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**SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE**

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**Copenhagen, 7–18 December 2009\***

**Item 6 of the provisional agenda**

**Research and systematic observation**

## **The Global Climate Observing System implementation plan: a provisional update including provisional cost estimates**

### **Submission from the secretariat of the Global Climate Observing System**

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its twenty-third session, requested the secretariat of the Global Climate Observing System (GCOS) to provide a comprehensive report at its thirtieth session on progress with the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (hereinafter referred to as the GCOS implementation plan), in addition to the regular reporting requested by the Conference of the Parties (COP) in decision 5/CP.10 (FCCC/SBSTA/2005/10, para. 94).
2. At its thirtieth session, the SBSTA expressed its appreciation for the report on progress with the GCOS implementation plan that was submitted by the GCOS secretariat in response to the above mandate. It noted that an updated GCOS implementation plan that takes into account emerging priorities, such as the need for data for adaptation, may assist in continuing progress with GCOS implementation. It therefore invited the GCOS secretariat to prepare, under the guidance of the GCOS Steering Committee, an update of the GCOS implementation plan before its thirty-third session, including a breakdown of costs involved (FCCC/SBSTA/2009/3, paras. 57–58).
3. At the same session, the SBSTA also invited the GCOS secretariat to provide a provisional updated implementation plan in conjunction with a provisional estimation of costs, before COP 15, and requested the secretariat to make this information available as a miscellaneous document (FCCC/SBSTA/2009/3, para. 58). In response to this request, the GCOS secretariat has submitted the provisional updated implementation plan contained in this document.
4. In accordance with the procedure for miscellaneous documents, this submission is attached and reproduced\*\* in the language in which it was received and without formal editing.

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\* Exact dates within the sessional period are subject to confirmation.

\*\* This submission has been electronically imported in order to make it available on electronic systems, including the World Wide Web. The secretariat has made every effort to ensure the correct reproduction of the text as submitted.

**FCCC/SBSTA/2009/MISC.12**

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**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**

## Editorial Note:

This draft 2010 Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC<sup>1</sup> was compiled based on an expert meeting in early February 2009, and subsequent iterations by a task team under leadership of Paul Mason (former Chair of the GCOS Steering Committee) with participation by GCOS panel chairs and GCOS, GOOS and GTOS secretariat staff. Further comments to earlier versions of this draft were received by GCOS sponsors and other GCOS partners. The draft responds to a request by Parties to the UNFCCC expressed at the June 2009 session of SBSTA.

The reader of this draft should note that:

- the document will be subject to a two-month web-based open review by the community from November 2009 until January 2010; it will be improved based on the comments received, and is planned to be finalized by April 2010;
- the estimated costs for undertaking the recommended Actions in this Plan are provisional estimates and will be reviewed in the light of comments received. The costs given are:
  - annual;
  - additional costs on top of the costs of existing networks, systems and activities that are required to meet climate needs, but that are in many cases not specifically designed for climate purposes;
  - including costs for continuing some existing networks, systems and activities undertaken for research purposes with no plans for continuity;
- rough estimates of needed expenditure by Annex-I Parties (developed countries) and expenditure needed in non-Annex-I Parties (mostly developing countries) have been undertaken.

The GCOS Steering Committee at its 17th session endorsed the release of this draft for submission to the UNFCCC secretariat and for open review, and will consider the document for approval once comments have been received.

Your feedback (to [gcospo@wmo.int](mailto:gcospo@wmo.int)) would greatly assist us in improving this document.

The GCOS Steering Committee (October 2009)

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<sup>1</sup> The 2004 version of this Plan is available at [http://www.wmo.int/pages/prog/gcos/Publications/gcos-92\\_GIP.pdf](http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf).

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## 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<sup>2</sup>. 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<sup>3</sup>, namely that:

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

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<sup>2</sup> 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](http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf) (completed by invitation of COP 9, 2003)

<sup>3</sup> 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<sup>4</sup> (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<sup>5</sup>, 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;

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<sup>4</sup> <http://www.earthobservations.org>

<sup>5</sup> 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-04 and '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
<b>Atmospheric</b> (over land, sea and ice)	<b>Surface<sup>6</sup>:</b> Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. <b>Upper-air:</b> Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance). <b>Composition:</b> Carbon dioxide, Methane, and other long-lived greenhouse gases. Ozone and Aerosol, supported by their precursors <sup>7</sup>
<b>Oceanic</b>	<b>Surface<sup>8</sup>:</b> 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, <b>Sub-surface:</b> Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers, Phytoplankton; Marine biodiversity and habitat properties <sup>9</sup>
<b>Terrestrial</b>	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 <sup>9</sup>

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<sup>10</sup>. 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 30<sup>th</sup> 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<sup>11</sup> (mostly developing countries) and by Annex-I Parties (developed countries).

<sup>6</sup> Including measurements at standardized, but globally varying heights in close proximity to the surface

<sup>7</sup> NO<sub>2</sub>, SO<sub>2</sub>, HCHO and CO in particular

<sup>8</sup> Including measurements within the surface mixed layer, usually within the upper 15m

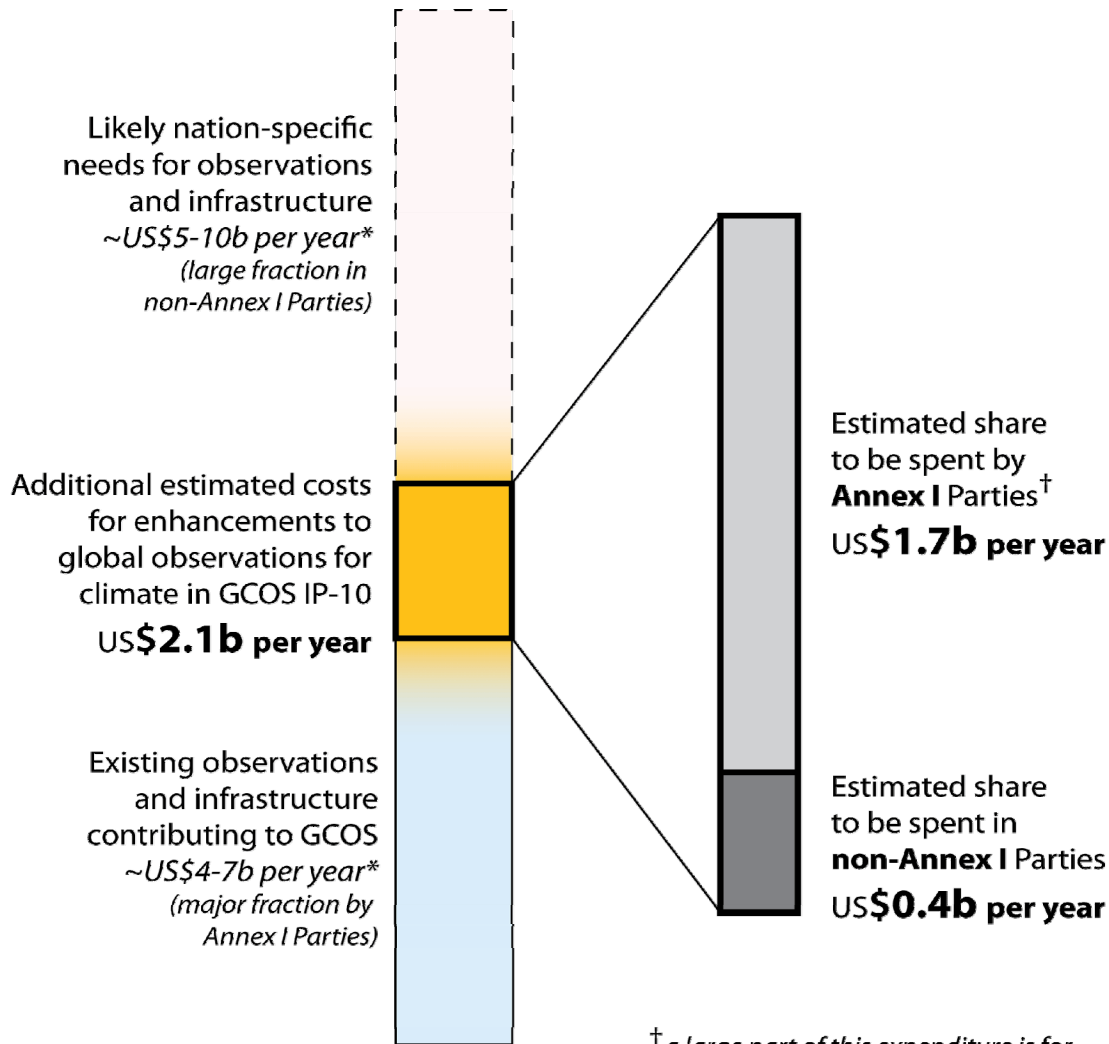
<sup>9</sup> At selected sites and areas (e.g., coral reefs; boreal and tropical forest areas)

<sup>10</sup> These funds are not necessarily secured in the future.

<sup>11</sup> 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.



\* rough estimates, not addressed in this Plan, not necessarily secured

<sup>†</sup> a large part of this expenditure is for networks and systems in extra-territorial areas (e.g., satellite, open-ocean, polar observing systems) for the benefit of all Parties

**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 <sup>12</sup>	5	0	0	0	5
Total Number of Actions	24	33	41	39	137
<b>Estimated total cost<sup>13</sup></b>	<b>260</b>	<b>810</b>	<b>680</b>	<b>360</b>	<b>2110</b>
Estimated share of total to be spent in non-Annex-I Parties <sup>14</sup>	160	110	100	60	430
Estimated share of total to be spent by Annex-I Parties <sup>15</sup>	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

<sup>12</sup> Costs covered in domain actions.

<sup>13</sup> 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).

<sup>14</sup> See previous footnote. Appendix 6 lists all non-Annex-I Parties to the UNFCCC.

<sup>15</sup> 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<sup>16</sup> 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<sup>17</sup> 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<sup>18</sup> 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

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<sup>16</sup> The Terms of Reference of GCOS National Coordinators are available at <http://www.wmo.int/pages/prog/gcos/index.php?name=NationalActivities>

<sup>17</sup> Reports are available through the UNFCCC Secretariat.

<sup>18</sup> 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](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<sup>19</sup>. 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)<sup>20</sup> 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

<sup>19</sup> 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>

<sup>20</sup> 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<sup>21</sup>. 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.

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<sup>21</sup> 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 (pCO<sub>2</sub>), 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.

# **Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (Provisional 2010 Update)**

**DRAFT v1.0**

**28 October 2009**

## **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.

### **1.2. Background**

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 Plan (IP-04) which was published in 2004<sup>22</sup>. The IP-04 was prepared at the request of the Ninth Session (2003) of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) (see Appendix 2). The IP-04 drew on the views of the Parties on the Second Report on the Adequacy of Global Observing Systems for Climate in Support of the UNFCCC<sup>23</sup> ('Second Adequacy Report') submitted by GCOS to SBSTA at its eighteenth session (June 2003).

The purpose of this IP-10 is to provide an updated set of actions required to implement and maintain a comprehensive global observing system for climate that will fulfil the commitments of the Parties under Articles 4 and 5 of the UNFCCC and will meet the needs of Parties for climate observations in support of the objectives of the Convention. This revised Plan updates the Actions in IP-04 taking account of progress in science and technology, increased emphasis of the Convention on adaptation, enhanced efforts to optimize mitigation measures, and the need for improved predictions of climate change. It focuses on the timeframe 2010-2015.

The Global Climate Observing System (GCOS) Steering Committee and Secretariat, in consultation with the GCOS sponsors and component observing systems, have prepared this Plan, 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). The revision recognises the progress made over the first five years of the plan, and outlined in the GCOS Progress Report 2004-

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<sup>22</sup> 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](http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf)

<sup>23</sup> 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).

2008<sup>24</sup>. It also considers perspectives arising from the 4th Assessment Report of the IPCC and a related joint GCOS-WCRP-IGBP workshop held in 2007<sup>25</sup>, 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 some new objectives and requirements.

In preparing this IP-10, the GCOS Steering Committee, Panels and Secretariat have:

- 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 Group on Earth Observations (GEO) in developing their broader Work Plans for the implementation of GEOSS;
- Identified implementation priorities, resource requirements and funding options;
- Included indicators for measuring progress in implementation.

The 2003 Second Adequacy Report provided a basic framework for an implementation plan through its overarching conclusions and its multiple findings. It called for:

- Global coverage of observations;
- Free and unrestricted exchange and availability of observations of the Essential Climate Variables (ECVs, see Table 1) required for global-scale climate monitoring in support of the UNFCCC;
- 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 4).

This Plan not only updates the material provided in the IP-04, but also to a limited extent the Systematic Observation Requirements for Satellite-based Products for Climate (GCOS-107, September 2006), the 'Satellite Supplement' to the IP-04. The IP-10 focuses on the next five years (see section 3.4), the actions in the IP-04 which have been completed have been removed, and all actions have been reviewed and updated taking current circumstances into account.

### **1.3. Purpose of this Plan – Essential Climate Variables**

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

- 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;
- Ensure the availability of information important in impact assessment and adaptation, and to the assessment of risk and vulnerability including the characterization of extreme events.

Sustained observations of the ECVs (see Table 3) is both technically feasible and cost-effective (see section 2.3 on 'Criteria used to Assign Priority'). The list of ECVs is evolving slowly as scientific 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

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<sup>24</sup> GCOS (2009): *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC*, GCOS-129, August 2009, <http://www.wmo.int/pages/prog/gcos/Publications/gcos-129.pdf>

<sup>25</sup> 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>

terrestrial), and recognizes the role of precursors in forming ozone and aerosols. Additionally, for clarity, some variables have a different name: 'ice sheets' were previously included in 'glaciers and ice caps' in the IP-04, and 'ocean acidity' and 'carbon dioxide partial pressure,' whose measurement allows characterization of ocean carbon content, replace 'ocean carbon' in the IP-04. Actions in the 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.

**Table 3: Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements**

Domain	Essential Climate Variables
<b>Atmospheric</b> (over land, sea and ice)	<p><b>Surface<sup>26</sup>:</b> Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.</p> <p><b>Upper-air:</b> Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).</p> <p><b>Composition:</b> Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol, supported by their precursors<sup>27</sup></p>
<b>Oceanic</b>	<p><b>Surface<sup>28</sup>:</b> 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</p> <p><b>Sub-surface:</b> Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers, Phytoplankton, Marine biodiversity and habitat properties<sup>29</sup></p>
<b>Terrestrial</b>	<p>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<sup>28</sup></p>

Observations of the ECVs are required for the purposes of monitoring and understanding climatic variations, detecting and attributing trends and validating and improving the models used for climate prediction. Some of the surface and near-surface ECVs are needed to study impacts and develop adaptive and mitigatory responses to climate change, for example the assessment of extreme rainfall events or the occurrence of storms.

Vertical profile information is required for most of the upper-air meteorological and atmospheric composition variables. Regions of key interest differ from variable to variable. Vertical depth profiles in the oceans, ranging from the skin and surface mixed layer ("surface") to deeper layers and the deep oceans ("sub-surface") are required for a range of ocean ECVs.

In addition to climate needs, observations of most of the ECVs have many more important application areas: for example, all standard meteorological variables are fundamental to support numerical weather forecasting; tropospheric ozone, aerosols and their precursors are among the determinants of tropospheric air quality; vegetation and land-cover maps are used for forestry and ecology/biodiversity assessments. Each application has differing accuracy and spatial/temporal resolution requirements but an appropriately sustained composite observing system for all ECVs would meet the needs of many other GEOSS applications and Societal Benefit Areas.

<sup>26</sup> Including measurements at standardized, but globally varying heights in close proximity to the surface

<sup>27</sup> NO<sub>2</sub>, SO<sub>2</sub>, HCHO and CO in particular

<sup>28</sup> Including measurements within the surface mixed layer, usually within the upper 15m

<sup>29</sup> At selected sites and areas (e.g., coral reefs; boreal and tropical forest areas)

Although the ECVs themselves are largely defined in terms of geophysical and geochemical variables, essential data relating to them may encompass measurements of quantities that relate to one or more ECVs. Examples are radiances measured from space that provide joint information on temperature, water vapour, aerosol and trace-gas concentrations, and bending angles from GPS radio occultation that provide information on temperature and water vapour. Such data are important in their own right as they may be used directly for model validation and change detection, and they may be the variable assimilated in reanalysis systems, and for which feedback on data quality is provided by reanalysis.

The ECVs are generally based on an intermediate dataset called a "Fundamental Climate Data Record" defined as follows: a Fundamental Climate Data Record (FCDR) denotes a long-term data record, involving a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of homogeneous products providing a measure of the intended variable that is accurate and stable enough for climate monitoring. FCDRs include the ancillary data used to calibrate them.

ECV products, which denote values or fields of geophysical variables derived from FCDRs, are sometimes generated by analyzing datasets from one or several data sources, sometimes obtained by blending satellite observations and in situ data, and using physical model frameworks (other documents use the term "Thematic Climate Data Record" (TCDR)<sup>30</sup> for such products).

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, the system 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 (metadata) is absolutely essential, as are historical and palaeoclimatic records to set the context for the interpretation of trends and variability.

#### **1.4. Earth system cycles and the structure of this document**

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 of these ECVs, sometimes across the domains (atmosphere, oceans, terrestrial) used in this Plan. Moreover, an individual variable often serves multiple application areas, such as within the nine GEOSS Societal Benefit Areas, or links with multiple cycles. To simplify the presentation, this document deals with each variable individually and assigns them to a single domain (Atmosphere: section 4; Oceans: section 5; Terrestrial: section 6) even though they may also be relevant to another domain. The approach taken is practical but it has been recognized that some the important links between the domains and within the cycles and application areas may be obscured. However the various links among ECVs, and of ECVs with Earth system cycles have been considered in developing this Plan.

## **2. The Strategic Approach to Implementation**

### **2.1. Basis**

As in the IP-04, this IP-10 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 implementation of this Plan is fully dependent on national efforts, success will be achieved only through internationally-coordinated action. Thus, 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:

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<sup>30</sup> For further discussion of the terms "Fundamental Climate Data Records (FCDRs)" and "Thematic Climate Data Records (TCDRs)" see e.g. National Research Council (2004): *Climate Data Records from Environmental Satellites*, The National Academies Press, Washington D.C., USA, 150pp.

- 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;
  - Establishment and adherence to internationally accepted standards for observations;
- Note of needs for national and regional-scale data for those variables that have a direct impact on adaptation and impacts;
- 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.

For the most part, observations are made within the context of designated global observing networks consisting of stations and systems that have been designated by countries for international data exchange as part of formally established international global observing systems. These include, for example, the Regional Basic Climatological Networks (RBCN) and Regional Basic Synoptic Networks (RBSN) of the Global Observing System (GOS) of the WMO World Weather Watch. These various networks serve many applications, of which climate is but one. For simplicity, this Plan recognises four categories of networks that provide observations specifically for climate purposes. These are:

- **Global Reference observing 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. These consist of formally identified GCOS Reference Networks such as the GCOS Reference Upper Air Network (GRUAN);
- **Global Baseline observing networks**, which involve a limited number of selected locations that are globally distributed and provide long-term high-quality data records of key global climate variables, as well as calibration for the comprehensive and designated networks. These are networks that have been formally identified as baseline climate networks by the GCOS Steering Committee and include, for example, the GCOS Surface Network (GSN), the GCOS Upper Air Network (GUAN), the GCOS Total Ozone and Ozone Profile Networks and the Baseline Surface Radiation Network;
- **Comprehensive 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. These include national climate reference networks, comprehensive national climate networks and national and regional networks which are operated primarily for non-climate reasons but which also provide important observations for climate purposes;
- **Ecosystem monitoring sites**, where long term observations of ecosystems and biomes are made in order to study climate impacts. To identify climate impacts, these measurements need to be made together with observations of the local physical climate and changes in surrounding environment such as land and water use.

In the text, linkages of those four categories with designated global networks are noted.

Although an ultimate goal, it is presently unrealistic to attempt to establish and operate networks at all levels for all climate variables. Consistent with the most pressing needs for adaptation, i.e. in the case of observations that have high direct climate impact, such as rainfall, attention is given to all relevant networks, including comprehensive networks. For other observations, critical mainly to science and understanding, attention is generally given to ensuring the implementation of baseline and reference networks, supplemented where possible by detailed global coverage from satellites.



The GCMPs and other related guides, such as the WMO Guide to Climatological Practices (WMO-No. 100), 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 been formally adopted or agreed by the UNFCCC, WMO, CEOS and other bodies (see Appendix 4).

## **2.2. Agents for Implementation**

GCOS is a composite of contributions from observing systems from a broad range of planned and existing programmes, often with observing mandates different from the requirements for climate. The coordination and guidance provided to these systems by this Plan 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, geophysicists, glaciologists, physicists, 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 observing systems contributing climate observations to GCOS include the established, largely domain-based global observing systems operated through the GCOS sponsoring organizations, including the IOC-led Global Ocean Observing System (GOOS), the FAO-led Global Terrestrial Observing System (GTOS), the World Meteorological Organization (WMO) Integrated Global Observing System (WIGOS) (the WMO Global Observing System (GOS), the Global Atmosphere Watch (GAW), and various WMO-sponsored hydrological networks), and the full suite of operational and experimental Earth observing satellite systems. Appendix 5 lists the main components and 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. These are collectively identified as the "Agents of Implementation" of GCOS.

The international research community contributes largely through the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) and DIVERSITAS, 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 planning and implementation of GCOS.

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<sup>31</sup>. Thus, it is the Parties themselves, through the various national agencies of Member countries of the GCOS sponsors 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 analyses and products are undertaken by national and 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.

Implementation depends upon close cooperation between many different organizations and agencies with complementary responsibilities. With the principal objective to enhance international coordination of Earth observation and to emphasize the importance of Earth observation for decision-making, the 1st Earth Observation Summit in 2003 established the Group on Earth Observations (GEO), with the aim to implement the Global Earth Observation System of Systems (GEOSS) within ten years. The

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<sup>31</sup> In some cases 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)).

GEOSS 10-Year Implementation Plan, adopted by GEO members in February 2005 and organized along nine 'Societal Benefit Areas' (SBAs), describes a strategy for coordinated comprehensive and sustained observations of the Earth system in order to improve monitoring of the changing state of the planet, increase understanding of complex Earth processes, and enhance the prediction of the impacts of environmental change, including climate change. Implementation of GEOSS also includes end-user products for nine SBAs – Weather, Climate, Water, Agriculture, Disasters, Biodiversity, Ecosystems, Energy, and Health. Further, the GEOSS strategy foresees building a comprehensive data architecture for a system of observing systems. GEO has been established outside the UN system; its membership includes 79 member nations and the European Commission as of 31 July 2009. It also has the participation of a number of other participating organizations. GEO 'Communities of practice' have been established for Societal Benefit Areas. The Integrated Global Observing Strategy (IGOS) Themes and their reports, which have provided valuable community statements of needs, have been incorporated into GEO and most of them continue to inform the process as GEO Communities of practice. Provisions for enhanced coordination of data exchange and access are being put in place. The GCOS has been identified as the climate observing component of GEOSS and this plan is intended to ensure that the observing system partners within GEO are fully aware of the climate requirements and that those climate requirements are met.

### **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 the Plan 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. As GCOS implementation progresses, continued 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**

Satellite remote sensing systems that provide global coverage and are well calibrated are being increasingly used for global observations of climate and become more important as longer time series are becoming available. 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 surface based 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 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 comprehensive 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, the GCOS is being implemented primarily through the setting of climate-relevant standards and requirements for its main component observing systems, e.g., WMO Integrated Global Observing System (WIGOS), 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, serve as major contributors to GCOS, often through some straightforward, operational changes such as providing adequate metadata, 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. These analyses recognise the inter-relationships between variables and the errors in each involved variable. 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 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 they 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 mainly in Europe, Japan and the USA, 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 and eventually fully coupled atmospheres-ocean-terrestrial 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 proxy reconstructions of past climates using 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 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 having developed country agencies work with organizations and personnel from developing countries; the donation of equipment, the training of personnel, etc. The GCOS Regional Workshop Programme, noted in section 0 below, constituted a major effort that the GCOS Secretariat undertook at the invitation of the UNFCCC COP to “identify the capacity-building needs and funding required in developing countries to enable them to collect, exchange and utilize data on a continuing basis in pursuance of the Convention.”<sup>32</sup> The Second

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<sup>32</sup> COP Decision 5/CP.5, November 1999.

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 deliberations at UNFCCC SBSTA-17 (New Delhi, 2002), the GCOS Cooperation Mechanism (GCM) was 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 (baseline) elements of the global climate observing system. Addressing such needs supports the requirements of the UNFCCC, IPCC, and other GCOS users. To do so is especially important to developing countries, and, in particular, to least-developed countries and small island developing states. The GCM 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 GCM is intended to address priority needs in atmospheric, oceanic, and terrestrial observing systems for climate, including data rescue, analysis and archiving activities. However, the activities that it has funded to date have been mainly in the atmospheric domain. It is intended to complement, and work in cooperation with, existing funding and implementation mechanisms (e.g., the 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, in particular, support capacity-building. The success of the mechanism will depend critically upon receiving adequate resources for both technical programme management and specific network needs.

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 of the data and products to societal issues, 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 the GCOS. For example, the collocation of observing facilities, as appropriate, at stations or observatories in the various reference and baseline networks promotes capacity building. 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 needs of the UNFCCC.

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, or
- External metrics such as national reports on systematic observation of the climate system to UNFCCC, regular assessments by the IPCC, evaluations from the scientific community (e.g., WCRP), inputs from monitoring centres for GCOS networks and component networks, inputs from the internationally-designated data and archive centres<sup>33</sup>.

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<sup>33</sup> See Table 9, and Table 13.

The further development of techniques and processes to adequately monitor all observational data streams for time dependent biases and the detection of systematic errors 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 estimated costs for implementing Actions in this Plan (Actions are given in sections 3 to 6 within boxed text) are 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<sup>34</sup>. 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.

Cost estimates in this Plan include the costs of augmenting existing systems in support of climate needs, the transition of systems from research to operations and costs for new systems needed to satisfy climate needs. For example, the cost for a weather satellite and its ground segment are not considered; only the extra cost to make this satellite 'climate-worthy' is counted. The cost for something entirely new required for climate that is not part of current plans/budgets is fully counted (this applies to many of the ocean and terrestrial domain Actions).

This Plan includes 137 Actions, 24 of which address GCOS-wide common over-arching and cross-cutting issues, 33 are actions specifically addressing the atmospheric domain, and 41 and 39 actions focus on the oceanic and terrestrial domains, respectively. In this Plan, costs are estimated in categories ranging from less than 1 million (M) USD, 1-10M USD, 10-30M USD, 30-100M USD to 100-300M US dollars (USD) per year. The costs for each Action in this Plan have been estimated using these cost categories.

Table 2 summarizes the costs of undertaking all Actions proposed in this Plan detailed by cross-cutting, atmospheric, oceanic and terrestrial domains, using average values<sup>35</sup> for each costing. Network costs noted are usually spread across many nations, and costs associated with individual facilities are often borne by one nation or a group of nations with specified cost sharing. In addition to cost estimates for Actions, SBSTA at its 30<sup>th</sup> session asked GCOS to provide a breakdown of those cost estimates "by region, 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 for enhancements needed to be spent in non-Annex-I Parties<sup>36</sup> (mostly developing countries) and by Annex-I Parties (developed countries).

A breakdown of costs per Action 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.

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<sup>34</sup> These funds are not necessarily secured in the future.

<sup>35</sup> 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).

<sup>36</sup> Appendix 6 lists all Annex-I and non-Annex-I Parties to the UNFCCC.

### 3. Over-Archiving/Cross-Cutting Actions

#### 3.1. Planning, Reporting and Oversight

##### 3.1.1. International Planning

The individual component observing 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 5). 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 invited to review and update their plans in light of this document in order to ensure they better serve the needs of the UNFCCC.

**Who:** International and intergovernmental organizations.

**Time-Frame:** Inclusion in plans by 2011 and continuing updates as appropriate.

**Performance Indicator:** Actions incorporated in plans

**Annual Cost Implications**<sup>37</sup>: 1-10M USD (10% in non-Annex-I Parties)

##### 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. 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 committees<sup>38</sup> 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.

In 2009, the Executive Heads of all four GCOS Sponsors advocated the establishment of GCOS National Coordinators and GCOS National Committees. The Sponsors will continue to emphasize the need for both their developed and developing country Members to undertake national coordination and planning for systematic climate observations where this is not currently being undertaken; and to produce and update national plans on a regular basis that indicate their contributions to the global observing system for climate, taking into account the actions included in this Plan.

##### **Action C2 [IP-04 C2]**<sup>39</sup>

**Action:** Designate national coordinators and/or committees, achieve national coordination, and produce national plans for contributions to the global observing system for climate in the context of this Plan.

**Who:** Parties, through the national representatives to GCOS Sponsor Organizations and designated GCOS National Coordinators.

**Time-Frame:** Urgent and ongoing.

**Performance Indicator:** Number of GCOS National Coordinators and/or national coordination committees in place.

**Annual Cost Implications:** 10-30M USD (70% in non-Annex-I Parties)

Efforts to enhance regional planning for the collection, processing and archiving of climate observations need to continue, as these efforts help to share the workload across many nations. Regional structures can also be effective mechanisms for building awareness, identifying needs, undertaking capacity building, and capturing resources.

<sup>37</sup> See section 2.2 (Executive Summary) and section 2.8 for cost definitions.

<sup>38</sup> The GCOS Steering Committee has developed guidelines for such functions. See <http://www.wmo.int/pages/prog/gcos/index.php?name=nationalactivities>

<sup>39</sup> Reference is made to corresponding (not necessarily identical, often follow-on) Actions in the IP-04, so they exist.

The GCOS Regional Workshop Programme established a framework for interested nations to work together to optimize their networks and identify both national and GCOS network needs in each of the ten regions covered by the Programme. Regional Action Plans (RAPs), the principal output of these workshops, have been developed, and some elements of the Plans have been supported by member nations and/or donors for implementation. The workshop programme was completed in 2006. However, despite repeated calls by the COP to Parties in a position to do so to support the implementation of the projects contained in the RAPs, lack of funding has restricted the number of projects that have been implemented to date. Moreover, some of the earlier Plans developed are now becoming dated. These need to be brought up to date to take account of actions already implemented but, more importantly, to emphasize continuing needs and to reassess current regional priorities.

Pending the availability of funding, the GCOS Steering Committee and Secretariat will continue to seek to facilitate the implementation of the Regional Action Plans, for example, through working with regional partners and donor organizations to organize implementation strategy meetings. One such meeting, which was held in Belize in January 2009, may serve as a model for other regions, since it brought together representatives of regional climate organisations, funding agencies, and countries with a commitment to improved climate observations in the Central America/Caribbean region to work out a RAP implementation strategy. A more ambitious and wider ranging activity that the GCOS Secretariat had a role in initiating to facilitate RAP implementation is the Climate for Development in Africa Programme (ClimDev Africa). This programme, which is expected to get underway in the second half of 2009, should lead to substantial climate observing improvements in Africa, among other things. In addition, the GCOS Secretariat will use the GCOS Cooperation Mechanism (see section 2.6 and 3.3) and other capacity-building programmes in an effort to match available funding with specific Regional Action Plan projects.

### **Action C3**

**Action:** Review the projects contained in RAPs for consistency with this Plan and update and revise the RAPs as necessary.

**Who:** Regional organizations and associations in cooperation with the GCOS Secretariat and the bodies responsible for the component observing systems.

**Time-Frame:** 2011.

**Performance Indicator:** Implementation strategy meetings held and number of RAP projects implemented.

**Annual Cost Implications:** 1-10M USD (90% in non-Annex-I Parties)

### **3.1.3. National Reporting**

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 the global observing system for climate. Updated guidelines<sup>40</sup> for such reporting, consistent with the IP-04, were endorsed by the UNFCCC COP-13 in 2007 (decision 11/CP.13). 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 these guidelines.

#### **Action C4 [IP-04 C4]**

**Action:** Report to the UNFCCC on systematic climate observations using current guidelines.

**Who:** Parties with the UNFCCC.

**Time-Frame:** Conforming with UNFCCC guidelines

**Performance Indicator:** Number of Parties reporting within specified timeframes.

**Annual Cost Implications:** 1-10M USD (70% in non-Annex-I Parties)

### **3.1.4. National Implementation**

Beyond planning and reporting, it is essential to initiate specific processes to ensure progress on the actual implementation of the plans. Sections 4, 5 and 6 make detailed suggestions for the

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<sup>40</sup> <http://www.wmo.int/pages/prog/gcos/index.php?name=unfcccguidelines>

implementation in the different domains. As noted earlier, because almost all actions ultimately occur at the national level, 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 the Plan up to date. The GCOS Secretariat will therefore continue to report regularly to the UNFCCC on the status of implementation.

**Action C5 [IP-04 C5]**

<p><b>Action:</b> Maintain oversight of implementation of national plans for systematic climate observations and products and report on progress. <b>Who:</b> The GCOS Steering Committee and Secretariat on behalf of the GCOS Sponsors. <b>Time-Frame:</b> Ongoing. <b>Performance Indicator:</b> Measurable progress in implementation of those components of GCOS which serve the needs of the UNFCCC. <b>Annual Cost Implications:</b> 1-10M USD (Mainly by Annex-I Parties)</p>
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### 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. The GCOS Secretariat will, with the agreement of the involved research entities and at the appropriate time, work with the relevant international programmes and their Members to help ensure the sustained operation of essential research networks and systems for the ECVs.

