WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

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

Provisional 2010 Update

DRAFT v1.0

28 October 2009

GCOS Secretariat

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL COUNCIL FOR SCIENCE

Executive Summary

1. Introduction

1.1. Context

The demand for information on climate has never been greater than today. Long-term, high-quality and un-interrupted observations of atmosphere, land and ocean are vital for all countries, as their economies and societies become increasingly affected by climate variability and change.

As highlighted by the IPCC Fourth Assessment Report, observations have demonstrated that warming of the climate system is unequivocal, and they must be sustained into the future to monitor the effectiveness of policies implemented to mitigate climate change. They are essential to support further research, to initialise predictions on timescales out to decades ahead, and for the development of the models used to make these predictions and longer-term scenario-based projections. Observations are used to assess social and economic vulnerabilities and to develop the actions needed across a broad range of sectors to adapt to climate variability and unavoidable change. They need to be recognised as essential public goods, where the value of global availability of data exceeds any economic or strategic value of withholding national data. In short, observations underpin all efforts by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to mitigate, and adapt to, climate change.

This 2010 edition of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (IP-10) replaces a similarly titled 10-year Plan (IP-04) which was published in October 2004[2]. Its purpose is to provide an updated set of actions required to implement and maintain a comprehensive global observing system for climate that will address the commitments of the Parties under Articles 4 and 5 of the UNFCCC and support their needs for climate observations in fulfilment of the objectives of the Convention. This revised Plan updates the Actions in the IP-04, taking account of recent progress in science and technology, increased focus on adaptation, enhanced efforts to optimize mitigation measures, and the need for improved predictions of climate change. It focuses on the timeframe 2010-2015.

Full implementation of the Global Climate Observing System (GCOS) – and the evolving climate information services it supports – is required to ensure that countries are able to understand, predict and manage their response to climate and climate change over the 21st century and beyond. This Plan, if fully implemented by the Parties, will provide observations of the Essential Climate Variables (ECVs) needed to make significant progress in the generation of global climate products and derived information; it will also provide support for the research, modelling, analysis and capacity building activities required by all Parties to the UNFCCC. The Plan also addresses the need for observational records to improve seasonal-to-interannual climate predictions.

This Plan does not attempt to fully address the needs and associated costs of Parties to build national observational capacity in support of assessments of local impacts and adaptation, and other specific national priorities. In addition, for all Parties to fully benefit from the observations and information that this Plan addresses, a substantial additional effort in building the scientific and technical capacity in many countries is needed.

It recognizes progress made over the past five years (since publication of the IP-04) and takes into consideration the main findings from the GCOS Progress Report 2004-2008[3], namely that:

- The increasing visibility of climate change has reinforced world-wide awareness of the importance of an effective Global Climate Observing System;

---

[2] GCOS (2004): *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*, GCOS-92, October 2004, http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf (completed by invitation of COP 9, 2003)

[3] GCOS (2009): *Progress Report on the Implementation of the GCOS in Support of the UNFCCC 2004-2008*, GCOS-129, August 2009, http://www.wmo.int/pages/prog/gcos/Publications/gcos-129.pdf

- Developed Countries have improved many of their climate observation capabilities, but national reports suggest little progress in ensuring long-term continuity for several important observing systems;
- Developing Countries have made only limited progress in filling gaps in their *in situ* observing networks, with some evidence of decline in some regions, and capacity building support remains small in relation to needs;
- Both operational and research networks and systems, established principally for other purposes, are increasingly responsive to climate needs including the need for timely data exchange;
- Space agencies have improved both mission continuity and observational capability, and are increasingly meeting the identified needs for data reprocessing, product generation, and access;
- The Global Climate Observing System has progressed significantly over the last five years, but still falls short of meeting all the climate information needs of the UNFCCC and broader user communities.

International awareness of the importance of global observing systems for all societal benefit areas has improved through the establishment of the Group on Earth Observations[4] (GEO) and the adoption of the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan. The GCOS is the climate observing component of the Global Earth Observation System of Systems (GEOSS). More on background and purpose of GCOS is given in Appendix 3.

