observing satellites, currently available data sets vary in nature, are of uncertain accuracy and use different land-cover type characterization systems. Data of similar nature are provided from different sources and at different spatial resolutions. There are currently no viable plans to establish operational satellite systems capable of providing the long-term records needed for observations of changing land cover. It is necessary, and feasible with present-day technology, to provide satellite-based optical systems at 10-30m resolution with temporal, spectral and data-acquisition characteristics that are consistent with previous systems. Commitment to fly such systems though has not yet been secured from Space Agencies.

Data sets characterizing global land cover are currently produced at resolutions of between 250m and 1km by several Space Agencies in close cooperation with the research community (especially those research groups participating in the GTOS technical panel Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD)). The lack of compatibility between these products makes it difficult to measure and monitor climate-induced or anthropogenic changes in land cover. A range of approaches is adopted, e.g., centralized processing using a single method of image classification (e.g., MODLAND), or a distributed approach using a network of experts applying regionally specific methods (e.g., GLC2000). Using a single source of satellite imagery and a uniform classification algorithm has benefits in terms of consistency, but may not yield optimum results for all regions and all land-cover types. Automated land-cover characterization and land-cover change monitoring thus remains a research priority.

It is necessary that land-cover classification systems and therefore map legends adhere to internationally-agreed standards. In the long-term, such standards should be agreed upon by the appropriate intergovernmental organization (see Action T1). In the near term, however, full benefit should be taken of existing initiatives, e.g., the FAO's Land Cover Classification System for legend harmonization and translation and the legends published by the IGBP and the GTOS GOFC-GOLD. As a minimum, new land-cover maps should be produced annually, documenting the spatial distribution of land-cover characteristics with attributes suitable for climate, carbon and ecosystem models, and using a common language for class definitions (e.g., include wetland information describing forest peat lands (boreal), mangroves, sedge grasslands, rush grasslands and seasonally-flooded forests, and area of land under irrigation), at 250m-1km resolution.

In addition to their use in Earth system models, these global products will help identify areas of rapid change, although the development of automated detection of changes in land-cover characteristics remains high on the research agenda. The production of such land-cover data sets will involve Space Agencies for processing the satellite data used in the database production, the FAO/science panels to ensure legend relevance and standards and the research community for optimizing image classification approaches. Mechanisms to fund such partnerships are emerging (e.g., the EU global monitoring for environment and security initiative) but not yet guaranteed on a sustained basis.

Global land-cover databases must also be accompanied by a description of by-class thematic/spatial accuracy. The CEOS/WGCV, working with GOFC-GOLD and GLCN is establishing agreed validation protocols, which should be used. The current protocols base accuracy assessment on a sample of high-resolution (1-30m) satellite imagery, itself validated by *in situ* observations wherever possible. To better quantify changes in land-cover characteristics, these high-resolution data should also be used for wall-to-wall global mapping at resolutions of 10-30m. Maps at this resolution are needed every 5 years over long time periods (several decades). Global data sets of satellite imagery at 30m resolution have been assembled for selected years (e.g., 1990 and 2000) and some regional land-cover maps have been generated from these. The technologies have been developed and tested (e.g., Landsat and the Satellite Probatoire d'Observation de la Terre High Resolution (SPOT HRV)), suitable methods for land-cover characterization on these scales exist, but institutional arrangements to ensure operational generation of land cover at these resolutions are not yet in place. Space agencies should thus assure that suitable optical sensors with 10-30m resolution are available for operational monitoring using the same data acquisition strategies as those systems in current operation.

Samples of high-resolution satellite imagery have also been used to estimate change and are proposed for example by the FAO's Global Land Cover Network. Initiatives such as these will provide much needed capacity-building and offer a framework for acquisition of *in situ* observations to support the satellite image-based monitoring. Such *in situ* networks will also provide information on how land is being used (as opposed to what is covering it). Land use cannot always be inferred from cover.

Action T22 (TF1)

Action: Establish international standards and specifications for the production of land-cover characterization maps.
Who: FAO, UNEP, GLCN and ISO (TC-211) in collaboration with GOFC-GOLD.
Time-Frame: Standards and specifications by 2005. Operation continuing.
Performance Indicator: Publication of standards.
Cost Implications: Category I.

Action T23 (TF8, TF9, TF10)

Action: Produce reliable accepted methods for land-cover map accuracy assessment.
Who: CEOS WGCV, in collaboration with GOFC-GOLD and GLCN.
Time-Frame: By 2005 then continuously.
Performance Indicator: Protocol availability.
Cost Implications: Category I.

Action T24 (TF8, TF9, TF10)

Action: Commit to continuous 10-30m resolution optical satellite systems with data acquisition strategies at least equivalent to the Landsat 7 mission for land cover.
Who: Space Agencies.
Time-Frame: Continuing.
Performance Indicator: Operational plans, data availability.
Cost Implications: Category IV.

Action T25 (TF8, TF9, TF10)

> **Action:** Develop an *in situ* reference network and apply CEOS WGCV validation protocols for land cover.
> **Who:** Parties' national services, research institutes and Space Agencies, in cooperation with GOFC-GOLD, CEOS/WGCV, FAO GLCN and the GTOS web-based data system TEMS.
> **Time-Frame:** Network established by 2009.
> **Performance Indicator:** Availability of validation statistics.
> **Cost Implications:** Category III.

Action T26 (TF8, TF9, TF10)

> **Action**: Generate annual products documenting global land-cover characteristics at resolutions between 250m and 1km, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.
> **Who:** Parties' national services, research institutes and Space Agencies through GLCN in collaboration with GOFC-GOLD research partners, and the IGOS land theme (IGOL).
> **Time-Frame:** By 2005, then continuously.
> **Performance Indicator:** Data set availability
> **Cost Implications:** Category III.

Action T27 (TF8, TF9, TF10)

> **Action:** Generate maps documenting global land cover at resolutions between 10m and 30m every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.
> **Who:** Space Agencies, in cooperation with GCOS, GTOS, GLCN and other members of CEOS.
> **Time-Frame:** First by 2005, then continuously.
> **Performance Indicator:** Availability of operational plans, funding mechanisms and eventually maps.
> **Cost Implications**: Category III.

ECV – Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)

fAPAR measures photosynthetic activity, and indicates the presence and productivity of vegetation. Spatially-detailed descriptions of fAPAR provide information about the strength and location of terrestrial carbon sinks, and can be of value in verifying the effectiveness of the Kyoto Protocol's flexible-implementation mechanisms. fAPAR is not directly measurable, but is inferred from models describing the transfer of solar radiation in plant canopies, using remote sensing observations as constraints. Generation of global fAPAR using NASA and ESA satellite measurements has recently commenced on a regular basis, but has been funded under research budgets, as are archiving and distribution. Daily recovery of fAPAR is possible in principle, but cloud and haze normally lead to fAPAR values that are multi-day "averages". GTOS and GCOS will encourage the Space Agencies and other entities to continue to generate and disseminate weekly to 10-day global fAPAR products at 250m-1km resolution. To detect trends in the presence of interannual variability requires long time series; hence the full existing archive of satellite data for which consistent correction for the atmosphere is possible (i.e., those having at least the blue channel in their spectral coverage) should be processed. fAPAR can be recovered from a range of sensors by various algorithms. The CEOS WGCV should lead benchmarking and comparison of these fAPAR products and the algorithms used to generate them. Reference sites making *in situ* observations should form part of this process. WGCV is identifying a core set of sites and measurement campaigns, which should be supported by the CEOS agencies and by national research budgets.

Action T28 (TF11)

> **Action:** Make fAPAR and LAI products available as gridded products at 250m to 1km resolution.
> **Who:** Space Agencies, coordinated through CEOS WGCV, with advice from GCOS/GTOS.
> **Time-Frame:** 2005.
> **Performance Indicator:** Agreement on operational product.
> **Cost Implications:** Category III.