The Technical Commissions of WMO and the Intergovernmental Oceanographic Commission (IOC), provide overall guidance and coordination on the implementation of their operational networks. It is vital for these Technical Commissions 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 C6 [IP-04 C7]**

<p><b>Action:</b> Ensure an orderly process for sustained operation of research-based networks and systems for ECVs. <b>Who:</b> All organizations operating component networks of GCOS <b>Time-Frame:</b> Continuous. <b>Performance Indicator:</b> Number of sustained networks and systems. <b>Annual Cost Implications:</b> &lt;1M USD (10% in non-Annex-I Parties)</p>
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**Action C7 [IP-04 C8]**

<p><b>Action:</b> Ensure all climate observing activities adhere to the GCMPs. <b>Who:</b> Parties and agencies operating observing programmes. <b>Time-Frame:</b> Continuous, urgent. <b>Performance Indicator:</b> Extent to which GCMPs are applied. <b>Annual Cost Implications:</b> Covered in domains.<sup>41</sup> See Action C9 for satellite component.</p>
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<sup>41</sup> 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). Much more support to the GCOS Cooperation Fund as a means to assist developing countries to improve their climate observing networks is needed, and, for that purpose, more developed-country Parties should become contributing members of the Mechanism. In addition, the GCOS Secretariat 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 C8 [IP-04 C9]

**Action:** Support the implementation of the global observing system for climate in developing countries and countries with economies in transition through membership in the GCOS Cooperation Mechanism and contributions to the GCOS Cooperation Fund.

**Who:** Parties (Annex-I), through their participation in multinational and bilateral technical cooperation programmes, and the GCOS Cooperation Mechanism.

**Time-Frame:** Immediately and continuous.

**Performance Indicator:** Resources dedicated to climate observing system projects in developing countries and countries with economies in transition; number of Parties contributing to the GCM.

**Annual Cost Implications:** Covered in the domains.

### 3.4. Earth Observation Satellites

Satellites now provide a vital means of obtaining observations of the climate system from a global perspective and comparing the behaviour of different parts of the globe (see Table 4). Further details and some update of satellite needs within IP-04 were provided in *Satellite Observation Requirements for Satellite-Based Products for Climate* (GCOS-107) in 2006. The satellite-related elements in this Plan build incrementally upon GCOS-107. The main new elements relative to GCOS-107 concern the precursors of aerosols and ozone. Other changes are small and reflect the changing status of current and planned satellite missions and product generation activities. A complete update of GCOS-107 building on this Plan is provisionally planned for 2011.

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 sufficiently homogeneous and accurate for climate purposes. To assist the space agencies, the GCMPs have been extended specifically for satellite observations (see Appendix 4). They address the following satellite-specific key operational issues:

- Continuity, homogeneity and overlap;
- Orbit stability;
- Sensor calibration;
- Data interpretation, sustained data products and archiving.

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. Missions targeted on observation of a particular domain may additionally provide valuable information

on another domain, as in the case of ocean colour and atmospheric aerosol, for example. Space agencies should ensure that they retrieve information in a mutually consistent and beneficial cross-domain manner, thereby maximising the use of their data across the domains. For some ECVs, space agencies working through the Committee on Earth Observation Satellites (CEOS) have established the CEOS Virtual Constellations as a mechanism led by expert teams to ensure coordination in agencies' operation and exploitation.

**Table 4: Essential Climate Variables for which satellite observations make a significant contribution (cf. Table 3).**

Domain	Essential Climate Variables
<b>Atmospheric</b> (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature, Wind speed and direction, Water vapour; Cloud properties, Carbon dioxide, methane, ozone and aerosol, supported by their precursors.
<b>Oceanic</b>	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity), Sea state, Salinity.
<b>Terrestrial</b>	Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Fire disturbance, Soil moisture.

Gaps in FCDRs must be avoided in order to produce consistent ECV data records that can be used for climate applications. Discontinuities due to missing observations or instrument changes can introduce an error in trend analyses. Analyses of potential future gaps in the satellite ECVs have been conducted, for example under the leadership of WMO and CEOS. These analyses should be routinely updated.

In addition to mission continuity and overlap (i.e., deployment of instruments that ensure homogeneity of FCDRs and derived ECV products), agencies have also given increased emphasis to the calibration of instruments and the intercomparison of sensors between satellites. The development of the Global Space-based Inter-calibration System (GSICS) jointly between the WMO Space Programme, CGMS and the CEOS WGCV will meet many of these needs when implemented. GSICS is designed to ensure the generation of well-calibrated FCDRs. GSICS also aims at improved characterizations of contemporary instruments and pertinent documentation for users. The important prelaunch calibration is addressed by CEOS WGCV and the establishment of best practice documents for different types of instruments are expected.

Meanwhile the Global Reference Upper Air Network (GRUAN) is being established as an international reference observing network of upper air measurements from the surface including radiosondes and surface remote sensing. About 40 stations are planned to make up the GRUAN providing a diverse geographical coverage. A few of these stations will provide benchmark profile measurements of temperature and water vapour by measuring simultaneously with different sensors. One application is to use the profiles along with radiation models for comparison with satellite radiance measurements. To make the climate observing system more resilient, GRUAN observations can be used as a transfer standard from one satellite to another especially if there is a gap due to an instrument failure. It is very important that such a network is put in place as soon as possible.

Implementation of the GCOS satellite component will also involve collecting and archiving all satellite metadata 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, for example through reprocessing of past records) requires the organization of data service systems that ensures an on-going accessibility to the data into the future. The GCOS Secretariat will coordinate its work in this area with the GEO Secretariat and with the CEOS as well as other institutions and groups, such as the Coordination Group for Meteorological Satellites (CGMS) and the WMO Space Programme. This will ensure the development

of plans for the implementation of the GCMPs and data services systems by the space agencies, and establish the appropriate mechanisms for the recording and archiving of satellite data and metadata.

The Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring initiative (SCOPE-CM) has been established with contributions from various space agencies and EUMETSAT as the secretariat. The SCOPE-CM focuses on the sustained generation of long-term ECV products including regular reprocessing. Other initiatives, such as the EUMETSAT Climate Monitoring Satellite Application Facility (CM SAF) and those initiated recently by ESA and NASA should be fostered and co-ordinated as long term activities.

Space agencies should, in addition, improve awareness by the community of available and planned satellite missions and data records, for example by maintaining a public domain database of past, current and planned satellite missions, including for each mission current status and information on data access and availability mechanisms.

#### **Action C9 [IP-04 C10]**

**Action:** Ensure continuity and over-lap of key satellite sensors; recording and archiving of all satellite metadata; 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:** Satellite agencies and satellite data reprocessing centres.

**Time-Frame:** Continuing, of high priority.

**Performance Indicator:** Continuity and consistency of data records.

**Annual Cost Implications:** TBD.

### **3.5. Integrated Climate Products**

#### **3.5.1. Generation and Use of Products**

While observations of the climate variables are an essential pre-requisite, the users in need of climate information generally require analyzed outputs and products. Thus developing analyzed products for all ECVs is vital; these products should always include estimates of the uncertainty inherent in the analysis. While the Parties are supporting a number of analysis centres for certain variables, additional operational analyses are required. International coordination of these activities is highly desirable to take advantage of scientific and technological advances, avoid duplication, and promote efficiency, complementarity and cooperation rather than competition. There are also too few analysis centres that are integrating observations of variables related to one another using data from different instruments or using other data or products to warn of potential issues. For example, the detection of sea ice from microwave emissivity might benefit from analyses of atmospheric surface temperature to indicate the occurrence of wet ice.

At the same time, it is important to recognize that alternative analysis approaches are required to verify the accuracy of the various outputs for specific variables. It is therefore essential for analysis centres to ensure thorough intercomparison of their products and some use of common algorithms and verification approaches so as to allow insight into errors and help product users to be aware of product differences.

Recognizing these issues, GCOS has recently developed guidelines for the generation of datasets and products meeting GCOS requirements<sup>42</sup>. These guidelines are intended to help producers of climate-relevant datasets and products to provide users with all the information they need to assess the suitability and maturity of the datasets and products for their particular applications.

Agencies and institutions supporting observing systems for climate should encourage as well as support the adoption of these guidelines, and thereby maximize the value of the datasets and products so generated for the user community. This would include support to international scientific expert groups undertaking critical comparisons of available datasets and products in a particular field or

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<sup>42</sup> 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>

providing guidance on the generation of new products. Further, international programmes and bodies should widely publicize the guidelines, and encourage their adoption.

#### Action C10

**Action:** Achieve adoption of the GCOS dataset and product guidelines, critical comparison of datasets/products and advice on product generation for all ECVs by the climate community.  
**Who:** Parties' national agencies, working with key international coordination bodies, such as CEOS, GEO, IGBP, IPCC TGICA, and coordinated through GCOS and WCRP.  
**Time-Frame:** Level of adoption of guidelines; number of datasets stating adoption of guidelines.  
**Performance Indicator:** Wide adoption by 2012.  
**Annual Cost Implications:** 1-10M USD (30% in non-Annex-I Parties).

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. Efforts should continue to promote an increase in the number of ECVs for which integrated products are being generated and improved, through coordinating actions by national and regional centres and programmes and by the intergovernmental organizations, within the over-all framework of GEOSS. Active research programmes to develop the tools necessary to produce climate-quality integrated analyses will be required for some ECVs (see sections 3.9, 4.6, 5.5 and 6.4).

#### 3.5.2. Reanalysis based on data assimilation

Real-time data assimilation and its use in reanalysis are other methods of generating integrated products. They exploit the physical relationships among a number of the variables and thus use many of the available types of observations. Data assimilation reanalysis is an increasingly powerful tool that has already provided comprehensive pictures of the climate system. Because an adequate observational record for global three dimensional reanalysis extends from about 1957 for atmospheric circulation variables, and from the 1980s at best for some atmospheric composition variables, the main 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, and although success is increasingly being achieved, much remains to be done. Ocean data assimilation and reanalysis activities include some climate-oriented efforts that show promising results and are now moving toward coupled data assimilation. Terrestrial activities have begun but need further development of modelling infrastructure, historical data and institutional engagement. Coupled reanalyses (atmosphere-ocean, atmosphere-land, and fully coupled climate system reanalyses) should provide more consistent fluxes, e.g. carbon fluxes, between domains, but are still a research activity (see section 1.4 on Earth system fluxes).

Although the quality of reanalyses is at present insufficient for a number of climate applications, there are good reasons to be optimistic. Improvements have been realised in bias corrections of both observations and models, but a major challenge remains to deal with the changing observing system, which adds considerable uncertainty to decadal and longer-term variability from reanalyses. 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 in a sustained way. Desirably, reanalyses should be staggered and take advantage of lessons learned from previous endeavours, but at present, reanalyses occur in a research domain with funds that come episodically and somewhat opportunistically. It is also essential to recognize and address the need to adequately vet and evaluate the new reanalyses (cf. Action C10). A more balanced and sustained reanalysis activity is desirable. The international reanalysis programme should give priority to: (a) extending current atmospheric reanalysis activities to meet requirements for monitoring climate variability and trends; (b) consolidating and extending ocean data-assimilation research activities by building on the outcome of Global Ocean Data Assimilation Experiment (GODAE) and ongoing and developing WCRP efforts to establish ocean reanalyses for the recent satellite era and for longer, paralleling atmospheric reanalysis periods; (c) establishing and further developing products relating to the composition and forcing of the climate system, (d) developing the high resolution land reanalyses required to account for the heterogeneity of the land surface, and (e) coupled climate reanalyses.

Regional reanalyses in the atmosphere and ocean have been undertaken and are in progress. These provide much higher resolution and focus on certain aspects of the system, such as the hydrological cycle or the Arctic, and can be used to satisfy some requirements of applications communities.

Reanalyses can also be used as boundary conditions with regional high resolution models to downscale to provide local information to better assess impacts of climate variations and change.

A promising new ensemble of reanalyses based solely on surface observations, and sea level pressure and sea surface temperature observations in particular, is underway<sup>43</sup> with a goal to provide over 100 years of reanalyses along with uncertainty estimates. In the northern hemisphere, such reanalyses should provide useful descriptions of the atmospheric circulation and a physically consistent set of atmospheric variables dating from before 1900. The products provide a basis for carrying out checks of the consistency of unused data such as early radiosondes, enabling derivation of homogenisation adjustments.

The outputs of the reanalysis programme will have wide use and should be easily available to the user community. This includes estimates of the quality of both the resulting analyses and the data used. Although reanalysis can enable value to be derived from a wide range of comprehensive data sources, a climate-quality reanalysis is best when the data sources include a significant fraction of data adhering to the GCMPs. The identified GCOS networks in the atmosphere and the networks of drifting buoys and sub-surface floats in the ocean are critical in this respect. Making national holdings of historical data available to the International Data Centres is an essential requirement for the effective conduct of reanalysis. Continued development of the datasets for reanalyses should also be part of an ongoing activity.

The GCOS Steering Committee, Panels and Secretariat will work with the respective technical commissions and international research programmes to foster coordinated production by the 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, including 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 metadata to internationally-mandated archives for inclusion in reanalysis programmes. The JSC for the WCRP and the GCOS Steering Committee (through their WOAP and AOPC panels) have jointly established a working group to enable exactly this task for atmospheric data.

**Action C11** [IP-04 C11]

**Action:** Prepare the atmospheric, oceanic, terrestrial and cryospheric datasets and metadata, including historic data records, for climate analyses and reanalyses.  
**Who:** Parties with Data Centres (e.g., WDCs), working together with technical commissions and the scientific community, especially the joint WOAP/AOPC Working Group on Observational Data Sets for Reanalysis  
**Time-Frame:** Now and ongoing.  
**Performance Indicator:** New or improved data sets available for analysis or reanalysis.  
**Annual Cost Implications:** Covered in domains.

**Action C12** [IP-04 C12]

**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.  
**Time-Frame:** Now and ongoing  
**Performance Indicator:** Quality and range of analyses of the ECVs.  
**Annual Cost Implications:** Covered in domains.

<sup>43</sup> Compo, G.P., J.S. Whitaker and P.D. Sardeshmukh, 2006. The feasibility of a 100-year reanalysis using only surface pressure data, Bull. Am. Met. Soc, 87, 175-190.

**Action C13 [IP-04 C13]**

**Action:** Establish a sustained capacity for global climate reanalysis and ensure coordination and collaboration among reanalysis centres.  
**Who:** National and international agencies.  
**Time-Frame:** Continue ongoing activity but with climate trends better addressed by 2014, and expansion into coupled reanalysis by 2016.  
**Performance Indicator:** Reanalysis centres endowed with long-term and coordinated programmes; cyclical flow of products of improving quality and widening range.  
**Annual Cost Implications:** 10-30M (Mainly Annex-I Parties)

### 3.6. Early Instrumental Data and Proxy Reconstructions of Past Climates

This Plan focuses primarily on the need to improve ongoing observation 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 30-40 years are insufficient to adequately characterize flood return times.
- Investigation of the relationships between atmospheric and oceanic circulation and extreme events, including possible changes in atmospheric teleconnections. In particular, most 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 30-40 years of observation. Although the past does not provide direct analogues for anthropogenic changes in atmospheric composition or changes in land cover, the recent few million years 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: earlier instrumental data, not digitally available, and proxy reconstructions based on documentary (early written material, based on human observations) biological, geophysical, geochemical or isotopic data. In the second of these, proxy data (often referred to as Palaeoclimatic Data) encompasses both natural and written archives.

There are, almost always, earlier records for many ECVs that have not been digitized yet. They are generally located in National Meteorological Service (NMS) archives and yearbooks, and in some countries will extend back considerably earlier than the formation of the NMS. In some cases the sources of earlier instrumental data may now exist in another country. These can also include 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; longer and more qualitative information (historical documentary sources) is available on a regional basis (depending on the extent of written historical sources) 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 at the Dome C site has provided a record going back to at least 740 000 years before the present time. Ice cores have inter-annual to interdecadal resolution in the recent few million years but the resolution degrades to multidecadal to multi-centennial in the oldest part of the record. Other natural proxy data 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, speleothems) 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 proxy 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.

A recent review of initiatives in proxy climate reconstruction and early instrumental potential throughout the world is given by Jones et al. (2009)<sup>44</sup>. This review resulted from a meeting in 2006 of the PAGES/CLIVAR intersection group.

### 3.6.1. Early Instrumental 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 actively addressing 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, metadata must be compiled about how, where and when observations were made. In the absence of adequate metadata, exhaustive investigative research is required to find, compile, and regenerate 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 metadata and comprehensive data sets are assembled, a demanding task remains; time-dependent biases within the datasets 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 metadata should be made available from 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, national agencies should be requested to retrieve archival data, including metadata, and lodge them with the appropriate International Data Centre (see Table 5).

**Table 5: ECVs targeted for special data archaeology efforts and the associated International Data Centres.**

ECVs	Data archive
Surface atmospheric variables	<b>WDC Asheville</b>
Oceanic variables	World Ocean Data Centres

<sup>44</sup> Jones, P.D., Briffa, K.R., Osborn, T.J., Lough, J.M., van Ommen, T.D., Vinther, B.M., Luterbacher, J., Wahl, E.R., Zwiens, F.W., Mann, M.E., Schmidt, G.A., Ammann, C.M., Buckley, B.M., Cobb, K.M., Esper, J., Goosse, H., Graham, N., Jansen, E., Kiefer, T., Kull, C., Küttel, M., Mosley-Thompson, E., Overpeck, J.T., Riedwyl, N., Schulz, M., Tudhope, A.W., Villalba, R., Wanner, H., Wolff, E. and Xoplaki, E., 2008: High-resolution paleoclimatology of the last millennium: a review of current status and future prospects, *Holocene* 19, 3-49.

Surface and oceanic variables reconstructed from proxy climatic variables	World Data Center for Paleoclimatology (NCDC, Paleoclimatology Branch, Boulder, USA)
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)	Hydrolare
Extent and mass balance of mountain glaciers and sub-polar ice caps	World Glacier Monitoring Service (WGMS)
<b>Biomass</b>	FAO Forest Resources Assessment Project (FRA)
Land cover (and use)	<b>Existing research networks</b>

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 datasets have a restricted 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, as the Global Land Cover Network (GLCN) (working with the appropriate national agencies) should request that national agencies retrieve archival data and make them available through appropriate International Data Centres.

**Action C14 [IP-04 C14]**

**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 (CCI), the WMO Commission for Hydrology (CHy), other appropriate coordinating bodies (e.g. the GTOS Secretariat), the appropriate national agencies, and designated International Data Centres.

**Time-Frame:** Continuing.

**Performance Indicator:** Data receipt at designated International Data Centres.

**Annual Cost Implications:** 10-30M USD (60% in non-Annex-I Parties).

**Action C15**

**Action:** Improving data holdings in International Data Centres (IDCs).

**Who:** IDCs to send details of their data possessions to each of the Parties. The Parties to respond back to the IDCs about the quality and quantity of the data and ensure that the IDCs hold all available data.

**Time-Frame:** Complete by 2014.

**Performance Indicator:** Percentage of responses from Parties.

**Annual Cost Implications:** 10-30M USD (60% in non-Annex-I Parties).

**3.6.2. Proxy Data Sets for Climate Reconstruction**

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 proxy 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 proxy climate and proxy 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 results with analyses of more recent historical and/or observational data will require strengthening of the mechanisms for interdisciplinary communication.

**Action C16 [IP-04 C15]**

**Action:** Undertake research initiatives to acquire high-resolution proxy 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.

**Annual Cost Implications:** 10-30M USD (60% in non-Annex-I Parties).

**Action C17 [IP-04 C16]**

**Action:** Improve synthesis of proxy climate and proxy 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.

**Annual Cost Implications:** 10-30M USD (80% in non-Annex-I Parties).

**Action C18 [IP-04 C17]**

**Action:** Preserve proxy climate and proxy environmental data (both the original measurements as well as the final reconstructions) 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.

**Annual Cost Implications:** 1-10M USD (30% in non-Annex-I Parties).

### 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 fundamental climate data records and records of derived data products are collected, retained and made accessible for analysis and application by current and future generations of users. It is noteworthy that data management has for some time been a principal element in some programmes, such as 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, prompt and regular flow of data to the user community and to the International Data Centres for the ECVs must be ensured. This is currently inadequate for a number of variables and networks, especially in the terrestrial domain. Lack of engagement, data policies, prevalence of short-term research funding or overall 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 a continuing concern. 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 or product subsets.

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 places a requirement on the International Data Centres and the space agencies for the practice of technological data stewardship. 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 the 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 be taken. 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 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, apparent biases and inhomogeneities in the data can be addressed if adequate metadata information is available to the analyst. International standards and procedures for the storage and exchange of metadata need to be extended to all variables and implemented for many climate-observing systems. Guidelines that begin to address this concern have been developed by the WMO CCI<sup>45</sup>. 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 standards 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, metadata, archival strategies, data formats etc. The opportunity for standardization extends beyond climate and includes the whole geosphere observation mandate being covered in GEOSS. It is proposed to organize a major effort in concert among the International Organization for Standardization (ISO) and representatives from the various component systems. The WMO Information System (WIS), which is an extension of the Global Telecommunication System (GTS), will be used for the exchange of data from the WMO Observing Systems. WIS has adopted the same data exchange systems as used by other major participants in GEOSS, and compliance with WIS automatically entails compliance with GEOSS. For instance, participants in WIS and GEOSS use the ISO 19115 metadata content standard for geographical information and the ISO 23950 interoperable search service, which can serve for extending the effort as broadly as possible. Because this approach uses well-known and compatible

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<sup>45</sup> WMO Guide to Climatological Practices – Third Edition (Draft);  
[http://www.wmo.int/pages/prog/wcp/ccl/guide/guide\\_climat\\_practices.html](http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.html)

standards, it is essential to foster the degree of data and information integration that is so vital to the understanding of climate.

#### Action C19

**Action:** Apply standards and procedures for metadata and its storage and exchange.  
**Who:** Operators of GCOS related systems, including data centres.  
**Time-Frame:** Initial implementation of the operational WIS and GEOSS systems is occurring in 2009, implementations will be ongoing thereafter  
**Performance Indicator:** Number of ECV related data sets accessible through standard mechanisms.  
**Annual Cost Implications:** <1M USD (20 k USD per data centre) (10% in non-Annex-I Parties).

#### Action C20

**Action:** Ensure timely, efficient and quality-controlled flow of all ECV data to International Data Centres, and timely flow of feedback to observing network management from monitoring centres.  
**Who:** Parties with coordination by appropriate technical commissions and international programmes.  
**Time-Frame:** Continuing, of high priority.  
**Performance Indicator:** Data receipt at centres and archives.  
**Annual Cost Implications:** 10-30M USD (70% in non-Annex-I Parties).

#### Action C21 [IP-04 C20]

**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:** Continuing, of high priority.  
**Performance Indicator:** Number of countries adhering to data policies favouring free and open exchange of ECV data.  
**Annual Cost Implications:** 1-10M USD (70% in non-Annex-I Parties).

#### Action C22

**Action:** Implement modern distributed data services, drawing on the experiences of the WIS as it develops, with emphasis on building capacity in developing countries and countries with economies in transition, both to enable these countries to benefit from the large volumes of data available worldwide and to enable these countries to more readily provide their data to the rest of the world.  
**Who:** Parties' national services and space agencies for implementation in general, and Parties through their support of multinational and bilateral technical cooperation programmes and the GCOS Cooperation Mechanism.  
**Time-Frame:** Continuing, with particular focus on the 2011 – 2014 time period.  
**Performance Indicator:** Volumes of data transmitted and received by countries and agencies.  
**Annual Cost Implications:** 30-100M USD (90% in non-Annex-I Parties).

### 3.8. The Need for Information on Climate Impacts for Adaptation

Environmental impacts and changes are due to many causes, with direct anthropogenic impacts often being the most significant; nevertheless climate change has the potential to change environments on large scales, to influence ecosystems, including the range of species, in any region and to have a strong, long-term impact on socio-economic systems and habitats<sup>46</sup>. The challenges of monitoring and being more able to adapt to, or mitigate changes vary greatly from region to region. Identifying such changes and attributing them to a cause, such as a changing climate, and assessing risks (e.g., for ecosystems or within urban regions) requires long time scales of observations and homogeneous, consistent practises in measuring the systems and variables under consideration. It also requires

<sup>46</sup> IPCC (2007): Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78 (Technical Summary).

either high spatial resolution or collocated time series of climate and other environmental influences, such as pollution and nearby changes in land use. In many cases, the nearest climate observations are some distance away from ecological monitoring sites, and interpolation of that information is not reliable. IPCC has started to systematically catalogue published studies meeting basic criteria for quality and consistency, but the range of information on ecosystems and habitats is limited to mostly phenological data. It is also clear that in many parts of the world, no studies are available. To provide improved information on the impacts of environmental change, including climate change, there is a need to encourage more long-term impact studies, and to ensure that these studies include measurements of basic geophysical climate variables and other, mostly socio-economic, factors.

### Action C23

**Action:** Develop and publish guidelines for undertaking impact assessments and to; ensure that data policies facilitate the exchange and archiving of all impact-relevant data.

**Who:** IPCC TGICA, GTOS and IGBP

**Time-Frame:** 2011

**Performance Indicator:** Guideline published.

**Annual Cost Implications:** <1M USD (10% in non-Annex-I Parties).

### Action C24

**Action:** Improve support to impact studies, encourage recognition by scientific funding bodies of the need to consider guidelines for the conduct of such impact studies, and encourage the definition of new impact-related ECVs.

**Who:** Parties and ICSU

**Time-Frame:** Ongoing.

**Performance Indicator:** Availability of supporting data; proposals for new ECVs.

**Annual Cost Implications:** 10-30M USD (50% in non-Annex-I Parties).

## 3.9. 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 and scientific programmes, such as WCRP, 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.

It is important to derive satellite products in a physically consistent way across ocean, land and atmosphere domains. For instance, what is commonly referred to as land surface albedo is not a surface property but a joint property of the surface and the overlaying atmosphere. Albedo estimates intrinsically depend on the state and composition of the atmosphere, including the distribution of clouds and aerosols. The development of integrated products (e.g., greenhouse gas emissions attributable to biomass burning) requires blending of different datasets and/or data sources, which need to be consistent over time and space. 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.

It is especially important for groups that develop new algorithms for retrievals of physical variables at different centres, agencies and countries recognize other related developments and compare results. It is essential that common algorithms be developed and applied even if specialize algorithms are also used. The evaluation and vetting of products and their intercomparison is an essential part of the observational process and should be fully funded.

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 overall atmospheric climate observing system comprises a complementary mix of *in-situ*<sup>47</sup> and satellite-based subsystems.

The *in-situ* subsystems are largely based on the WMO WWW networks for surface and upper-air observations, and the WMO GAW networks for atmospheric composition. The GCOS implementation strategy has placed an initial emphasis on the full implementation of baseline networks. These include the GSN and the GUAN for the surface and upper-air meteorological variables and the phased establishment of GAW networks for all the composition variables. The latter has made progress but needs to be completed. Full implementation of the emerging GCOS Reference Upper-Air Network is also needed as a key component that provides climate data of intrinsic high value and contributes to the calibration of data from both the general *in-situ* networks and the satellite subsystems.

The careful management of data and their associated metadata 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 which hold the basic archives. For most atmospheric ECVs, such centres and programmes currently exist; however, as pointed out below, there are several gaps and weaknesses that need to be addressed.

Satellite observations play a crucial role in attaining global coverage of virtually all atmospheric climate variables. Emerging arrangements for the calibration of data and the formation of satellite data records for climate purposes have been outlined in section 3.4.

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. Integration of data from the complete mix of in-situ networks and satellite

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<sup>47</sup> The term *in-situ* is used to denote any ground-based or air-borne measuring system, including non-satellite remote-sensing systems

subsystems is achieved through the process of reanalysis, which by incorporating historical data with consistent algorithms provides the potential to yield homogeneous, consistent, multivariate products with either global or more-detailed regional coverage, as discussed in 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, and where many impacts of climate change will be felt and necessitate adaptation. Climate analysis has traditionally placed emphasis on surface temperature, precipitation and pressure data. Temperature and precipitation have the greatest impact on natural systems and human activities, with pressure allowing a perspective on the meteorological systems that drive the weather. More recently, wind speed, wind direction and sunshine data have become increasingly important as Parties consider measures to adapt to future climate change, as these data are also essential for the design of renewable energy systems, which include wind and solar farms as well as hydroelectric systems. Wind, water vapour, sunshine and surface radiation are also associated with a range of direct impacts.

There is an increasing need for local, high-frequency surface atmospheric data on climate, to characterize extremes for the purposes of monitoring and research, and more generally to meet needs relating to impacts, vulnerabilities and adaptive responses. This Plan identifies a number of actions to improve the availability of the required observations and data products for precipitation. It also identifies actions to enhance the frequency of reporting and general operation of the WWW/GOS surface synoptic network, so that its data more fully meet climate needs. Several actions that will improve observation of extremes over sea are also specified.

Notwithstanding the improvements in observation that are called for, and the scope for recovery of past observations, there will inevitably be limitations in the spatial and temporal coverage of in-situ near-surface observations over land that cannot be compensated by observations from space, and limitations in observational coverage of the past. Atmospheric reanalysis provides a complete coverage in space and time within the constraints of model resolution. Use of the products of reanalysis to develop links between meteorological conditions and socio-economic impacts is viewed as a key approach to develop the relationships needed to interpret the output of climate projection models for the purpose of assessing needs and options for adaptation. This brings with it requirements for reanalysis regarding the resolution in space and time of its products, in addition to general requirements for accuracy and homogeneity.

As networks evolve, it is important to note that the usefulness of all the ECVs in the Atmospheric Domain is enhanced through collocated measurements of terrestrial and ecosystem properties. Greater efforts should be made to establish sites where many of the ECVs for both the Atmospheric and Terrestrial Domains are observed. In addition, although not reflected in an explicit action in this Plan, specific attention needs to be paid to the measurement of the ECVs in the urban environment where an increasing proportion of the world's population resides and where specific issues of adaptation arise.

The observational networks and satellite data required to monitor and analyse the ECVs in the Atmospheric Surface Domain are shown in Table 6, together with the current status of each observing network and system (see next page).

**Table 6: Observation networks and systems contributing to the surface component of the Atmospheric Domain.**

<b>ATMOSPHERIC DOMAIN – SURFACE</b>				
<b>ECV</b>	<b>Contributing Network(s)</b>	<b>Status</b>	<b>Contributing Satellite Data</b>	<b>Status</b>
<b>Temperature</b>	GCOS Surface Network.	At least 95 % of stations are active, but only about 80% transmit CLIMAT reports.	Sea-surface temperature (IR, microwave).	Operationally supported
	Full WWW/GOS surface network.	Need data from entire network to be available for climate purposes; data receipt from many countries is inadequate.		
	Buoys and ships.			
	Additional national networks (see also Oceanic section, Sea-surface Temperature ECV).			
<b>Pressure</b>	GCOS Surface Network.	At least 95 % of stations are active, but only about 80% transmit CLIMAT reports.		
	Full WWW/GOS surface network.	Some inconsistencies in pressure reduction methods to mean sea level.		
	Additional national networks.	Some national networks inadequate for climate studies.		
	Buoys and ships (see Ocean Surface section).			
<b>Wind Speed/ Direction</b>	GCOS Surface Network.	Wind is still not included in GSN.	Scatterometer.	Continuing operational uncertainty for two-scatterometer constellation
	WWW/GOS synoptic network.		Passive microwave for wind speed.	
	Additional national networks.		Polarimetric microwave radiometry for wind vectors	
	Buoys and ships (see Ocean Surface section).			
<b>Precipitation</b>	GCOS Surface Network.	At least 95 % of stations are active, but only about 80% transmit CLIMAT reports.	Passive microwave, VIS/IR on GEO.	High priority for climate applications
	Full WWW/GOS surface network.	Quality of data and quantity of reports are variable.	Precipitation radar.	Uncertainty for continuity of precipitation radar, Temporal and spatial sampling limitations.
	Additional national meteorological and hydrological gauge networks; island networks.	Most countries operate national high-resolution precipitation networks, but data are often not available internationally, or available only with time delay.		
	Surface-based radar networks.	Radar data not globally exchanged; spatial and temporal sampling limitations.		
	Buoys			

<b>Water Vapour</b>	GCOS Surface Network. Full WWW/GOS synoptic network. Ships and moored buoys	Water vapour is only partly included in CLIMAT reports, and not monitored. . VOSclim fleet declining; no measurement from drifting buoys		
<b>Surface Radiation Budget</b>	BSRN. WWW/GOS synoptic network. Additional national networks.	High-quality data, but coverage should be extended and continuity secured. Quality and coverage of routine radiation data is inadequate for climate purposes. Limited availability of high-quality data in national networks.	GEWEX Surface Radiation Budget project	Solar from satellites For longwave, satellite data are used to estimate cloud parameters and near-surface thermodynamics fields are typically taken from NWP models

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 surface 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 implemented through 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, carries out detailed analysis of the problems in the receipt of GSN observations and works with national services to resolve them. Figure 2 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, and by moored and drifting buoys. 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 water vapour) are addressed here. Satellite measurements are critical to the observing strategies addressing the global distribution of the essential atmospheric surface variables over the ocean. The combination of both land and marine data is vital for the true assessment of climate change over the planet.