The August-September 2009 World Climate Conference-3 (WCC-3) decided to establish a new Global Framework for Climate Services (GFCS) to provide a full range of climate information and prediction services for all climate-sensitive sectors in all countries. The detailed design of the GFCS by the proposed task force of high-level independent advisors must be expected to address the need, identified in the WCC-3 Conference Statement, for "major strengthening of [..] the Global Climate Observing System and all its components and associated activities." The future GCOS, addressing the full observational needs of the GFCS, is thus likely to involve a substantial investment in establishment and strengthening of national climate observing networks beyond those included in this Plan.

1.2. Background to this Plan

The Global Climate Observing System (GCOS) Steering Committee and Secretariat, in consultation with the GCOS sponsors and component observing systems, have prepared this Plan (IP-10), seeking to respond to the request by SBSTA 30 (cf. Appendix 1), and to abide by the general guidance provided by COP 9 in its request for the IP-04 (decision 11/CP.9, cf. Appendix 2). Completion of a provisional version of the IP-10 for consideration by Parties at the Fifteenth Session of the COP in December 2009 responds to an invitation by the UNFCCC SBSTA at its 30th session in June 2009. The updated Plan recognises the progress made over the first 5 years and outlined in GCOS (2009), the Progress Report which was submitted in draft form to the UNFCCC SBSTA 30 in June 2009. It also considers perspectives arising from the IPCC Fourth Assessment Report and a related joint GCOS-WCRP-IGBP workshop held in 2007[5], as well as the UNFCCC Nairobi Work Programme with its focus on adaptation. The report also recognises the various technical advances and changes to institutional arrangements since 2004, including the formation of the GEOSS. Whereas most parts of the report have been simply updated, where needed, some sections have undergone more substantial revision, including the identification of new objectives and requirements.

This IP-10:

Takes into consideration existing global, regional and national plans, programmes and initiatives;
Is based on extensive consultations with a broad and representative range of scientists and data users, including an open review of the Plan;

- Is based on close collaboration with the Group on Earth Observations (GEO) in developing their broader Work Plans for the implementation of GEOSS;
- Identifies implementation priorities, resource requirements and funding options;

[4] http://www.earthobservations.org
[5] GCOS, WCRP, IGBP (2008): *Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report*, GCOS-117, January 2008, http://www.wmo.int/pages/prog/gcos/Publications/gcos-117.pdf

- Includes indicators for measuring its implementation.

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.

Key Need 1: Urgent action and clear commitment by Parties to sustain, and build upon, the achievements in systematic observation of climate since 2004 are required to ensure that the Parties have the information they need to plan for and manage effectively their response to climate change.

As noted above, this Plan addresses primarily the needs of the UNFCCC for systematic observation of the climate system; implementation of its recommendations would equally underpin a broad range of climate applications for the benefit of Parties.

2.1. Essential Climate Variables

The purpose of this Plan is to specify the actions required to implement a comprehensive observing system for the Essential Climate Variables (ECVs) that would address Articles 4 and 5 of the UNFCCC. The list of ECVs (see Table 1) is evolving slowly as requirements change and as technological developments permit. The updated list of ECVs now includes soil moisture, soil carbon, ocean oxygen content, and habitat properties (both marine and terrestrial), and recognizes the role of precursors in forming some atmospheric composition ECVs. Additionally, for clarity, some variables have a different name: 'ice sheets' were previously included in 'glaciers and ice caps' in the IP-04and 'ocean acidity' and 'carbon dioxide partial pressure,' whose measurement allows characterization of ocean carbon content, replace 'ocean carbon' in the IP-04. Actions in this Plan related to emerging ECVs, such as soil carbon, are more limited in expected achievement over five years and often the focus of research initiatives. This Plan also notes the need to support both detailed reference measurements of a wide range of physical variables and long-term ecosystem monitoring at a range of global sites.

2.2. Implementation Actions and Associated Cost Implications

The Plan includes some 137 specific actions to be undertaken, mostly over the next five 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 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 least-developed countries.

For many ECVs, although the Plan focuses on meeting global requirements, global data and products are also relevant to regional and local needs. Additionally, for the ECVs critical to impacts assessments and adaptation, the need for data at the regional and national scale is recognized. This includes data needed to characterize extreme events, which are usually of a small scale and/or short-

lived, and for which the Plan recommends actions to support both regional and global estimates. Finally, the Plan will be updated over time as networks and systems become operational and as new knowledge and techniques become available.