Action T29 (TF12)

Action: Establish a calibration/validation network of *in situ* observing sites for fAPAR and LAI (reference sites). **Who:** Parties' national and regional research centres, in cooperation with Space Agencies coordinated by CEOS WGCV, GCOS and GTOS. **Time-Fame:** Network operational by 2006. **Performance Indicator:** Data available to analysis centres. **Cost Implications**: Category III.

ECV – Leaf Area Index

LAI measures the amount of leaf material in an ecosystem, which imposes important controls on processes, such as photosynthesis, respiration and rain interception, that couple vegetation to climate. Hence, LAI appears as a key variable in many models describing vegetation-atmosphere interactions, particularly with respect to the carbon and water cycles.

LAI can be estimated by *in situ* measurements using commercially available LAI meters. Around 20 sites have been established as part of the LAInet programme sponsored by NASA, and this is complemented by the BIGFOOT programme and LAI measurements at some Flux and Energy Exchange Network (FLUXNET) sites. CEOS WGCV is playing a coordinating role in this work. Benchmarking and consistency checking are required for the global archive of LAI measurements.

For reasons set out below, in some parts of the globe (e.g., the humid tropics) LAI can only be measured by *in situ* methods. However, the measurement network is sparse. The development and maintenance of reference sites to address this inadequacy should be addressed. Building on existing networks such as FLUXNET, LAInet and BIGFOOT should be seen as a possible way to improve this situation (see Action T3). The CEOS WGCV has begun to coordinate this through the creation of a centralized database, an activity that should continue.

The retrieval of reliable LAI estimates from space is still difficult: when the canopy cover is sparse, reflectance measurements are dominated by soil properties and the accuracy of the LAI is low; for LAI values exceeding 3 or 4, the measurements saturate. Also, since the LAI measured by satellites is inferred from reflectance, it is tightly coupled to fAPAR. Nonetheless, regular global LAI estimates from space are currently being produced and should be continued (this requires little extra resource above that required to produce fAPAR). These have the same spatial resolutions (250m-1km) and temporal frequencies (7 to 10 days) as the fAPAR products.

Benchmarking and comparison of these LAI products is essential. The CEOS WGCV should lead this activity, exploiting *in situ* observations from designated reference sites, and building on the validation activities currently being undertaken by the Space Agencies and associated research programmes.

Action T30 (TF11)

Action: Evaluate the various LAI satellite products and benchmark against ground truth to arrive at an agreed operational product. **Who:** Parties' national and regional research centres, in cooperation with Space Agencies and CEOS WGCV and TOPC. **Time-Frame:** Benchmark by 2006/7. **Performance Indicator**: Agreement on operational product. **Cost Implications:** Category II.

ECV – Biomass

Biomass plays two major roles in the climate system: (i) photosynthesis withdraws CO_2 from the atmosphere and stores it as biomass; (ii) the quantity of biomass consumed by fire affects CO_2, other trace gases and aerosol emissions. Only above-ground biomass is measurable with some accuracy at the broad scale, while below-ground biomass stores a very large part of total carbon stocks and is rarely measured. Most nations have schemes to estimate woody biomass through forest inventories (little is recorded on non-forest biomass, except through agricultural yield statistics); this typically forms the basis for the annual reporting on forest resources required by the UNFCCC. Experimental airborne sensors have demonstrated technologies for estimating biomass (low-frequency radar, lidar), and are suitable for satellite implementation that could provide global above-ground biomass information at sub-kilometric resolutions. There are limitations to these technologies, some known (for example, saturation of radar backscatter at higher levels of biomass), some still the subject of research.

National inventories differ greatly in definitions, standards and quality, and the detailed information available at national level is normally unavailable internationally. Nonetheless, these form the basis of the country-by-country summary statistics, published by the FAO in their FRAs. Some regional harmonization efforts, such the European Forest Inventory, lead to improved input. Nevertheless, biases and uncertainties in these summary values are not quantified. The only available global gridded biomass data set is that from the World Resources Institute, based on existing databases supplemented by satellite observations. The accuracy, resolution and currency of this data set are unknown.

Although a unified standard for biomass inventories will be a long-term aim, the achievable medium-term aim, with marginal resource implication, is adequate reporting of the methods employed by countries, together with an accuracy assessment. This information should be included in the FAO FRAs and then be incorporated into the Forest Resource Information System.

Progress towards creating global gridded biomass data sets can be achieved by appropriately-designed satellite and aircraft missions, notably active microwave and laser systems. The Space Agencies should plan for such missions, supported by experimental programmes to reduce their risks.

Action T31 (TF11)

Action: Develop methodology for forest inventory information and begin acquisition of data.
Who: Parties and FAO.
Time-Frame: By 2009.
Performance Indicator: Availability of consistent statistical information.
Cost Implications: Category II.

ECV – Fire Disturbance

The emissions of greenhouse gases and aerosols from fires are important climate forcing factors; fires also have a large influence on the storage and flux of carbon in the biosphere and atmosphere and can cause long-term changes in land cover. Fire is a prominent disturbance factor in most vegetation zones throughout the world. In many ecosystems, fire is a natural, essential, and ecologically significant force, modifying physical and biological attributes, shaping landscape diversity, and influencing energy flows and biogeochemical cycles, particularly the global carbon cycle. In some ecosystems, however, fire is a less common process that severely damages vegetation and can lead to long-term degradation. Such ecosystems, particularly in the tropics and the boreal zone, are becoming increasingly vulnerable to fire due to growing population, economic and land-use pressures, and such shifts could also be a strong indicator of changing climate.

The use of fire as a land-management tool is embedded in the culture and traditions of many societies, particularly in the developing world. Given the rapidly changing social, economic and environmental conditions occurring in developing countries, marked changes in fire regimes can be expected, with uncertain local, regional, and global consequences. Even in regions where fire is natural (e.g., the boreal zone), more frequent severe fire weather conditions have created recurrent major fire problems in recent years. The incidence of extreme wildfire events is also increasing elsewhere the world, with adverse impacts on economies, livelihoods, and human health and safety that are comparable to those associated with other natural disasters such as earthquakes, floods, droughts and volcanic eruptions. Despite the prominence of these events, current estimates of the extent and impact of vegetation fires globally are far from complete.

Several hundred million hectares of forest and other vegetation types, including organic layers of periodically dry peat-lands, are estimated to burn annually throughout the world, consuming several billion tons of dry matter and releasing gaseous compounds and aerosol that affect the composition and functioning of the global atmosphere and human health. However, the vast majority of these fires are not monitored or documented. Informed policy- and decision-making clearly requires timely quantification of fire activity and its impacts nationally, regionally and globally. Such information is currently largely unavailable. Some Space Agencies, working with the research community, have been generating regional and global fire disturbance products (burnt area and active fire). Spaceborne thermal and optical sensors have been used to determine the location of active fire events, the spatial extent of the burnt area and the location and size of smoke plumes and haze. Monthly measurements of global burnt area are required at a spatial resolution of 250m (minimum resolution of 1km). Active fires should be monitored daily from Low Earth Orbit polar orbiting satellites near the peak of the daily fire activity. Some geostationary satellites allow monitoring of active fires at a coarser resolution every 15 minutes. A global suite of fire products from the operational geostationary satellites needs to be developed.

These moderate-resolution products can complement detections from sensors on polar orbiting satellites, provide information and diurnal dynamics of fire activity and fill the gaps in coverage. The GTOS science panel GOFC-GOLD is establishing global fire observing network building on contributory projects. The Space Agencies should promote the integration of satellite-based fire products into gaseous compound and aerosol modelling systems.

Improved communication between the atmospheric modelling and remote sensing communities is needed to establish data coverage and quality requirements. The GCOS and GTOS science panels will facilitate this dialogue.

The various space-based products require validation, and inter-comparisons would confirm the suitability of these products. Validation of medium- and coarse-resolution fire products involves field observations and the use of high-resolution imagery, in strong collaboration with local fire management organizations and the research community. The CEOS WGCV, working with the GOFC-GOLD, is establishing internationally-agreed validation protocols, which should be applied to all data sets before their release.