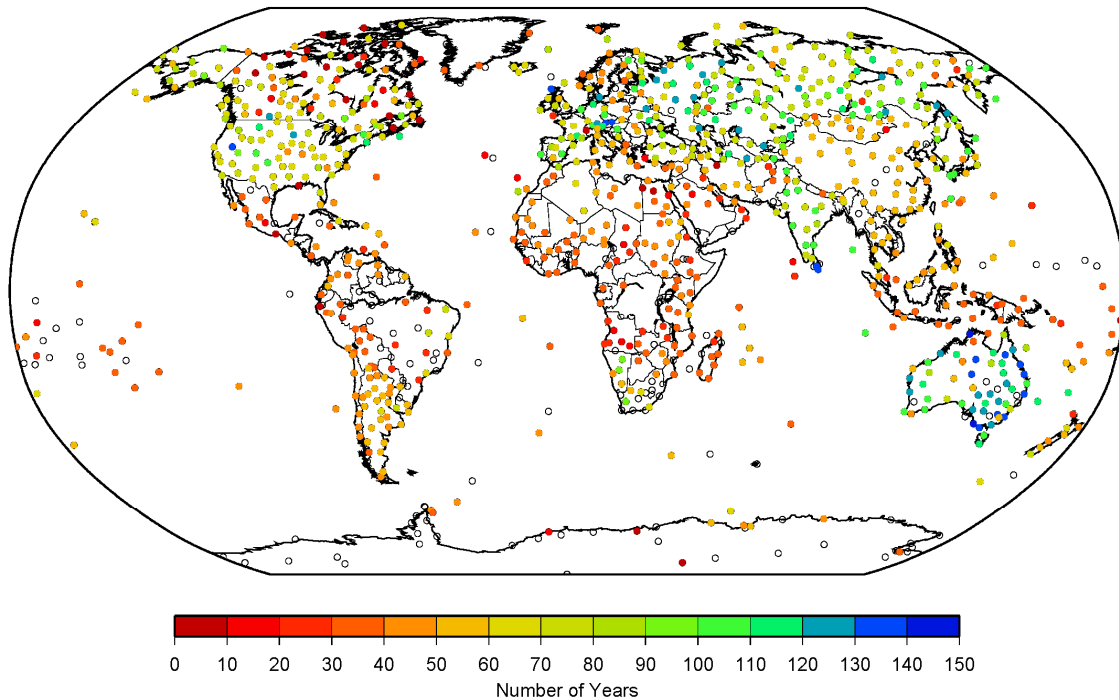
**Action A1**

**Action:** Improve the availability of near-real-time and historical GSN data.  
**Who:** National Meteorological Services, in coordination/cooperation with WMO CBS, with advice from the AOPC  
**Time-Frame:** Continuous for monitoring GSN performance and receipt of data at Archive Centre  
**Performance Indicator:** Data archive statistics at WDC Asheville and National Communications to UNFCCC.  
**Annual Cost Implications**<sup>48</sup>: 10-30M USD (70% in non-Annex-I Parties).

<sup>48</sup> See section 2.2 (Executive Summary) and section 2.8 for cost definitions.

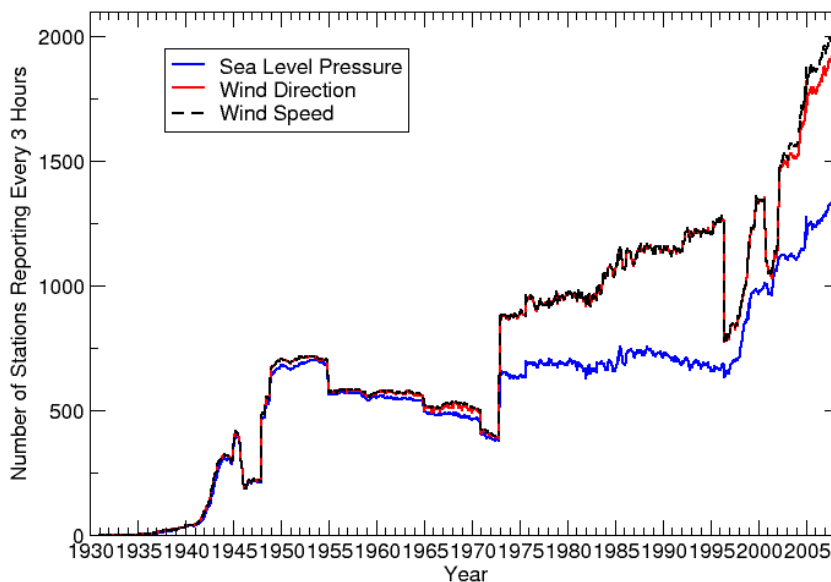


Number of Years of Daily Data in GSN/GHCN-Daily Archive (Any Variable)



**Figure 2: Length of historical climate time series for GSN stations available at the GSN Archive Centre, NCDC (Source: NCDC).**

While the WWW/GOS synoptic observing networks have been developed primarily to support weather prediction, their high spatial density and frequent sampling means that they are of increasing importance to the climate community, especially for the studies of extremes and of impacts, vulnerabilities and adaptation. GCOS, through the WMO CBS, WMO CCI and WMO RAs, and WMO WWW encourages more frequent reporting for the Regional Basic Synoptic Network (RBSN) of the WWW/GOS (cf. Figure 3).



**Figure 3: Number of stations in the Regional Basic Synoptic Network reporting every 3 hours, as received by the World Data Centre for Meteorology, Asheville (Source: NCDC).**

**Action A2 [IP-04 A2]<sup>49</sup>**

**Action:** Obtain further progress in the systematic transmission of both hourly SYNOP reports and CLIMAT reports from the WWW/GOS RBSN.  
**Who:** National Meteorological Services, in cooperation/coordination with WMO CBS, WMO CCI, WMO RAs and WMO WWW.  
**Time-Frame:** Continuous, with significant improvement in receipt of RBSN synoptic and CLIMAT data by 2014.  
**Performance Indicator:** Data archive statistics at WDC Asheville.  
**Annual Cost Implications:** 1-10M USD (60% in non-Annex-I Parties).

National vulnerability and adaptation 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 CCI and their RAs will be needed to attain the goal of complete network implementation. Good station metadata such as accurate station heights and location coordinates are required.

**Action A3 [IP-04 A3]**

**Action:** Apply the GCMPs to all measurements relevant for climate from surface networks.  
**Who:** National Meteorological Services, in coordination with WMO CBS, WMO CCI, WMO RAs and GCOS Secretariat.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Quality and homogeneity of data and metadata submitted to International Data Centres.  
**Annual Cost Implications:** 10-30M USD (70% in non-Annex-I Parties).

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 has been provided by the WMO Commission for Instruments and Methods of Observation (CIMO), in cooperation with WMO CCI and WMO CBS. Guidelines need to be implemented, and the consequences of transition assessed.

**Action A4 [IP-04 A4]**

**Action:** Implement guidelines and procedures for the transition from manual to automatic surface observing stations. Expert review of impact of increasing use of automatic stations on the surface climate data record.  
**Who:** Parties operating GSN stations for implementation. WMO CCI in cooperation with the WMO CIMO, WMO CBS for the review.  
**Time-Frame:** Ongoing for implementation. Review by 2014.  
**Performance Indicator:** Implementation noted in National Communication.  
**Annual Cost Implications:** 1-10M USD (60% in non-Annex-I Parties).

**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 – Air 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 buoys), and sea ice (from the Arctic and Antarctic buoy networks) is required, as described below in section 5.

<sup>49</sup> Reference is made to corresponding (not necessarily identical, often follow-on) Actions in the IP-04, so they exist.

## ECV – 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 30 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. Although there has been a significant improvement in recent years, the OOPC, working through the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), and the national agencies that deploy drifting buoys, should endeavour to ensure that surface pressure sensors are included as a component of the suite of instruments on all buoys deployed (see section 0).

### Action A5<sup>50</sup> [IP-04 A5]

**Action:** Seek cooperation from organizations operating drifting buoy programmes to incorporate atmospheric pressure sensors as a matter of routine.

**Who:** Parties deploying drifting buoys and buoy-operating organizations, coordinated through JCOMM with OOPC and AOPC.

**Time-Frame:** Complete by 2014.

**Performance Indicator:** Percentage of buoys with sea-level pressure (SLP) sensors.

**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties).

## ECV – Precipitation

Since precipitation often occurs on small space and time scales, the density of the networks appropriate for surface temperature and pressure is insufficient for precipitation. Many nations have organized and operate special rain gauge and radar networks 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 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, as promptly as possible. Continuing research is required to overcome some outstanding measurement problems such as undercatch of snow. National radar data need to be exchanged and combined with gauge data to contribute to global estimates of precipitation.

### Action A6 [IP-04 A6]

**Action:** Submit all precipitation data, including hourly totals where possible and radar-derived precipitation products, from national networks to the International Data Centres.

**Who:** National Meteorological Services with coordination through the WMO CCI.

**Time-Frame:** Continuous

**Performance Indicator:** Percentage of nations providing all precipitation data to the International Data Centres. Percentage of stations for which hourly data available.

**Annual Cost Implications:** 1-10M USD (60% in non-Annex-I Parties).

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 many 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 surface-based precipitation observations. Stable continuation and enhancement of the satellite systems contributing to precipitation observation (such as passive microwave and high-frequency IR geostationary measurements) is 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

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<sup>50</sup> See also Action O8.

requirement into their medium and long-range planning. The CEOS Precipitation Constellation has been set up to establish an international framework to guide, facilitate and coordinate the continued advancements of multi-satellite global precipitation products.

#### Action A7

<p><b>Action:</b> Ensure continuity of satellite precipitation products.<sup>51</sup></p> <p><b>Who:</b> Space agencies</p> <p><b>Time-Frame:</b> Continuous.</p> <p><b>Performance Indicator:</b> Long-term homogeneous satellite-based global precipitation products.</p> <p><b>Annual Cost Implications:</b> 10-30M USD (for generation of climate products, assuming missions funded for other operational purposes) (Mainly by Annex-I Parties).</p>
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Some observations of precipitation over the oceans are particularly important for the calibration of satellite observations. 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 [IP-04 A8]

<p><b>Action:</b> Equip all buoys in the Ocean Reference Mooring Network with precipitation-measuring instruments.</p> <p><b>Who:</b> Parties deploying moorings in cooperation with JCOMM and OOPC.</p> <p><b>Time-Frame:</b> Complete by 2014.</p> <p><b>Performance Indicator:</b> Number of instruments deployed and data submitted to International Data Centres.</p> <p><b>Annual Cost Implications:</b> &lt;1M USD (Mainly by Annex-I Parties).</p>
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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 data availability, to accommodate the full suite of GCOS requirements. Estimates of precipitation in high latitudes remain a challenge.

#### Action A9 [IP-04 A9]

<p><b>Action:</b> Develop and implement improved methods for observing precipitation and deriving global precipitation products that take into account advances in technology and fulfil GCOS requirements.</p> <p><b>Who:</b> Parties' national research programmes through WCRP in cooperation with GCOS.</p> <p><b>Time-Frame:</b> Continuous.</p> <p><b>Performance Indicator:</b> Implemented methods; improved (in resolution, accuracy, time/space coverage) analyses of global precipitation.</p> <p><b>Annual Cost Implications:</b> 10-30M USD (40% in non-Annex-I Parties)..</p>
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### 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 data. More representative and homogeneous wind speed and direction estimates may be derived from pressure data, and high-frequency pressure data can in particular be useful in stormy situations. Moreover, the higher resolution four-dimensional data assimilation systems now used for reanalysis are capable of making use of hourly data. There has been a significant recent increase in the exchange of three-hourly or hourly data on the GTS, but there remains scope for improvement. Action A2 calls for the more

<sup>51</sup> 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.

frequent reporting of SYNOP data that is required. This is of particular importance for the characterization of extreme weather events.

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 invaluable 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 a two-scatterometer constellation 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. The CEOS Ocean Surface Vector Wind Constellation is working towards coordinated space agency action in this area.

**Action A10<sup>52</sup> [IP-04 A11]**

**Action:** Ensure continuous generation of wind-related products from AM and PM satellite scatterometers or equivalent observations.  
**Who:** Space agencies.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Long-term satellite observations of surface winds every six hours.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**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. Surface water vapour data has begun to be studied in a global climate context and initial results are encouraging. Continued efforts to provide historical data to the GCOS analysis and archive centres are needed.

**Action A11 [IP-04 A12]**

**Action:** Submit water vapour data from national networks to the International Data Centres.  
**Who:** National Meteorological Services through WMO CBS and International Data Centres with input from AOPC.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Data availability in analysis centres and archive, and scientific reports on the use of these data.  
**Annual Cost Implications:** <1M USD (60% in non-Annex-I Parties).

**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, but has very limited spatial coverage. It should be expanded substantially beyond its current number of about 40 stations, 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

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<sup>52</sup> See also Action O23.

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. A very useful contribution is the GEWEX SRB project, which should be continued indefinitely. Continuous improvements are needed to attain the required climate quality. The strong link to *in-situ* data, e.g. from the BSRN, helps to anchor the satellite and model-based data to the spatially sparse but more accurate surface measurements.

**Action A12 [IP-04 A13]**

**Action:** Submit surface radiation data with quality indicators from national networks to the World Radiation Data Centre (WRDC).  
**Who:** National Meteorological Services and others, in collaboration with the WRDC.  
**Time-Frame:** Establish Global Surface Radiation Network by 2011.  
**Performance Indicator:** Data availability in WRDC.  
**Annual Cost Implications:** <1M USD (20% in non-Annex-I Parties).

**Action A13 [IP-04 A14]**

**Action:** Ensure continued long-term operation of the BSRN and expand the network to obtain globally more representative coverage. 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:** Ongoing.  
**Performance Indicator:** The number of BSRN stations regularly submitting data to International Data Centres.  
**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

**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 7.

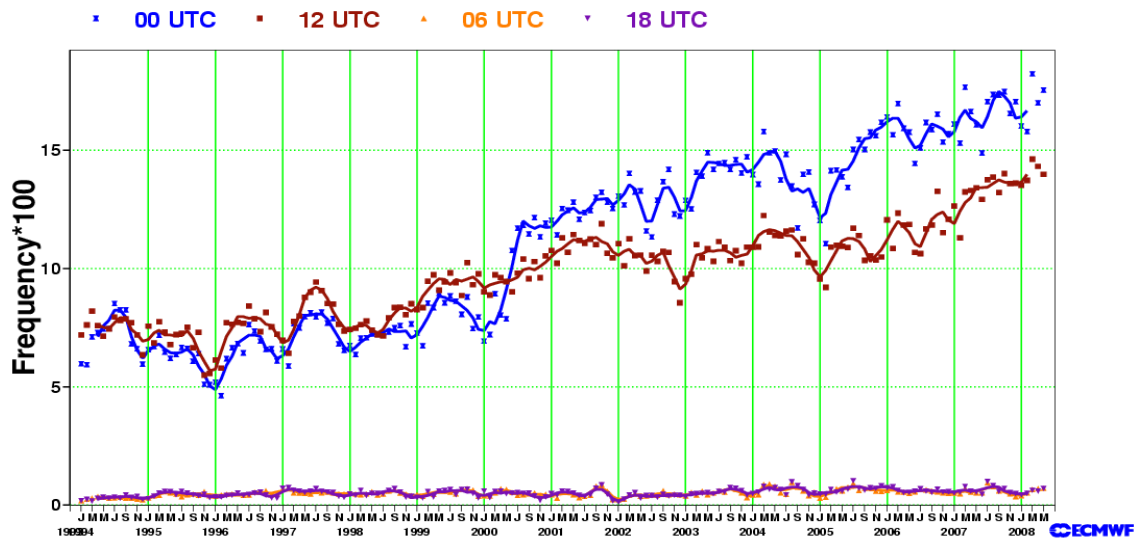
**Table 7: Observation networks and systems contributing to the upper-air component of the Atmospheric Domain.**

ATMOSPHERIC DOMAIN – UPPER-AIR				
ECV	Contributing Network(s)	Status	Contributing Satellite Data	Status
<b>Temperature</b>	GCOS Upper-Air Network (GUAN).	About 90% of stations are reporting regularly; only two completely silent	Microwave sounders	Need to ensure continuity of MSU-like radiance bands.
	Reference network of high-quality and high- altitude radiosondes (GRUAN).	International cooperation continues to work towards establishing the reference network.	GPS radio occultation.	Continuity for GPSRO constellation needs to be secured
	Full WWW/GOS radiosonde network.	Many stations do not provide two observations each day.	Infrared sounders	
	Commercial aircraft.	Aircraft observations are valuable but limited to specific routes and levels.		

<p><b>Wind Speed and Direction</b></p>	<p>GUAN.  Full WWW/GOS radiosonde network.  PILOT balloons  Radar (profilers).  Commercial aircraft.</p>	<p>About 90% of stations are reporting regularly; only two completely silent         Radar data are not globally distributed.   Aircraft observations are valuable but limited to specific routes and levels.</p>	<p>Visible and infrared (atmospheric motion vectors) from geostationary and polar orbit satellites.         Lidar</p>	<p>Continuity of polar winds at risk;         Awaiting ESA Aeolus demonstration; no continuity planned.</p>
<p><b>Water Vapour</b></p>	<p>GUAN.  Reference network of high-quality and high-altitude radiosondes (GRUAN).  Full WWW/GOS radiosonde network.  Ground-based GPS receiver network.  Commercial aircraft.</p>	<p>Accuracy of water vapour measurements is improving, but is still inadequate for climate purposes in the upper troposphere and lower stratosphere.  Accurate reference sondes measuring upper-tropospheric and lower-stratospheric humidity are needed.      Wider international exchange of data is needed  Aircraft data are potentially useful but limited to specific routes and levels.</p>	<p>Microwave imagers and sounders; Infrared sounders      GPS radio occultation;  Infrared and microwave limb sounders   Solar occultation  NIR images over land</p>	<p>Continuity assured for operational microwave and IR sounders;  Continuity uncertain for microwave imagery  Continuity uncertain for research satellites and GPS constellation.</p>
<p><b>Cloud Properties</b></p>	<p>Surface observations (GSN, WWW/GOS).</p>	<p>Surface observations of cloud cover provide an historical but uncertain record, and continuity is a concern; Reprocessing of cloud data is needed.</p>	<p>Visible, infrared and microwave radiances from geostationary and polar orbiting satellites;   Cloud radar and lidar (research).</p>	<p>Cloud top temperature, microphysical properties and coverage are all operational.</p>
<p><b>Earth Radiation Budget</b></p>			<p>Broadband short- and longwave and total solar irradiance   GERB geostationary measurements provide high time resolution broadband data.</p>	<p>Continuity and good calibration of measurements is of critical importance  NPP/NPOESS will provide a CERES-like record starting in 2011.  GERB useful for process studies, but no follow-on instrument.</p>

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. Some problems in the performance of the radiosonde network occur because observations are not being taken due to a lack of resources. The data are unevenly distributed over the globe with relatively high-density coverage over much of the Northern Hemisphere, but 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 through implementation of the more complete reporting enabled by the BUFR code. It is also highly desirable to have observations twice per day as this allows radiation biases to be partly assessed.

## Monthly counts of Radiosondes received at ECMWF Temperature 10 hPa - GUAN



**Figure 4: Frequency of receipt of temperature data from GUAN radiosondes reaching the stratospheric level of 10 hPa at GUAN Monitoring Centre 1994-2008 (Source: ECMWF).**

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 their activities to promote testing of instruments and tracking equipment, technology improvements, capacity-building 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 currently consists of 164 radiosonde stations fairly evenly distributed over the globe. Figure 4 gives an indication of the increase in GUAN performance over the past years. The AOPC works 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).

### Action A14 [IP-04 A15]

**Action:** Improve operation of the GUAN, including infrastructure and data management.  
**Who:** Parties operating GUAN stations in cooperation with GCOS Secretariat and WMO CBS.  
**Time-Frame:** Ongoing.  
**Performance Indicator:** Percentage of data archived in WDC Asheville.  
**Annual Cost Implications:** 10-30M USD (70% in non-Annex-I Parties).

Outstanding issues concerning the quality of radiosonde measurements for climate monitoring and change-detection purposes have led to a proposal for a GCOS Reference Upper Air Network (GRUAN) of about 40 sites routinely deploying high-quality radiosondes and making other ground-based measurements such as from ozone sondes, GPS delay and lidars. In addition to making a vital direct contribution to climate monitoring across all climate zones, this network will be extensively used to calibrate and validate various satellite observations and is expected also to provide new information on humidity in the upper troposphere and lower stratosphere needed to understand better the role of water vapour in the radiation budget..

GRUAN planning was initiated at workshops held in 2006 and 2007 and documented in GCOS-112. Under the auspices of the AOPC Working Group on Atmospheric Reference Observations (WG ARO), the concept of a GRUAN was further developed, and DWD (Germany) with its Meteorological Observatory Lindenberg – Richard-Aßmann-Observatory was selected from among four volunteering



organisations to be the Lead Centre for the GRUAN. An initial set of 14 candidate GRUAN sites has been selected (GCOS-121). Plans for implementation continue under the auspices of AOPC, its WG ARO and the GRUAN Lead Centre.

#### Action A15

**Action:** Continue implementation of the GCOS Reference Upper-Air Network of high-quality radiosondes and other supporting observations, including operational requirements and data management, archiving and analysis.

**Who:** National Meteorological Services and research agencies, in cooperation with AOPC, WMO CBS and the Lead Centre for GRUAN.

**Time-Frame:** Implementation largely complete by 2013.

**Performance Indicator:** Number of sites contributing reference-quality data for archive and analysis.

**Annual Cost Implications:** 30-100M USD (20% in non-Annex-I Parties).

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. The value of the observations for both weather and climate purposes would be enhanced by transition from the current (TEMP) coding standard to the more comprehensive (BUFR) standard, but progress on this has been slow. Additional data sources, such as vertically pointing radar systems (wind profilers) and data from aircraft (both at flight level and on ascent and descent), have become 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 improved reporting. Lidar measurements of wind profile from space could form another important long-term data source; the ESA ADM/Aeolus global vertical wind profiling satellite mission should demonstrate the feasibility and usefulness of this type of measurement.

#### Action A16 [IP-04 A17]

**Action:** Improve implementation of the WWW/GOS radiosonde network compatible with the GCMPs and provide data in full compliance with the BUFR coding convention.

**Who:** National Meteorological Services in cooperation with WMO CBS and WMO RAs.

**Time-Frame:** Continuing.

**Performance Indicator:** Percentage of real-time upper-air data received in BUFR code with no quality problems.

**Annual Cost Implications:** 10-30M USD (60% in non-Annex-I Parties).

The provision of metadata concerning 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. Methods have been developed to enable radiosonde metadata to be combined with proxy metadata derived from comparison with reanalyses. The metadata may then be applied to homogenise radiosonde records for use in trend estimation and future reanalyses. Special efforts are required to obtain radiosonde metadata records and to include them as important elements in the future observing strategy.

#### Action A17 [IP-04 A18]

**Action:** Submit metadata 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:** Ongoing.

**Performance Indicator:** Percentage of sites giving metadata to WDC Asheville.

**Annual Cost Implications:** <1M USD (50% in non-Annex-I Parties).

Satellite radiances provide measurements of several global atmospheric upper air variables, temperature and water vapour in particular. However they can be subject to biases from uncertainties in the sensor calibration and data pre-processing (e.g. cloud removal). The Climate Absolute Radiance and Refractivity Observatory (CLARREO) Mission has been proposed as a key component of the future climate observing system providing an absolute calibration traceable to SI standards. It will underfly the satellites used for climate monitoring and will serve as a tool for satellite intercalibration to provide a climate benchmark radiance dataset. One component of CLARREO

involves the measurement of spectrally resolved thermal infrared and reflected solar radiation at high absolute accuracy. Coupled with measurements from on-board GPS radio occultation receivers, this will provide a long-term benchmarking data record for the detection, projection, and attribution of changes in the climate system. It will also provide a source of absolute calibration for a wide range of visible and infrared Earth observing sensors, increasing their value for climate monitoring. The second component of CLARREO involves ensuring the continuity of measurements of incident solar irradiance and Earth radiation budget data which is specifically addressed in A24 below.

#### Action A18

**Action:** Implement and evaluate a satellite climate calibration mission, e.g. CLARREO .  
**Who:** Space agencies (e.g., NOAA, NASA, etc)  
**Time-Frame:** Ongoing  
**Performance Indicator:** Improved quality of satellite radiance data for climate monitoring.  
**Annual Cost Implications:** 100-300M USD (Mainly by Annex-I Parties).

#### 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<sup>53</sup> Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit A (AMSU-A) on NOAA and Metop) 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 (or equivalent) instrument should be regarded as sufficient cause to launch a new satellite in the series. The new high-resolution infrared sounders such the NASA Atmospheric Infrared Sounder (AIRS), EUMETSAT's IASI on the Metop series and NOAA's future CrIS improve the vertical resolution of satellite-derived temperature soundings, which should significantly improve the monitoring of temperature change. Atmospheric temperature sounding data play an important role, along with radiosonde and aircraft data in reanalyses of temperature and other upper-air variables. Radiosonde temperatures form an important climate data record in their own right, albeit requiring careful homogenisation to account for instrumental and real-time processing changes. Aircraft temperatures are also prone to biases for which adjustments need to be developed by reanalysis centres.

#### Action A19

**Action:** Ensure the continued derivation of MSU-like radiance data and establish FCDRs from the high-resolution IR sounders, following the GCMPs.  
**Who:** Space agencies.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Quality and quantity of data; availability of data and products.  
**Annual Cost Implications:** 1-10M USD (for generation of datasets, assuming missions, including overlap and launch-on-failure policies, are funded for other operational purposes) (Mainly by Annex-I Parties).

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" the other types of temperature measurement, and supplement the GRUAN in this regard. RO instruments are flown on multiple low Earth orbiting satellites. The COSMIC fleet of satellites provides real-time data and the GRAS instrument on EUMETSAT's Metop is the first of a series of operational RO instruments. Real-time use of the data has been established and a positive impact on NWP has been demonstrated. Climate applications are being developed by providing consistent time series of

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<sup>53</sup> National Oceanic and Atmospheric Administration (NOAA).

bending angles and refractivity profiles. The introduction of other global navigation satellite systems (GNSS) offers opportunities for further improvement in coverage of RO data.

#### **Action A20**

**Action:** Ensure the continuity of the constellation of GNSS RO satellites.

**Who:** Space agencies

**Time-Frame:** Ongoing; replacement for current COSMIC constellation needs to be approved urgently to avoid or minimise a data gap.

**Performance Indicator:** Volume of data available and percentage of data exchanged.

**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

#### **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 between successive observations and assigning their height by estimating their temperature to provide “satellite winds” over the ocean. These estimates are even more accurate when based on data acquired from multiangular instruments such as MISR, since height information is derived from the parallax in the data and does not involve assumptions about temperature profiles. These data are part of the WWW/GOS designed for weather forecasting and will have application for climate through their incorporation in reanalysis.

The ADM/Aeolus mission will pioneer wind-lidar measurement from space. If the data from this mission demonstrate significant value for climate purposes, careful and prompt consideration will need to be given to the implementation of follow-on missions (see also Action A10).

#### **ECV – Upper-air Water Vapour**

Water vapour is a key gas in the atmosphere since it is both radiatively and chemically active. It is the strongest of the greenhouse gases (GHGs) on the planet, though largely influenced indirectly rather than directly by anthropogenic activity. In the upper troposphere and lower stratosphere, it is a key indicator of convection and radiative forcing. In the stratosphere, water vapour is a source gas for OH which is chemically active in the ozone budget. There is recent evidence that the Brewer Dobson circulation is changing in the tropics due to climate change, which alters the balance of water vapour in the Upper Troposphere (UT) and Lower Stratosphere (LS) markedly and has a strong feedback on climate change.

Broad-scale information on tropospheric water vapour is provided by operational passive microwave, infrared and UV/VIS satellite instruments. Infrared instruments have more recently been enhanced by high spectral resolution infrared sounders. Requirements for stable operation and processing, as expressed in Action A7 for precipitation, apply for water vapour. 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 Global Precipitation Measurement mission) has an important role to play.

The capability to observe continuous total column water vapour data from ground-based GPS receivers is well established and these data are exchanged and used operationally in NWP centres. The network of GPS receivers should be extended across all land areas to provide global coverage, and the data should be freely exchanged for climate purposes. Collocating GPS receivers at GRUAN sites is important.

**Action A21 [IP-04 A21]**

**Action:** Finalise standard and implement exchange of data globally from the networks of ground-based GPS receivers.  
**Who:** WMO CIMO and WMO CBS in cooperation with national agencies.  
**Time-Frame:** Finalisation of standard urgent, implementation by 2012.  
**Performance Indicator:** Number of sites providing data.  
**Annual Cost Implications:** <1M USD (20% in non-Annex-I Parties).

Global high vertical resolution measurements of H<sub>2</sub>O in the UT/LS by limb observations are also essential. The required limb sounding also yields invaluable information on ozone and other chemical composition variables. Action A25 in section 4.3 calls for the required measurements.

Calibration of the data from the various satellite sensors is a very important issue, and for this the implementation of the GRUAN (Action A15) will provide essential data.

**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 from 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 relating to cloud microphysics. The comprehensive global operational cloud products from MODIS and MISR serve as reference for an extended period of time (almost a decade as of this writing). High-resolution infrared and microwave soundings (e.g., from HIRS) also contribute to better understanding of cloud properties. Actions should be taken to avoid gaps in these advanced cloud products by using other available satellite systems (e.g. FY-3) and by upgrading future sensors to capabilities equivalent to these systems. Because of the importance of the observation of cloud amount, microphysical characteristics and radiative properties, and their variation in time, continued research on improving observational capabilities is required.

The effect on cloud formation and cloud lifetime of aerosol is one of the largest uncertainties in climate modelling. Detailed measurements of cloud microphysics in combination with aerosol measurements are needed to improve current estimates. Besides the cloud observations described above and the aerosol observations described for the atmospheric composition domain in section 4.3, combined LIDAR-RADAR measurements (ground-based, aircraft and satellite) are needed to study the aerosol-cloud interaction for research. Detailed field campaigns jointly measuring in-situ cloud condensation nuclei and aerosol size and distribution are needed to study the atmospheric processes of the indirect aerosol effect.

**Action A22 [IP-04 A22]**

**Action:** Ensure continuation of the measurements needed to extend the 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. Pursue reprocessing as continuous activity taking into account lessons learnt from preceding research.  
**Who:** Space agencies, for processing.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Long-term availability of global homogeneous data at high frequency.  
**Annual Cost Implications:** 1-10M USD (for generation of datasets and products) (Mainly by Annex-I Parties).

**Action A23 [IP-04 A23]**

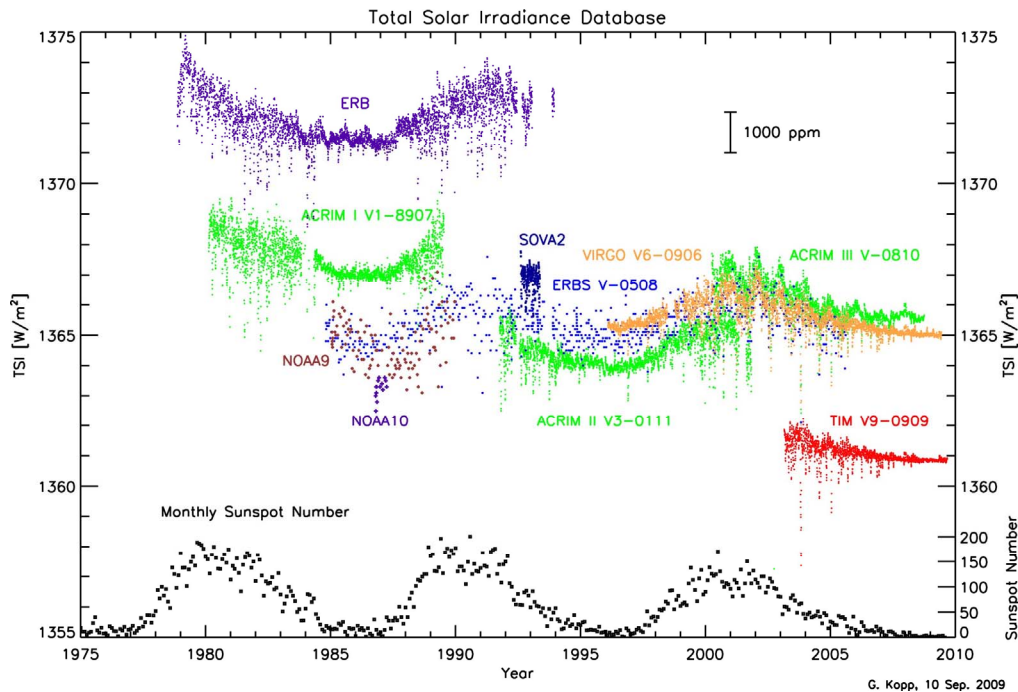
**Action:** Research to improve observations of the three-dimensional spatial and temporal distribution of cloud properties.  
**Who:** Parties' national research and space agencies in cooperation with the WCRP.  
**Time-Frame:** Continuous.  
**Performance Indicator:** New cloud products.  
**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

**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 directional 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 continuing priority for CEOS and CGMS in their planning process. The requirement for this overlap is demonstrated in Figure 5 below.