Priority in implementing this Plan should be given specifically to 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.

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**[6]**:**	Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.
	Upper-air:	Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).
	Composition:	Carbon dioxide, Methane, and other long-lived greenhouse gases. Ozone and Aerosol, supported by their precursors[7]
Oceanic	**Surface**[8]**:**	Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour (for biological activity), Carbon dioxide partial pressure, Ocean acidity,
	Sub-surface:	Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers, Phytoplankton; Marine biodiversity and habitat properties[9]
Terrestrial	River discharge, Water use, Ground water, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture, Terrestrial biodiversity and habitat properties[9]	

The estimated costs of implementing Actions in this Plan are given as additional annual costs on top of the costs of existing networks, systems and activities that are required to address climate needs but that are in many cases not specifically designed for climate purposes[10]. These include costs for continuing some existing networks, systems and activities undertaken for research purposes with no plans for continuity. Figure 1 schematically illustrates the cost estimates in this Plan, and also shows current and needed expenditures for climate-related observing networks, systems and activities that are *not* encompassed in this Plan. This information would have to be obtained through national institutions and organizations responsible for those systems.

Table 2 gives a summary of the costs of undertaking all Actions proposed in this Plan, detailed by cross-cutting, atmospheric, oceanic and terrestrial domains. In addition to cost estimates for Actions, SBSTA at its 30th session asked GCOS to provide a breakdown of those cost estimates "by region and observing system and between developed and developing countries." In response to this call, for all Actions in this Plan, as given in Figure 1 and Table 2, indicative estimates have been made of the share of annual expenditure needed to be spent in non-Annex-I Parties[11] (mostly developing countries) and by Annex-I Parties (developed countries).

---

[6] Including measurements at standardized, but globally varying heights in close proximity to the surface
[7] NO2, SO2, HCHO and CO in particular
[8] Including measurements within the surface mixed layer, usually within the upper 15m
[9] At selected sites and areas (e.g., coral reefs; boreal and tropical forest areas)
[10] These funds are not necessarily secured in the future.
[11] Appendix 6 lists all Annex-I and non-Annex-I Parties to the UNFCCC.

Of particular importance to developing countries of all sizes are the observations related to surface and upper-air meteorological variables, river runoff, glaciers, permafrost, tide gauges and land cover to support the adaptation planning and the provision of national climate services.

A breakdown of costs by regions (e.g., the regions used in the GCOS Regional Workshop Programme) has not been done due to an insufficient basis of information. Supplementing the global cost estimates in this Plan by regional detail could be achieved through a specific call to non-Annex-I Parties to report on their climate observing systems and related needs, including cost estimates.