The validation protocols include the establishment of accuracy measures that are useful for the specific target user community. Institutional arrangements between the fire data producer and user communities need to be made to improve communication and to facilitate the exchange of remote sensing and *in situ* validation data. TOPC will work with the CEOS WGCV and GOFC-GOLD to establish an International Data Centre of validation data for product development.

The Space Agencies should continue to generate, archive and distribute individual fire products, but a single International Data Centre should provide centralized identification of data holders. The Global Fire Monitoring Centre could, in the first instance, act as such a data centre.

Earth observation satellites have been providing measurements suitable for fire mapping from the early 1980's. A historical record (1982-2004) of fire activity and burnt area should be prepared by reprocessing these archived data. A comprehensive inventory of the historical records of satellite data needs to be compiled. An inter-comparison of fire products from different sensors, including sensors from different platforms and from the same satellite series, need to be carried out to minimize spatial and temporal discontinuities. Community consensus on regionally-applicable algorithms needs to be developed.

An important question is related to fire intensity and severity, which are important determining agents of the impact of fire on the ecosystem including post-fire development. There is a range of ecosystems where fires of low to medium intensity and severity are beneficial for ecosystem stability and productivity. High-severity fires coupled with other natural and anthropogenic disturbances will lead to destruction of vegetation cover and secondary disasters, resulting in loss of ecosystem stability, productivity and a net flux of carbon to the atmosphere and terrestrial deposits. A new suite of remote sensing-based fire intensity and severity products needs to be developed, taking advantage of the improved sensor characteristics on current research and experimental satellites.

The transition of experimental products to the operational domain needs to be facilitated. Data continuity to the new generation sensors on future operational environmental satellite series needs to be ensured.

Action T32 (TF14)

Action: Reanalyze the historical fire disturbance satellite data (1982 to present). **Who**: Space Agencies, working with research groups coordinated by GOFC-GOLD. **Time-Frame:** By 2010. **Performance Indicator:** Establishment of a consistent data set. **Cost Implications:** Category III.

Action T33 (TF14)

Action: Continue the generation of active fire and burnt area products. **Who:** Space Agencies, in collaboration with GOFC-GOLD. **Time-Frame:** Continuous. **Performance Indicator:** Availability of data. **Cost Implications:** Category III.

Action T34 (TF13, TF14)

Action: Apply CEOS WGCV and GOFC-GOLD validation protocol to fire disturbance data. **Who:** Space Agencies and research organizations. **Time-Frame:** By 2006. **Performance Indicator:** Publication of accuracy statistics. **Cost Implications:** Category II.

Action T35 (TF13)

Action: Make gridded fire and burnt area products available through a single International Data Centre. **Who:** United Nations-affiliated Global Fire Monitoring Center (GFMC), through GOFC-GOLD. **Time-Frame**: Continuous. **Performance Indicator:** Continued operation of the GFMC. **Cost Implications:** Category II.

6.3. Terrestrial Domain – Data Management

The internationally-designated data centres and archives that have been identified are shown in Table 18. For the *in situ* observation networks, adequate sustained funding of the centres and their operation is required. A major component of the Terrestrial Domain observing systems is satellite remote sensing and the production of integrated analysis products. The Space Agencies and associated research organizations producing the analyses also provide the data management and archiving function. TOPC will need to monitor the data management and archive performance of this informal network to ensure that data and products are available and follow the GCMPs.

Table 18. International Data Centres and Archives – Terrestrial Domain.

Network or System	International Data Centres and Archives	Coordinating Body
Global Terrestrial Network – Rivers (proposed)	GRDC	WMO CHy
Global Terrestrial Network – Lakes (proposed)	None designated	WMO CHy
Snow Cover (WWW/GOS synoptic network)	NCDC	
National and other meteorological/climatological networks	National and other archives	
Global Terrestrial Network for Glaciers; National Glacier Monitoring Networks	World Glacier Monitoring Service (WGMS); National and other archives	ICSU, FAGS

Global Terrestrial Network for Permafrost; National Permafrost Monitoring Networks	NSIDC; National archives	International Permafrost Association
Albedo reference benchmark network (proposed)	Space Agencies	CGMS
Global Land Cover Network	Space Agencies; FAO; Global Land Cover Facility	GOFC-GOLD, FAO, UNEP
Fire Disturbance	Global Fire Monitoring Center	UNEP
TEMS	TEMS, GOSIC, GCMD	FAO, NOAA
FRA	Forest Resource Information System	FAO

In addition to the data centres associated with each ECV, it would be beneficial to have a central clearing house identifying holders of all the variables. This would facilitate access to multiple variables. GTOS has made considerable progress in the development of the Terrestrial Ecosystem Monitoring System (TEMS), a web-based international directory and networking tool for the input and web publication of variables and site information for terrestrial *in situ* measurements important to regional and global change. This system and network could be utilized as the central clearing house for the terrestrial ECVs.

Action T36 (CF6)

Action: Expand TEMS to support the meta-data collection, collation and publication needs of the terrestrial ECVs and associated data centres.
Who: Parties' national services and research programmes contributing to TEMS, in cooperation with GTOS, GOSIC, and GCMD, and in consultation with the GCOS Secretariat.
Time-Frame: By 2006.
Performance Indicator: Number of stations and nations submitting data to TEMS, Communication to UNFCCC.
Cost Implications: Category II.

6.4. Terrestrial Domain – Scientific and Technological Challenges

Some current and emerging ECVs call for concerted collaborative research efforts to bring them to the status of operationally-monitored ECVs within the Global Climate Observing System. The key priorities are:

- Development and deployment of airborne and spaceborne microwave and lidar systems for measurement of above-ground biomass; and
- Development of satellite-based systems for the measurement of soil moisture (e.g., drawing on missions such as SMOS and Hydros) and validation of these products building on existing soil-moisture data archives at Rutgers University (USA) and national networks in, e.g., Russian Federation, China, and the USA.

Soil moisture is an emerging ECV, which may be ready to be included in an operational climate observing system in the next 10 to 15 years. Soil moisture has an important influence on land-atmosphere feedbacks at climate time scales, because it has a major effect on the partitioning of incoming radiation into latent and sensible heat, and on the allocation of precipitation into runoff and infiltration. Changes in soil moisture have a serious impact on agricultural productivity, forestry and ecosystem health. Monitoring soil moisture is critical for managing these resources. This variable must be developed within the GCOS framework to ensure proper coordination with other land surface variables. The soil moisture activities can build on the soil-moisture data archive at Rutgers University, national networks (Russian Federation, China, USA) and new satellite missions including SMOS and Hydros. The various ways of representing soil moisture from satellite and *in situ* measurements needs rationalization. This could be achieved by an expanded network of reference stations to support the validation of satellite measurements with *in situ* data. This global terrestrial network for soil moisture GTN-SM will be coordinated by TOPC.

Action T37 (TF1)

Action: Develop an experimental soil-moisture product from existing networks and satellite observations. **Who:** Parties' national services and research programmes, through IGWCO and TOPC in collaboration with Space Agencies. **Time-Frame**: 2009: development of an experimental product; 2011: quasi-operational production of a soil-moisture product. **Performance Indicator:** Availability of validated global satellite derived product and functioning GTN-SM providing observations to an associated archive centre. **Cost Implications:** Category II.

6.5. Terrestrial Domain – Synthesis and Consolidation of Actions

Thanks to the research programmes of many nations (including those of their Space Agencies), GCOS could, within the next five years, provide all the essential climate variables from the Terrestrial Domain listed below. The framework for these actions is generally in place, but the institutional arrangements supporting them are less well-developed for some than for others – and none have long-term, sustained, operational status. Additional, and as yet unsecured, national commitment is needed to complete the networks identified in the first three actions; the following six will be completed if established partnerships continue to be supported.