**Action A24 [IP-04 A24]**

**Action:** Ensure continuation of Earth Radiation Budget observations.  
**Who:** Space agencies.  
**Time-Frame:** Ongoing.  
**Performance Indicator:** Long-term data availability at archives.  
**Annual Cost Implications:** 30-100M USD (Mainly by Annex-I Parties).



**Figure 5: 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 in the past by as much as 9  $Wm^{-2}$ , and more recently systematically by around 4  $Wm^{-2}$  so that continuous time series are only made possible by overlapping measurements from different satellites. (Source: <http://spot.colorado.edu/~koppq/TSI> accessed 24 September 2009).**

### 4.3. Atmospheric Domain – Composition

#### 4.3.1. General

A number of atmospheric trace constituents have an important role in climate forcing and feedbacks. The ECV list includes water vapour, CH<sub>4</sub>, CO<sub>2</sub>, and ozone and aerosols. In addition, the records of precursors of ozone and aerosols are included to improve the ability to detect and attribute changes in ozone and aerosol in both the troposphere and the lower stratosphere, although some precursors are important variables for air quality and thus climate-change impacts in their own right. Water vapour is considered in the upper-air part of this document (4.2). The atmospheric composition ECVs are listed in Table 8 together with the observational networks and satellites involved in global measurements. This is based in part 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.

Understanding the sources and sinks for CO<sub>2</sub> and CH<sub>4</sub> is crucial. One of the challenges is to distinguish between natural and anthropogenic sources, for which accurate global measurements are required. While the atmospheric burden of CO<sub>2</sub> is increasing quite steadily by about 0.5% per year, the rise in methane concentration levelled off during the last decade. However, from 2006 to 2007 methane increased by 6 ppb in the atmosphere, the largest rise since 1998, and there was a further increase from 2007 to 2008, although it is still too early to state with certainty that these increases represent the beginning of a new upward trend of methane. There are large uncertainties in the budget of methane, and observations combined with modelling are needed for better understanding of the sources and sinks.

N<sub>2</sub>O is a greenhouse gas which mainly originates from agriculture, but is also produced by natural sources, i.e. soils and ocean. These sources are diffusive and therefore it is not easy to obtain from inverse modelling. There is also a large variability in the stratosphere.

Halocarbons are currently a minor contribution to GHGs but they are potent GHGs and represent a potential long-term threat. Some of them (CFCs and HCFCs) are regulated by the Montreal Protocol, since they are also ozone depleting gases, but they might not be phased out before 2040 and may show increasing concentration before 2040. Others do not deplete ozone and are therefore not governed by the Montreal Protocol. Concentrations of some of them are increasing rapidly.

Projections of a changing climate have added a new dimension to the issue of the stratospheric ozone layer and its recovery. New data and models show the interconnections between these two global environmental concerns. Projected stratospheric cooling will inhibit ozone recovery. On the other hand, ozone-depleting chemicals and ozone itself provide positive forcing of climate. The reduction of ozone-depleting substances not only helped the ozone layer but also lessened climate forcing. Because of the close interaction between climate and stratospheric processes there is a continuing need to monitor atmospheric composition throughout the troposphere and stratosphere. Being able to distinguish changes arising from a decrease in ozone-depleting substances from those due to other sources of climate forcing is essential for establishing climate policy.

Changes in tropospheric composition have an impact on air quality as well as climate change. Several tropospheric trace gases and aerosols play key roles in both domains. Tropospheric ozone and aerosols are both radiatively active and air pollutants. Other trace gases, such as NO<sub>2</sub>, SO<sub>2</sub>, CO, and HCHO, are not directly active radiatively but are precursors for tropospheric ozone and secondary aerosols (i.e. aerosols that are formed in the atmosphere). Methane is a precursor for tropospheric ozone and stratospheric water vapour, as well as a GHG. Observations of precursors are needed for an emission-based view on the radiative forcing (due to both anthropogenic and natural sources) by tropospheric ozone and secondary aerosols.

Estimates of the emissions of the precursors are still very uncertain and are mostly based on inventories compiled using socio-economic statistics. More accurate knowledge of the emission sources is urgently needed as input to climate and air quality models, which are used both for climate monitoring via data assimilation and for climate prediction. High spatial and temporal resolution is needed for accurate emission estimates, especially for NO<sub>2</sub> and SO<sub>2</sub>.

Recent studies, including some providing input to the IPCC process, have considered the coupling of air quality and climate change, not only by the direct link via tropospheric composition but also because climate change will lead to different air pollution levels, which in turn will lead to different regional forcings (e.g. by recurrent dust or biomass burning events) and impact on global change. Future implementations of air quality legislation will reduce emission sources of pollutants that are either directly radiatively active (e.g., aerosols) or precursors to tropospheric ozone and secondary aerosols.

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, cover and lifetime. The IPCC has identified anthropogenic aerosols as the most uncertain climate forcing constituent. Detailed information on aerosols is needed to make progress in our understanding and quantification of their impact. Information on aerosol optical depth alone is insufficient; data are needed also on aerosol composition, density as well as particle size and shape.

In accord with the IGACO strategy, CEOS agencies (through the Atmospheric Composition Constellation Team) and countries are working, in consultation with WMO GAW and GCOS, to develop the composite *in-situ* and satellite observing system needed to quantify better the distribution of the atmospheric composition ECVs. This will enable sources, transport and sinks to be estimated through integration of measurements using data assimilation. These activities also support the development of the models that are vital to this objective and are carried out in collaboration with ongoing programmes administered by WCRP and the WMO Atmospheric Research and Environment Programme.

**Table 8: Observational networks and systems contributing to the Atmospheric Domain – Composition.**

ATMOSPHERIC DOMAIN – COMPOSITION				
ECV	Contributing Network(s)	Status	Contributing Satellite Data <sup>54</sup>	Status
<b>Carbon Dioxide</b>	GCOS Comprehensive Network for CO <sub>2</sub> , consisting of: GAW <sup>55</sup> continuous surface monitoring network.	Operational; Partial network; Operational data management.	SWIR and high-resolution IR	Continuity in IR operational instruments but products are immature and limited; A dedicated research satellite mission to provide better global products has been launched in 2009 (GOSAT), but continuity of such SWIR measurements need to be assured.
	GAW surface flask sampling network.	Operational; Partial network; Operational data management.		
	Airborne sampling.	Limited operational aircraft vertical profiling initiated.		
	TCCON network (ground based FTIR)	Operational, partial network		

<sup>54</sup> For complete listing and details of past, present and future satellite missions, see the IGOS IGACO Theme Report.

<sup>55</sup> GAW includes networks operated by NOAA/CMDL, CSIRO and many other WMO Members.

<p><b>Methane and other long-lived greenhouse gases</b></p>	<p>GCOS Comprehensive Network for CH<sub>4</sub>, consisting of: GAW continuous surface monitoring network.</p> <p>GAW surface flask sampling network.</p> <p>AGAGE, SOGE and University of California at Irvine, USA.</p> <p>Airborne sampling.</p> <p>NDACC<sup>56</sup></p>	<p>Operational; Partial network; Operational data management.</p> <p>Operational; Partial network; Operational data management.</p> <p>Operational; Partial network; Operational data management.</p> <p>Limited operational aircraft vertical profiling initiated.</p> <p>Total column measurements of methane, N<sub>2</sub>O and certain halocarbons. <a href="http://www.ndsc.ncep.noaa.gov/data/data_tbl/">http://www.ndsc.ncep.noaa.gov/data/data_tbl/</a></p>	<p>IR nadir sounders</p> <p>SWIR nadir sounders</p> <p>IR and microwave limb sounders</p>	<p>Satellite measurements on CH<sub>4</sub> are maturing and are part of operational satellites.</p> <p>MLS, HIRDLS performs N<sub>2</sub>O measurements in the stratosphere as well as of the other GHGs. Future research satellites might continue this, but there is uncertain continuity of profiling limb sounders.</p>
<p><b>Ozone</b></p>	<p>GCOS Global Baseline Profile Ozone Network (GAW ozonesonde network, including NASA SHADOZ and NDACC).</p> <p>GCOS Global Baseline Total Ozone Network (GAW column ozone network (filter, Dobson and Brewer stations)).</p> <p>NDACC</p>	<p>Mature operational balloon sonde network.</p> <p>Mature operational ground-based total column network.</p> <p>High-quality measurements with specialised instruments, such as lidars, FT-IR interferometers, microwave and DOAS spectrometers</p>	<p>UV nadir and limb sounders</p> <p>IR nadir sounders ; IR and MW limb sounders</p>	<p>Operational continuity for column ozone;</p> <p>No future operational or research high vertical resolution profiling currently planned after 2015.</p>
<p><b>Precursors</b></p>	<p>MAXDOAS, SAOZ ground-based</p> <p>NO<sub>2</sub> lidar</p> <p>In-situ network from environmental agencies</p> <p>FTIR</p> <p>NDACC</p> <p>Aircraft (IAGOS, CO)</p>	<p>Small research MAXDOAS network exists (BREDOM); this should be extended</p> <p>SAOZ and in-situ network exists</p> <p>Several FTIR sites, no network.</p> <p>IAGOS network</p>	<p>UV/VIS/NIR/SWIR sounders</p> <p>Nadir IR sounders</p>	<p>Precursors are measured by research satellites and operational satellites in future.</p> <p>Information on high spatial and temporal resolution is limited.</p>

<sup>56</sup> NDACC = Network for the Detection of Atmospheric Composition Change. <http://www.ndacc.org>



<b>Aerosol Properties</b>	BSRN; NASA AERONET; WMO GAW; backscatter lidar networks.	Ground based aerosol optical depth (e.g. AERONET, WMO GAW) networks are operational, global coordination in progress.	Solar occultation  Visible/near-IR imagers  Lidar profiling  UV nadir   Polarimetry  Multiangular viewing	Planned operational continuity for column products;  No operational missions planned for aerosol type and aerosol size   Research missions for profiling tropospheric aerosols;  No plans for continuity of stratospheric profiling.

Observations need to conform to the data quality objectives set by user consultation. They should be made freely accessible to users in a timely manner and to the appropriate data archive centres. Transition from research to operations or coordination of successive research missions is needed to ensure continuity of measurement. Improved and consistent retrieval algorithms are a priority requirement for the precursor ECVs.

Observations of the vertical profiles of water vapour (see ECV Upper-air Water Vapour) and the chemical composition ECVs is critical for understanding, monitoring and modelling climate. High vertical resolution is needed in the upper troposphere and lower stratosphere (UT/LS), and information is needed up to the stratopause. This requires a strategy for the joint use of detailed *in-situ* measurements complemented by satellite measurements for global coverage. Limb-sounding has demonstrated its value for providing the essential satellite data. Such data bring significant benefit to data assimilation systems, and current data providers have worked to satisfy user needs for near-real-time data delivery to operational centres.

An enhanced set of ground-based remote-sensing measurements is needed for the validation of satellite observations and data products for the composition ECVs. In particular, there is a need to implement a concerted programme for *in-situ* observations of the vertical profiles of water vapour, GHGs, ozone, aerosols and precursors utilizing commercial and research aircraft, pilotless aircraft, balloon systems, ground-based lidars, MAXDOAS, FTIR systems, exploiting the contribution that the GRUAN (Action A15) can bring to this activity.

**Action A25**

**Action:** Establish long-term series of limb-scanning satellite measurements of profiles of water vapour, ozone and other important species from the UT/LS up to 50km.  
**Who:** Space agencies, in conjunction with WMO GAW.  
**Time-Frame:** Ongoing, with urgency in initial planning to minimize data gap  
**Performance Indicator:** Continuity of UT/LS and upper stratospheric data records.  
**Annual Cost Implications:** 100-300M USD (including mission costs) (Mainly by Annex-I Parties).

**Action A26**

**Action:** Establish a network of ground stations (MAXDOAS, lidar, FTIR) capable of validating satellite remote sensing of the troposphere.  
**Who:** Space agencies working with existing networks and environmental protection agencies.  
**Time-Frame:** Urgent  
**Performance Indicator:** Availability of comprehensive validation reports and near-real-time monitoring based on the data from the network.  
**Annual Cost Implications:** 10-30M USD (30% in non-Annex-I Parties).

### 4.3.2. Specific Issues – Composition ECVs

#### ECVs – Carbon Dioxide and Methane, and other GHGs

The GAW comprehensive network (Figure 6) forms the basis of the GCOS Comprehensive Networks for CO<sub>2</sub> and CH<sub>4</sub>. There are major gaps to be filled in terrestrial sink regions as well as over the southern oceans. Sites that measure fluxes and concentrations from major regional research projects could be added to fill some of these gaps. NOAA/ESRL is a WMO GAW member and major partner in the comprehensive network, and hosts the WMO primary standards for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O. Many other WMO GAW participants (e.g., Australia, Japan, France and 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.

Other *in situ* measurements will provide the observational resources to undertake regional analyses. Measurement of the isotopic composition of CO<sub>2</sub> and methane can help to distinguish between various emissions and thus improve our understanding of the budgets of these gases.

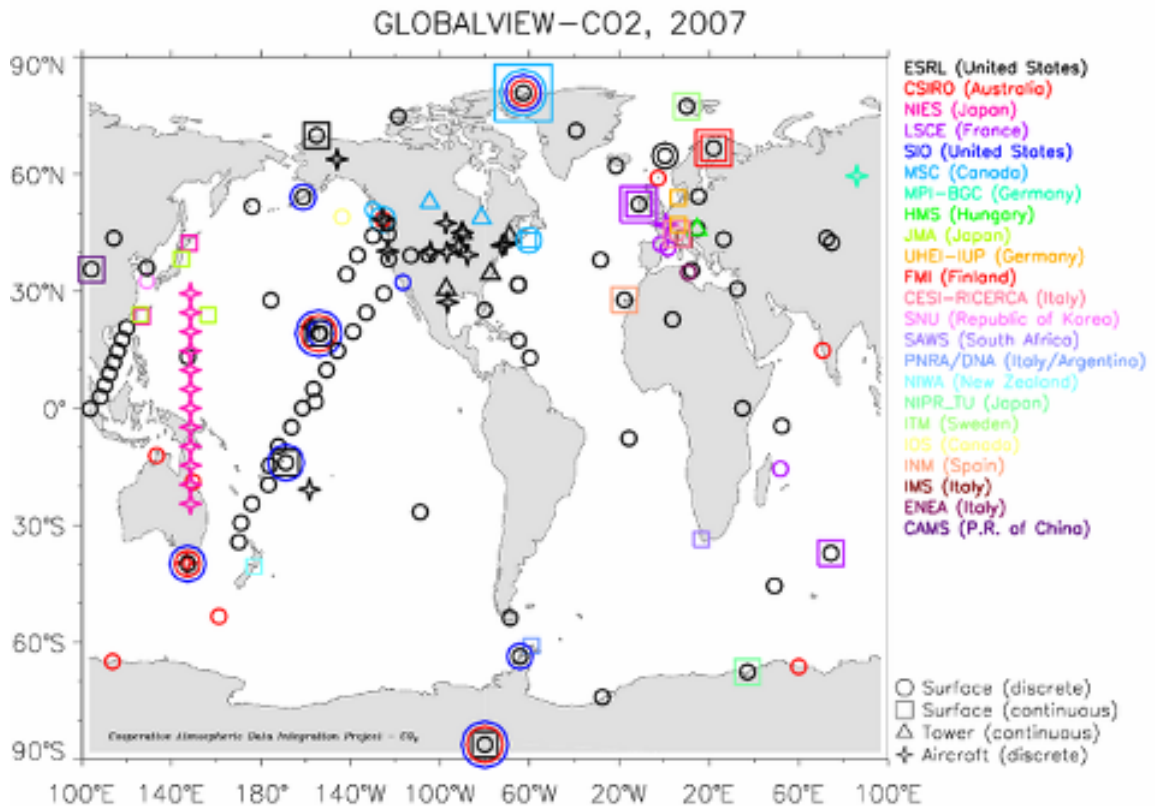
#### Action A27 [IP-04 A27]

**Action:** Maintain and enhance the GCOS Comprehensive Networks for CO<sub>2</sub> and CH<sub>4</sub> coordinated by WMO GAW.  
**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:** Ongoing  
**Performance Indicator:** Dataflow to archive and analyses centres  
**Annual Cost Implications:** 10-30M USD (50% in non-Annex-I Parties).

Satellite measurements are emerging as an important component of the overall observing system for CO<sub>2</sub> and CH<sub>4</sub>. The SCIAMACHY instrument made the first global measurements of CH<sub>4</sub>, and its data are being used in inverse modelling studies to quantify CH<sub>4</sub> emissions. The AIRS and IASI high-resolution IR sounders are providing information on both CO<sub>2</sub> and CH<sub>4</sub>, though with limited vertical range, and their data too have been used in flux inversions via data assimilation. The recently launched GOSAT mission is starting to provide more complete information. Experience with the use of the data from GOSAT will guide the development of the space-based component of the observing system for these two major GHGs.

#### Action A28

**Action:** Assess the value of the data provided by current space-based measurements of CO<sub>2</sub> and CH<sub>4</sub>, and develop and implement proposals for follow-on missions accordingly.  
**Who:** Parties' research institutions and Space agencies  
**Time-Frame:** Urgent, to minimise data gap following GOSAT  
**Performance Indicator:** Assessment and proposal documents; approval of consequent missions  
**Annual Cost Implications:** 1-10M USD initially, increasing with implementation (10% in non-Annex-I Parties).



**Figure 6: Current configuration of the comprehensive WMO GAW network for CO<sub>2</sub>-based data contained at the WDC for Greenhouse Gases in Japan. The network for CH<sub>4</sub> is almost identical (Source: WDC-GG).**

The other GHGs are generally well mixed in the troposphere, and it is sufficient for monitoring purposes to measure them with a limited number of stations worldwide. Observations of N<sub>2</sub>O by in situ flask networks are in place. Stratospheric trend monitoring of N<sub>2</sub>O is done by FTIR measurements. MLS performs measurements of N<sub>2</sub>O in the stratosphere. It is very difficult to measure N<sub>2</sub>O in the troposphere from satellites. The AGAGE network comprises five stations and collaborating networks contribute with another six stations. This gives global coverage from Spitsbergen in the north to Tasmania in the south. Halocarbons must be monitored closely, albeit from a relatively small number of stations, because once they enter the atmosphere, some of them will remain for hundreds, even thousands of years.

**Action A29 [IP-04 A29]**

**Action:** Maintain networks for halocarbon and N<sub>2</sub>O and SF<sub>6</sub> measurements.  
**Who:** Parties' national research agencies and national services, through WMO GAW.  
**Time-Frame:** Ongoing.  
**Performance Indicator:** Data flow to archive and analyses centres.  
**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

**ECV – Ozone**

Routine measurements of column ozone from ground-based UV spectrometers are established under the guidance of the WMO GAW programme. Calibration of instruments is an ongoing requirement. Coarse ozone profiles measurements are provided from these spectrometers through the Umkehr technique. In-situ ozone profiles are measured to about 30 km using ozone sondes. The GAW program maintains a network of about 40 ozone-sonde stations and collaborates with other networks such as the NASA/Southern Hemisphere Additional Ozone Sondes (SHADOZ). Recent calibration and data protocols have significantly improved the accuracy of these data, but more needs to be done to ensure prompt data supply in uniform code formats, as the data are important for monitoring the quality of satellite data retrievals and products from data assimilation systems operated in near-real-

time. Ground-station networks such as NDAAC also provide profiles using lidar and microwave techniques. Ground-based measurements still have very limited coverage in the tropics and southern hemisphere. Both GAW column ozone and total ozone networks have been recognized as the GCOS Global Baseline Profile Ozone Network and the GCOS Global Baseline Total Ozone Network.

**Action A30** [IP-04 A30]

**Action:** Maintain the quality of the GCOS Global Baseline (Profile and Total) Ozone Networks coordinated by the WMO GAW and seek to increase coverage in the tropics and southern hemisphere. Improve timeliness of provision of data to users and promote adoption of a single code standard.

**Who:** Parties' national research agencies and services through WMO GAW and partners, in consultation with AOPC.

**Time-Frame:** Ongoing.

**Performance Indicator:** Network coverage and operating statistics.

**Annual Cost Implications:** 1-10M USD (50% in non-Annex-I Parties).

There is a record of ozone observation from space that extends back over more than thirty years. It comprises both nadir UV and IR measurements and limb measurements in the spectral range from the UV to the microwave. Combining data from the nadir sounders with the higher vertical resolution data from limb sounders provides essential information on tropospheric ozone amounts. Established capability exists to assimilate ozone data in operational NWP and reanalysis systems. Combination of ground and satellite observations has provided unique information on the evolution of the Antarctic ozone hole and global ozone trends. These datasets along with research-satellite measurements of other species involved in ozone chemistry (chlorine and nitrogen compounds and water vapour) are being used on a continuing basis in WMO/UNEP Assessments supporting the Montreal Protocol and its Amendments. There is an ongoing need to extend and refine the existing data records and integrated products, taking account of the biases seen between the datasets produced from the various instruments.

Nadir measurements of ozone are set to continue for the foreseeable future from operational satellite systems, but measurements of high vertical resolution profiles will cease under present plans when the last of the current and near-future missions comes to an end in about 2015. The CEOS agencies are considering follow-on capabilities, but missions may not be in place in time to avoid a serious gap in provision of this crucial type of data. Action A25 calls for continuation of vertical profile measurements from space using limb-sounding.

**Action A31**

**Action:** Continue production of satellite ozone data records (column, tropospheric ozone and ozone profiles) suitable for studies of interannual variability and trend analysis. Reconcile residual differences between ozone data sets produced different satellite systems.

**Who:** Parties' space agencies

**Time-Frame:** Ongoing.

**Performance Indicator:** Statistics on availability and quality of data.

**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**ECV – Aerosol Properties**

*In-situ* aerosol measurements are included in the WMO GAW observing programme, where the intent has been to obtain measurements representative of the major geographical and exposure regimes, including the Aerosols Robotic System (AERONET) and BSRN sites. In addition, several limited regional networks of measurements directly related to aerosol properties are in place for addressing air quality and acidification issues, as well as for supporting satellite system calibration and validation. Satellite measurements beginning with those from AVHRR provide long-term information on aerosol optical depth, and recent dedicated aerosol research missions are providing not only more accurate measurements of optical depth, but also data on aerosol size, type and vertical profile.

Although there is an increasing amount of aerosol data available, more *in-situ* and space-based measurements are needed in both the troposphere and the lower stratosphere. A concerted effort to integrate the available measurements of aerosol optical properties and to expand the measurements

has begun, and may be viewed as an important step in developing a concerted system for global aerosol monitoring. The development and generation of consistent products combining the various sources of data are essential. The physical and chemical composition of aerosols needs to be routinely monitored at a selected number of globally-distributed surface sites. There is likely to be an ongoing need for future operational capabilities for aerosol monitoring from space to be augmented by research missions, and the strategy for an integrated international system for global aerosol measurement from space needs developing. There is also an ongoing need for reprocessing of past satellite observations using better calibration, cloud screening and aerosol microphysics to obtain a historical record.

There is also an important source of long-term records on atmospheric aerosol abundance and composition in glacial ice (see Actions C15 to C17). Joint measurements of cloud and aerosol properties are required for quantifying aerosol-cloud interactions (see ECV Cloud Properties).

**Action A32 [IP-04 A31]**

**Action:** Develop and implement a coordinated strategy to monitor and analyze the distribution of aerosols and aerosol properties. 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 for the next two decades, and propose arrangements for coordinated mission planning.

**Who:** Parties' national services, research agencies and space agencies, with guidance from AOPC in cooperation with WMO GAW, AERONET.

**Time-Frame:** Ongoing, with definition of baseline in-situ components and satellite strategy by 2011.

**Performance Indicator:** Designation of GCOS baseline network(s). Strategy document, followed by implementation of strategy.

**Annual Cost Implications:** 10-30M USD (20% in non-Annex-I Parties).

**Supporting measurement of precursors for aerosols and ozone**

Global observation of the precursors NO<sub>2</sub>, SO<sub>2</sub>, HCHO and CO (in addition to CH<sub>4</sub>, covered earlier) has been shown to be feasible from space. In the last ten years major progress has been made in measuring these species in the troposphere and lower stratosphere using a range of instruments, and it will be possible to extend the data record forward to several decades with data that will come from existing and planned operational missions. Studies have shown that emission estimates using inverse modelling techniques and satellite data can help to reduce the uncertainties in emission data bases, and first studies are being performed combining precursor and aerosol data from space to obtain information on aerosol composition. Emerging integrated data products for the ozone and aerosol ECVs from comprehensive chemical data assimilation systems will be improved by assimilating observations of the precursors, as this will lead to better background model fields of ozone and aerosol. Combining observations of the precursors with those of tropospheric ozone and aerosols will be crucial for attributing change to natural and anthropogenic sources. High temporal and spatial resolution is needed to improve the emission estimates, especially for short-lived trace gases with a large diurnal cycle such as NO<sub>2</sub> and SO<sub>2</sub>.

Information from in-situ observations is needed to exploit the value of the satellite measurements of the precursors and validate data products (Action A26). Since retrieval is dependent on profile assumptions, albedo and cloud, research activities have to be undertaken to improve existing retrieval techniques, using a combination of *in-situ*, satellite and model information.

**Action A33**

**Action:** Ensure continuity of products based on space-based measurement of the precursors (NO<sub>2</sub>, SO<sub>2</sub>, HCHO and CO in particular) of ozone and aerosols and derive consistent emission databases, seeking to improve temporal and spatial resolution.

**Who:** Space agencies in collaboration with national environmental agencies and meteorological services

**Time-Frame:** Requirement has to be taken into account now in mission planning, to avoid a gap in the 2020 timeframe.

**Performance Indicator:** Availability of the necessary measurements, appropriate plans for future missions, and derived emission data bases.

**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

**4.4. Atmospheric Domain – Data Management**

Data management is a key consideration in the establishment of GCOS baseline networks (see Table 9). 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 more homogeneous digital historical records, and a greater focus is needed on the collection and archiving of digital metadata associated with observing networks. In many countries, historical measurements have been archived only in paper records, and a concerted international effort continues to be needed to ensure that the global digital historical record is as comprehensive as possible. For other networks, real-time and delayed-mode analysis centres are being established. Actions to establish improved data management for most of the atmospheric composition variables are critical, and one focus of the actions related to these ECVs is 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 identified as a priority. The WWW Global Telecommunication System (GTS) and the WMO Information System (WIS) must continue to be developed in this respect.

**Table 9: International Data Centres and Archives – Atmospheric Domain.**

Network or System	International Data Centres and Archives	Coordinating Body
<b>Atmosphere Surface</b>		
GCOS Surface Network	GCOS GSN Monitoring Centre (DWD, JMA) GCOS GSN Analysis Centre (NCDC) GCOS GSN Archive (WDC Asheville) WMO CBS GCOS Lead Centres (JMA, NCDC, DMN (Morocco), INM (Mozambique), IRIMO (Iran), DMC (Chile), BoM (Australia), BAS (UK))	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 Asheville Global Precipitation Climatology Centre (DWD)	WMO CCI, WMO CBS and WMO RAs
Baseline Surface Radiation Network	World Radiation Monitoring Centre (Alfred Wegener Institute, AWI, Bremerhaven) World Radiation Data Centre (St. Petersburg)	AOPC with WCRP
<b>Atmosphere Upper-air</b>		
GCOS Upper-air Network	GCOS GUAN Monitoring Centres (ECMWF) GCOS GUAN Analysis Centres (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	GCOS Reference Upper Air Network (GRUAN, Lindenberg, Germany)	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	None designated	WMO CBS
<b>Atmosphere Composition</b>		
GCOS Comprehensive Network for CO <sub>2</sub> and CH <sub>4</sub> (GAW continuous surface monitoring network)	WDC-GG (JMA) NOAA- ESRL (Boulder) Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory)	WMO CAS
GCOS Comprehensive Network for CO <sub>2</sub> and CH <sub>4</sub> (GAW surface flask sampling network)	WDC-GG (JMA) NOAA- ESRL (Boulder)	WMO CAS
GCOS Global Baseline Profile Ozone Network, GCOS Global Baseline Total Zone Network, NDACC	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 and Precursors: AERONET GAW baseline network Lidar network	World Data Centre for Aerosols (NILU)	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 and associated metadata are available for analysis by all interested groups.

The amount and diversity of satellite data concerning atmospheric composition variables are especially significant because of the large data volumes associated with some missions, and the number of research missions and space agencies involved. The efficiency and effectiveness of the user 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 metadata. Agencies that maintain these data archives should work together to make this goal a reality.

Cross-cutting data management Actions C19, C20, C21 and C22 are especially applicable in this regard.

#### 4.5. Atmospheric Domain – Integrated Global Analysis Products

Although data from GCOS baseline networks or satellites can be used as 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 particular means to generate a range of integrated global products in the Atmospheric Domain, particularly for the upper atmosphere where a wide variety of *in-situ* and satellite data can be used to produce very detailed analyses. Major reanalyses of the meteorological ECVs have been undertaken by the European Centre for Medium-Range Weather Forecasts (ECMWF), the Japan Meteorological Agency (JMA) and the US National Centers for Environmental Prediction, and additional activities are in progress in the USA. Input data for reanalysis have been assembled by the reanalysis community with the assistance of the archive, monitoring and research community. Establishing formal cooperative arrangements between the centres in Europe, USA and Japan that carry out global reanalyses would allow each successive reanalysis to build more completely on the data sets and results of the previous ones.

Actions in section 4.3 have addressed the need to monitor the detailed regional and temporal distribution of the atmospheric concentrations of GHGs and aerosols, especially over the continents.

In addition, research on global data assimilation methods is needed to achieve optimal global analyses of the ECVs and estimates of sources and sinks, especially 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 the atmospheric composition ECVs. Data assimilation for atmospheric composition variables is far less mature than for the meteorological variables, but significant progress has been made in Europe in the development of atmospheric services under the auspices of the Global Monitoring for Environment and Security (GMES) initiative. There is a need for observational 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 many there remain outstanding issues requiring research. These include:

- Characterization of the three-dimensional spatial and temporal distribution of cloud properties, and the relationship with moisture and wind fields;
- Global monitoring of the composition and distribution of aerosols and their precursors, and linked observation of aerosol and cloud for study of their interactions;
- Global monitoring of water vapour especially at the surface and in the upper troposphere and lower stratosphere, and linked observation of water vapour and cloud, especially for deep convection;
- Unbiased estimation of high temporal resolution precipitation amount and type, especially over the oceans, over high latitudes and over areas of complex orography;
- Combination of in-situ and space-based measurements of greenhouse gases in reanalysis and inverse modelling; e.g., development of active (lidar) and passive sensors for the estimation of column CO<sub>2</sub> from satellites;
- Development of consistent climate quality reanalysis products for all ECVs.

### **5. OCEANIC CLIMATE OBSERVING SYSTEM**

#### **Role of the Oceans in the Climate System**

The ocean plays critical, but generally not obvious, roles in the fundamentally coupled ocean-atmosphere-land Earth climate system. Perhaps the most obvious uncoupled role is through sea level, which directly affects society at the coasts. Less obviously, but very importantly, transport of heat from the tropics toward the poles is a major factor in determining the surface temperature of many nations; east-west transport of water in the tropical Pacific controls the onset and evolution of El Niño events; transport along and under ice shelves may determine how rapidly they separate from land. The ocean holds about 50 times more carbon than the atmosphere, and its sediments thousands of times more.

The ocean also varies on decadal time scales and will experience greater changes than will result from climate change over the same period. The upwelling zones of the ocean provide nutrients that support some of the most biologically productive zones of the planet, and there is growing evidence that oceanic physical and chemical changes strongly control ocean ecosystems and may affect them more in the decades ahead. Tracking the heat and carbon stored and the exchanges of heat, moisture, momentum and greenhouse gases with the atmosphere are vital for understanding and forecasting the evolution of climate variability and change. Observing changes in the biogeochemical system and in marine ecosystems is critical to projecting their future states, as well as the ocean's ability to continue to provide food to vulnerable societies.

Sea level is a critical variable for low-lying regions, and globally 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. Local sea-level changes can also be strongly influenced by regional and local circulation changes, by isostatic rebound from the last glaciation period, and by land use changes. Sea-surface temperature is a critical variable for the coupled atmosphere-ocean system. In addition to the surface atmospheric variables, others of note include sea ice, sea-surface salinity, and partial pressure of carbon dioxide ( $p\text{CO}_2$ ). Ocean colour is used to indicate biological activity. Ocean life is dependent on the biogeochemical status of the ocean,



which is affected by changes in its physical state and circulation. Sea ice is important as an indicator of climate change as well as through its albedo feedback and its impact on polar ecosystems. Melting or forming sea ice affects salinity and hence density and ocean currents. Technology is developing rapidly to permit additional observations in coastal regions and for boundary currents, narrow straits and shallow regions (choke points where flow is limited), biogeochemical variables, primary productivity, and other ecosystem variables.