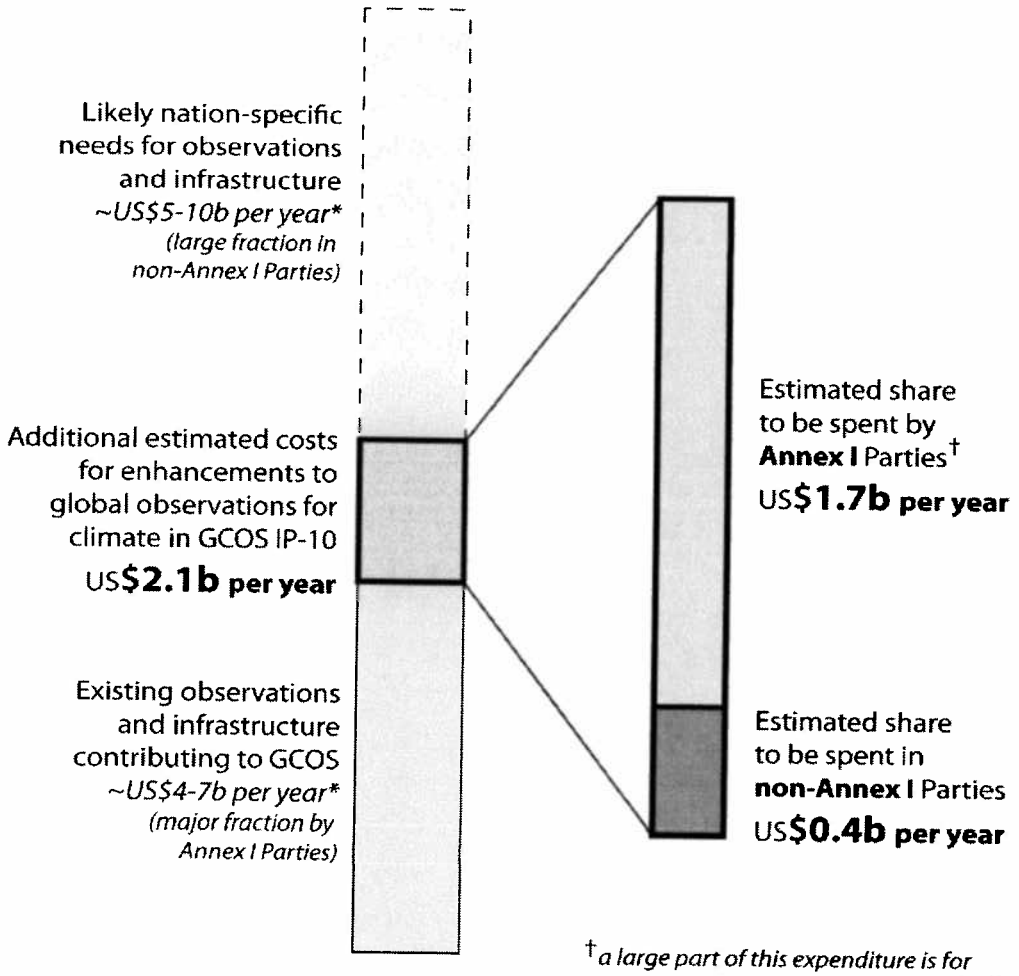

Figure 1: Global additional cost estimates encompassed in this Plan (GCOS IP-10) compared to global estimates of total annual costs for observations and associated infrastructure contributing to GCOS, and likely global annual costs for nation-specific needs.

Table 2: Summary of additional annual costs for implementing the Actions in this Plan (GCOS IP-10; in million (M) US dollars; see Figure 1 for context)

Cost Category*	Number of Common Actions	Number of Atmospheric Actions	Number of Oceanic Actions	Number of Terrestrial Actions	Total
<1M	3	6	7	7	23
1M-10M	7	12	21	25	65
10M-30M	8	11	6	5	30
30M-100M	1	2	7	2	12
100M-300M	0	2	0	0	2
Uncosted Actions[12]	5	0	0	0	5
Total Number of Actions	24	33	41	39	137
Estimated total cost[13]	**260**	**810**	**680**	**360**	**2110**
Estimated share of total to be spent in non-Annex-I Parties[14]	160	110	100	60	430
Estimated share of total to be spent by Annex-I Parties[15]	100	700	580	300	1680

Key Need 2: Parties need, both individually and collectively, to commit to the full implementation of the global observing system for climate and to sustain a mix of high-quality satellite measurements, ground-based and airborne *in situ* measurements, and remote-sensing measurements, as well as to 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 and on ships, buoys, floats, ocean profilers, balloons, samplers, and aircraft, as well as from all forms of remote sensing including satellites. Metadata (i.e., information on where and how the observations are taken) are absolutely essential, as are historical and palaeoclimatic records that set the context 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 to translate the Plan into reality. Collectively, all of these entities are referred to in the Plan as the 'Agents for Implementation'.

3.1. International, Regional and National Agents

The networks, systems, data centres and analysis centres identified within this Plan are almost all funded, managed and operated by national entities to address 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. The GCOS Steering Committee, Panels and Secretariat will continue to emphasize with all relevant international and intergovernmental

[12] Costs covered in domain actions.
[13] Rounded to the nearest 10M USD. Estimates assume average costs (in USD) of 0.5M (for <1M category), 5M (for 1-10M category), 20M (for 10-30M category), 65M (for 30-100M category) and 200M (for 100-300M category).
[14] See previous footnote. Appendix 6 lists all non-Annex-I Parties to the UNFCCC.
[15] See previous footnote. Appendix 6 lists all Annex-I Parties to the UNFCCC.