GCOS can only meet its climate observing goals if every one of the actions is eventually supported by robust institutional commitment on a sustained basis – not from research programmes alone. Nevertheless, access to a more complete suite of climate variables depends on the outcome of longer-term research and planning (five to ten years, and beyond). This will lead to the improvement of the system through inclusion of emerging variables, such as soil moisture; it will strengthen the river discharge network; it will establish much needed, but non-existent networks covering lakes and measures of plant productivity; it will result in reliable measures of land-cover change and provide a proven basis for reversing the contraction of some *in situ* networks (especially snow) by blending measurements from space with those from the ground.

Specific five-year milestones include:

- Reporting from all nodes of the Global Terrestrial Network for Glaciers (GTN-G), including the Global Land Ice Measurements from Space (GLIMS).
- Reporting from all nodes of the Global Terrestrial Network – Rivers (GTN-R) 380 priority stations near the downstream end of the largest rivers of the world.
- Reporting from all nodes of the Global Terrestrial Network for Permafrost (GTN-P).
- Generation of Northern and Southern Hemisphere snow extent maps.
- Generation of digital elevation maps of the ice sheet surfaces.
- Characterization of land cover (the location and extent of inland water-bodies, vegetation type, snow and ice, barren, artificial surfaces, fractional tree cover) at 250-500m resolution.
- Production of global directional hemispherical reflectance factor (or black sky albedo).
- Generation of global measures of fraction of Absorbed Photosynthetically Active Radiation (fAPAR).
- Generation of global active fire and burnt area data sets at 250m-1km resolution.

In the longer term (5 to 10 years) all of the above will be sustained and

- GTN-R will be expanded to cover near real-time reporting of river discharge data from all significant rivers.
- A new baseline network recording lake level and area (GTN-L) will be established.
- A network for ground-water and aquifer monitoring will be designed.
- The contraction of the distribution and number of snow-depth monitoring stations will be reversed.
- Global land-cover change will be mapped at 30m resolution.

- Methods used to establish biomass in forest inventories will be harmonized and collected.
- A globally-representative network of reference sites measuring LAI (*in situ*) and above-ground biomass will be established.
- Representations of soil moisture from satellite and *in situ* measurements will be rationalized and global measures generated.

(Intentionally blank)

Appendix 1

Decision 11/CP.9 - Global Observing Systems for Climate

The Conference of the Parties,

Recalling Article 4.1(g)–(h) and Article 5 of the Convention,

Further recalling its decisions 14/CP.4 and 5/CP.5,
Having considered conclusions of the Subsidiary Body for Scientific and Technological Advice at its fifteenth, sixteenth, seventeenth and eighteenth sessions,

Having considered and noted with appreciation The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC (second adequacy report)*,*

Recognizing the importance of collaboration among the sponsoring agencies of the Global Climate Observing System,

Recognizing further the need for a clear definition of the long-term needs of the Convention and of the short-term priorities concerning the support of systematic observation and networks, in particular taking into account the needs of developing countries,

Recognizing also the value of indigenous knowledge in supplementing regional and national climate monitoring systems,

Welcoming the efforts of the *ad hoc* Group on Earth Observations to develop a 10-year implementation plan for a comprehensive, coordinated and sustained Earth observing system or systems,

Welcoming further the establishment of the Global Climate Observing System Cooperation Mechanism by Members of the sponsoring agencies of the Global Climate Observing System, under the guidance of the Global Climate Observing System steering committee, as well as the flexible approach that has been adopted to participation in the mechanism,

Noting that the Global Climate Observing System Cooperation Mechanism will address priority needs for improvements in global observing systems for climate in developing countries,

1. *Requests* Parties to review the second adequacy report within the context of their national capabilities and to consider what actions they can take individually, bilaterally, multilaterally and through coordinated international programmes to address the findings, noting, in particular:

(a) The importance of maintaining the operation of baseline stations in the long term;
(b) That homogeneous long-term climate records represent a national heritage and are necessary, *inter alia*, to improve the basis for climate assessment and adaptation measures;
(c) The wealth of information that can be provided through the digitization, analysis and exchange of historical information;
(d) The importance of adhering to applicable adopted principles of free and unrestricted exchange of data and products, especially with respect to the set of Essential Climate Variables as defined in the second adequacy report;
(e) The value of reporting on such actions in national communications;

2. *Requests* the Global Climate Observing System secretariat, under the guidance of the Global Climate Observing System steering committee, taking into account international and intergovernmental mechanisms, to coordinate the development of a phased 5- to 10-year implementation plan for the integrated global observing systems for climate, using a mix of high-quality satellite and *in situ* measurements, dedicated infrastructure and targeted capacity-building, such a plan:

(a) To draw on the second adequacy report and the views of Parties;
(b) To take into consideration existing global, regional and national plans, programmes and

initiatives, such as the Global Monitoring for Environment and Security programme and the Integrated Global Observing Strategy partnership;
(c) To be based on extensive consultations with a broad and representative range of scientists and data users;
(d) To include indicators for measuring its implementation;
(e) To identify implementation priorities, resource requirements and funding options;

3. *Invites* the Global Climate Observing System secretariat and the *ad hoc* Group on Earth Observations to collaborate closely in developing their respective implementation plans;

4. *Invites* the *ad hoc* Group on Earth Observations to treat global climate monitoring as a priority and to adopt a balanced approach to the application of *in situ* and remote-sensing systems for climate monitoring;

5. *Invites* the Global Climate Observing System secretariat to provide a progress report on the development of the implementation plan to the Subsidiary Body for Scientific and Technological Advice, at its twentieth session;

6. *Requests* the Global Climate Observing System secretariat to conduct an open review of the implementation plan before its completion and to submit the final implementation plan to the Subsidiary Body for Scientific and Technological Advice, at its twenty-first session;

7. *Invites* Parties to participate actively in the above-mentioned review process;

8. *Invites* the sponsoring agencies of the Global Climate Observing System, and in particular those of the Global Terrestrial Observing System, in consultation with other international or intergovernmental agencies, as appropriate, to develop a framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate, and associated data and products, taking into consideration possible models, such as those of the World Meteorological Organization/Intergovernmental Oceanographic Commission Joint Commission for Oceanographic and Marine Meteorology, and to submit a progress report on this issue to the Conference of the Parties at its eleventh session;

9. *Invites* the relevant national entities, in cooperation with the sponsoring agencies of the Global Climate Observing System and other international and intergovernmental agencies, to make available on a sustained basis a range of integrated climate products relevant to the needs of the Convention, as identified in the second adequacy report;

10. *Invites* the Global Climate Observing System secretariat, in conjunction with the Global Ocean Observing System secretariat, to provide information to the Subsidiary Body for Scientific and Technological Advice, at its twenty-second session, on progress made towards implementing the initial ocean climate observing system;

11. *Requests* the Subsidiary Body for Implementation, when next reviewing the guidelines for the preparation of national communications:

(a) To incorporate into the guidelines the supplementary reporting format developed by a group of Parties and made available to the Subsidiary Body for Scientific and Technological Advice at its thirteenth session;
(b) To replace the “GCOS/GOOS/GTOS Climate Monitoring Principles”, annexed to decision 4/CP.5, with the modified set agreed by the World Meteorological Organization at its Fourteenth Congress and approved by the Committee on Earth Observation Satellites at its seventeenth plenary, to better reflect the needs and capabilities of the *in situ* and satellite monitoring communities;

12. *Encourages* all Parties to provide reports on systematic observation in accordance with the agreed reporting guidelines, in recognition of the importance of accurate, credible and comprehensive information on global observing systems for climate as a basis for planning and implementing priority improvements;

13. *Urges* Parties in a position to do so, in particular Parties included in Annex I to the

Convention, to support, including by contributing to relevant funding mechanisms such as the Global Climate Observing System Cooperation Mechanism, the priority needs, identified in the Second Adequacy Report and Regional Action Plans, in developing countries, especially the least-developed countries and small island developing States, noting that filling the gaps in baseline atmospheric networks is an urgent need that should be met during the next two years;

14. *Requests* the Global Climate Observing System secretariat to include information on the operation of the Global Climate Observing System Cooperation Mechanism in its regular reports to the Conference of the Parties.