## Observing the Oceans

The composite surface and sub-surface ocean observing networks, as described in the IP-04, include global monitoring of certain ECVs where this is feasible. Monitoring of other ECVs depends on observations from reference stations or sites, or, in the case of sub-surface ocean carbon, nutrients and tracers, repeat ship-based surveys. Very recently, there have been significant contributions to sub-surface ocean measurements, particularly in data-sparse areas near ice margins from animal-mounted conductivity, temperature and depth (CTD) devices. 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, and thus merits sponsorship from a range of sources.

At the same time, despite this 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 IP-04 and this update 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.

Not all of the oceanic ECVs can yet be cost-effectively observed globally on the desired space and time scales with existing technology. For this reason, ocean reference network activities are important 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 ocean observing system for climate 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.

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 emergence of the GOOS Coastal Ocean Observing System programme provides a systematic pathway for both consideration of climate requirements and implementation in coastal waters. In addition to observing the physical ocean variables, it is critical at selected sites to have observations of marine biodiversity and habitat properties as these are important to both support the sustainable use of ocean resources and monitoring the impacts that climate change and other environmental changes may produce. 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.

### Ocean Data Analysis

Ocean reanalyses of the time-varying ocean circulation are necessary to provide dynamically-constrained syntheses of ocean temperature, salinity, currents and sea level observations and to explore the relationship between the physical ocean state with ecosystems and biochemical variability and change. Ocean analysis, reanalysis/state estimation and ocean data assimilation and forecasting systems are underway in a number of nations. Enhancement and coordination of the suite of these efforts, needed to meet the specific needs of the UNFCCC, started under the CLIVAR/GODAE umbrella. Some of the efforts began to provide ocean initial conditions for decadal forecasts and emphasis is now on improving the systems and moving them forward into coupled assimilation efforts. Sustaining ocean reanalysis/assimilation needs to be a priority of the GCOS IP to make maximum use of the ocean data. Key needs in this area are noted below in section 5.4.

### Agents for Implementation

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 and the IOC I-GOOS 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 in Actions, it is understood that such groups mostly provide coordination and that the ultimate responsibility lies with nations and their agencies.

Most *in situ* observing activities in the oceans continue to be carried out under research agency support and on research programme time limits. A particular concern is the fragility of the financial arrangements that support most of the present effort; 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 ocean observations and analyses remain the national and regional research organizations, with their project-time-scale focus and emphasis on principal investigator-driven activities.

Implementation of the observing system depends on national actions by research and operational agents of implementation. The regular reporting by Parties on systematic observation to the UNFCCC includes national institutional arrangements and ocean observation activities, should be encouraged (see Action C4) and utilized to assess progress in national action.

The multi-purpose nature of the global ocean and climate observing systems means that there is an ongoing need to ensure balance and relevance. The GOOS/GCOS Ocean Observation Panel for Climate (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 users of the observing system.

### Action O1 [IP-04 O1]<sup>57</sup>

**Action:** Analyze the ocean section of national reports on systematic observation for climate to the UNFCCC, and encourage non-Annex-I Parties to contribute reports.

**Who:** IOC, I-GOOS JCOMM, in consultation with GOOS

**Time-Frame:** Conforming to UNFCCC guidelines.

**Performance Indicators:** Number of Parties providing reports on their ocean observing activities.

**Annual Cost Implications<sup>58</sup>:** <1M USD (10% in non-Annex-I Parties).

<sup>57</sup> Reference is made to corresponding (not necessarily identical, often follow-on) Actions in the IP-04, so they exist.

<sup>58</sup> See section 2.2 (Executive Summary) and section 2.8 for cost definitions.

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 partnerships between operational and research programmes will be required and should include, *inter alia*, the Partnership for Observations of the Global Oceans (POGO), science teams such as for the Ocean Surface Topography and Ocean Surface Vector Winds Constellation teams, Aquarius/SAC-D, and SMOS Science Teams, and specialized space agencies.

### Implementation in Coastal Regions

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 direct and tangible benefits, in particular in improving regional and local understanding of the impacts of climate change and to inform decisions on adaptation. Work under the UNFCCC Nairobi Work Programme has begun to address the need for sustained observations to improve Parties' understanding of climate impacts and vulnerability, and to support their adaptation decisions. For the Oceanic Domain, this primarily means monitoring and analyses for shallow seas and coastal waters. In this connection, there is a particular need to improve coastal ocean observations in many non-Annex-I Parties.

National and regional participation in the coastal module of GOOS provides one framework for coordinated development and operation of observing efforts in coastal waters. The OOPC and the GOOS Panel for Integrated Coastal Observations (PICO), through the GOOS Scientific Steering Committee, must ensure that the requirements for coastal observations of certain ECVs, including sea-surface temperature, sea level, sea state and marine habitat properties at selected sites, are fully taken into account in the implementation plan of the coastal GOOS. 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 Actions in this Plan and thus 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, but has been hampered by political considerations.

#### Action O2 [IP-04 O5]

**Action:** Establish national and regional plans, and implement them to improve coastal observations to address national needs for climate information.  
**Who:** All coastal Parties.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Publication of regional and national coastal climate observing system plans, and progress against indicators in the published plans.  
**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties).

## 5.1. Oceanic Domain – Surface

### 5.1.1. General

Table 10 lists the components of the Oceanic Domain surface observing system. 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 (see Action O41).

**Table 10: Implementation of the Oceanic Domain – Surface composite network components, their associated coordinating bodies and ECVs observed.**

Component Network	ECVs	Coordinating Body
Global surface drifting buoy array on 5x5 degree resolution	SST, SLP, position-change-based Current	JCOMM Data Buoy Cooperation Panel

(1250)		
Global tropical moored buoy network (~120)	Typically <b>SST and Surface vector wind</b> ; Can include <b>SLP, Current, Air-sea flux variables</b>	JCOMM Tropical Moored Buoy Implementation Panel (TIP/DBCP)
VOS fleet	All feasible surface ECVs	JCOMM Ship Observations Team (SOT)
VOSclim	All feasible surface ECVs plus extensive ship metadata	JCOMM SOT
Global reference mooring network (29)	All feasible surface ECVs	OceanSITES (JCOMM)
GLOSS Core Sea-level Network, plus regional/national networks	<b>Sea level</b>	JCOMM GLOSS
Carbon VOS	<b>pCO<sub>2</sub>, SST, SSS</b>	IOCCP, OOPC pilot activity
Sea-ice buoys	<b>Sea ice</b>	International Arctic/Antarctic Buoy Programme (JCOMM DBCP)
Global Coral Reef Monitoring Network; Sea-grass net global coastal monitoring network; High-resolution optical imagery (Landsat-class)	<b>Marine Biodiversity and Habitat Properties</b>	PICO
Satellite IR (polar orbit and geostationary)	<b>SST, Sea ice</b>	CEOS, CGMS
AMSR-class microwave SST satellite	<b>SST, Wind speed, Sea ice</b>	CEOS, CGMS
Surface vector wind satellite (two wide-swath scatterometers are highly desired)	<b>Surface vector wind, Sea ice</b>	CEOS, CGMS
Ocean colour satellite (SeaWiFS-class)	<b>Ocean colour</b> ; Chlorophyll concentration (biomass of <b>Phytoplankton</b> )	CEOS, IOCCG
High-precision satellite altimetry	<b>Sea-level</b> anomaly from steady state, <b>Sea state</b>	CEOS, CGMS
Complementary-orbit (sun-synchronous) satellite altimetry	<b>Sea level</b>	CEOS, CGMS
Satellite SAR	<b>Sea ice, Sea state</b>	CEOS, 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.

**Action O3 [IP-04 O6]**

**Action:** Improve number and quality of climate-relevant marine surface observations from the VOS. Improve metadata acquisition and management for as many VOS as possible through VOSclim, together with improved measurement systems.

**Who:** National meteorological agencies and climate services, with the commercial shipping companies.

**Time-Frame:** Continuous.

**Performance Indicator:** Increased quantity and quality of VOS reports.

**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

Satellites are an important element in the surface ocean observation system, and space agencies, working through CEOS, CGMS, and WMO, in their response to GCOS requirements, should 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 O4** [IP-04 O7]

**Action:** Ensure coordinated implementation of CEOS Virtual Constellations for each ocean surface ECV, in relation to in-situ ocean observing systems.  
**Who:** CEOS space agencies, in consultation with JCOMM and GCOS.  
**Time-Frame:** Continuous.  
**Performance Indicators:** Annually updated charts on adequacy of commitments to space-based ocean observing system from CEOS.  
**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties and implementation cost covered in Actions below).

A sparse global suite of surface flux 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 metadata; and knowledge of the environment (ancillary measurements). OceanSITES will define a network of about 30-40 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 7). Where practical, integration of the surface reference sites with other related initiatives that also require fixed-location time-series measurements should be undertaken.

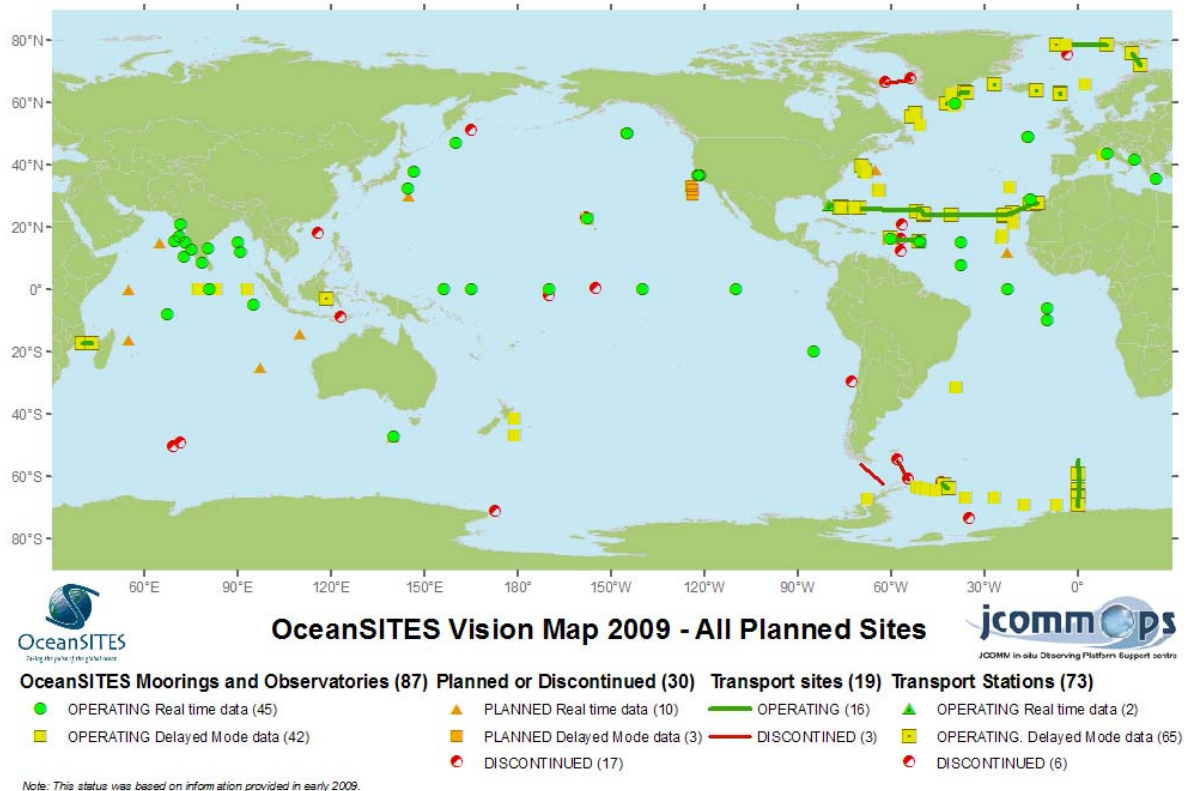
**Action O5** [IP-04 O8]

**Action:** Complete and maintain a globally-distributed network of 30-40 surface moorings as part of the OceanSITES Surface Reference Mooring Network.  
**Who:** Parties' national services and ocean research agencies responding to the OceanSITES plan.  
**Time-Frame:** Network complete by 2014.  
**Performance Indicator:** Moorings operational and reporting to archives.  
**Annual Cost Implications:** 30-100M USD (10% in non-Annex-I Parties).

The health of the ocean ecosystems may be influenced by changes in the ocean physical properties and to determining such impacts will require an improved monitoring capability. 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* instruments 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<sup>59</sup>.

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<sup>59</sup> 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.



**Figure 7: Map showing the planned distribution of the Ocean Reference Mooring Network (Source: [http://www.oceansites.org/images/200908\\_VISION.png](http://www.oceansites.org/images/200908_VISION.png)).**

**Action O6**

**Action:** Develop and deploy a ship-based reference network of robust autonomous *in situ* instrumentation for biogeochemical and ecosystem variables.  
**Who:** Parties' national ocean research agencies supported by the IGBP, IOCCG.  
**Time-Frame:** Plan published and pilot project deployed by 2014.  
**Performance Indicator:** Pilot project implemented; progress towards global coverage with consistent measurements  
**Annual Cost Implications:** 10-30M USD (10% in non-Annex-I Parties).

**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 some of 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 comprise:

- Surface drifters;
- Tropical moored buoy network;
- VOS;
- VOSclim;
- Reference mooring network;
- Argo profiling float network;
- SOOP expendable bathythermograph (XBT) network;

- Satellite IR (polar orbiting and geostationary);
- Satellite microwave.

Figure 8 shows the distribution of drifting and moored buoys as of October 2009 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 metadata 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.

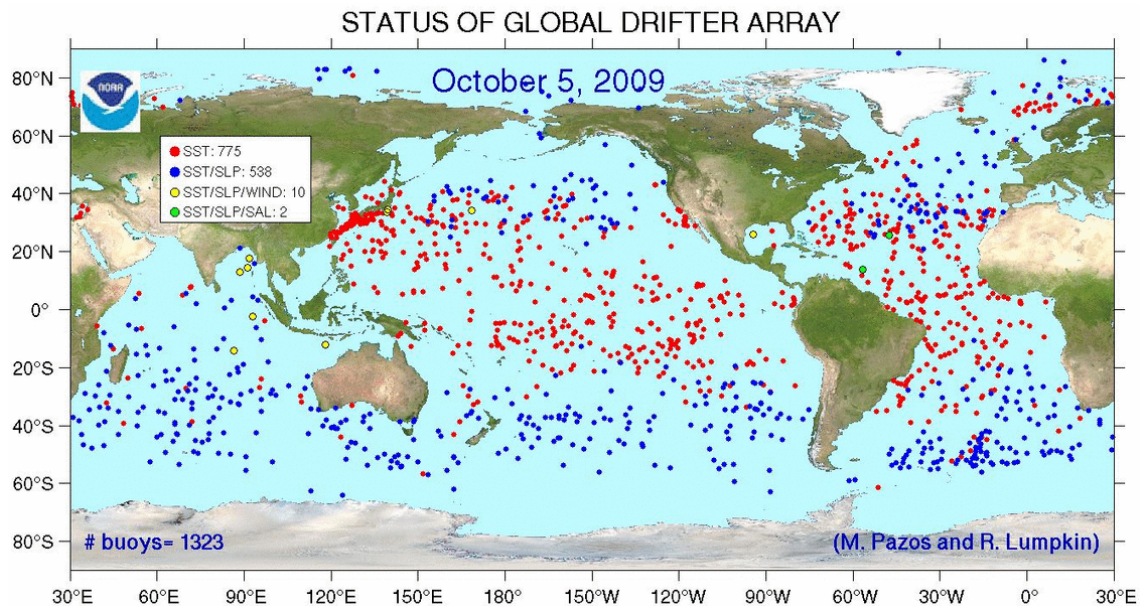


Figure 8: The distribution of drifting and moored buoys as of October 2009 (Source: <http://www.aomi.noaa.gov/phod/graphics/dacdata/globpop.gif>).

To address the issues raised above, the following set of actions is 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 O7 [IP-04 O9]

**Action:** Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting IR and geostationary IR measurements, combined with passive microwave coverage, and appropriate linkage with the comprehensive *in situ* networks noted in O8.  
**Who:** Space agencies coordinated through CEOS, CGMS, and WMO Space Programme.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Agreement of a CEOS Virtual Constellation for SST.  
**Annual Cost Implications:** 1-10M USD (for generation of datasets) (Mainly by Annex-I Parties).

The OOPC will work through JCOMM and its panels to realize global coverage of the composite *in situ* programme. This includes: maintenance of the surface drifter component to sustain 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 (about 120 moorings in all, see Action O27); and the sparse global reference time series network (referred to in Action O5 above).

### Action O8<sup>60</sup> [IP-04 O10]

**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) and an enhanced VOS effort.  
**Who:** Parties' national services and research programmes through JCOMM, Data Buoy Cooperation Panel, Tropical Mooring Implementation Panel, and the Ship Observations Team.  
**Time-Frame:** Continuing (sustain drifting buoy array, complete Tropical Moored Buoy network and enhance VOS by 2014).  
**Performance Indicator:** Data submitted to analysis centres and archives.  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

The Group on High-Resolution SST (GHRSSST) and the SST climate community will lead continued research into integrated, climate-quality products that overcome deficiencies in current products that are based on subsets of the available data. They will also improve communication with those communities providing cloud and aerosol estimates and passive microwave coverage in order to improve the quality of satellite IR SST retrievals.

### ECV – Sea Level

Tide gauge sea-level data constitute one of the few long historical ocean climate time series. An enhanced coastal tide gauge network is very essential to monitor relative coastal sea level changes, locally. But in general, sampling and global coverage of sea level change by the tide gauge network is inadequate. To monitor global sea level change and to put regionally observed changes into the global context, satellite ocean surface topography altimeter are essential. Knowledge of global sea-level variability increased substantially in 1993 when the NASA/CNES TOPEX/POSEIDON mission 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 about 300 gauges has been recommended as the desired *in situ* measurement network. Unfortunately, data are not available to the global community from a number of these gauges. Ideally, all gauges in this network should become geocentrically-located. Figure 9 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 of sea level, but also the impact of human action on subsidence which locally can be of the same order as global sea level change. Spatial scales of subsidence are small requiring a substantial enhancement of the local tide gauge network in critical regions. Jointly with the tide gauge network, continued operation of high-precision satellite altimetry and sun-synchronous altimeter measurements complete the sea-level network. Together they represent an integrated strategy for monitoring of sea-level variability and change globally and on regional scale. The Arctic Ocean is an essential component of this and needs to be observed as well.

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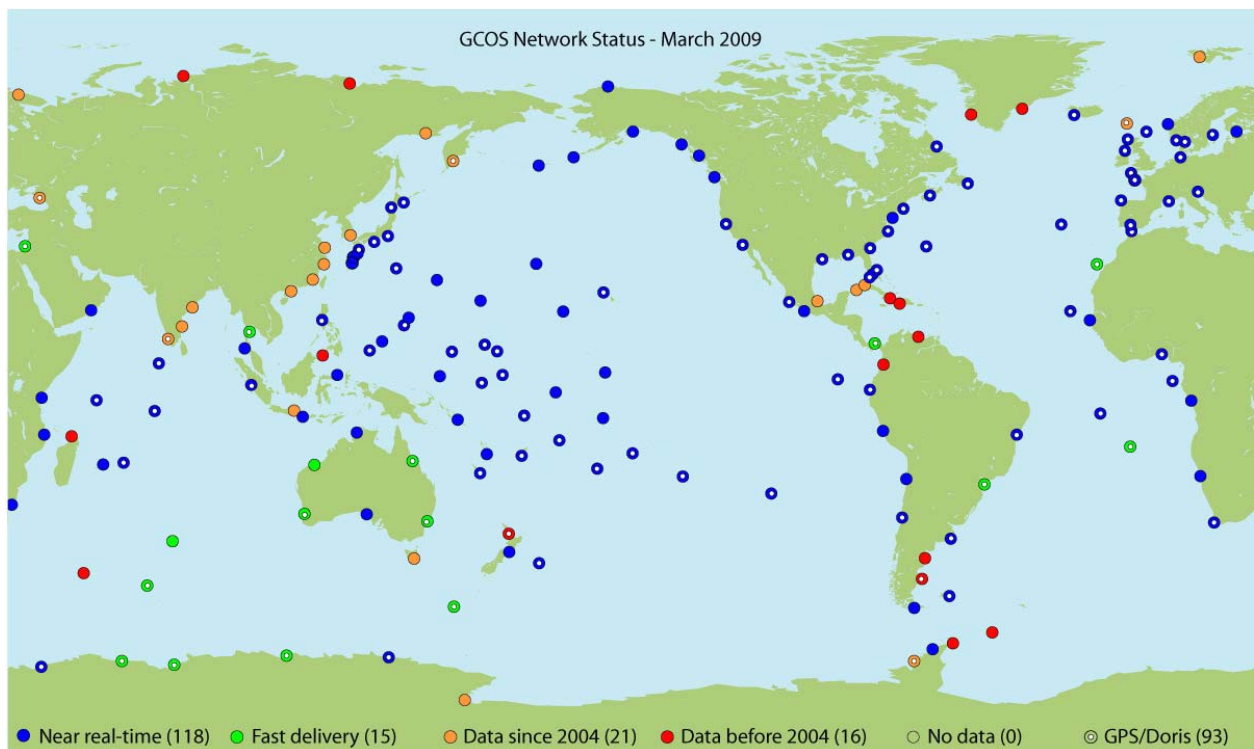
<sup>60</sup> See also Action A5.



Effective and timely data exchange of data that are being put into the same geodetic reference frame between nations is essential 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, foster needed regional enhancement and will foster the improvement of global and regional tide models.

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.
- Satellite high-precision measurements of the time-mean and time-varying geoid.



**Figure 9: Sea-level gauges in the GCOS subset of the GLOSS Core Network. "Near real-time" and "Fast Delivery" stations provide high-frequency sea level (hourly or better reports) which are necessary for understanding of sea-level variability in addition to mean sea-level rise. Near real-time stations (blue) provide data typically within 1 hour of collection; Fast delivery (green) within one month. Delayed-mode data within 5 years (orange) or greater (red) include monthly averages provided to the Permanent Service for Mean Sea Level (PSMSL). White dots are placed on tide gauges that are geo-referenced, measuring local land movements, in order to measure absolute sea-level change.**

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 caused by human activities. 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 lack of detailed knowledge of mass being exchanged between polar ice sheets and the ocean would introduce a substantial uncertainty in understanding predictions of sea level change which can by far exceed the uncertainties arising from changes in the density field of the ocean.
- 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 is 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 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 O9 [IP-04 O11]**

**Action:** Implement the GLOSS Core Network of about 300 tide gauges, with geocentrically-located high-accuracy gauges. Ensure real-time exchange and archiving of high-frequency data. Put all regional and local tide gauge measurements to the same global geodetic reference system. Ensure historical sea-level records are recovered and exchanged. Include sea-level objectives in the capacity-building programmes of GOOS, JCOMM, WMO, other related bodies, and the GCOS system improvement programme.

**Who:** Parties' national agencies coordinated through GLOSS of JCOMM.

**Time-Frame:** Complete by 2014.

**Performance Indicator:** Data availability at International Data Centres, global coverage, number of capacity-building projects.

**Annual Cost Implications:** 1-10M USD (70% in non-Annex-I Parties).

One high-precision altimeter is required at all times with planned extensive overlaps between successive missions, as well as two sun-synchronous, high spatial resolution altimeters to provide the needed sampling. In addition, continuous precise geoid measurements are required to provide a reference for the altimeter data, to determine mass redistribution within the ocean, and to provide estimates of mass exchange from the cryosphere into the ocean. GCOS, through its participation in the WMO Consultative Meetings on High Level Policy on Satellite Matters, CGMS, and CEOS will continue to emphasize the need for the continued operation of high-precision and sun-synchronous satellite altimeters (in accordance with the GCMP). Implementing the CEOS Constellation for Ocean Surface Topography is planned to provide a sustained, systematic capability to observe the surface topography of global oceans.

**Action O10 [IP-04 O12]**

**Action:** Ensure continuous coverage from one high-precision altimeter and two sun-synchronous, higher-resolution altimeters

**Who:** space agencies with coordination through the CEOS Constellation for Ocean Surface Topography, CGMS and the WMO Space Programme.

**Time-Frame:** Continuous.

**Performance Indicator:** Satellites operating, and provision of data to analysis centres.

**Annual Cost Implications:** 30-100M USD (Mainly by Annex-I Parties).

## 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:

- Argo (with advances in profiling the upper 5 m).
- Surface drifters (with advances in anti-biofouling of conductivity sensors).
- Subset of Ship of Opportunity Programme (SOOP) network carrying thermosalinographs (TSGs).
- Tropical moored buoy network.
- Global reference mooring network.
- Research vessels carrying out repeat hydrographic sections.
- SOOP Expendable Conductivity, Temperature and Depth System (XCTD).

To address these issues the following actions are proposed that 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 O11 [IP-04 O15]

**Action:** Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships.  
**Who:** Parties' national services and ocean research programmes through IODE and JCOMM in collaboration with CLIVAR.  
**Time-Frame:** By 2014.  
**Performance Indicator:** Data availability at International Data Centres.  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

The OOPC through the WCRP endorses research efforts to demonstrate the feasibility of measuring salinity using microwave radiances from space, in particular the current efforts through the ESA Soil Moisture and Ocean Salinity (SMOS) Mission and the NASA/CONAE Aquarius/SAC-D Mission.

### Action O12 [IP-04 O16]

**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 2014.  
**Performance Indicator:** Reports in literature and to OOPC.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

## ECV – Carbon Dioxide Partial Pressure

The surface ocean partial pressure of CO<sub>2</sub>, *p*CO<sub>2</sub>, is a critical parameter of the oceanic inorganic carbon system (i) because it determines the magnitude and direction of the exchange of CO<sub>2</sub> between the ocean and atmosphere, and (ii) because it is a good indicator for changes in the upper ocean carbon cycle. In addition, it is an oceanic parameter that can be routinely measured with high accuracy and precision. First measurements of *p*CO<sub>2</sub> have been initiated in the early 1960s, and the sampling network has grown substantially since then. However, most efforts so far have been driven by single investigators, while only recently international coordination efforts, largely led by IOCCP, have been initiated. As a result, the international network of surface *p*CO<sub>2</sub> observations is in the early stages of development. Current network activities include:

- Approximately 20 operational programmes underway measuring  $p\text{CO}_2$ ; approximately 12 of these programmes are doing full trans-basin sections. Nearly all of these programmes are funded by time-limited funds, and many of them are nearing the end of their funding period.
- 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.

Although this network has provided the basis for estimating the climatological air-sea fluxes of  $\text{CO}_2$ , the observations are inadequate to resolve year-to-year variations and to provide flux estimates at any resolution higher than several hundred kilometres.

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

- Improved technology/automation for on-board systems including careful calibration.
- 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 objective mapping routines and interpolation techniques including remote-sensing and model-data assimilation. Auxiliary observations that have proven to be particularly useful are sea-surface temperature, mixed layer depth, and surface chlorophyll.

To address these issues the following action is proposed that IOCCP, in consultation with the OOPC, will develop an internationally-agreed implementation strategy for a surface  $p\text{CO}_2$  network VOS, drifter and time series observations from the Surface Reference Mooring Network and other platforms together with associated products.

#### Action O13 [IP-04 O17]

**Action:** Develop and implement an internationally-agreed strategy for measuring surface  $p\text{CO}_2$ .  
**Who:** IOCCP in consultation with OOPC, implementation through national services and research programmes.  
**Time-Frame:** Implementation strategy for end-2010; full implementation by 2014.  
**Performance Indicator:** Flow of data into internationally-agreed data archives.  
**Annual Cost Implications:** 1-10M USD (Mainly Annex-I Parties).

#### ECV – Ocean acidity

Ocean acidification, commonly referred to as the ongoing decrease in the pH of the Earth's oceans caused by their uptake of carbon dioxide from the atmosphere, is a major and growing threat to marine ecosystems, particularly to marine calcifying organisms such as corals and calcifying plankton. It is mainly determined by the prevailing equilibrium in solution of calcium (as carbonates and bicarbonates) and  $\text{CO}_2$ . In order to fully characterize this chemical state of the inorganic carbon system in the surface ocean, a second property, in addition to  $p\text{CO}_2$ , needs to be measured, i.e. either dissolved inorganic carbon (DIC), alkalinity (Alk – a measure of the content of carbonate or bicarbonate), or pH. These measurements need to be undertaken with high accuracy and precision, otherwise wrong conclusions about critical properties, such as the saturation state of the seawater with regard to  $\text{CaCO}_3$ , will be drawn. High accuracy and precision measurements systems have been available for all parameters for quite some time already, i.e. pH, Alk, and DIC, but continuous systems are currently available only for pH. However, these continuous pH systems are generally not accurate enough. Development activities are currently underway, but need to be substantially enhanced.

Current network activities include a small number of ship-board-based timeseries sites where at least two of the four inorganic carbon properties are regularly measured, a small number of mooring sites and a few underway systems, where either pH or DIC is regularly measured.

Since no plans currently exist for a scale-up of these activities, a major development effort is required in order to

- Develop the technology/automation for autonomous systems that pay attention to careful calibration.

- Development of an internationally-agreed implementation strategy to identify priorities for the sustained system.
- Start a pilot trans-basin sustained observing programme, and develop new programmes according to implementation strategy priorities.

#### Action O14

**Action:** Develop instrumentation for the autonomous measurement of either DIC, Alk, or pH with high accuracy and precision.

**Who:** Parties' national research programmes coordinated through IOCCP

**Time-Frame:** Strategy: 2010, technology: 2012; pilot project: 2014.

**Performance Indicator:** Development of instrumentation and strategy, demonstration in pilot project

**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

#### 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 surface ocean colour and ecosystem variables, including chlorophyll-a and its distribution with depth, remains limited. In addition, enhanced *in situ* sampling of ocean colour and ecosystem variables is technically feasible.

Ocean colour radiance (OCR) is the wavelength-dependent solar energy captured by an optical sensor looking at the sea surface. These water-leaving radiances contain latent information on the optical constituents of the sea water, in particular the pigments (primarily chlorophyll-a) contained in the phytoplankton. At satellite altitudes the relatively weak OCR signal (10-20% of incident solar radiation) also has to propagate through the atmosphere before detection.

Cross-calibrated OCR from multiple satellites will be merged to provide a Fundamental Climate Data Record (FCDR) of water-leaving radiances in the visible spectrum from which scientific data products related to marine ecosystems and ocean biogeochemistry for near-surface global ocean and coastal waters are calculated. To accurately calculate the effect of the atmosphere on the water-leaving radiance reaching satellite altitudes requires additional measurements in the near-infrared.

The most important OCR data products currently in use are chlorophyll-a concentration (a proxy for phytoplankton biomass), coloured organic matter (COM), particulate organic carbon (POC), and suspended sediments. Other products are in development. OCR data products are the only measurements related to biological and biogeochemical processes in the ocean that can be routinely obtained at ocean basin and global ocean scales. These products are used to assess ocean ecosystem health and productivity and the role of the oceans in the global carbon cycle, to manage living marine resources, and to quantify the impacts of climate variability and change.

Continuous climate quality OCR measurements have been available for more than a decade. OCR network activities and systems (have/will) include:

- Current and future polar-orbiting global OCR satellite missions, particularly SeaWiFS, MERIS on Envisat, MODIS-Aqua, OCM on Oceansat-2, OLCI on Sentinel 3A and 3B, SGLI on GCOM-C, VIIRS on NPOESS-C1 (and possibly on NPP), and future NASA and CNES instruments under consideration. Other instruments such as China's COCTS and Korea's planned GOCI are also of interest, though these are not collecting global data.
- The SIMBIOS (Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies) Project, the GlobColour Project, the SAFARI (Societal Applications in Fisheries & Aquaculture using Remotely-Sensed Imagery) Project, ChloroGIN (The Chlorophyll Global Integrated Network), and the SeaBASS (SeaWiFS Bio-Optical Archive and Storage System) System.
- Various bio-optical fixed (e.g., MOBY, BOUSSOLE) and mobile platforms for data collection (both surface and sub-surface), calibration, validation, and development of products.

Key issues or impediments to success related to the development of a coordinated and sustained colour OCR observing system are:

- Continuity of climate-research quality OCR observations.
- Lack of free and timely access to and sharing of calibrated OCR data, including Level-0 satellite data,
- Lack of developing and sharing in-situ databases, ocean colour radiances and derived products of sufficient quality to use for calibrating and validating satellite data products.
- Difficulty of sustaining projects for cross-calibrating and merging OCR data across satellite sensors to support global and regional scientific data products.
- Need for continued research and technology development efforts to provide new and improved OCR data streams, algorithms and products, particularly for complex Case 2 waters.

To address the issues raised above, GCOS and GOOS are supporting the plans being developed through participating CEOS space agencies to implement an Ocean Colour Radiometry (OCR) Virtual Constellation (OCR-VC). 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 Satellite Supplement to the IP-04, as well as to promote associated research.