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

Recognizing the commonality of national needs for regional climate information, regional planning, and implementation of climate observing system components is particularly needed since it provides an effective means of sharing workloads and addressing common issues. Examples for needs that typically need to be met on a regional basis are e.g., data management and exchange and related capacity building.

Key Need 4: Parties should identify common needs related to climate data and information in their region, and work with neighbouring countries on a regional basis.

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 (particularly in the ocean and terrestrial domains). 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 committees 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. In 2009, the Executive Heads of all four sponsors of GCOS jointly urged countries to appoint GCOS National Coordinators[16] and/or establish GCOS National Committees.

Key Need 5: Parties are encouraged to establish effective institutional responsibilities for oceanographic and terrestrial observations on the national level.

Key Need 6: Parties should produce national plans on their climate observing, archiving and analysis activities that are encompassed by this Plan. This could be assisted by establishing National GCOS Coordinators and National GCOS Committees.

Reporting by the Parties[17] 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 Need 7: Parties are requested to submit information on their activities related to systematic observation of all ECVs as part of their national communications to the UNFCCC utilizing the Reporting Guidelines[18] approved by COP 13 in 2007.

3.2. Participation by all Parties

The UNFCCC COP recognizes the importance of systematic observation in developing countries, particularly for adaptation to climate change. There are many ways that systems can be improved, including, for example, through developed-country agencies working with organizations and personnel

[16] The Terms of Reference of GCOS National Coordinators are available at http://www.wmo.int/pages/prog/gcos/index.php?name=NationalActivities
[17] Reports are available through the UNFCCC Secretariat.
[18] See UNFCCC (2008): *Decision 11/CP.13 Reporting on global observing systems for climate*, FCCC/CP/2007/6/Add.2 http://www.wmo.int/pages/prog/gcos/documents/Decision_11-CP13.pdf

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, multi-governmental 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. This has happened to a limited degree, with some engagement of both additional national and donor support and by focussing on a small number of networks, but much more dedicated support and a broader perspective on all networks contributing to the GCOS is needed. Capacity building in the ocean and terrestrial domains is particularly challenging due to the widespread lack of institutional structures in developing countries.

The GCOS Cooperation Mechanism 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 Need 8: 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, by participating in the GCOS Cooperation Mechanism, and by contributing to the GCOS Cooperation Fund.

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.

The GCOS Regional Workshop Programme, implemented between 2000 and 2006 established a framework for interested nations (in developing countries and economies in transition) 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 have been developed and some elements of them have found support from member nations and/or donors for implementation.

Nevertheless, many of the priority projects included in the Regional Action Plans have not yet been implemented[19]. In addition to the continuing need for implementation of the existing projects in these plans, many projects may now need to be updated and/or refined to address current priority needs.

Key Need 9: Parties should continue to work on implementing the priority projects in the GCOS Regional Action Plans, and update and refine the projects contained in them as necessary.

4. Availability of Climate Data and Products

4.1. High-Quality Climate Data: Exchange and Access

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 internationally-recognized data centres (International Data Centres henceforth)[20] that are highly effective in: (i) actively collecting data, (ii) ensuring consistency and quality of the data, (iii) ensuring that adequate metadata are provided, (iv) being functional on a long-term basis, (v) maintaining effective user access and data dissemination mechanisms. These IDCs are a critical function and are supported on a voluntary basis by a number of Parties. Those Parties are encouraged to recognize the important role these Centres play and to ensure that they are effectively managed and well-supported on a long-term basis. The Plan also

[19] As noted in the Conclusions by SBSTA 30 (FCCC/SBSTA/2009/L.6) and GCOS (2009): *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008*, GCOS-129, WMO/TD-No. 1489, http://www.wmo.int/pages/prog/gcos/Publications/gcos-129.pdf

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

seeks to strengthen existing IDCs and encourage commitments for new Centres so all ECVs have an appropriate infrastructure.

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. The national reports to the UNFCCC on systematic observation should be taken as an opportunity to check whether these activities are undertaken to a satisfactory level.

Key Need 10: Parties should ensure regular and timely submission of climate data to International Data Centres for all ECVs.

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 and the IP-04 point 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 metadata 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 metadata.