(Intentionally blank)

Appendix 2

The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC

Summary

The Second Report on the Adequacy of the Global Observing Systems for Climate was prepared in response to a request from the GCOS Steering Committee and endorsed by the UNFCCC Subsidiary Body on Scientific and Technological Advice (SBSTA) at its 15th session in November 2001. The goals of the Report were to:

- Determine what progress has been made in implementing climate observing networks and systems since the First Adequacy Report in 1998;
- Determine the degree to which these systems meet with scientific requirements and conform with associated observing principles; and
- Assess how well the current systems, together with new and emerging methods of observation, will meet the needs of the Convention.

The Second Adequacy Report concluded that there have been improvements in implementing the global observing systems for climate, especially in the use of some satellite information and in the provision of some ocean observations. However, serious deficiencies remain in their ability to meet the identified needs. For example:

- Atmospheric networks are not operating with the required global coverage and quality;
- Ocean networks lack global coverage and commitment to sustained operation; and
- Global terrestrial networks remain only partially implemented.
- Satellite operations while critical for global coverage need to better reflect climate requirements and the maintenance of key sensors ensured.
- There remain unmet requirements for the production of global integrated analysis products.

The SBSTA 18 noted that the "second adequacy report provides an opportunity to build momentum among governments to improve the global observing systems for climate, but that work remains to be done to identify priorities for actions, to remedy deficiencies within the domain-based networks, and to estimate the cost implications". It requested Parties to submit views on the priorities for actions arising from the second adequacy report, "as a further step towards the development by the GCOS secretariat of an implementation plan for integrated global observations for climate".

Findings

COMMON FINDINGS

CF1: Up to the present, operational satellites have not had climate observation as a priority objective and research missions were not planned to measure multidecadal long-term trends. In consequence, satellite observations for most environmental variables have not met the accuracy and homogeneity requirements for climate. Some research satellites have been able to operate for long periods of time to provide data sets useful for long-term climate studies. The continuation of the attention being given by the Space Agencies to addressing the accuracy and homogeneity requirements for climate would significantly enhance the value of satellite observations to the global observing systems for climate.

CF2: The Space Agencies need collectively to endorse and adopt policies that would implement the GCMPs for satellite observations contained in Appendix 2. Implementation priority is required for those variables with clear climate importance and without adequate *in situ* baseline support.

CF3: Additional analyses are required for most variables, especially for those in the Oceanic and Terrestrial Domains.

CF4: A small number of reanalysis centres are required, with adequate staff and data processing, as part of an internationally-coordinated programme for the preparation of integrated climate products. The international reanalysis programme should give initial priority to: (a) extending current atmospheric reanalysis activities to meet requirements for monitoring climate variability and trends; (b) building on and extending ocean data-assimilation research activities such as GODAE to establish ocean reanalyses for the recent satellite era, and for longer if practicable; and (c) developing products relating to the composition and forcing of the climate system. The outputs of the reanalysis programme should be widely and easily available to the user community.

CF5: An essential requirement for the effective conduct of reanalysis will be the provision of national holdings of historical data to the International Data Centres.

CF6: Adequate meta-data are essential for climate observations. In their absence exhaustive investigative research is required to find, compile, and integrate information on how, where and when observations were taken in order to effectively interpret the data.

CF7 : At the present time scientists are struggling to address all aspects of data archaeology. This includes retrieving data inaccessible because the recording media are outdated, national data exchange is restricted, or resources are inadequate to make them easily accessible.

CF8: When historical climate observations from GCOS baseline networks have been digitized, quality controlled and homogenized, the rehabilitated data and their associated meta-data should be available in International Data Centres.

CF9 : Users seeking information for global analyses often find access to large amounts of already-collected data unavailable for use because of national and international data policies.

CF10 : The rapidly-increasing volume of raw observations that must be saved and stored in an archive is such that the data are too often inaccessible to many users.

CF11: At the present time, even large centres are barely keeping pace with the influx of new data. This is especially true when observing systems are put in place without adequate consideration of the technological data-stewardship requirements for data archive and access.

CF12 : Procedures for the storage and exchange of meta-data need to be developed and implemented.

CF13 : International Data Centres and Space Agencies need to give high priority to making use of modern information and communication technology to ensure effective access and long-term migration, and thus ultimate preservation, of the rapidly-growing volumes of climate-related data.

CF14: When problems in the observations and reporting of the observations are not identified and corrected as soon as possible, errors and biases accumulate in the data and the climate records can be irreparably damaged.

CF15: International agencies, working with their technical commissions and the GCOS Secretariat, should address the inadequacies related to scientific data stewardship, including the introduction of adequate near real-time observing system performance monitoring and monitoring for time-dependent biases.

CF16: Efforts to enhance regional planning for the collection, processing and archiving of climate observations need to continue, as this shares the workload across many nations.

CF17: All nations require active national coordination and planning processes as well as plans for systematic climate observation.

CF18: Reporting on systematic climate observation activities by the Parties as part of their national communications under the UNFCCC has been valuable in the planning and implementation of global observing systems for climate.

CF19: The transition of a research network or satellite observation into operational status requires the development and implementation of plans for: (i) an institution or organization to assume operational responsibility for making the observations and for their distribution, analysis, and archiving; (ii) sustained sources of funding; and (iii) a framework that provides for national commitment to continue to make the required observations.

CF20: Multinational funding mechanisms are required to support high-priority global observing systems for climate in developing countries and some countries with economies in transition. Support is needed for capacity-building, infrastructure issues and sustained operational activities.

ATMOSPHERIC DOMAIN

AF1: The problems with the observation and exchange of GSN data, which have been reported regularly over the past decade, require the urgent attention of nations. Many developing countries need assistance and capacity-building to resolve these problems.

AF2: The support of maritime Parties is required for the implementation of the VOSClim programme to improve measurement of air temperature and water vapour over the oceans.

AF3: There is an urgent need for the establishment of a composite marine-surface network involving VOS, surface-drifting buoys, air-sea moorings and satellites to make measurements of the surface atmospheric variables over the ocean. This is especially important for the high southern latitudes and other regions with few shipping routes.

AF4: Global and regional estimates of precipitation and their variability can be significantly improved by nations routinely exchanging their current and historical observations with the International Data Centres.

AF5: The remaining discrepancies among the different estimates of precipitation over the oceans from satellite observations need to be resolved and a reference network of ocean-surface precipitation stations established on key islands and moored buoys around the globe.

AF6: Drifting buoys deployed in the southern oceans have ameliorated uncertainties in surface pressure fields, and should be continued in conjunction with sea-surface temperature measurements.

AF7: Satellite scatterometer observations measure ocean wind fields and will need to be continued as part of the operational global observing systems for climate.

AF8: The BSRN provides high-quality measurements of radiation at the surface, and should be expanded and adequately supported.

AF9: There should be further work on extending the climate record through data recovery and the collection and synthesis of high-resolution palaeoclimatic data.

AF10: There remains a significant problem with the availability of data from up to one third of both the GUAN and full radiosonde network, especially in the tropics. These problems are occurring either because observations are not being taken due to a lack of resources, or because data are not being exchanged.

AF11: Inadequately-documented radiosonde performance, changes in types of sondes, and lack of overlap during these changes damage the continuity of the record and severely limit the utility of these observations for climate purposes. Adoption of the GCMPs for all of the GUAN, and to the greatest extent possible for the full radiosonde network, should be a high priority for the Parties.

AF12: In order to continue the historical microwave radiance record, there is a need for homogeneous and continuous monitoring of specific radiances by satellite, with increased attention to the calibration of instrument and orbital characteristics.

AF13: GPS occultation measurements provide a promising new technology to retrieve profiles of atmospheric refractive index. GPS receivers could be incorporated on operational meteorological satellites to provide useful temperature estimates in the upper troposphere and stratosphere.