#### **Action O15 [IP-04 O18]**

<p><b>Action:</b> Implement plans for an Ocean Colour Radiometry (OCR) Virtual Constellation (VC)</p> <p><b>Who:</b> CEOS space agencies in consultation with IOCCG and GEO.</p> <p><b>Time-Frame:</b> Complete OCR-VC plan in 2009, with subsequent implementation.</p> <p><b>Performance Indicator:</b> Global coverage with consistent sensors operating according to the GCMPs; flow of data into agreed archives.</p> <p><b>Annual Cost Implications:</b> 30-100M USD (10% in non-Annex-I Parties).</p>
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#### **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, it is proposed that the JCOMM Expert Team on Waves and Surges implement wave measurement systems as part of the Surface Reference Mooring Network.

### Action O16 [IP-04 O19]

**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 2014.  
**Performance Indicator:** Sea state measurement in the International Data Centres.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

### 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* and shore-based 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, it is proposed that OOPC 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 O17<sup>61</sup> [IP-04 O20]

**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:** 2014.  
**Performance Indicator:** Number of global current fields available routinely.  
**Annual Cost Implications:** <1M USD (10% in non-Annex-I Parties).

### ECV – Sea Ice

Sea-ice variability is a key indicator of climate variability and change. A sea-ice component<sup>62</sup> of the cryosphere research effort is ongoing, e.g., through the Climate and Cryosphere (CliC) project of the

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<sup>61</sup> See Action A10.

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.

**Action O18 [IP-04 O21]**

**Action:** Document the status of global sea ice analysis and reanalysis product uncertainty (via a quantitative summary comparison of sea-ice products), to prepare a plan to improve the products.

**Who:** Parties' national agencies supported by WCRP/CliC and JCOMM ETSI.

**Time-Frame:** By end of 2011.

**Performance Indicators:** Peer-reviewed articles on state of sea ice analysis uncertainty; Publication of internationally-agreed strategy to reduce uncertainty

**Annual Cost Implications:** <1M USD (Mainly Annex-I Parties).

There are presently cryosphere-dedicated research 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-2). These satellites are critical to providing sea-ice thickness and drift, and such measurements need repeating at decadal intervals. 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.

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).
- 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.

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<sup>62</sup> 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.



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, it is proposed that space agencies, through CGMS and CEOS are working with GCOS and the WMO Space Programme continue the sustained satellite (microwave, SAR, visible and IR) operations addressing sea ice. The JCOMM will work with the OOPC and CliC to improve the *in situ* observations from sea-ice buoys, visual surveys, and ULS.

**Action O19** [IP-04 O22]

**Action:** Plan, establish and sustain systematic *in situ* observations from sea-ice buoys, visual surveys (SOOP and Aircraft), and ULS in the Arctic and Antarctic.  
**Who:** Arctic Party research agencies, supported by the Arctic Council; Party research agencies, supported by CLIVAR Southern Ocean Panel; JCOMM, working with CliC and OOPC.  
**Time-Frame:** Internationally-agreed plans published by end 2010, implementation build-up through 2014.  
**Performance Indicators:** Publication of internationally-agreed plans, establishment of agreements/frameworks for coordination of sustained Arctic and Southern ocean observations, implementation according to plan.  
**Annual Cost Implications:** Plan and agreement of frameworks: <1M USD; Implementation: 10-30M USD (Mainly Annex-I Parties).

**Action O20** [IP-04 O23]

**Action:** Ensure sustained satellite-based (microwave, SAR, visible and IR) sea-ice products.  
**Who:** Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS, and CEOS; National services for *in situ* systems coordinated through WCRP/CliC and JCOMM.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Sea-ice data in International Data Centres.  
**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

**ECV – Phytoplankton**

Climate variability and change has and will continue to significantly impact plankton in the ocean, both the microflora (e.g., phytoplankton) and the microfauna (e.g., zooplankton), over both short (seasonal

to interannual) and long-term (decadal) time scales. Changes in temperature, salinity, freshwater discharge and loadings of sediments and nutrients, acidification, light, wind forcing, and currents impact the abundance, distribution, phenology, diversity, and productivity of these organisms. This has both ecological as well as socio-economic implications. Sustained, coordinated efforts are necessary to assess and monitor these changes over time.

Contributing networks and satellite observations include continuous Plankton Recorder Tows, Ocean Colour Radiances observed by satellites, and OceanSITES reference moorings.

Issues to address relative to assessing and monitoring plankton include the development of standards for species specification and optical characteristics. To address this, the following actions are proposed:

#### **Action O21**

**Action:** Establish plan for, and implement, global Continuous Plankton Recorder surveys  
**Who:** Parties' national research agencies, working with SCOR and GOOS/OOPC  
**Time-Frame:** Internationally-agreed plans published by end 2010; implementation build-up through 2014.  
**Performance Indicators:** Publication of internationally-agreed plans; establishment of agreements/frameworks for coordination of sustained global Continuous Plankton Recorder surveys; implementation according to plan.  
**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties ).

#### **Action O22**

**Action:** Develop technology for underway plankton survey capabilities  
**Who:** Parties' national research agencies, working with SCOR and GOOS/OOPC  
**Time-Frame:** Continuous  
**Performance Indicators:** Successful pilot deployment of new technologies.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties)

### **ECV – Marine Biodiversity and Habitat Properties**

Marine habitats (e.g., coral reefs, mangroves, seagrass beds, intertidal zones, kelp forests) are extremely sensitive to the impacts of climate variability and change. In particular, changes in sea level, temperature, salinity, precipitation, freshwater inputs, light, ocean acidification, wind forcing, currents, waves et al. can all lead to significant habitat alterations and loss, especially in combination with local anthropogenic disturbances and forcing (e.g., changes in land cover and land use, eutrophication). Coral reefs especially are at significant risk, facing more frequent and severe bleaching events and disease outbreaks associated with warmer oceans, as well as rising ocean acidification, sea level, and severe storm impacts.

Contributing networks and satellite observations include:

- The Global Coral Reef Monitoring Network (GCRMN).
- The sea grass net global coastal monitoring network.
- High spatial resolution optical satellite sensors (Landsat et al.) and
- Low resolution environmental satellite monitoring (SST et al.)

Issues and needs relative to observation of coral reef and other marine habitats include:

- *In situ* networks do not provide adequate coverage or sampling relative to the required space and time scales.
- Need to improve connections between global, regional and local observing and sampling efforts, and improve coordination and information flow amongst remote sensing, *in situ* monitoring and modelling efforts.
- Need to develop and expand local research and monitoring capacity.
- Ecological monitoring needs to be accompanied by socio-economic monitoring toward improved coordinated management efforts.

- Improved data management and exchange mechanisms are needed, particularly across the land-sea interface.
- Develop capacity in remote sensing and *in situ* monitoring to respond rapidly to reporting of unusual or anomalous events on coral reefs.
- Develop and sustain a high spatial and spectral resolution capacity to assess coral reef and other marine habitat changes, particularly hyperspectral satellite observations.

To address the issues raised above, it is proposed that PICO, OOPC work with GCRMN and other partners to establish a global network of long-term observation sites covering all major ocean habitats and encourage collocation of physical measurements to enable clearer identification of climate changes at these sites (see also Actions C23, C24).

### Action O23

**Action:** Establish a global network of long-term observation sites covering all major ocean habitats and encourage collocation of physical measurements  
**Who:** Parties' national research agencies, supported GOOS/PICO, OOPC, GCRMN and other partners  
**Time-Frame:** 2014.  
**Performance Indicators:** Implementation status of network.  
**Annual Cost Implications:** 30-100M USD (50% in non-Annex-I Parties).

## 5.2. Oceanic Domain – Sub-surface

Table 11 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 11: Implementation of the Oceanic Domain – Sub-surface composite network components, their associated coordinating bodies and ECVs observed.**

Component Network	ECVs	Coordinating Body
41 repeat XBT line network	<b>Temperature</b>	JCOMM SOOP
About 120 tropical moorings	<b>Temperature; Salinity, Current</b> , other autonomously observable ECVs feasible	JCOMM TIP
30-40 reference moorings network	All autonomously observable ECVs	OceanSITES (JCOMM)
Sustained and repeated ship-based hydrography network	All feasible ECVs, including those that depend on obtaining water samples	IOCCP, CLIVAR, other national efforts
Argo network	<b>Temperature, Salinity, Current</b>	Argo Steering Team
Critical current & transport monitoring	<b>Temperature</b> , heat, freshwater, carbon transports, mass	CLIVAR, IOCCP
Regional and global synthesis programmes	Inferred <b>Currents</b> , transports	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, 30-40 surface reference moorings network and about 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<sub>2</sub> inventory on a global and basin scale (see Figure 10).

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 (about 30 sections repeated on a roughly 10 year cycle, but more frequently where necessary because of known time scales of variability<sup>63</sup>). Reassess the sampling requirements after the first full repeat in order to account for the hitherto underappreciated interior ocean variability.

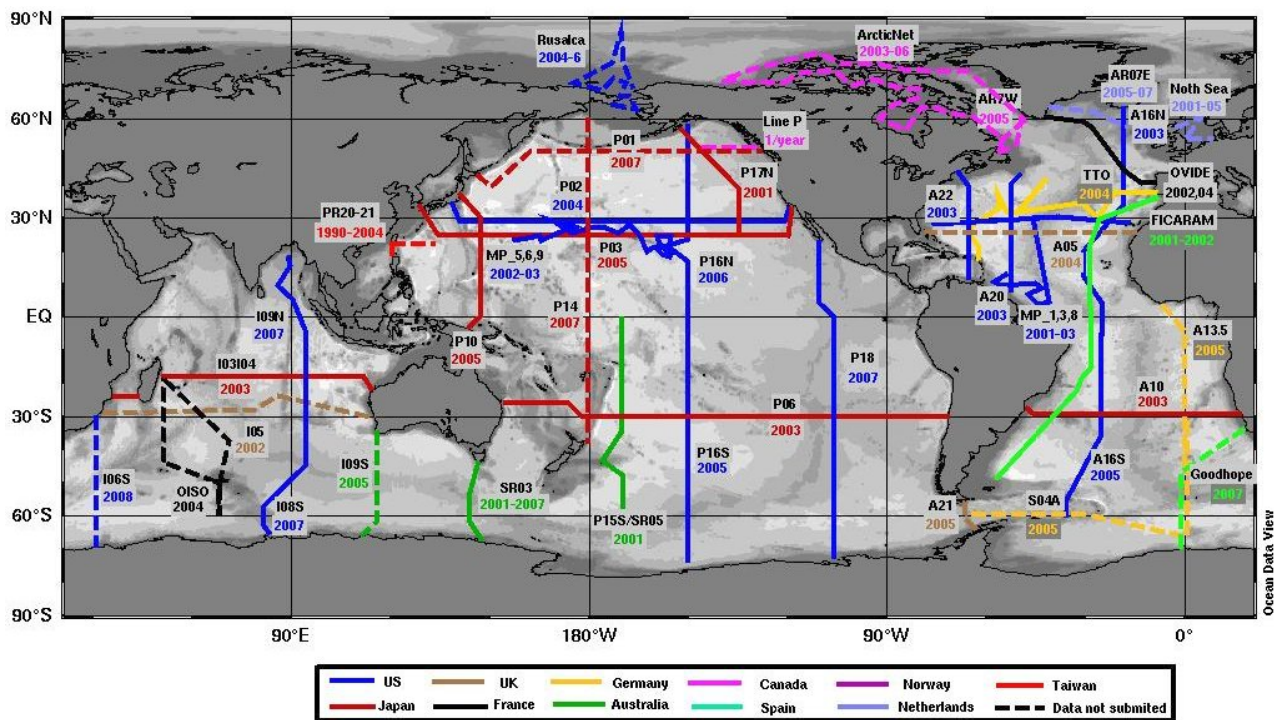


Figure 10: Map of completed International Repeat Hydrography Program sections, with colours indicating the country responsible. The dashed lines indicate data not submitted to the internationally-agreed data archive.<sup>64</sup> Data from certain hydrographic lines led by scientists from nearly all the countries involved in the Program have not yet been submitted to the international data archive.

<sup>63</sup> No long-term commitments are in place for repeat section surveys; continuation of existing research activities, with about a 40% enhancement, is needed.

<sup>64</sup> [http://cdiac.ornl.gov/oceans/RepeatSections/repeat\\_map.html](http://cdiac.ornl.gov/oceans/RepeatSections/repeat_map.html)

**Action O24 [IP-04 O25]**

**Action:** Development of a plan for systematic global full-depth water column sampling for ocean physical and carbon variables in the coming decade; implementation of that plan  
**Who:** National research programmes supported by the GOSHIP project and IOCCP  
**Time-Frame:** Continuing.  
**Performance Indicator:** Published internationally-agreed plan from the GOSHIP process, implementation tracked via data submitted to archives. Percentage coverage of the sections.  
**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

The Ship Observations Panel of JCOMM will coordinate the agreed basin-spanning Ship-of-Opportunity XBT/XCTD Repeat Section Programme (a combination of about 40 frequently-repeated sections and of high-density sections (about a 30% increase).

**Action O25 [IP-04 O26]**

**Action:** Sustain the Ship-of-Opportunity XBT/XCTD trans-oceanic network of about 40 sections.  
**Who:** Parties' national agencies coordinated through the Ship Observations Team of JCOMM.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Data submitted to archive. Percentage coverage of the sections.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

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

**Action O26 [IP-04 O27]**

**Action:** Sustain the about 3000 Argo global profiling float network, reseeding the network with replacement floats to fill gaps and maintain density (about 800 per year).  
**Who:** Parties participating in the Argo Project and in cooperation with the Observations Coordination Group of JCOMM.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Number of reporting floats. Percentage of network deployed.  
**Annual Cost Implications:** 30-100M USD (10% in non-Annex-I Parties).

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 total, about 120 moorings are needed, measuring temperature, salinity and currents as fully as possible over the upper 500m of the water column (see also Action O8).

**Action O27 [IP-04 O28]**

**Action:** Complete implementation of the current Tropical Moored Buoy, total network of about 120 moorings  
**Who:** Parties national agencies coordinated through the Tropical Mooring Panel of JCOMM.  
**Time-Frame:** Array complete by 2011.  
**Performance Indicator:** Data acquisition at International Data Centres.  
**Annual Cost Implications:** 30-100M USD<sup>65</sup> (20% in non-Annex-I Parties).

WCRP will develop ocean climate reanalyses, including all appropriate historical data assimilated into ocean models, to create climate variability and trend analyses, and to support seasonal-interannual to decadal climate prediction. They will also encourage other efforts to develop analyses and reliable data sets and products of climate variability and trends.

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<sup>65</sup> See also Action O8.

**Action O28 [IP-04 O29]**

**Action:** Develop projects designed to assemble the *in situ* and satellite data into a composite reference reanalysis dataset, and to sustain projects to assimilate the data into models in ocean reanalysis projects.

**Who:** Parties' national ocean research programmes and space supported by WCRP.

**Time-Frame:** Continuous.

**Performance Indicator:** Project for data assembly launched, availability and scientific use of ocean reanalysis products.

**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

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 O29 [IP-04 O30]**

**Action:** Work with research programmes to develop autonomous capability for biogeochemical and ecological ECVs, for deployment on OceanSITES and in other pilot project reference sites.

**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  $p\text{CO}_2$ , ocean acidity, oxygen, nutrients, phytoplankton, marine biodiversity, habitats, with other ecosystem parameters available for use in reference network applications.

**Annual Cost Implications:** 1-10M USD (50% in non-Annex-I Parties).

## 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:

- 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 O24-O28.**

### 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 O24-O28.**

### **ECV – Sub-surface Carbon**

The oceanic uptake of anthropogenic carbon is a key element of the planetary carbon budget. Over the last 250 years, the ocean has removed about 45% of the CO<sub>2</sub> that has been emitted into the atmosphere as a result of fossil fuel burning. 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, and biological activity). At present, the community consensus is that the best strategy for monitoring the long-term ocean carbon uptake is via a global ocean carbon inventory network that measures both dissolved inorganic carbon and alkalinity. ..With present technology, a major improvement in our knowledge can be achieved with the agreed full-depth repeat survey programme (see Figure 10), also benefiting from the the air-sea exchange of CO<sub>2</sub> information obtained from the surface ocean pCO<sub>2</sub> network. This requires also strong commitments from the participating institutions and nations with regard to fast submission of the data to the data centres in order to facilitate the large-scale synthesis.

However, the first results from the repeat survey indicates that the level of variability is higher than originally expected, requiring a re-assessment of whether the original plan is adequate to fully characterize the decadal time change of the oceanic inventory of anthropogenic CO<sub>2</sub>. In addition, the proposed sampling network is inadequate to determine early responses of the oceanic carbon cycle to global climate change.

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 O13, O15, O22 and O24.**

### **ECV – Sub-surface Oxygen**

Oxygen is an excellent tracer for ocean circulation and ocean biogeochemistry, but it is also essential for all higher life. Future projections indicate that the oceanic oxygen levels will decrease substantially, in part because of ocean warming and increased stratification, a process often referred to as ocean deoxygenation, but also because of increased nutrient loadings in nearshore environments that lead to eutrophication. In a business as usual scenario, the ocean is projected to lose nearly 20% of its oxygen. This will have dramatic consequences for marine biogeochemistry and marine life, as the ocean's oxygen minimum zones will expand substantially, and large swaths of ocean will appear that have oxygen levels below which fast swimming fish can survive.

The classical method to measure oxygen (Winkler method) is a discrete method that provides highly accurate and precise oxygen measurements. In the recent years, autonomous sensors have made large progresses and are now available for long-term deployments with sufficient accuracy and stability.

Current networks and systems that contribute to the observation of sub-surface oxygen are:

- Repeat survey network.
- Reference station network.
- Plus a few Argo floats that have been equipped with oxygen sensors.

These networks are research and/or pilot programmes and require substantial up-scaling in order to adequately sample sub-surface oxygen variability. Particularly attractive is the possibility to link the recently developed sensors with autonomous platforms (e.g. Argo floats) to create a large-scale observing network.

**See Actions O5 and O24.**

#### **Action O30**

**Action:** Deploy a global pilot project of oxygen sensors on profiling floats  
**Who:** Parties, in cooperation with the Argo Project and the Observations Coordination Group of JCOMM.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Number of floats reporting oxygen.  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

#### **ECV – Sub-surface Nutrients (phosphate, nitrate, silicates, silicic acid)**

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 sub-surface nutrient variability.

Additional action: develop standards.

**See Actions O5, O22 and O24.**

#### **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 O5, O15 and O24.**

#### **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 and transports 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 transport monitoring efforts (e.g., choke points, sill overflows, boundary currents, MOC) needed.
- Tropical and reference station currents seriously under-sampled for change detection.

**See Actions O19, O22 and O26-O29.**

### 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.

A plan for comprehensive data management procedures has been published<sup>66</sup> as well as an IOC data strategy.<sup>67</sup> The JCOMM plan recognizes the contribution of the joint JCOMM-IODE pilot project for end-to-end data management as well as recommending a wide spectrum of other data management activities that are needed and being addressed. Details of the procedures are in preparation by IODE and JCOMM in cooperation with the WMO Commission for Instruments and Methods of Observation, and will be a part of a pilot project in the WMO Integrated Global Observing Systems (WIGOS) for oceanographic and marine meteorological data. Wider implementation of the plan by ocean data managers is needed.

Within the framework of the WMO Information System (WIS), WMO is working towards the adoption of metadata standards and the extension of the current GTS by introducing new internet-based technology and rationalizing 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.

Three data management functions within the Oceanic Domain are particularly important: Firstly, the ability to efficiently and effectively communicate data (and metadata) 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

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<sup>66</sup> JCOMM (2008): *JCOMM Data Management Plan*. JCOMM Technical Report No. 40, [http://www.jcomm.info/components/com\\_oe/oe.php?task=download&id=5205&version=1.0&lang=1&format=1](http://www.jcomm.info/components/com_oe/oe.php?task=download&id=5205&version=1.0&lang=1&format=1)

<sup>67</sup> IOC (2007): *IOC Strategic Plan for Oceanographic Data and Information Management (2008-2011)*. IOC Manuals and Guides No. 51, [http://www.ioc-unesco.org/components/com\\_oe/oe.php?task=download&id=6139&version=1.0&lang=1&format=1](http://www.ioc-unesco.org/components/com_oe/oe.php?task=download&id=6139&version=1.0&lang=1&format=1).

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 WIS for exchange of data in real time and near real time. Other data sets, particularly from hydrographic cruises, are exchanged via other means. 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 within the WIS.

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.

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.

**Action O31** [IP-04 O32]

<p><b>Action:</b> Monitoring the implementation of the IOC Data Policy. <b>Who:</b> JCOMM. <b>Time-Frame:</b> Continuous. <b>Performance Indicator:</b> Reports by JCOMM to the IOC. <b>Annual Cost Implications:</b> 1-10M USD (10% in non-Annex-I Parties).</p>
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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 O32** [IP-04 O33]

<p><b>Action:</b> Develop and implement comprehensive data management procedures. <b>Who:</b> IODE and JCOMM. <b>Time-Frame:</b> Project plan updated by 2012. <b>Performance Indicator:</b> Plan Update published. <b>Annual Cost Implications:</b> 1-10M USD (20% in non-Annex-I Parties).</p>
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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 metadata including syntactic and semantic (description, search) metadata.

**Action O33 [IP-04 O34]**

**Action:** Undertake a project to develop an international standard for ocean metadata.  
**Who:** IODE and JCOMM in collaboration with WMO CBS and ISO.  
**Time-Frame:** Standard developed by 2011.  
**Performance Indicator:** Publication of standard for an agreed initial set of the ECVs. Plan to progress to further ECV.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

The IODE and JCOMM, in collaboration with the WIS 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 O34 [IP-04 O35]**

**Action:** Undertake a project to apply the innovations emerging from the WMO Information System, 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 2012.  
**Performance Indicator:** Report published.  
**Annual Cost Implications:** <1M USD (10% in non-Annex-I Parties).

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 O35 [IP-04 O36]**

**Action:** Plan and implement a system of regional, specialized and global data and analysis centres for each ocean ECV.  
**Who:** Parties' national services under guidance from IODE and JCOMM.  
**Time-Frame:** Plan finished by 2012, implementation following.  
**Performance Indicator:** Plan published; access to data streams by ECV  
**Annual Cost Implications:** 10-30M USD (30% in non-Annex-I Parties).

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

**Action O36 [IP-04 O37]**

**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.  
**Annual Cost Implications:** 1-10M USD (30% in non-Annex-I Parties).

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 (GTSP) and GOSUD.

**See Action O22.**

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 O37 [IP-04 O38]**

**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:** Continuing

**Performance Indicator:** Capacity to communicate data from ocean instrumentation to ocean data centres.

**Annual Cost Implications:** 1-10M USD (50% in non-Annex-I Parties).

## 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 several nations, but it is important to enhance, sustain and coordinate 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 ocean assimilation/state estimation 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 continuous integrated ocean analysis products to address climate user requirements including those of the UNFCCC:

OOPC, JCOMM, in close collaboration with CLIVAR and WOAP/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 O38 [IP-04 O39]**

**Action:** Develop plans for and coordinate work on data assembly and analyses.

**Who:** JCOMM, in collaboration with CLIVAR, CliC, WOAP, GODAE, and other relevant research and data management activities.

**Time-Frame:** 2013

**Performance Indicator:** Number of ocean climatologies and integrated data sets available.

**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties).

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 JCOMM 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 jointly with climate-quality products through CLIVAR/GSOP. 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 O39 [IP-04 O40]**

**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:** 2013.  
**Performance Indicator:** Number of global oceanic climate analysis centres.  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

CLIVAROOPC, in coordination with OOPCCLIVAR and other relevant research programmes, will develop plans for sustained pilot projects for ocean reanalysis projects, including a frequent inter-the comparison and evaluation of the results of different reanalysis results. CLIVAR in coordination with OOPC and WOAP will also develop plans for pilot coupled data assimilation projects and the use of coupled and ocean state estimation results for the initialization of coupled forecast models.

**Action O40 [IP-04 O41]**

**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.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

## 5.5. Oceanic Domain – Scientific and Technological Challenges

### 5.5.1. Observing Coastal Zones

To enlarge the benefit from global climate observations, it is imperative to address the utility of GCOS to the residents of the Earth's coastal zones. This requires special attention to the observing requirements and biogeophysical variability of this region. Observing these complex, dynamic regions, particularly from space, is typically much more challenging than making global and basin-scale ocean observations. Particular issues and challenges to be dealt with include cloud cover, bathymetry, the gravity field, tides, variable wind, wave and current fields, terrestrial loadings and inputs (natural and anthropogenic), diverse optical constituents (Case 2 waters), radio frequency interference, diverse atmospheric aerosols and water vapour. An expansion is needed of *in situ* platforms (fixed and mobile) and sensors to better address not only physical but particularly biological and biogeochemical parameters, extending what is measured, where, where and how often, and automating sampling as much as possible. Further work is equally required on integrating open ocean and coastal circulation and climate modelling efforts, linking ocean and watershed models across the land-sea interface, linking natural data with socio-economic data, and providing robust nowcasts, forecasts, and long term predictions and climate scenario assessments..

### 5.5.2. Global-scale observation capabilities

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.

Research programmes are currently the primary source of funding 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.

### Action O41 [IP-04 O3]

**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.  
**Annual Cost Implications:** 30-100M USD (10% in non-Annex-I Parties).

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<sup>68</sup> 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 study marine genomics and 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.

## 6. TERRESTRIAL CLIMATE OBSERVING SYSTEM

### 6.1. General

The terrestrial part of the climate system provides human beings with important resources such as food, fibre, forest products and water. At the same time, variability and changes of the hydrological and biogeochemical cycles are coupled with the climate system and affect the livelihood of millions of people. The primary way in which the terrestrial domain features in climate variability and change is through changes in water storage, carbon storage and other influences and feedbacks due to changes in land cover and the cryosphere. Precipitation, evapotranspiration, groundwater, soil moisture, lake levels, glaciers and river discharge constitute critical components of the hydrological cycle, with often direct impact on water availability and, for instance, droughts and floods.

Land has a wide variety of natural features, slopes, vegetation and soils that affect water budgets, carbon fluxes and reflective properties of the surface. Land is often covered by vegetation; importantly, by now, almost 40% of the Earth surface is under some form of management. Land use changes the characteristics of the land surface and thus can induce important local climate effects, especially through changes in albedo, roughness, soil moisture and evapotranspiration. When large areas are concerned (tropical deforestation) regional and even global climate may be affected. Land is covered by snow and ice on a seasonal basis, and it features glaciers, ice sheets, permafrost, and frozen lakes. Snow and ice-albedo play an important role in the feedback to climate. Further, as land-based ice, such as a glacier, melts, it affects rivers and contributes directly to sea-level rise. Disturbances to land cover (vegetation change, fire, disease and pests) have the capacity to alter climate and the soil (e.g., permafrost) but also respond to climate in a complex manner through changes in biogeochemical and physical properties. Precise quantification of the rates of change of several land

<sup>68</sup> Profiling floats with a positioning capability achieved by directional gliding.

components is important to determine whether feedback or amplification mechanisms through terrestrial processes are operating within the climate system, such as positive feedback between temperature rise and the carbon cycle. Increasing significance is being placed on terrestrial data for both fundamental climate understanding and impact and mitigation assessment.

Atmospheric CO<sub>2</sub> is increasing on a global scale while the natural sources, sinks and stocks, as well as human interventions in the carbon cycle, exhibit profound regional variations. Assessments of regional carbon budgets help to identify the processes responsible for controlling larger-scale fluxes. A lack of reliable data at appropriate scales and resolutions prevents the scientific community from making accurate assessments for the entire globe, but regional scale carbon budgets provide unique opportunities to independently verify and link methods and observations over a wide range of spatial scales. For example, it is possible to compare “top-down” atmospheric inversion estimates with land-based or ocean-based “bottom-up” direct observations of localized carbon fluxes. On land, as well as in the oceans, the basic components of such budgets include measurements of carbon stocks and exchanges with the atmosphere.

The sensitivity of carbon pools to changing climate forms a highly uncertain component of the regional and global carbon cycle. The C<sub>4</sub>MIP intercomparison showed the large range of future predicted CO<sub>2</sub> concentration as various models have different parameterizations of the climate-carbon system. It has become obvious from this intercomparison, however, that CO<sub>2</sub> levels may increase sharply in the future due to positive feedback between temperature rise and the carbon cycle.

Foundations exist for both the *in situ* observation networks and the space-based observing components of the terrestrial domain ECVs but these still need to be strengthened. Improving the understanding of the terrestrial components of the climate system, of the causes and responses of this system to change, and assessing the consequences of such change in adapting to and mitigating climate change is vital to society. Better observations of the terrestrial carbon-related variables have assumed greatly increased relevance in the context of implementing the UNFCCC Bali Road Map.

## Standards

Many organizations make terrestrial observations, for a wide range of purposes and as a result, 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 and the IP-04 noted the need for an international framework to:

- Prepare and issue regulatory and guidance material for making terrestrial observations.
- Establish common standards for networks, data management, and 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.

Following a request by the UNFCCC<sup>69</sup> regarding the development of such an international framework, the GTOS Secretariat in 2007 proposed three implementation options. These included an option that involves the International Organization for Standardization (ISO). With additional guidance provided by the SBSTA 27, GTOS and partners reached a consensus to proceed with developing a joint UN-ISO based framework for setting and maintaining standards for terrestrial observations of ECVs. The proposed framework foresees the establishment of a joint steering group, with specific roles for the participating UN organizations (in defining the requirements for standardization and providing technical inputs) and for the ISO (in leading the standards development effort). The ISO recognition of WMO as a standards-setting organization further strengthens the foundation for the proposed framework. Implementation of the framework is underway.

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<sup>69</sup> UNFCCC (2004): Report of the Conference of the Parties on its ninth session, held at Milan from 1 to 12 December 2003. Addendum. Part two: Action taken by the Conference of the Parties at its ninth session (doc. FCCC /CP/2003/6/Add.1, decision 11/CP.9, para. 8).

An assessment of the status in the development of standards for each of the terrestrial ECVs has been made<sup>70</sup>, underpinning the technical work of the framework. Where necessary, the development of standards needs to be completed, and national bodies and research groups need to be engaged, through the proposed UN/ISO framework, to ensure these standards be progressively and formally adopted by the diverse institutions involved in their observational practices in the terrestrial domain. Regular reports on progress in this domain are required.

### Action T1

<p><b>Action:</b> Ensure the development of observational standards and protocols for the each of the terrestrial ECVs; promote adoption of standards on a national level.</p> <p><b>Who:</b> GTOS, in conjunction with the sponsors of the UN/ISO terrestrial framework (WMO, FAO, ICSU, UNEP, UNESCO)</p> <p><b>Time-Frame:</b> Develop a work plan for the development of standards by 2010; UN/ISO framework implemented by 2012; national-level adoption of standards by 2014</p> <p><b>Performance Indicator:</b> Number of terrestrial ECVs with international standards; uptake of standards by Parties (percentage of terrestrial ECV observations following standards)</p> <p><b>Annual Cost Implications</b><sup>71</sup>: &lt;1M USD, increasing to 1-10M USD (Mainly by Annex-I Parties).</p>
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Despite the lack to date of an international standard-setting framework for terrestrial ECV observations, some progress is being made on the provision of the terrestrial observations required by the UNFCCC as shown in Table 12. International Data Centres for some variables are functioning at a basic level (see Table 13, 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., GTOS science panels and a Land Product Validation Group within the CEOS Working Group on Calibration and Validation (WGCV)). Concerted efforts to evaluate and benchmark some of the terrestrial products have started.

### Exchange of Hydrological Data

With regard to global observations of hydrological variables, GCOS secretariat and TOPC, in consultation with the hydrology programme of WMO and other involved organizations, has established 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, and to demonstrate the value of integrated global hydrological products for science, operational monitoring and policymaking. Activities within GTN-H are reported to the WMO CHy to assist its support to the global monitoring of rivers, lakes, ground water and water use, among others, in conjunction with the proposed terrestrial framework (see Action T1). The monitoring programmes are envisaged to involve the establishment of GCOS/GTOS 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, but generally many other national and international agencies are involved. Coordination within the hydrological domain is therefore clearly needed.

### Action T2

<p><b>Action:</b> Achieve national recognition of the need to exchange global-level hydrological data of all variables encompassed by GTN-H, in particular the GCOS/GTOS baseline networks and facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks.</p>
<p><b>Who:</b> GTN-H Coordinator, WMO, GCOS, GTOS, in consultation with GTN-H Partners</p>
<p><b>Time-Frame:</b> Continuing; 2011</p>
<p><b>Performance Indicator:</b> Number of datasets available in International Data Centres; Number of available demonstration products</p>
<p><b>Annual Cost Implications:</b> &lt;1M USD (Mainly by Annex-I Parties)</p>

<sup>70</sup> <http://www.fao.org/gtos/topcECV.html>

<sup>71</sup> See section 2.2 (Executive Summary) and section 2.8 for cost definitions.



### Calibration/validation and Monitoring of Terrestrial Biodiversity and Habitats at Selected Sites

Many if not most of the terrestrial ECVs (such as fAPAR, LAI, biomass, and albedo), are too heterogeneous spatially to make global *in situ* measurements practical. They are typically measured at a limited number of research sites or retrieved from space measurements over large areas. There are two key requirements for in situ measurements in the context of long-term global climate measurements. One is to ensure that a representative set of biomes are properly and consistently documented over long periods of time (decades or more). This will allow the details of natural vegetation changes and carbon stocks to be carefully monitored at key locations. A second need for such measurements is to establish a set of reference sites delivering essential ground data for the validation of satellite-derived products that do provide extensive geographical coverage for these variables (see Action T28 dealing specifically with calibration/validation of fAPAR and LAI). Relatively homogeneous sites, at scales comparable to the typical spatial resolution of modern sensors, are preferable, but a detailed characterization of the spatial variability of those sites is required.