4.2. 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 un-interrupted 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 Need 11: Parties need to ensure that their climate-observing activities which contribute to GCOS adhere to the GCMPs.

4.3. Data Stewardship and Management

Climate observations that are well documented, and have good metadata 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 metadata 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 Need 12: International standards for metadata for all ECVs need to be adopted and maintained by the Parties in creation and archiving of climate data records.

4.4. Products

Use of observations for policy and planning purposes depends on access to information beyond the basic observations. To meet the needs of all Parties for climate information, the global observing

system for climate must support the generation of 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. Such products need to be well documented and accompanied by information which helps users to assess their quality and applicability[21]. 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 needs of this Plan for all domains.

Key Need 13: 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 Need 14: 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.

5. Ensuring the Adequacy of Climate Observing 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.

Describing and understanding Earth system cycles, such as the water, carbon and energy cycle, generally requires knowledge of sets of ECVs and their variability in time and space, for example for the estimation and validation of fluxes. This requires an integrated view on these ECVs, sometimes across the domains (atmosphere, oceans, terrestrial) used in this Plan. Moreover, an individual variable often serves multiple application areas, or links with multiple cycles.

Some of the key domain-specific components merit highlighting in the following paragraphs.

5.1. Atmospheric Domain

Many atmospheric observing systems, including some satellite components, are relatively mature, having been in existence for several decades or more. Although generally established for purposes other than climate, the data that they have provided are an essential part of the current climate record. As a result, a basic requirement for the atmospheric domain is to ensure continuity of operation of the comprehensive atmospheric observing networks and systems, implementing improvements where required and ensuring full international data exchange. Ground-based networks and some space-based measurements provide in particular the basic observations of the surface climate variables that most directly impact on natural and human systems. These observations are needed to assess vulnerabilities and adaptive responses to climate change, and the surface networks that provide them need to be operated with a density of observation in space and time that is fit for this purpose. Reanalysis of the comprehensive and diverse observational record using data assimilation provides integrated products, and needs sustaining and developing because of its capability and potential for meeting widespread requirements for processed and reprocessed data.

---

[21] GCOS (2009): *Guideline for the Generation of Satellite-based Datasets and Products Meeting GCOS Requirements*, GCOS-128, WMO/TD-No. 1488, http://www.wmo.int/pages/prog/gcos/Publications/gcos-128.pdf

Baseline networks such as the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN) (subsets of the full WMO WWW/GOS surface and upper-air networks) and the WMO/GAW networks for greenhouse gases and ozone, plus related satellite observations such as provided for thirty years from microwave sounding, provide the basic observations for directly monitoring the climate system. Extension of the networks to cover all atmospheric ECVs and full operation including application of the GCMPs is a continuing fundamental requirement. As recently recognised by steps taken towards establishing a GCOS Reference Upper-Air Network (GRUAN), the system of comprehensive and baseline measurements needs to be complemented by a limited number of sites providing data to a high reference standard of measurement. There is also a corresponding need for sustained measurement of key variables from space to a reference standard. The unique value of historical satellite-based datasets, such as the 30-year record provided by the Advanced Very High Resolution Radiometer (AVHRR) should be fully exploited through coordinated and sustained reprocessing.

Key Need 14: Parties need to: (a) sustain and refine the comprehensive atmospheric in-situ and satellite-based observing systems, ensuring the provision of surface data adequate for assessing impacts and adaptive responses; (b) fully implement the baseline networks and systems and operate them in accordance with the GCMPs; (c) ensure timely and complete international exchange of data from both comprehensive and baseline networks; (d) establish the GRUAN network for reference upper-air measurements and a complementary system for reference measurements from satellites, and (e) support reanalysis and reprocessing activities.

Better observation of the water cycle is a general requirement for understanding and supporting the modelling and prediction of climate. Of the variables concerned, precipitation is of considerable additional importance because of the extent of its direct societal impact. Precipitation is, however, one of the most difficult quantities to observe to the extent needed to meet climate needs, because its physical nature makes reliable point measurement challenging, amounts can vary widely in space and time, and impacts themselves can depend sensitively on location and timing. There is thus a pressing need to develop and implement improved observation and estimation of precipitation, from local to global scale.