AF14: A few reference sites should be established in key regions to provide high-quality upper-tropospheric and stratospheric observations of temperature and water vapour profiles based upon protocols used at Boulder, USA.

AF15: The column water vapour observations over land from ground-based GPS receivers should be exploited globally through international coordination.

AF16: Clouds and water vapour provide the strongest and most uncertain feedbacks in the climate system. Priority should be given to the development of an effective strategy for monitoring these variables.

AF17: Satellite observation of the ERB must be continued without interruption and with strict adherence to the GCMPs. Measurements of solar irradiance as well as upwelling radiation are required. Continuous measurements with high spectral resolution, and with adequate spatial and temporal sampling, are needed to understand changes.

AF18: Continuous and homogeneous observations should be made of the spatial and temporal distribution of greenhouse gases including carbon dioxide to help determine sources and sinks. This should be accomplished through the continued support of current stations, the enhancement of the GAW global network in selected regions, and the advancement of appropriate satellite observations. These capabilities should be fully exploited by the development and implementation of atmospheric composition real-time analysis and reanalysis products.

AF19: There is a need for improved distribution and calibration of ground-based observations to support the use of satellite data for global monitoring of ozone.

AF20: GAW, its partners (including the Space Agencies) and GCOS need to consolidate baseline measurements and further develop a strategy for obtaining continuous homogeneous observations to characterize the nature and radiative properties of aerosols.

AF21: Improved estimates of climate forcings and natural variability on multiple time scales based on the instrumental and palaeoclimate reconstructions are needed.

AF22: There is a need for observations from specialized research studies to support improved understanding of processes and the development of models used for climate simulation and prediction. This is in addition to the need for on-going systematic observations of the climate system outlined in this Report.

AF23: Many nations require additional financial resources to conduct observing programmes at the scale required for the development of statistical relations for use with downscaling from global and/or regional model projections.

AF24: Studies on regional impacts of, and vulnerability to, climate change, especially changes in extreme events require national and regional climate observing networks at a finer scale, in addition to the GCOS baseline networks. When requested for the purposes of impact studies and extreme events, daily and/or hourly observations of the climate variables should be provided to the appropriate International Data Centre.

OCEANIC DOMAIN

OF1: The feasibility of observing climate changes in the global ocean has been demonstrated. Since the First Adequacy Report the ocean community has reached agreement on an initial integrated and composite system, developed new technologies, has established mechanisms to foster more effective international collaboration (including the JCOMM) and has begun the demonstration of community capability to generate ocean climate products (e.g., GODAE).

OF2: Research programmes are the primary source of funding for many elements of the present oceanic climate observing system. Continuing strong involvement of the research community is needed. An orderly process to bring new technology into pilot project use and then sustained use in the oceanic climate observing system has been agreed. Institutional encouragement and financial support is needed to ensure that this process results in the sustained operation of the agreed initial system.

OF3: The absence of global coverage and the lack of sufficient high-quality observations of the key variables remain the key weaknesses in the surface ocean network. For a few variables, such as sea-surface temperature and mean sea-level pressure, cost-effective technologies are available to address this weakness. For other variables, considerable research and development are required.

OF4: A sparse global array of surface reference moorings (29) can provide essential air-sea flux information for testing models and the evaluation of climate change projections. It also can provide needed platforms for development of new observing system sensors.

OF5: At present levels of coverage and operations, global analyses of SST are not adequate to meet all of the needs of the UNFCCC. However, global climate-accuracy SST analysis is achievable through enhanced global deployment of existing technology (1,250 surface drifters and 119 tropical moorings), with more than 200 ships participating in the VOSClim project and the improved operation of satellite sensors.

OF6: At present, global knowledge of SSS is not adequate. Improvement in SSS analysis accuracy is limited by available technology. New satellite sensors hold promise of improved global coverage, although special *in situ* observing efforts will be needed to evaluate sustained sensor performance.

OF7: Knowledge of sea-ice changes is not adequate. A sea-ice component of cryosphere research effort is ongoing. Recent satellite launches including ICESat, CryoSat and the AMSR-E instrument on Aqua will provide new remote ice measurements. *In situ* observing efforts and climate ice analysis and reanalysis are needed.

OF8: Present knowledge of global sea-level variability and change is not adequate. Monitoring of global sea level is technically feasible at present, but requires at minimum a global array of geocentrically-located high-accuracy water level gauges (86), continued operation of high-precision satellite altimetry and effective data exchange between nations.

OF9: Knowledge of ocean ecosystem change is not adequate at present. Satellites provide global coverage of surface ocean colour, but the linkage between ocean colour and ecosystem variable remains limited. Research is underway to improve knowledge of the relationships between ocean colour and ecosystem variables, including chlorophyll-a. Enhanced *in situ* sampling of ocean colour and ecosystem variables is technically feasible.

OF10: Measurements from the deep ocean are a critical contribution to characterizing ocean climate variability and change. At present the most effective approaches involve combinations of regular, deep-ocean surveys and surface altimetry.

OF11: Systematic sampling of the global upper ocean is needed to fully characterize ocean climate variability. Global implementation of proven techniques remains to be accomplished. This will be addressed through implementation of the agreed upper-ocean network (specifically 3,000 Argo profiling floats, 41 repeat XBT lines, 29 surface reference moorings, 119 tropical surface moorings).

OF12: Carbon cycle parameters should be measured at reference sites and full-depth carbon inventory surveys are needed to enable full interpretation of carbon cycle changes. Additional global pCO_2 measurements are required to document the decadal uptake by the oceans of anthropogenic CO_2. In addition to the full-depth surveys, present consensus requires implementation of 29 surface reference-moored buoys and at least 25 selected VOS. Further sensor development for autonomous pCO_2 and carbon system measurements is needed.

OF13: Proper attribution of the causes of ocean change requires a commitment to characterizing ocean variability. Comprehensive and baseline networks, as well as reference stations can provide the needed information. Global coverage and long-term commitment are the most significant challenges.

OF14: Ocean data and ocean climate analyses are important for supporting the testing of climate change models and evaluation of the ocean state/structure of predictions of future changes of the climate system. The global comprehensive networks together with baseline and reference networks as described previously can provide the needed information, with particular emphasis on three-dimensional analyses and climatologies and time series.

OF15: Adequately characterizing extreme regional sea-level events requires that high-frequency sea-level observations need to be taken and exchanged and historical data from tide gauges need to be provided to the International Data Centres. Capacity-building efforts in developing countries for undertaking local sea-level-change measurements can benefit the global system and foster needed regional enhancement.

OF16: Obtaining full national and regional benefit from GCOS efforts will depend on the development of integrated regional and national observing systems and special products for shallow sea and coastal waters. National and regional participation in the GOOS Coastal Module provides one framework for coordinated development and operation of observing efforts in national waters.

TERRESTRIAL DOMAIN

TF1: There is a requirement for the establishment of an international mechanism that would prepare and issue regulatory and guidance material relating to terrestrial observing systems and management of their data and associated products.

TF2: The Parties need to provide the observations identified by the GTN–H, in particular those on river discharge, lakes, reservoirs and wetlands, and ground water, to the associated International Data Centres. In spite of repeated calls by the international community for free and unrestricted exchange of hydrological data, this still does not happen.

TF3: The contraction of *in situ* observations should be halted and there is an urgent need to develop optimal procedures to blend surface observations of snow with visible and microwave satellite data and related airborne measurements.

TF4: Mass-balance measurements of glaciers and ice caps need to be re-initiated in Patagonia, New Zealand and Africa so that changing patterns can be monitored globally. Archived Earth observation data should be analyzed to determine trends over the last two decades. Observations should be provided to the World Glacier Monitoring Service.

TF5: New temperature boreholes and *in situ* observations of active layer thickness need to be established in both hemispheres by the Parties at sites identified by the Permafrost Network with the observations provided to the Network's International Data Centre.

TF6: There is a need to: (1) establish a benchmark for assessing land-surface albedo products, and (2) implement a system to retrieve land-surface albedo from existing geostationary platforms on a daily and global basis.