In addition, as noted in section 3.8 concerning information on climate impacts for adaptation, climate change has the potential to change environments on large scales, to influence ecosystems, including the range of species in any region and to have a strong, long-term impact on habitats. This again confirms the need to study, at selected sites, representative areas within biomes, and to observe, in addition to LAI, fAPAR, biomass and albedo mentioned above, climate-relevant aspects of terrestrial biodiversity and habitat properties.

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<sup>72</sup> [IP-04 T3, T29]<sup>73</sup>

**Action:** Development of a subset of current LTER and FLUXNET sites into a global reference network for ecological monitoring sites with sustained funding perspective.  
**Who:** Parties' national services and research agencies, FLUXNET organizations, NEON, ICOS, in association with CEOS WGCV, CGMS-GSICS, GTOS (TCO and TOPC)  
**Time-frame:** Implementation by 2010  
**Performance Indicator:** Plan for the development and application of standardized protocols for the measurements of fluxes and state variables  
**Annual Cost Implications:** 30-100M USD (40% in non-Annex-I Parties)..

In addition to information on CO<sub>2</sub> fluxes (see Action T33), FLUXNET sites provide measurements of evaporation from the land which are an important part of the hydrological cycle, supplementing long term in-situ observations of pan-evaporation. Land use and climate change may induce changes in the amount and distribution of evaporation. Global evaporation products are beginning to be derived from atmospheric and terrestrial reanalysis projects and a combination of satellite products, and need independent in-situ verification.

#### Action T4

**Action:** Develop an experimental evaporation product from existing networks and satellite observations  
**Who:** Parties, national services, research groups through GTN-H, IGWCO and TOPC  
**Time frame:** 3-5 years  
**Performance indicator:** Availability of a validated global satellite product of total evaporation  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

<sup>72</sup> See also Actions A15, A27, A30.

<sup>73</sup> Reference is made to corresponding (not necessarily identical, often follow-on) Actions in the IP-04, so they exist.

**Table 12. Observation networks and systems contributing to the Terrestrial Domain ECVs.**

<b>ECV</b>	<b>Contributing Network(s)</b>	<b>Status</b>	<b>Contributing Satellite Data</b>	<b>Status</b>
<b>River Discharge</b>	GCOS/GTOS Baseline Global Terrestrial Network - River Discharge (GTN-R) based on the TOPC priority list.	Stations selected, non-contributing stations approached	Research concerning laser/radar altimetry for river levels and flow rates.	Operational laser altimeters not scheduled; Earth Observation (EO)-based network only research.
<b>Lake Level/Area</b>	GCOS/GTOS Baseline Lake Level/ Area Network based on TOPC priority list. To include freeze-up/break-up.	Stations selected, approached by Hydrolare	Altimetry, high-resolution optical and radar imagery and reprocessing of archived data.	Operational laser altimeters not scheduled. Question mark over high-resolution systems continuity. EO-based network only research.
<b>Ground Water (Levels and Use)</b>	None, but many national archives of ground-water level do exist.	GTN-GW needs to be established	Gravity missions	Gravity measurements operational, continuity needs to be secured
<b>Water Use (Area of Irrigated Land)</b>	No network, but a single geo-referenced database exists.		Any high-/medium-resolution optical/ radar systems.	Lack of high-resolution optical continuity.
<b>Snow Cover</b>	WWW/GOS synoptic network (depth).  National Networks (depth and snow water equivalent).	Synoptic and national networks have significant gaps and are ALL contracting.  Northern and Southern Hemisphere monitored operationally for extent and duration.	Moderate to high resolution optical for extent/duration.  Passive microwave for snow water equivalent.	Moderate to high resolution optical and microwave sensor system follow-on is programmed.
<b>Glaciers and Ice Caps</b>	GTN-G coordinates national monitoring networks.	Major geographic gaps still need to be closed; especially concerning glacier mass balance measurements inadequate.	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.
<b>Ice Sheets</b>	Program for Arctic Regional Climate Assessment; International Trans-Antarctic Scientific Expedition.	Large uncertainty in mass balances and dynamics  Ocean ice interaction major weakness	Gravity mission, Synthetic Aperture Radar and laser altimetry	Satellite altimetry research missions will help; Lack of laser altimetry mission continuity
<b>Permafrost and seasonally-frozen ground</b>	GTN-P coordinates National Monitoring Networks.	Major geographical gaps. National data centres need to be established	Derived near-surface temperature and moisture (e.g., from ERS/Radarsat, AVHRR, MODIS, AMSR-E).	No direct operational sensors to detect permafrost; no products.
<b>Albedo</b>	CGMS; CEOS/WGCV; MODLAND; Atmospheric Radiation	No designated baseline network.	Multi-angular sensors. Geostationary Polar orbiters.	Use of operational meteorological satellites and moderate-resolution

	Measurement sites.		GCMPs applied to measurements.	optical polar orbiters. Continuation of multi-angular missions required
<b>Land Cover</b>	FAO Global Land Cover Network; GOFC-GOLD.	First generation products available.	Any high-/medium-resolution optical/radar systems.	Moderate resolution good; High-resolution optical system continuity required.
<b>fAPAR</b>	CEOS/WGCV; FLUXNET; GTOS Net Primary Productivity.	Still no designated baseline network exists.	Optical, multispectral and multiangular.	Moderate spatial resolution multi-spectral good; Continuation of multiangular measurements required.
<b>LAI</b>	CEOS/WGCV; FLUXNET; GTOS	Still no designated baseline network exists.	Optical, multispectral and multiangular.	Moderate spatial resolution multi-spectral good; Continuation of multiangular measurements required.
<b>Above ground biomass</b>	FAO's FRA; FLUXNET; No global datacenter for non-forest biomass	No designated baseline network exists; FRA data not currently applicable for high-resolution spatial analysis.	Low-frequency radar, optical and laser altimetry.	Laser/radar missions currently planned; need to be implemented
<b>Soil moisture</b>	FLUXNET; GTN-SM needs to established	No designated baseline network exists.	Active and passive microwave missions	Continuity after the research missions required
<b>Fire Disturbance</b>	GOFC Regional Networks., GFMC	Some geographical gaps exist.	Optical and thermal.	Geostationary and moderate to high-resolution optical systems continuity required.

## 6.2. Specific Issues – Terrestrial Domain ECVs

### ECV – River Discharge

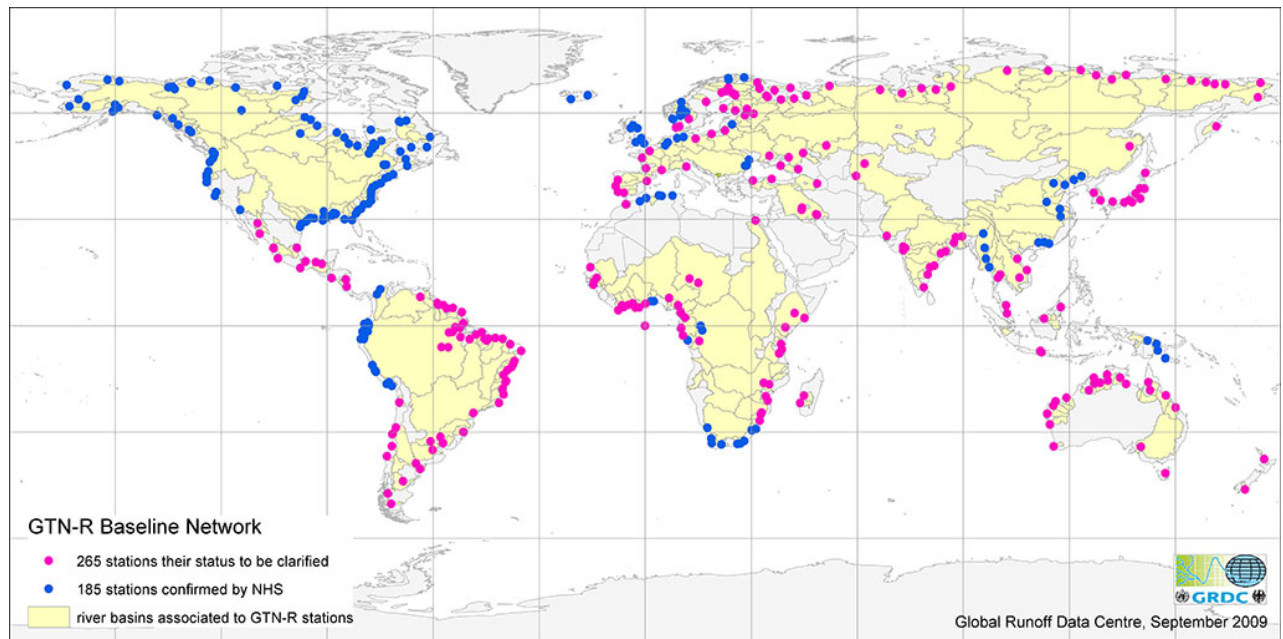
River discharge plays an important role in driving the climate system, as the freshwater inflow to the oceans may influence thermohaline circulation. The statistical properties of river discharge are an indicator for climatic change and variability as they reflect changes in precipitation and evapotranspiration, and are influenced in the longer term by land cover. River discharge data are also required for the calibration and validation of climate and impact models, trend analysis and socio-economic investigations. Monthly observations of river discharge are generally sufficient to estimate continental runoff into the ocean, though daily data are needed to calculate the statistical parameters of river discharge, e.g. for impact analyses extreme discharge.

Most countries monitor river discharge, yet many are reluctant to release their data. 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 do 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). In addition to better access to existing data, the tendency of shrinking observational networks, especially the closing of stations with long records, in some countries needs to be reversed<sup>74</sup>.

Research into interferometric and altimetry-based approaches to river water level and discharge monitoring from satellites are being developed by the space agencies, 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.

Based on past demands for data, the GRDC has proposed reference network of river discharge stations near the downstream end of the largest rivers of the world – as ranked by their long-term average annual volume. These stations, a subset of existing gauging stations around the world, collectively form a new GCOS/GTOS 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. This network is now being adjusted in consultation with national hydrological services, and a total of 185 stations have been confirmed, with the status of another 265 stations not yet clarified (see Figure 10).



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

The WMO, through CHy, will request that the National Hydrological Services responsible for the stations marked in Fig. 10 as pending: (a) evaluate the identified gauging stations, determine their

<sup>74</sup>Kundzewicz, Z. W., Mata, L. J., Arnell, N., Döll, P., Kabat, P., Jiménez, B., Miller, K., Oki, T., Şen, Z. & Shiklomanov, I. (2007) Freshwater resources and their management. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, (eds Parry, M. L., Canziani, O. F., Palutikof, J. P., Hanson, C. E. & van der Linden, P. J.), Cambridge University Press, Cambridge, UK and New York, NY, USA

operational status and provide the GRDC with this information, i.e., all existing data and metadata, 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 (definition of “near-real-time”).

Whilst the emphasis will be initially on the 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 ~20,000 USD 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.

**Action T5 [IP-04 T4]**

**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 priority reference 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:** 2011

**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.

**Annual Cost Implications:** 1-10M USD (60% in non-Annex-I Parties).

**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 contained in the 150 largest lakes. Most of these large lakes are hydrologically open. Closed-basin lakes are more sensitive to changes in regional water balance and therefore better indicators 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 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/GTOS baseline network, the Global Terrestrial Network – Lakes (GTN-L). For this purpose, 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 10cm.

Satellite-based observations can substantially contribute to the monitoring of lake level and area, using appropriate visible and near-infrared imagery, radar imagery and altimetry, especially in areas without in-situ monitoring capability. In addition, observing the surface temperature of lakes (using mainly high-resolution infrared imagery) can serve as an indicator for regional climate monitoring, since it is linked to lake freeze-up and break-up dates.

The International Data Centre on the Hydrology of Lakes and Reservoirs (HYDROLARE) was established at the State Hydrological Institute in St. Petersburg. HYDROLARE operates under the

auspices of WMO. An agreement on the establishment of HYDROLARE was signed between ROSHYDROMET and WMO on May 2008.

HYDROLARE is working with National Hydrological Services (through WMO CHy) and other institutions and agencies providing and holding data on lakes and reservoirs to continue, or where necessary initiate, monitoring of these priority lakes and provide data to HYDROLARE. 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 GTN-L lakes and provide the measurements to HYDROLARE. TOPC in collaboration with HYDROLARE is maintaining the list of GTN-L sites.

**Action T6 [IP-04 T6]**

<p><b>Action:</b> Submit weekly/monthly lake level/area data to the International Data Centre; submission of weekly/monthly altimeter-derived lake levels by space agencies to HYDROLARE. <b>Who:</b> National Hydrological Services through WMO CHy, and other institutions and agencies providing and holding data; space agencies; HYDROLARE. <b>Time-Frame:</b> 90% coverage of available data from GTN-L by 2012. <b>Performance Indicator:</b> Completeness of database <b>Annual Cost Implications:</b> 1-10M USD (40% in non-Annex-I Parties)</p>
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The publication of measurement time series for the 19<sup>th</sup> and 20<sup>th</sup> centuries would considerably enhance the value of ongoing monitoring by allowing baseline measurements to be extended to cover most of the post-industrial period. There are only isolated measurements for the period prior to the 19<sup>th</sup> century, and it is therefore not appropriate to place any priority in obtaining earlier measurements.

**Action T7 [IP-04 T7]**

<p><b>Action:</b> Submit weekly/monthly lake level and area data measured during the 19<sup>th</sup> and 20<sup>th</sup> centuries for the GTN-L lakes to HYDROLARE. <b>Who:</b> National Hydrological Services, and other agencies providing and holding data in cooperation with WMO CHy and HYDROLARE. <b>Time-Frame:</b> Completion of archive by 2012. <b>Performance Indicator:</b> Completeness of database; <b>Annual Cost Implications:</b> &lt;1M USD (40% in non-Annex-I Parties).</p>
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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, and timing of lake ice break-up). Whenever possible, these variables should be measured by National Hydrological Services and other responsible agencies holding data, in association with measurements of lake level and area, and be submitted to HYDROLARE.

**Action T8 [IP-04 T8]**

<p><b>Action:</b> Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of lakes in GTN-L to HYDROLARE. <b>Who:</b> National Hydrological Services and other institutions and agencies holding and providing data; space agencies. <b>Time-frame:</b> Continuous. <b>Performance Indicator:</b> Completeness of database <b>Annual Cost Implications:</b> &lt;1M USD (40% in non-Annex-I Parties).</p>
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The initial target of 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**

**ECV – Groundwater**

An appreciable amount – nearly 30% – of the world's total freshwater resources (i.e., including snow/ice) is estimated to be stored as groundwater. Today groundwater it is the source of about one third of global water withdrawals. Groundwater is by far the largest available reservoir of liquid freshwater (approx. 10.5 million km<sup>3</sup>). Estimates of the number of people who depend on groundwater supplies for drinking range from 1.5 to 3 billion. Global groundwater abstraction grew ten-fold in the last 50 years, concentrated in agriculture (approx. 90%), in particular in Asia. Groundwater use, in relative terms, has increased in the recent decades as compared to surface water use. On the one hand, groundwater use is technically more complicated and more expensive than surface water use but, on the other hand, it is more reliable and safer. Groundwater storage, recharge and discharge are critical aspects of climate change impacts and adaptation. Over the past several years, important progress has been made towards global-scale groundwater monitoring with *in situ* well observations as a foundation and more is expected over the next decade. In particular, the feasibility of satellite observation of groundwater storage variations using the Gravity Recovery and Climate Experiment (GRACE) mission has been demonstrated. The representation of groundwater storage in land surface models has advanced significantly.

#### Action T9

**Action:** Establish prototype GTN-GW and Global Groundwater Monitoring Information System (GGMIS), the web-portal for all GTN-GW datasets. Delivery of readily available data and products to information system.

**Who:** IGRAC, in cooperation with TOPC

**Time-Frame:** 2014

**Performance Indicator:** Reports to WMO CHy on the completeness of the GTN-GW record held in the IGRAC, including the number of stations and nations submitting data to the IGRAC; web-based delivery of products to the community.

**Annual Cost Implications:** 1-10M USD (40% in non-Annex-I Parties).

In the longer term, full implementation of the Global Terrestrial Network – Groundwater (GTN-GW) should be accomplished, including contributions from satellites (e.g., gravity missions like GRACE).

#### ECV – 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, and hence will become more sensitive to drought. 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.

Information on changes in the area of irrigated land and the amount of water used for irrigation 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 defines requirements for information on irrigation water use by international, regional, national and local communities and archives and disseminates information related to irrigation water use through its on-line AQUASTAT database on water resources and irrigation, available on the web.

Most products are incomplete but two global products are available, namely the Global Irrigated Area Map (GIAM) developed by the International Water Management Institute (May 2007 update) and a map of irrigated areas, prepared by the University of Frankfurt, Germany, in collaboration with FAO, available through AQUASTAT. Finer resolution products are available for some regional and national areas. A priority is production of gridded global data sets of irrigated area using satellite data at 250 m resolution on a regular basis. Attention should be paid to this in future land-cover databases (see ECV Land Cover). 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. For proper assessment of water use, regular information on the timing and frequency of irrigation is also needed in addition to mapping irrigated areas.

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 not available. However, research projects could support the eventual integration of satellite and *in situ* measurements such as improvements in the land-cover characterization.

There is a need for more quality assurance of data submitted to the database and FAO is developing a new set of guidelines and protocols for national reporting.

#### Action T10 [IP-04 T9]

**Action:** Archive and disseminate information related to irrigation and water resources through the FAO AQUASTAT database and other means. Assure adequate quality control for all products.

**Who:** FAO.

**Time-Frame:** By 2010.

**Performance Indicator:** Information contained in the AQUASTAT database.

**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties).

#### ECV - Soil Moisture

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, subsurface flow 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 *in situ* soil moisture activities can build on the soil-moisture data archive at Rutgers University, national networks (Russian Federation, China, USA) while the new satellite missions including SMOS and SMAP will add to our observing capability from space. The various ways of representing soil moisture from both satellite and *in situ* measurements need harmonization and ultimately standardisation. This could be achieved by an expanded network of reference stations to support the validation of satellite measurements with *in situ* data. With this objective, a Global Terrestrial Network for Soil Moisture (GTN-SM) will be initiated with the aid of TOPC.

#### Action T11

**Action:** Develop a record of validated globally gridded near surface soil moisture from satellites

**Who:** Parties' national services and research programmes, through GEWEX and TOPC in collaboration with space agencies.

**Time frame:** 2014

**Performance indicator** Availability of globally validated soil moisture products from the early satellites until now.

**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

#### Action T12

**Action:** Develop Global Terrestrial Network on Soil Moisture

**Who:** Parties' national services and research programmes, through IGWCO, GEWEX and TOPC in collaboration with space agencies.

**Time frame:** 2012

**Performance indicator:** Fully functional GTN-SM with a set of *in situ* observations (possibly co-located with reference network, cf. T3), with standard measurement protocol and data quality and archiving procedures.

**Annual Cost Implications:** 1-10M USD (40% in non-Annex-I Parties).



## 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 as well as in many other high altitude locations.. Snow thickness and snow-cover duration affect the permafrost thermal state, the depth and timing of seasonal soil freeze/thaw /break-up, and melt of 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) budget restrictions and attempts to reduce the cost of surface networks often result in reduced coverage or automated measurement using different instrumentation whose compatibility is not yet determined and (d) many existing datasets are not readily accessible.

The submission of in-situ snow observations has continued to show some decline due to financial pressures in many countries, leading to closures of remote northern observation stations. Data receipt from those remaining stations has also been an issue, with few stations including snow data in their submissions to the Global Telecommunication System (GTS), and not all providing the WMO reports (SYNOP) that normally include snow. Furthermore, there is no systematic global monitoring of the amount and quality of in-situ snow-related reports exchanged over the GTS. As a result, the creation of well calibrated satellite products is made more difficult.

### Action T13 [IP-04 T10]

**Action:** Strengthen and maintain existing snow-cover, snowfall observing sites; ensure that sites exchange snow data internationally, and establish global monitoring of that data on the GTS; recover historical data.

**Who:** National Meteorological and Hydrological Services and research agencies, in cooperation with WMO and WCRP, with advice from TOPC and AOPC and GTN-H.

**Time-Frame:** Continuing; receipt of 90% of snow measurements in Int'l Data Centre .

**Performance Indicator:** Data submission to national centres such as the National Snow and Ice Data Center (USA) and World Data Services.

**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

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 upon 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 1966, with weekly maps available from 1966 to 1999 and daily maps in subsequent years.

Southern Hemisphere snow extent maps have been available since 1999 from the NASA EOS MODIS sensor. NSIDC provides a weekly global snow extent product which combines optical (MODIS) and passive microwave (SSM/I) data for the period 2000 to the present. 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 and the International Association of Cryospheric Sciences (IACS), 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 T14 [IP-04 T11]**

**Action:** Obtain integrated analyses of snow cover over both hemispheres.  
**Who:** Space agencies and research agencies in cooperation with CliC, with advice from TOPC, AOPC and IACS  
**Time-Frame:** Continuous.  
**Performance Indicator:** Availability of snow-cover products for both hemispheres.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**In situ data:**

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 metadata; and data rescue and digitization. The provision of necessary resources to improve and make available existing archives of snow data will require national efforts. The emerging WMO Global Cryosphere Watch is expected to provide facilitated access to such data.

The Canadian Meteorological Centre has produced global daily 1/3 deg.snow-depth analyses, and daily snow-depth data from the WMO data stream. These data are available from NSIDC for the period March 1998 to the present. WWW/GOS Synoptic Reports for the United States are available through NCDC. There is a new effort within Asia CliC to obtain station snow depth data from as many sources in Eurasia as possible. An in situ data set (station and transect) for North America for the period 1980 to 2004 for more than 15,000 locations is available from NSIDC. Updates are expected. NSIDC has updated the Russian station snow depth data until 2000 for over 200 stations. 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.

**Satellite data:**

Global snow water equivalent (SWE) products are available from AMSR-E since 2002. Refinements to the algorithm continue as validation experiments are undertaken. MODIS provides daily, weekly and monthly snow extent for both Northern and Southern Hemispheres beginning in 2000.

An experimental mission to measure hydrological properties of global snow cover was proposed in 2004 to NASA's Earth System Science Pathfinder programme, the Cold Land Processes Pathfinder, specifically for snow water equivalent measurements in mountain regions using dual-frequency SAR, and the same concept, known as the CoreH2O mission, is currently the subject of Phase-A studies by ESA as the possible next mission in its Earth Explorer series.

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. A global snow product generated from the blending of in situ and satellite data is one of the goals of the ESA GlobSnow project.

The TOPC in consultation with the AOPC, WCRP-CliC and WMO CBS will establish standards and protocols for measuring snow cover and SWE, 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 (cf. T1), funding for report preparation, and funding for filling gaps in networks.

**ECV – Glaciers and Ice Caps**

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, combining detailed process-

oriented in-situ studies (annual mass balance) with coverage of large glacier ensembles in entire mountain systems by satellite information (glacier inventories, digital elevation models).

GTN-G is a collaboration between the World Glacier Monitoring Service (WGMS of the International Association for the Cryospheric Sciences (IACS), FAGS/ICSU, UNEP and UNESCO), the Global Land Ice Measurement from Space (GLIMS) project and NSIDC at Boulder Colorado. The WGMS is in charge of collecting and disseminating standardized data from in-situ measurements worldwide through a network of national correspondents and principal investigators. The GLIMS project – now reinforced by the ESA-funded GlobGlacier project – to complete modern glacier inventories with digital terrain information in key regions of the world and the NSIDC provide systematic satellite observations from for example ASTER, NASA/USGS Landsat, SPOT and other commercial satellites and help with 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.

Measurements of glacier and ice cap extent and mass balance must be made by national services, governmental and research groups to determine regional volume changes using cost-saving methodologies (index stakes with repeated mapping, DEM-differencing) in order to inter- and extrapolate in time and space using detailed local measurements at higher time resolution (winter/summer, year) and corresponding numerical models simulations (reconstruction, future scenarios). Mass balance measurements of glaciers and ice caps are now being (re-)initiated in equatorial Africa, Patagonia, New Zealand and the Himalayas so that patterns of glacier changes can be monitored globally. A quality rating must be attributed to the long-term mass balance observations.

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 yearly time intervals of, at horizontal resolutions of 30m. The inventory will be performed by a network of experts in different regions working in close cooperation with those space agencies operating high-resolution optical sensors with stereographic image acquisition capabilities. The GTN-G is now coordinating the production of the inventory relating to the turn and beginning of the century and will plan for the next inventory of key regions concerning conditions around 2010 to 2020.

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), implements a web-based data management and data dissemination system of existing historical records and archived high-resolution satellite data.

**Action T15 [IP-04 T13]**

**Action:** Maintain current glacier observing sites and add additional sites and infrastructure in South America, Africa, the Himalayas and New Zealand; attribute quality levels to long-term mass balance measurements; complete satellite-based glacier inventories in key areas.  
**Who:** Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS, NSIDC.  
**Time-Frame:** Continuing, new sites by 2015.  
**Performance Indicator:** Completeness of database held at NSIDC from WGMS and GLIMS.  
**Annual Cost Implications:** 10-30M USD (50% in non-Annex-I Parties).

**Action T16 [IP-04 T14]**

**Action:** Ensure continuity of laser, altimetry and gravity satellite missions adequate to monitor ice masses over decadal timeframe.  
**Who:** Space agencies, in cooperation with WCRP/CliC, TOPC  
**Time-Frame:** New sensors to be launched: 10-30 years.  
**Performance Indicator:** Appropriate follow-on missions agreed.  
**Annual Cost Implications:** 30-100M USD (Mainly by Annex-I Parties).

## ECV Ice Sheets

Our understanding of the timescale of ice sheet response to climate change has changed dramatically since the last decade. Rapid changes in ice-sheet mass have surely contributed to abrupt changes in climate and sea level in the past. The mass balance loss of the Greenland Ice Sheet increased in the late 1990s to 100 gigatonnes per year ( $\text{Gt a}^{-1}$ ) or even more than  $200 \text{ Gt a}^{-1}$  for the most recent observations in 2006. It is extremely likely that the Greenland Ice Sheet is losing mass and very likely on an accelerated path since the mid-1990s. The mass balance for Antarctica as a whole is close to equilibrium, but with a likely net loss since 2000 at rates of a few tens of gigatonnes per year. The largest losses are concentrated along the Amundsen and Bellinghausen sectors of West Antarctica and the northern tip of the Antarctic Peninsula. The potentially sensitive regions for rapid changes in ice volume are those with ice masses grounded below sea level such as the West Antarctic Ice Sheet, with 7 m sea level equivalent (SLE), or large glaciers in Greenland like the Jakobshavn, also known as Jakobshavn Isbræ and Sermeq Kujalleq (in Greenlandic), with an over-deepened channel reaching far inland. There are large mass-budget uncertainties from errors in both snow accumulation and calculated ice losses for Antarctica ( $\sim\pm 160 \text{ Gt a}^{-1}$ ) and for Greenland ( $\sim\pm 35 \text{ Gt a}^{-1}$ ). Most climate models suggest that climate warming would result in increased melting from coastal regions in Greenland and an overall increase in snowfall. However, they do not predict the substantial acceleration of some outlet glaciers that we are observing. This results from a fundamental weakness in the existing models, which are incapable of realistically simulating the outlet glaciers that discharge ice into the ocean.

Observations show that Greenland is thickening at high elevations, because of the increase in snowfall, which was predicted, but that this gain is more than offset by an accelerating mass loss, with a large component from rapidly thinning and accelerating outlet glaciers. Although there is no evidence for increasing snowfall over Antarctica, observations show that some higher elevation regions are also thickening, likely as a result of high interannual variability in snowfall. There is little surface melting in Antarctica, and the substantial ice losses from West Antarctica and the Antarctic Peninsula are very likely caused by increased ice discharge as velocities of some glaciers increase. This is of particular concern in West Antarctica, where bedrock beneath the ice sheet is deep below sea level, and outlet glaciers are to some extent “contained” by the ice shelves into which they flow. Some of these ice shelves are thinning, and some have totally broken up, and these are the regions where the glaciers are accelerating and thinning most rapidly.

Recent observations show a high correlation between periods of heavy surface melting and increase in glacier velocity. A possible cause is rapid meltwater drainage to the base of the glacier, where it enhances basal sliding. An increase in meltwater production in a warmer climate will likely have major consequences on ice-flow rate and mass loss. Recent rapid changes in marginal regions of the Greenland and West Antarctic ice sheets show mainly acceleration and thinning, with some glacier velocities increasing more than twofold. Many of these glacier accelerations closely followed reduction or loss of their floating extensions known as ice shelves.

Efforts should be made to (i) reduce uncertainties in estimates of mass balance and (ii) derive better measurements of ice-sheet topography and velocity through improved observation of ice sheets and outlet glaciers. This includes utilizing existing satellite interferometric synthetic aperture radar (InSAR) data to measure ice velocity, the use of observations of the time-varying gravity field from satellites to estimate changes in ice sheet mass, and monitoring changes in ice sheet topography using tools such as satellite radar (e.g., Envisat and Cryosat-2), laser (e.g., ICESat-1/2), and wide-swath altimeters (see Action T16).

Monitoring the polar regions with numerous satellites at various wavelengths is essential to detect change (i.e., melt area) and to understand processes responsible for the accelerated ice loss of ice sheets and the disintegration of ice shelves to estimate future sea level rise. Further, aircraft observations of surface elevation, ice thickness, and basal characteristics should be utilized to ensure that such information is acquired at high spatial resolution along specific routes, such as glacier flow lines, and along transects close to the grounding lines. In-situ measurements (e.g., firn temperature profile, surface climate) are equally important in assessing surface mass balance and understanding recent increases in mass loss.

### Action T17

**Action:** Ensure continuity of *in situ* ice sheet measurements and fill critical measurement gaps.

**Who:** Parties, working with WCRP/CliC, IACS and SCAR.

**Time-Frame:** Ongoing

**Performance Indicator:** Integrated assessment of ice sheet change supported by verifying observations

**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

### Action T18

**Action:** Research into ice sheet model improvement to assess future sea level rise.

**Who:** WCRP/CliC sea level cross-cut, IACS and SCAR..

**Time-Frame:** international initiative to assess sea level rise within 5+ years

**Performance Indicator:** Reduction of sea level rise uncertainty in future climate prediction from ice sheet contributions to within 20% of thermal expansion of the ocean.

**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

### ECV – Permafrost

Frozen ground (permafrost temperatures and depth of seasonal freezing/thawing) reacts sensitively to climate and environmental change in high latitude and mountain regions. Corresponding changes result in the thermal mode of permafrost and subsurface conditions and have important impacts on terrain stability, coastal erosion, surface and subsurface water, the carbon cycle and vegetation development. Combined monitoring of meteorological and hydrological variables, soil and vegetation parameters, carbon dioxide and methane fluxes and the thermal mode of the active layer and permafrost on upgraded “reference sites” is the recommended approach to development of observations. 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/GTOS baseline network for these variables. The Geological Survey of Canada (Ottawa) maintains borehole metadata files and coordinates thermal data management and dissemination. Every five years, the NSIDC prepares and distributes a Circumpolar Active Layer Permafrost System CD containing information and data acquired in the previous 5 years. The establishment of permafrost national centres to collect and analyze data is recommended.

GTN-P currently involves 16 participating countries, with hundreds of active sites in the Circumpolar Active Layer Monitoring (CALM) network and identified boreholes for monitoring permafrost thermal state, though some of these need to reactivate their measurement campaigns, and soil vertical displacement measurements and permafrost temperatures measurements should become a part of active layer monitoring. GTN-P has also identified 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 few reference sites are recommended to be planned and established, and this will establish a baseline network of Thermal State of Permafrost (International Network of Permafrost Observatories (INPO)).

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, Russian Academy of Sciences “Evolution of Cryosphere” Program, Canadian transects, and Permafrost and Climate in Europe activities, GEF in Mongolia, among others. Measurement and reporting standards are emerging, but further work is needed to prepare and publish definitive reporting standards. Upscaling techniques for research sites and permafrost networks, first of all on upgraded reference sites, are required to complement active layer and thermal observing networks with monitoring of active geological processes (e.g. slope processes, thermokarst and lakes development, coastal dynamics, and surface terrain stability).

**Action T19 [IP-04 T15]**

**Action:** Refine and implement international observing standards and practices for permafrost and combine with environmental variable measurements. Establish national data centres.  
**Who:** Parties' national services/research institutions and International Permafrost Association.  
**Time-Frame:** Complete by 2010.  
**Performance Indicator:** Implemented guidelines and establishment of national centres.  
**Annual Cost Implications:** <1M USD (10% in non-Annex-I Parties).

**Action T20 [IP-04 T16]**

**Action:** Ensure continuity of the existing GTN-P borehole and active layer networks and upgrade existing sites, and build "reference sites"  
**Who:** Parties' national services/research institutions and International Permafrost Association. IGOS-P cryosphere to ensure continuity and associated Earth observation derived variables.  
**Time-Frame:** Continuing.  
**Performance Indicator:** Number of sustained sites; Completeness of database.  
**Annual Cost Implications:** 10-30M USD (20% in non-Annex-I Parties).