Key Need 16: Parties need to: (a) submit all national precipitation data, including hourly totals and radar-derived products where available, to the International Data Centres; (b) develop and implement improved methods for ground-based measurement of precipitation; (c) plan for sustained operation of a constellation of satellites providing data on precipitation, building on the system to be implemented in the Global Precipitation Measurement mission; and (d) support the continued development of improved global precipitation products.

Greenhouse gases and aerosols are the primary agents in forcing climate change. For the greenhouse gases, elements of the required in-situ networks are in place but extension and attention to calibration are needed. Also needed is assessment and development of missions for complementary observations of carbon dioxide and methane from space, placing emphasis on use of data from the resulting composite observing system to meet needs for improved estimation of surface fluxes. Aerosol is a complex variable and this Plan calls for development and implementation of a coordinated strategy to monitor and analyze the distribution of aerosol properties and precursor species. The strategy should address the definition of a baseline GCOS network or networks for in-situ measurements, assess the needs and capabilities for operational and research satellite missions, and propose arrangements for coordinated mission planning.

Key Need 17: Parties need to: (a) develop further the baseline network for key greenhouse gases; (b) utilize and refine existing networks to establish a global baseline network for aerosol optical depth; and (c) develop and implement coordinated and complementary strategies for long-term satellite measurements of carbon dioxide, methane and aerosols.

Measurements of total solar irradiance and the Earth radiation budget provide overall monitoring of the solar radiative forcing of climate and the net greenhouse effect within the atmosphere. Clouds strongly affect the radiation budget and provide the most uncertain feedbacks in the climate system. It is vital to maintain continuity of long-term records and resolve uncertainties in measurements and analyses of radiation and clouds. Cloud properties, including their link with aerosols, are of particular importance and there is a continuing need for research to improve their monitoring. Surface radiation

measurements over land are an important complementary observation and the baseline surface radiation network needs to be extended to achieve representative global coverage.

Key Need 18: Parties need to: (a) ensure the continued operation and analysis of satellite measurements of solar irradiance and the Earth radiation budget; (b) support research to improve current capabilities for monitoring clouds as a high priority; and (c) extend the network of supporting surface measurements.

5.2. Oceanic Domain

Substantial progress in implementing the IP-04 ocean domain recommendations has been made: the ice-free upper 1500 metres of the ocean are being observed systematically for temperature and salinity for the first time in history. Commitments to continuity of a number of critical ocean satellite sensors have been made.

However, most in situ observing activities continue to be carried out under research agency support and on research programme time limits; thus the financial arrangements that support most of the present effort are quite fragile.

There has been very limited progress in the establishment of national ocean or climate institutions tasked with sustaining a climate-quality ocean observing system. Thus, the primary Agents for Implementation for most in situ ocean observations and climate analyses remain the national and regional research organizations, with their project-time-scale focus and emphasis on principal investigator-driven activities.

Data sharing remains incomplete, particularly for tide gauges and biogeochemical ECVs. Data archaeology needs to continue. Although progress has been made on recovery of the ocean historical dataset, continuing efforts in data rescue, digitization and data sharing are needed.

Key Need 19: Parties need to: (a) designate and support national Agents for Implementation for implementing this system; (b) establish effective partnerships between their ocean research and operational communities towards implementation; and (c) engage in timely, free and unrestricted data exchange.

The ocean plays critical, but generally not obvious, roles in the fundamentally coupled ocean-atmosphere-land Earth climate system. The ocean varies strongly on interannual and decadal time scales, and will undergo much greater changes from these over the next few decades than will result from climate change over the same period. Sea level is a critical variable for low-lying regions; globally, it is driven by volume expansion or contraction due to changes in sub-surface ocean density, and by exchange of water between the oceans and other reservoirs, such as land-based ice, and the atmosphere. Developing confidence in forecasts of oceanic variability and change will require accurate datasets over the entire world ocean. The composite near-surface and sub-surface ocean observing networks described here, include global monitoring of certain ECVs where this is feasible. In some other cases, monitoring of ECVs depends on observations from reference stations or sites, or in case of sub-surface ocean carbon, nutrients and tracers, on repeat ship-based surveys. A variety of actions are necessary to sustain the progress made and to extend the capabilities of these networks.