TF7: Archived data from geostationary platforms should be reprocessed to form a global climatology of albedo for the entire period of available measurements.

TF8: An international body should advise on standards for the production of land-cover maps, specifically in terms of the resolution and land-type characterization to be employed.

TF9: Existing land-cover data should be analyzed and/or reprocessed, wherever possible, to ensure the compatibility of maps produced for the last decade. New land-cover maps should be produced every five years.

TF10: Historical land-use data sets could be significantly improved if more and better-documented inventory data sets were made available.

TF11: Daily global fAPAR and LAI products should continue to be generated by Space Agencies and other entities and made widely available. The validation of these products, currently being undertaken by the Space Agencies and associated research programmes, should be continued.

TF12: Reference sites making *in situ* observations of fAPAR and LAI are essential both for validation and to redress the intrinsic limitations in the satellite-derived measurements.

TF13: Space Agencies should continue to fly sensors capable of detecting burnt areas and active fires, and global burnt-area and active-fire products should continue to be produced. The quality of the various fire products should be established.

TF14: Archived Earth observation data should be reprocessed to produce a consistent data set on fire disturbances and their trends.

TF15: Continued support for the long-term operation of a representative set of terrestrial flux measurement towers (FLUXNET) is required. With adjustments to the distribution of sites to include under-represented ecosystems and an expansion to the range of collocated measurements, FLUXNET could form a reference network at some point in the future.

(Intentionally blank)

Appendix 3

GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles[48]:

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.

[48] The ten basic principles were adopted by the Conference of the Parties to the UN Framework Convention on Climate Change through decision 5/CP.5 of COP-5 at Bonn in November 1999.

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.

Appendix 4

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.

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)

Glossary of Acronyms

AERONET	AEROSOL ROBOTIC NETWORK
AGAGE	ADVANCED GLOBAL ATMOSPHERIC GASES EXPERIMENT
AIRS	ATMOSPHERIC INFRARED SOUNDER (NASA)
AMSR	ADVANCED MICROWAVE SCANNING RADIOMETER (JAXA)
AMSR-E	ADVANCED MICROWAVE SCANNING RADIOMETER FOR EOS (NASA/JAXA)
AMSU	ADVANCED MICROWAVE SOUNDING UNIT (NOAA)
AOPC	ATMOSPHERIC OBSERVATION PANEL FOR CLIMATE
AQUASTAT	INFORMATION SYSTEM ON WATER AND AGRICULTURE (FAO)
Argo	GLOBAL ARRAY OF PROFILING FLOATS
ATMS	ADVANCED TECHNOLOGY MICROWAVE SOUNDER
AVHRR	ADVANCED VERY HIGH RESOLUTION RADIOMETER (NOAA)
BSRN	BASELINE SURFACE RADIATION NETWORK
CALIPSO	CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATIONS
CALM	CIRCUMPOLAR ACTIVE-LAYER MONITORING
CAS	COMMISSION FOR ATMOSPHERIC SCIENCES (WMO)
CBS	COMMISSION FOR BASIC SYSTEMS (WMO)
CCl	COMMISSION FOR CLIMATOLOGY (WMO)
CEOS	COMMITTEE ON EARTH OBSERVATION SATELLITES
CERES	CLOUDS AND EARTH’S RADIANT ENERGY SYSTEM (NASA)
CFC	CHLOROFLUOROCARBON
CGMS	COORDINATION GROUP FOR METEOROLOGICAL SATELLITES
CHAMP	CHALLENGING MINISATELLITE PAYLOAD (GERMANY)
CHy	COMMISSION FOR HYDROLOGY (WMO)
CIMO	COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION (WMO)
CliC	CLIMATE AND CRYOSPHERE PROJECT (WCRP)
CLIVAR	CLIMATE VARIABILITY AND PREDICTABILITY PROJECT (WCRP)
CMDL	CLIMATE MONITORING AND DIAGNOSTICS LABORATORY (NOAA)
CNES	CENTRE NATIONAL D’ETUDES SPATIALES
COP	CONFERENCE OF THE PARTIES (TO UNFCCC)
COSMIC	CONSTELLATION OBSERVING SYSTEM FOR METEOROLOGY, IONOSPHERE AND CLIMATE
CrIS	CROSS-TRACK INFRARED SOUNDER (NOAA)
CryoSat	CRYOSPHERE SATELLITE (ESA)
CSIRO	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION (AUSTRALIA)
DODS	DISTRIBUTED OCEANOGRAPHIC DATA SYSTEM
DWD	DEUTSCHER WETTERDIENST (GERMANY)
ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
ECV	ESSENTIAL CLIMATE VARIABLE (AS DEFINED BY GCOS SECOND ADEQUACY REPORT (GCOS-82))
EO	EARTH OBSERVATION
ERB	EARTH RADIATION BUDGET
ERS	EUROPEAN REMOTE SENSING SATELLITE (ESA)
ESA	EUROPEAN SPACE AGENCY
ETHZ	EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE ZÜRICH (SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH)
EUMETSAT	EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES
FAGS	FEDERATION OF ASTRONOMICAL AND GEOPHYSICAL DATA ANALYSIS SERVICES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FAPAR	FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION

FRA	FOREST RESOURCES ASSESSMENT PROJECT (FAO)
FLUXNET	FLUX AND ENERGY EXCHANGE NETWORK
FSA	FEDERAL SPACE AGENCY (RUSSIAN FEDERATION)
FWIS	FUTURE WMO INFORMATION SYSTEM
GAW	GLOBAL ATMOSPHERE WATCH (WMO)
GCMD	GLOBAL CHANGE MASTER DIRECTORY
GCMP	GCOS CLIMATE MONITORING PRINCIPLES
GCOS	GLOBAL CLIMATE OBSERVING SYSTEM
GDPFS	GLOBAL DATA PROCESSING AND FORECASTING SYSTEMS
GDPS	GLOBAL DATA PROCESSING SYSTEM (WWW)
GEF	GLOBAL ENVIRONMENT FACILITY
GEO	GROUP ON EARTH OBSERVATIONS
GEOSS	GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS
GERB	GEOSTATIONARY EARTH RADIATION BUDGET EXPERIMENT (EUMETSAT)
GEWEX	GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (WCRP)
GFMC	GLOBAL FIRE MONITORING CENTER
GHG	GREENHOUSE GAS
GLCN	GLOBAL LAND COVER NETWORK
GLIMS	GLOBAL LAND ICE MEASUREMENTS FROM SPACE
GLOSS	GLOBAL SEA LEVEL OBSERVING SYSTEM
GODAE	GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT
GODAR	GLOBAL OCEANOGRAPHIC DATA ARCHAEOLOGY AND RESCUE
GOFC-GOLD	GLOBAL OBSERVATION OF FOREST AND LAND COVER DYNAMICS (GTOS)
GOME	GLOBAL OZONE MONITORING EXPERIMENT
GOOS	GLOBAL OCEAN OBSERVING SYSTEM
GOS	GLOBAL OBSERVING SYSTEM (WMO)
GOSAT	GREENHOUSE GASES OBSERVING SATELLITE (JAXA)
GOSIC	GLOBAL OBSERVING SYSTEMS INFORMATION CENTER
GOSUD	GLOBAL OCEAN SURFACE UNDERWAY DATA PILOT PROJECT
GPCP	GLOBAL PRECIPITATION CLIMATOLOGY PROJECT
GPS	GLOBAL POSITIONING SYSTEM
GRA	GOOS REGIONAL ALLIANCE
GRDC	GLOBAL RUNOFF DATA CENTRE
GSN	GCOS SURFACE NETWORK
GTN	GLOBAL TERRESTRIAL NETWORK
GTN-G	GLOBAL TERRESTRIAL NETWORK FOR GLACIERS
GTN-H	GLOBAL TERRESTRIAL NETWORK FOR HYDROLOGY
GTN-L	GLOBAL TERRESTRIAL NETWORK – LAKES
GTN-P	GLOBAL TERRESTRIAL NETWORK FOR PERMAFROST
GTN-R	GLOBAL TERRESTRIAL NETWORK – RIVERS
GTN-SM	GLOBAL TERRESTRIAL NETWORK FOR SOIL MOISTURE
GTOS	GLOBAL TERRESTRIAL OBSERVING SYSTEM
GTS	GLOBAL TELECOMMUNICATION SYSTEM (WWW)
GTSPP	GLOBAL TEMPERATURE-SALINITY PROFILE PROGRAM
GUAN	GCOS UPPER-AIR NETWORK
HALOE	HALOGEN OCCULTATION EXPERIMENT
HIRDLS	HIGH RESOLUTION DYNAMICS LIMB SOUNDER
HYDROS	HYDROSPHERE STATE MISSION (NASA)
IASI	INFRARED ATMOSPHERIC SOUNDING INTERFEROMETER (EUMETSAT)
ICESat	ICE, CLOUD AND LAND ELEVATION SATELLITE (NASA)
ICOADS	INTERNATIONAL COMPREHENSIVE OCEAN-ATMOSPHERIC DATA SET PROJECT
ICSU	INTERNATIONAL COUNCIL FOR SCIENCE
IGACO	INTEGRATED GLOBAL ATMOSPHERIC CHEMISTRY OBSERVATIONS
IGBP	INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME
IGOS	INTEGRATED GLOBAL OBSERVING STRATEGY
IGOS-P	INTEGRATED GLOBAL OBSERVING STRATEGY PARTNERSHIP
IGWCO	INTEGRATED GLOBAL WATER CYCLE OBSERVATIONS
IMD	INDIAN METEOROLOGICAL DEPARTMENT

IOC	INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)
IOCCG	INTERNATIONAL OCEAN COLOUR COORDINATING GROUP
IOCCP	INTERNATIONAL OCEAN CARBON COORDINATION PROJECT
IODE	INTERNATIONAL OCEANOGRAPHIC DATA AND INFORMATION EXCHANGE
IPA	INTERNATIONAL PERMAFROST ASSOCIATION
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IPY	INTERNATIONAL POLAR YEAR
IR	INFRARED
ISO	INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ISRO	INDIAN SPACE RESEARCH ORGANISATION
JAXA	JAPAN AEROSPACE EXPLORATION AGENCY
JCOMM	JOINT TECHNICAL COMMISSION FOR OCEANOGRAPHY AND MARINE METEOROLOGY
JMA	JAPAN METEOROLOGICAL AGENCY
LAI	LEAF AREA INDEX
LIDAR	LIGHT DETECTION AND RANGING SYSTEM
MERIS	MEDIUM RESOLUTION IMAGING SPECTROMETER (ESA)
METOP	METEOROLOGICAL OPERATIONAL POLAR SATELLITE
MIPAS	MICHELSON INTERFEROMETER FOR PASSIVE ATMOSPHERIC SOUNDING
MISR	MULTIANGLE IMAGING SPECTRORADIOMETER
MODIS	MODERATE RESOLUTION IMAGING SPECTRORADIOMETER (NASA)
MODLAND	MODIS LAND GROUP
MOPITT	MEASUREMENTS OF POLLUTION IN THE TROPOSPHERE
MSC	METEOROLOGICAL SERVICE OF CANADA
MSU	MICROWAVE SOUNDING UNIT (NOAA)
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (USA)
NCDC	NATIONAL CLIMATIC DATA CENTER (NOAA)
NDSC	NETWORK FOR DETECTION OF STRATOSPHERIC CHANGE
NESDIS	NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE (NOAA)
NOAA	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (USA)
NPOESS	NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM
NSIDC	NATIONAL SNOW AND ICE DATA CENTER (USA)
NWP	NUMERICAL WEATHER PREDICTION
OCO	ORBITING CARBON OBSERVATIONS
OOPC	OCEAN OBSERVATIONS PANEL FOR CLIMATE
OPENDAP	OPEN-SOURCE DATA ACCESS PROTOCOL
POGO	PARTNERSHIP FOR OBSERVATION OF THE GLOBAL OCEANS
RA	REGIONAL ASSOCIATION (WMO)
RBSN	REGIONAL BASIC SYNOPTIC NETWORKS (WWW/GOS)
RO	RADIO OCCULTATION
ROSHYDROMET	RUSSIAN FEDERAL SERVICE FOR HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING
SAC-C	ARGENTINE SATELITE DE APLICACIONES CIENTIFICAS-C (ARGENTINA)
SAGE	STRATOSPHERIC AEROSOL AND GAS EXPERIMENT
SAR	SYNTHETIC APERTURE RADAR
SBI	SUBSIDIARY BODY FOR IMPLEMENTATION (UNFCCC)
SBSTA	SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE (UNFCCC/COP)
SBUV	SOLAR BACKSCATTER ULTRAVIOLET RADIOMETER
SCIAMACHY	SCANNING IMAGING ABSORPTION SPECTROMETER FOR ATMOSPHERIC CARTOGRAPHY
SCOR	SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH
SEAWIFS	SEA-VIEWING WIDE FIELD-OF-VIEW SENSOR (NASA)
SHADOZ	SOUTHERN HEMISPHERE ADDITIONAL OZONESONDES
SLP	SEA-LEVEL PRESSURE
SOGE	SYSTEM FOR OBSERVATION OF HALOGENATED GREENHOUSE GASES IN EUROPE

SOOP	SHIP OF OPPORTUNITY PROGRAMME
SPOT HRV	SATELLITE PROBATOIRE D'OBSERVATION DE LA TERRE HIGH RESOLUTION
SMOS	SOIL MOISTURE AND OCEAN SALINITY MISSION
SSM/I	SPECIAL SENSOR MICROWAVE/IMAGER
SSS	SEA-SURFACE SALINITY
SST	SEA-SURFACE TEMPERATURE
SURFA	SURFACE FLUX ANALYSIS PROJECT
SWE	SNOW WATER EQUIVALENT
TAO	TROPICAL ATMOSPHERE OCEAN PROJECT
TEMS	TERRESTRIAL ECOSYSTEM MONITORING SYSTEM
TIP	TROPICAL MOORED BUOY IMPLEMENTATION PANEL
TOMS	TOTAL OZONE MAPPING SPECTROMETER (NASA)
TOPC	TERRESTRIAL OBSERVATION PANEL FOR CLIMATE
TOPEX/POSEIDON	OCEAN SURFACE TOPOGRAPHY ALTIMETER EXPERIMENT (NASA/CNES)
TRMM	TROPICAL RAINFALL MEASURING MISSION (JAXA/NASA)
ULS	UPWARD LOOKING SONAR
UNEP	UNITED NATIONS ENVIRONMENT PROGRAMME
UNESCO	UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
UNFCCC	UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE
USGS	US GEOLOGICAL SURVEY
UV	ULTRAVIOLET
VOS	V OLUNTARY OBSERVING SHIP
VOSCLIM	VOLUNTARY OBSERVING SHIP CLIMATE PROJECT
WCRP	WORLD CLIMATE RESEARCH PROGRAMME
WDC	WORLD DATA CENTRE
WDC ASHEVILLE	WORLD DATA CENTRE FOR METEOROLOGY, ASHEVILLE (NCDC)
WDC-GG	WORLD DATA CENTRE FOR GREENHOUSE GASES
WGCV	WORKING GROUP ON CALIBRATION AND VALIDATION (CEOS)
WGMS	WORLD GLACIER MONITORING SERVICE
WMO	WORLD METEOROLOGICAL ORGANIZATION
WOUDC	WORLD OZONE AND ULTRAVIOLET RADIATION DATA CENTRE
WWW	WORLD WEATHER WATCH (WMO)
XBT	EXPENDABLE BATHYTHERMOGRAPH
XCTD	EXPENDABLE CONDUCTIVITY, TEMPERATURE AND DEPTH SYSTEM

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