Key Need 20: Parties need to ensure climate quality and continuity for essential ocean satellite observations of ocean surface ECVs: wind speed and direction, sea-surface temperature, sea-surface salinity, sea level, sea state, sea ice, and ocean colour

Key Need 21: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) an enhanced network of tide gauges; (b) an enhanced surface drifting buoy array; (c) an enhanced tropical moored buoy network; (d) an enhanced voluntary observing ship network including salinity measurements; (e) the surface reference mooring network, (f) a globally-distributed plankton survey network, and (g) international coordination of coral reef monitoring.

Key Need 22: 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) ship of opportunity trans-oceanic temperature

sections; and (d) the Tropical Moored Buoy and reference mooring networks referred to in Key need 21 above.

A number of important research planning and subsequent implementation actions deal with the establishment of an observing network for the partial pressure of carbon dioxide (pCO2), the measurement of the state and change of carbon sources and sinks in the oceans, and the measurement of the state and change of marine biodiversity and key ocean habitats.

Continuing climate research and technology programmes for the oceans are needed to enhance the efficiency and effectiveness of observing strategy, 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, and for improved understanding of ocean biogeochemistry and ecosystems. Continued research is also needed for improving the estimates of uncertainty, for understanding the mechanisms of climate change, to improve understanding of the impacts of climate change and variability, and to underpin decisions on adaptation to climate change.

Key need 23: Parties need to support research and pilot project actions to develop global sustained observing capability for biogeochemical and ecosystems ECVs: carbon dioxide partial pressure, ocean acidity, nutrients, oxygen, tracers, marine biodiversity and habitat properties.

5.3. Terrestrial Domain

Increasing significance is being placed on terrestrial data for estimating climate forcing and better understanding of climate change and variability, as well as for impact and mitigation assessment. The recognition of this has led to substantial progress in a number of areas in the terrestrial domain. There has also been significant progress in defining internationally accepted standards for the terrestrial ECVs, forming the basis of an international framework for the development and promulgation of such standards in all countries. Progress in establishing institutional support for in situ networks has been slow, leading to networks that are still poorly coordinated and harmonized, despite the considerable effort of the research community to keep them running.

This Plan proposes actions designed to achieve an initial coordinated and comprehensive observational programme for all terrestrial ECVs. Given the highly-variable nature of the land surface, most terrestrial ECVs have a particularly strong satellite component essential for global coverage, whereas in-situ measurements provide key and detailed information at particular sites. A few terrestrial ECV depend by their nature on in-situ observations. This includes permafrost, soil carbon, river discharge and groundwater.

Hydrological variables are of critical societal importance. Many are observed but not well exchanged for the purposes of assessing global climate change. The Plan proposes specific actions to continue with the implementation of the global networks for hydrology (including specific lakes and rivers components), and to develop the emerging networks for groundwater and soil moisture. Observations of the terrestrial cryosphere – glaciers, ice sheets and for permafrost – and of their changes over time are equally important.

Key Need 24: Parties are urged to: (a) fill the identified gaps in the global networks for terrestrial hydrology and cryosphere, and maintain those networks; ((b) provide support for the designated International Data Centres; and (c) submit current and historical data to the International Data Centres.

In the Terrestrial Domain it is essential to obtain global products for most ECVs from a range of satellite sensors supported by in-situ measurements. A coordinated in situ reference network is needed for: 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.

Satellite instruments relevant for terrestrial ECVs range from high-resolution optical spectrometers and complex multi-spectral multi-angular imagers to radar and lidar systems. Many of these instruments

are currently flying on research-type missions, and plans for continuity are needed to ensure sustained terrestrial observations.

Monitoring land-based carbon stocks and their variability is one of the critical tasks that a combination of satellite and in-situ observations needs to meet. For example, in-situ observations of carbon-related ECVs are critical, for example the measurement of carbon content of soils, as well as important for the calibration and validation of satellite-derived land-cover-related products.

Key Need 25: Parties are urged to support the sustained operation of satellite instruments and the sustained generation of the satellite-based product relevant for terrestrial ECVs.

Key Need 26: Parties are urged to develop a global network of terrestrial calibration and reference sites to monitor soil and land-cover-related variables, key biomes and to provide the observations required in the calibration and validation of satellite data.

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 global datasets.

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.