Declining permafrost areas and seasonally-frozen ground form a dynamic whole. Observing the extent of seasonally frozen ground is an important activity in monitoring permafrost decline.

**Action T21 [IP-04 T17]**

**Action:** Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally-frozen ground in non-permafrost regions  
**Who:** Parties, space agencies, national services and NSIDC, with guidance from International Permafrost Association with IGOS-P Cryosphere.  
**Time-Frame:** Complete by 2013.  
**Performance Indicator:** Number and quality of mapping products published.  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

**ECV – Albedo**

Terrestrial albedo is a joint property of the land surface and of the overlying atmosphere; it controls the 'supply' side of the surface radiation balance and is required to estimate the net absorption and transmission of solar radiation in the soil-vegetation system. It 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, sowing and harvesting crops, burning rangeland, etc.).

Land surface albedo is sometimes monitored in situ on a national basis but these observations are not coordinated in a global network. space agencies have been generating global albedo products, in particular from the MODIS and MISR sensors (NASA), from 2000 onwards, or Meteosat (EUMETSAT) since the mid-nineties. Future products should be expected to deliver at least the same level of quality, for instance on the basis of the VIIRS instrument and current or future geostationary platforms, although the current lack of commitment to launch and continue to operate multiangular sensors seriously hampers the feasibility of delivering high quality albedo products in the future.

Daily-average surface albedo values have been derived experimentally from a single geostationary satellite, using a state of the art algorithm designed at the European Commission Joint Research Centre. In response to a CGMS action, EUMETSAT has started to reprocess archives of observations from the Meteosat instrument, using that algorithm, in order to generate historical time series of broadband albedo over long periods of time. A separate preliminary investigation by EUMETSAT has also shown the feasibility of generating this ECV on a near-global basis, using multiple geostationary satellites. The Japanese Meteorological Agency has recently expressed interest in coordinating the reprocessing of existing historical archives to generate such a global product over as long a period as possible, in the context of the Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) initiative.

Mono-angular multispectral sensors on polar-orbiting platforms usefully complement this monitoring system by providing more comprehensive spatial coverage. However, the accuracy of these estimates needs to be assessed, in particular with respect to their sensitivity to perturbing factors, because the algorithms used to generate albedo products from these systems typically rely on the accumulation of data over two weeks or more, when surface properties can change appreciably, e.g., with the occurrence or disappearance of snow on the ground.

The generic term 'albedo' often refers to a variety of different geophysical variables, which correspond to different definitions and measurements: climate models typically require the ratio of the outgoing flux of radiation over the incoming flux (known as the bihemispherical reflectance factor), in a couple of broad spectral bands, while actual measurements and currently available derived products correspond to hemispherical conical reflectance and directional hemispherical reflectance factors in a limited set of narrow spectral bands. Such products often depend on specific assumptions on the state of the atmosphere, or on the relative contributions of diffuse and direct radiation. As of this writing, existing products generated by different instruments or space agencies at spatial resolutions ranging from 1 to 5 km lack consistency and exhibit small but consistent biases that need to be resolved. This calls for comprehensive evaluation of the corresponding algorithms, the comparison of these albedo estimates with in situ and other measurements, and the benchmarking and cross-comparison of these products. Progress along these lines will consolidate confidence in the algorithms and justify the reprocessing of existing archives to generate long and coherent time series of global albedo products at the best available resolution. A fully characterized and broadly accepted global albedo product will be very valuable not only for climate studies but also as a reference for further studies and as a benchmark for other sensors and instruments.

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. Further collaboration between the scientific communities involved is expected to result in improved methods and data for assimilation and reanalysis purposes. This goal will also require extensive algorithm benchmarking and product validation activities, as well as concerted efforts to archive and make available such standardized albedo products to the weather, climate and other scientific communities, in a form readily usable by these models.

**Action T22** [IP-04 T19]

**Action:** Obtain, archive and make available in-situ calibration/validation measurements and collocated albedo products from all space agencies generating such products, and promote benchmarking activities to assess the quality and reliability of albedo products.

**Who:** Space agencies in cooperation with CEOS WGCV.

**Time-Frame:** Full benchmarking/intercomparison by 2012.

**Performance Indicator:** Publication of inter-comparison/validation reports.

**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

Comparing albedo products measured in situ with those derived from space platforms is fraught with difficulties, because of the large differences in scale, spatial and temporal resolution, differences in measurement protocols, and other practical issues. Nevertheless, such efforts must be pursued to ensure that existing products remain clearly linked to in situ measurements, to allow comparisons between similar products derived from different instruments, to evaluate the quality of new products as they become available, and to test the performance of algorithms after they have been updated.

**Action T23** [IP-04 T21]

**Action:** Implement globally coordinated and linked data processing to retrieve land surface albedo from a range of sensors on a daily and global basis, using both archived and current Earth Observation systems.

**Who:** space agencies, through the CGMS and WMO Space Programme.

**Time-Frame:** Back-process archived data by 2012, then continuously generated.

**Performance Indicator:** Completeness of archive.

**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties)

## ECV – Land Cover

Land cover and its changes modify the services provided to human society (e.g., provision of food, fibre, recreational opportunities, etc.), force climate by altering 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 inferred using data from Earth observing satellites, currently available data sets vary in terms of data sources employed, spatial resolution and thematic content, have different types and patterns of thematic accuracy and many use different land-cover type classification systems, although improvement has been made in using common standards. 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. Commitments to short-term continuity of this class of observations, such as the Landsat Data Continuity Mission and Sentinel-2, are vital steps, though long-term commitments still need to be secured. The CEOS Land Surface Imaging Constellation has been instigated to promote the effective and comprehensive collection, distribution and application of space-acquired imagery of the land surface.

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 (GOF-C-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, GlobCover), 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 the associated map legends adhere to internationally-agreed standards<sup>75</sup>. Such standards should eventually be agreed upon by the UN/ISO Terrestrial Framework (see Action T1). In the near term, however, full benefit should be taken of existing initiatives, e.g., the FAO Land Cover Classification System for legend harmonization and translation, and the legends published by the IGBP and the GTOS GOF-C-GOLD. The process of harmonization and translation of existing legends will be strengthened with the FAO new Land Cover Meta Language (LCML). The LCML will be an operational tool to formalize the meaning of any existing land cover classification/legend according to the latest ISO standards.

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 moderate (250m-1km) resolution. Grid-scale information on the percentage of tree, grass and bare soil cover should ideally also be made available.

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 are 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 GOF-C-GOLD and GLCN has published 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

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<sup>75</sup> <http://www.fao.org/gtos/ECV-T09.html>



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 at least every 5 years over long time periods (several decades) to assess land cover change. Global data sets of satellite imagery at 30m resolution have been assembled for selected years (e.g., 1990, 2000 and 2005) and some regional land-cover maps have been generated from these. The technologies have been developed and tested (e.g., Landsat, Sentinel-2 and the Satellite Probatoire d'Observation de la Terre High Resolution (SPOT HRV)), and suitable methods for land-cover characterization on these scales exist. Space agencies should assure that suitable optical sensors with 10-30m resolution are available for operational monitoring using data acquisition strategies comparable to systems in current operation.

While, at the time of writing, it was not yet clear what methodology would be put in place under the UNFCCC in connection with the proposed implementation of Reducing Emissions from Deforestation and forest Degradation in developing countries (REDD), relevant space agencies under CEOS have agreed to supply, on a regular basis, the high-resolution data necessary for the generation of fine-resolution land cover maps to support such a methodology. Such a commitment would also provide the basis for the observations needed to meet Action T26 and T27.

Samples of high-resolution satellite imagery have also been used to estimate change and are proposed for example by the FAO Global Land Cover Network and the FAO Forest Resource Assessment. 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 T24 [IP-04 T23]**

**Action:** Produce reliable accepted methods for land-cover map accuracy assessment.  
**Who:** CEOS WGCV, in collaboration with GOF-C-GOLD and GLCN.  
**Time-Frame:** By 2010 then continuously.  
**Performance Indicator:** Protocol availability.  
**Annual Cost Implications:** <1M USD (10% in non-Annex-I Parties).

**Action T25 [IP-04 T25]**

**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 GOF-C-GOLD, CEOS/WGCV, FAO GLCN, and in coordination with Action T28.  
**Time-Frame:** Network established by 2010.  
**Performance Indicator:** Availability of validation statistics.  
**Annual Cost Implications:** 1-10M USD (50% in non-Annex-I Parties).

**Action T26 [IP-04 T26]**

**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 their accuracy.  
**Who:** Parties' national services, research institutes and space agencies through GLCN in collaboration with GOF-C-GOLD research partners, and the IGOS land theme (IGOL).  
**Time-Frame:** By 2010, then continuously.  
**Performance Indicator:** Data set availability  
**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

**Action T27 [IP-04 T27]**

**Action:** Generate maps documenting global land cover based on continuous 10-30m land surface imagery every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of their accuracy.  
**Who:** Space agencies, in cooperation with GCOS, GTOS, GLCN and other members of CEOS.  
**Time-Frame:** First by 2012, then continuously.  
**Performance Indicator:** Availability of operational plans, funding mechanisms, eventually maps.  
**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

**ECV – Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)**

The Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is a non-dimensional value that measures to the fraction of the incoming solar radiation at the top of the vegetation canopy that contributes to plants' photosynthetic activity, and thus indicates the presence and productivity of live green 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. Space agencies, including NASA and ESA, and research institutions such as the EC JRC have been generating FAPAR products on a regular basis, using a variety of sensors. These efforts, including archiving and distribution, remain funded by research budgets and are in need of more systematic support to ensure the continuous, long-term operational availability of this product. Daily recovery of FAPAR is possible in principle, but cloud and thick aerosols often obscure the surface and result in incomplete maps. This issue is normally addressed by generating time-composited FAPAR maps that aim to convey information on central tendencies (statistical first moments of the distribution) while providing as complete a spatial coverage as possible. To detect trends in the presence of inter-annual variability requires long time series. To that end, existing archives of satellite data from instruments such as SeaWiFS have been reprocessed to generate long time series that are coherent and consistent with the most recent sensors (e.g., MERIS). This is best achieved with sensors that include a blue channel, which is particularly sensitive to atmospheric aerosols. This effort may need to be periodically repeated in the future to take advantage of further advances in algorithm design and to improve the compatibility and reliability of the products, or to extend the records further back in time using even more sophisticated approaches to compensate for the absence of blue band measurements. GTOS and GCOS encourage the space agencies and other entities to continue to generate and disseminate weekly to 10-day global FAPAR products at spatial resolutions of 2 km or better (modern sensors offer the possibility of systematically generating global products at a spatial resolution of about 300 m).

FAPAR is recovered from a range of sensors by various algorithms using the visible and infrared parts of the spectrum, and the accuracy and reliability of these products is not always properly documented. Currently available products have been shown to exhibit significant differences, which detract from their usefulness in downstream applications. The CEOS WGCV, in collaboration with GCOS and GTOS, should lead the comparison and evaluation of these FAPAR products as well as the benchmarking of the algorithms used to generate them. Reference sites making in situ observations should be fully engaged in this process, and it would be appropriate if these sites were the same reference sites as those used for other purposes (see Action T3), provided that these sites offer a reasonable degree of spatial homogeneity over spatial scales comparable to the resolution of the sensors. 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 [IP-04 T29]<sup>76</sup>**

**Action:** Establish a calibration/validation network of in situ observing sites for FAPAR and LAI (reference sites) and conduct systematic, comprehensive evaluation campaigns to understand and resolve differences between the products and increase their accuracy.

**Who:** Parties' national and regional research centres, in cooperation with space agencies coordinated by CEOS WGCV, GCOS and GTOS.

**Time-Frame:** Network operational by 2012.

**Performance Indicator:** Data available to analysis centres.

**Annual Cost Implications:** 1-10M USD (40% in non-Annex-I Parties).

**ECV – Leaf Area Index (LAI)**

LAI measures the amount of plant leaf material in an ecosystem. It is typically expressed as a non-dimensional value giving the number of square meters of leaf material per square meter of ground. This variable plays important roles in models that represent processes, such as photosynthesis, respiration and rain interception, which couple vegetation to the climate system through the radiation, carbon and water cycles. Hence, LAI appears as a key variable in many models describing vegetation-atmosphere interactions.

LAI can be estimated in situ by destructive sampling or with the help of commercially available dedicated instruments. It is routinely measured at a number of research sites dealing with surface climate, ecological or agricultural issues. 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 in many regions of the world; it should be maintained and ideally expanded to become much more representative of the diversity of ecosystem conditions. The development and maintenance of reference sites to address this inadequacy should be addressed, as explained elsewhere in this document. Building on existing networks such as FLUXNET, LAInet and BIGFOOT is 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 remains difficult: when the canopy cover is sparse, reflectance measurements are dominated by soil properties and the accuracy of the LAI is low; while for LAI values exceeding 3 or 4, optical measurements lose their sensitivity to changes in LAI (signal saturation). Also, since the LAI measured by satellites is usually inferred from spectral reflectances in the visible and infrared spectrum, it is de facto coupled to FAPAR estimates, even though both variables are in principle independent and play quite different roles in the climate system. Nonetheless, regular global LAI estimates from space are currently being produced and this effort should be continued (it requires little extra resource above that required to produce FAPAR). These LAI products have the same spatial resolutions (250m-1km) and temporal frequencies (7 to 10 days) as the FAPAR products. Recent research is exploring the feasibility of estimating LAI (and above-ground biomass) from microwave sensors and these efforts should also be pursued.

Benchmarking and comparison of these LAI products is essential to resolve differences between products and to ensure their accuracy and reliability. The CEOS WGCV should lead this activity in collaboration with GCOS and GTOS, 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.

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<sup>76</sup> See Action T3.

**Action T29 [IP-04 T30]**

**Action:** Evaluate the various LAI satellite products and benchmark them against in situ measurements to arrive at an agreed operational product.

**Who:** Parties' national and regional research centres, in cooperation with space agencies and CEOS WGCV, GCOS/TOPC and GTOS.

**Time-Frame:** Benchmark by 2012.

**Performance Indicator:** Agreement on operational product.

**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

**Action T30 [IP-04 T28]**

**Action:** Operationalize the generation of FAPAR and LAI products as gridded global products at spatial resolution of 2 km or better over time periods as long as possible.

**Who:** space agencies, coordinated through CEOS WGCV, with advice from GCOS/GTOS.

**Time-Frame:** 2012.

**Performance Indicator:** One or more countries or operational data providers accept the charge of generating, maintaining and distributing global FAPAR products

**Annual Cost Implications:** 10-30M USD (10% in non-Annex-I Parties).

**ECV – Above-ground Biomass**

Vegetation above-ground biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a global store of carbon comparable in size to atmospheric carbon, while changes in the amount of vegetation biomass due to deforestation significantly affect the global atmosphere by acting as a net source of carbon, and vegetation systems have the potential either to sequester carbon in the future or to become an even larger source. Depending on the quantity of biomass, vegetation cover can have a direct influence on local, regional and even global climate, particularly on air temperature and water vapour. Therefore, a global assessment of biomass and its dynamics is an essential input to climate change prognostic models and mitigation and adaptation strategies.

Biomass plays two major roles in the climate system: (i) photosynthesis withdraws CO<sub>2</sub> from the atmosphere and stores it as biomass, some of which goes into long-term stores in the soil; (ii) the quantity of biomass consumed by fire affects CO<sub>2</sub>, other trace gases, e.g CH<sub>4</sub>, CO and aerosol emissions.

Only above-ground biomass is measurable with some accuracy at the broad scale, while below-ground biomass stores a 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 of biomass 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, such as those published by the FAO in their Forest Resource Assessments.

Progress towards creating global gridded biomass data sets can be achieved by appropriately-designed satellite and aircraft missions, notably active microwave and laser systems. Space agencies should plan for such missions. ESA currently has the BIOMASS long-wavelength radar mission under Phase-A study as one of three possibilities for the next Earth Explorer mission. NASA is also considering a vegetation canopy lidar as part of the instrument package on the proposed DesDynl mission.

### Action T31

**Action:** Develop globally gridded demonstration datasets of above ground biomass across all biomes  
**Who:** Parties, space agencies, national institutes, research organisations, FAO in association with GTOS and TOPC  
**Time frame:** 2012.  
**Performance Indicator:** Availability of global gridded estimates of above ground biomass and associated carbon content  
**Annual Cost Implications:** 1-10M USD (20% in non-Annex-I Parties).

### ECV - Soil carbon content

Soils represent the largest terrestrial carbon pool. On seasonal to decadal timescales, carbon sinks may be explained by changes in biomass, but on longer time scales soil carbon stocks become more relevant. Globally, the largest soil carbon stocks are primarily located in wetlands and peatlands, most of which are located on permafrost and in the tropics. This soil carbon is vulnerable to changes in the hydrological cycle as well as to changes in permafrost dynamics (in the boreal zone) while tropical peatlands are severely threatened by deforestation and transformation of primary forest into plantations. The total amount of carbon stored in soils and its distribution is still highly uncertain and new estimates of carbon content at various depths are urgently needed.

The change in soil organic carbon is largely influenced by anthropogenic activities and particularly through the conversion of natural ecosystems to agricultural land. The soil organic carbon is contained within micro-aggregates and a part is lost through respiration and/or erosion after their destruction. Soil organic carbon varies as a function of the texture, bulk density, microbiologic activity, and organic matter contained in the vegetation. Many authors have proposed quantification of the carbon stored in soils and study of the role of soils as both a source and sink of carbon (Post et al., 1982; Eswaran, 1993; Sombroek et al., 1993; Batjes, 1996). Comprehensive measurements of soil organic carbon involves identifying the different soil types and extracting soil samples. Since this is particularly labour-intensive and costly, a composite sampling method is necessary.

### Action T32

**Action:** Develop a global database of soil carbon measurements, and techniques for extrapolation to global gridded products of soil carbon  
**Who:** Parties, national institutes, research organisations and FAO, in association with GTOS and TOPC  
**Time frame** 2012-2014  
**Performance Indicator:** Completeness of database and availability of prototype soil carbon maps  
**Annual Cost Implications:** 1-10M USD (10% in non-Annex-I Parties).

The identification of changes in soil carbon may be possible over long time scales at a limited number of sites identified under Action T32, e.g., those selected under Action T3, but additional and perhaps more accurate information on changes in soil carbon may be inferred from measurements of the annual cycle of carbon flux at these sites.

Such understanding and monitoring of greenhouse gas emissions and sinks is a fundamental step towards avoiding dangerous climate change. Obtaining verifiable and agreed estimates of regional CO<sub>2</sub> sources and sinks is very important in the ongoing UNFCCC negotiation cycle to define emission reductions after the Kyoto Protocol. The consensus is that data assimilation systems that use both terrestrial and atmospheric data (i.e. GAW concentration data) will ultimately provide the required carbon fluxes at the required accuracy. Such systems are under development.

Earth observation data from various sources are useful to derive indicators of carbon flux (LAI, fAPAR), but only document some of the carbon cycle processes; e.g., FAPAR provides information on CO<sub>2</sub> uptake, and satellite-based land surface imagery is essential for estimating emissions due to forest clearance. Assimilation of concentration data, and column provided by passive or active satellite sensors, together with a priori estimates of terrestrial fluxes and an atmospheric transport model, allows determination of large, continental scale fluxes with uncertainties. The NOAA CarbonTracker

scheme is probably the most advanced of these tools, but, as with all assimilation schemes, depends strongly on both the quantity and quality of atmospheric and surface data.

All FLUXNET sites maintain continuous CO<sub>2</sub> flux measurements based on the eddy covariance technique covering various biomes around the world. Standards for data acquisition processing and archiving have been set in the framework of large international scale projects (GTOS-TCO, GCP) and continental scale carbon projects (CarboEurope, CarboAfrica, US, Carbon Cycle Plan etc). These standards should be implemented, preferable through centralised data quality control centres and agreed protocols like under the GAW umbrella. Integrated proposed carbon observing systems such as ICOS, potentially provide the long-term monitoring capability to move the research network into a GCOS/GTOS baseline network.

### Action T33

**Action:** Develop globally gridded estimates of terrestrial carbon flux from in situ observations and satellite products and assimilation/inversions models.

**Who:** Reanalysis centres, research organisations, in association with national institutes, space agencies, FAO/GTOS (TCO and TOPC)

**Time Frame:** 2014-2019

**Performance indicator:** Availability of data assimilation systems, and global time series of maps of various terrestrial components of carbon exchange (e.g. GPP, NEP, NBP)

**Annual Cost Implications:** 10-30M USD (Mainly by Annex-I Parties).

### ECV – Fire Disturbance

Fire disturbance is characterised by large spatial and temporal variations on multiple timescales, diurnally, seasonally and inter-annually. Hundreds of millions of 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 (including GHGs) and aerosol that affect the composition, state and evolution of the global atmosphere, the climate, and human health. By consuming vegetation and emitting aerosols and trace gases, fires have a large influence on the storage and flux of carbon in the biosphere and atmosphere, can cause long-term changes in land cover, and affect land-atmosphere fluxes of energy and water.

The use of fire as a land-management tool is embedded in the culture and traditions of many societies, particularly in the developing world, and fire is a prominent disturbance factor in most vegetated zones. In many such ecosystems, fire acts as 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 can severely damage vegetation and lead to long-term degradation. Some ecosystems, particularly in the tropics and boreal zone, are becoming subject to increasing fire due to growing population, economic and land-use pressures; such shifts could also be an indicator of changing climate. Fires are expected to become more severe under a warmer climate (depending on changes in precipitation), giving a positive feedback. In some ecosystems the amount of burned biomass can vary by an order of magnitude, especially between wet and dry years, and these strong year-to-year variations may influence the interannual change seen in the global atmospheric CO<sub>2</sub> growth rate.

Prior to the use of satellite data, the vast majority of fires were not monitored or documented. More frequent severe fire weather conditions, together with increased human actions, have created recurrent major fire problems in some regions, with adverse impacts on economies, livelihoods, and human health and safety. Informed policy- and decision-making clearly requires timely and accurate quantification of fire activity and its impacts nationally, regionally and globally. Some space agencies, working with the research community, have been generating regional, and more occasionally global, fire disturbance products (mainly burnt area maps and the locations of actively burning fires) using spaceborne thermal and optical sensors. More recently, some active fire products have included measurement of the Fire Radiative Power (FRP), which is directly related to the rate of fuel consumption and thus rate of release of carbon, trace gases and aerosol. The burned area, active fire detection and FRP datasets together form the Fire Disturbance ECV, and the separate products can

be combined to generate improved information e.g. mapping of fire affected areas to the fullest extent, including the timing of burning of each affected grid-cell. Estimates of total dry matter fuel consumption (and thus carbon emission) can be calculated from these products. By applying species-specific emissions factors, emission totals for the various trace gases and aerosols can then be calculated.

Fires are typically patchy and heterogeneous. Measurements of global burnt area are therefore required at a spatial resolution of 250m (minimum resolution of 500m) from optical remote sensing, ideally on a weekly basis and if possible with day of burn information. Detection of actively burning fires and measurement of FRP is often adequately done at lower spatial resolutions (1km), but the sensor must have microwave and thermal infrared spectral channels having a wide dynamic range to avoid sensor saturation. Active fires should be detected from Low Earth Orbit satellites multiple times per day, with one of the measurements being located near the peak of the daily fire cycle, and their FRP should be calculated. Cloud cover data should be provided at the time of each overpass to allow uncertainty and/or correction factors to be derived for potential obscuration of fires by cloud and smoke. Some geostationary satellites allow active fire and FRP data generation at coarser spatial resolutions as rapidly as every 15 minutes to provide the best sampling of the fire diurnal cycle that may be required for certain applications (e.g. temporal integration of FRP data to estimate total carbon emissions; linking to atmospheric chemistry models/observations). Geostationary products also offer a near-real time capability. A global suite of fire products from the operational geostationary satellites needs to be developed.

The various space-based products require validation and inter-comparison. 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 GOF-C-GOLD, is establishing internationally-agreed validation protocols, which should be applied to all data sets before their release. FRP observations made at moderate spatial resolutions require correction factors to be applied to statistically adjust for the non-detection of the weaker, but potentially very frequent, small fire component of the burning regime. Deployment of a higher spatial resolution (100 - 250m) FRP-capable active fire detection instrument should be considered to sample this component of the fire regime and help develop these factors.

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 GOF-C-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 Portal should provide centralized identification of data holders.

An important additional piece of information is related to fire intensity and severity, which are central to determining the impact of fire on ecosystems and which may help to constrain the fire efficiency term required to convert burned area measures into fuel consumption estimates. 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. FRP measurements should be useful here, but additional information may be derived from differences observed in pre- and post-fire optical measurements.

The transition of experimental fire 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, and products need to be intercompared and combined to provide best estimates of total fuel consumption together with uncertainties over long timescales.

**Action T34 [IP-04 T32]**

**Action:** Reanalyze the historical fire disturbance satellite data (1982 to present).  
**Who:** Space agencies, working with research groups coordinated by GOF-C-GOLD.  
**Time-Frame:** By 2012.  
**Performance Indicator:** Establishment of a consistent data set.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**Action T35 [IP-04 T33]**

**Action:** Continue generation of burnt area, active fire and FRP products from low orbit satellites consistent, including version intercomparisons to allow un-biased, long-term record development.  
**Who:** Space agencies, in collaboration with GOFC-GOLD.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Availability of data.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**Action T36 [IP-04 T34]**

**Action:** Apply CEOS WGCV and GOFC-GOLD validation protocol to fire disturbance data.  
**Who:** Space agencies and research organizations.  
**Time-Frame:** By 2010.  
**Performance Indicator:** Publication of accuracy statistics.  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**Action T37 [IP-04 T35]**

**Action:** Make gridded burnt area, active fire and FRP products available through links from a single International Data Portal.  
**Who:** Coordinated through GOFC-GOLD.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Continued operation of the GFMC.  
**Annual Cost Implications:** <1M USD (Mainly by Annex-I Parties).

**Action T38**

**Action:** Develop set of active fire and FRP products from the global suite of operational geostationary satellites  
**Who:** Through operators of geostationary systems and GOFC-GOLD.  
**Time-Frame:** Continuous.  
**Performance Indicator:** Availability of products  
**Annual Cost Implications:** 1-10M USD (Mainly by Annex-I Parties).

**ECV – Habitat properties**

The observation of terrestrial biodiversity and habitat properties at selected sites are covered under Action T3 and issues are noted in the preceding text.

**6.3. Terrestrial Domain – Data Management and Reanalysis**

**Terrestrial Reanalysis**

As in other fields of science, and most prominently in the atmospheric sciences, data assimilation and reanalysis techniques have taken on a prominent role in offering a practical way to ensure the consistency between the various products that are being generated. This is achieved by explicitly taking into account the degree of uncertainty associated with both models (which are always simplified representations of reality) and a priori estimates, as well as input data (which are always observed or measured with a finite accuracy). The techniques developed by atmospheric scientists and other geophysicists are now being applied to the analysis of satellite data over land (including its interaction with the atmosphere) and permit the retrieval of products such as the components of the surface carbon cycle or albedo in such a way that the accuracy of the resulting product is documented as part of the procedure. This approach helps determine objectively the respective contributions of both models and data, the optimal ways to improve the observing system to increase the accuracy of the results, and naturally generates products that are much easier to incorporate in larger models (e.g., climate models). In the near future, it is likely that multiple land surface products (e.g., albedo and FAPAR) will be jointly retrieved through such procedures, thereby ensuring that they are all mutually consistent. The reprocessing of existing satellite remote sensing archives with these advanced tools should thus be encouraged, especially in the context (or perhaps in advance) of large scale reanalysis



exercises over multiple decades. It is recommended that a review of the state of the art in land surface albedo (LSA) estimation from space measurements be made in coordination with GCOS AOPC/TOPC to begin the reanalysis of existing datasets by including the following tasks:

- Benchmark existing products (continuation and extension of the initial effort to compare Meteosat, MODIS, and MISR LSA products), both in space and time, and propose ways and means to merge such products to generate truly global products with adequate coverage in Polar Regions.
- Investigate the compatibility between albedo products derived from bi-directional reflectance observations acquired by sensors on geostationary and polar-orbiting platforms.
- Evaluate the factors affecting the quality of LSA products and in particular their dependency on related atmospheric products (e.g., clouds and aerosols).
- Investigate the drawbacks, limitations and obstacles that have prevented the effective use of these albedo products in GCMs and recommend ways to address these issues.
- Promote sensitivity studies and other appropriate projects aimed at documenting the role and impact of LSA products in climate models, with a view to establishing precise requirements on the characteristics of this product.

This approach could also very usefully be applied in the case of the soil moisture ECV. A number of land assimilation projects have assessed soil moisture on a global scale such as the Global Soil Wetness Project (<http://www.iges.org/gswp/>). These projects have produced significant apparent differences between model outputs but with similar variations from year to year in model projections. Therefore it appears that there are systematic differences in the projections that are computer model dependent. Reanalysis of in situ and satellite data integrated into Earth-system dynamic models could improve our understanding of soil moisture observations and model projections.

The internationally-designated data centres and archives that have been identified in the terrestrial domain are shown in Table 13. 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 13. International Data Centres and Archives – Terrestrial Domain**

<b>Network or System</b>	<b>International Data Centres and Archives</b>	<b>Coordinating Body</b>
Global Terrestrial Network – Rivers	GRDC	WMO CHy
Global Terrestrial Network – Lakes	HYDROLARE	WMO CHy, WMO CCI
Snow Cover (WWW/GOS synoptic network)	NSIDC, NCDC	GTN-H
National and other meteorological/climatological networks	National and other archives	WMO CBS
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	space agencies	BSRN, CGMS

network (proposed)		
Global Land Cover Network	space agencies; FAO; Global Land Cover Facility	GOFC-GOLD, FAO, UNEP
Fire Disturbance	Global Fire Monitoring Centre; Fire Information for Resource Management System (FIRMS)	UNEP, FAO
Forest Resource Assessment	Forest Resource Information System	FAO
FLUXNET	Oak Ridge National Laboratory in collaboration with national and other archives	Unclear

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 portal for metadata on terrestrial in situ measurement sites, including biogeophysical variables addressed by each site, that are important to assess regional and global change. This portal could be utilized as the central clearing house for in-situ observations of terrestrial ECVs. TEMS has been developed in collaboration with the Global Observing Systems Information Centre (GOSIC), which by itself provides access to data and metadata from GCOS and GTOS networks and systems.

**Action T39 [IP-04 T36]**

<p><b>Action:</b> Revision of TEMS with improved focus on the monitoring of terrestrial ECVs  <b>Who:</b> Parties' national services and research programmes contributing to TEMS, in cooperation with GTOS, GOSIC, and GCMD, and in consultation with the GCOS Secretariat.  <b>Time-Frame:</b> By 2012.  <b>Performance Indicator:</b> Improvement of site coverage measuring terrestrial ECVs  <b>Annual Cost Implications:</b> 1-10M USD (Mainly by Annex-I Parties).</p>
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**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;
- Addressing the cross-cutting challenge of sea level: assessment of ice loss from ice sheets, ice velocity, isostatic rebound, thermal expansion, sea ice;
- Monitoring biodiversity;
- Assessment of extremes in the terrestrial domain;
- Development of active (lidar) and passive sensors for the estimation of column CO<sub>2</sub> through satellites (cf. section 4.6);
- Development of carbon data assimilation schemes integrating observation from satellite, flasks, flux stations, and soil and forest inventories.
- Integrated Earth System Analysis, for consistent retrieval of ECVs through assimilation and reanalysis.
- Develop pilot soil moisture products from in-situ and satellite measurements, and models.

## Appendix 1

### **UNFCCC SBSTA 30: Conclusion on Agenda Item 6 (Research and Systematic Observation)<sup>77</sup>**

[...]

11. The SBSTA noted that an updated GCOS implementation plan that takes into account emerging priorities, such as the need for data for adaptation, may assist in continuing progress with GCOS implementation. It therefore invited the GCOS secretariat to prepare, under the guidance of the GCOS Steering Committee, an update of the GCOS implementation plan before its thirty-third session [in November 2010].

12. The SBSTA invited the GCOS secretariat to include, in this updated GCOS implementation plan, a breakdown of costs involved. The costs should be broken down by region, observing system and between developed and developing countries. The SBSTA invited the GCOS secretariat to provide a provisional updated implementation plan in conjunction with a provisional estimation of costs, before the fifteenth session of the Conference of the Parties, and requested the secretariat to make this information available as a miscellaneous document.

[...]

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<sup>77</sup> See FCCC/SBSTA/2009/L.6 at <http://unfccc.int/resource/docs/2009/sbsta/eng/l06.pdf>

## Appendix 2

### 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.

## Appendix 3

# Background on GCOS and the IP-04

### Origin and purpose of GCOS

The Global Climate Observing System (GCOS) was established, in 1992, in parallel with the negotiation of the UNFCCC, as a joint initiative of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commissions (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). Its purpose and concept of operation are set down in the 1998 revision of the original February 1992 WMO-IOC-UNEP-ICSU Memorandum of Understanding (MOU) on GCOS.

The stated purpose of GCOS is to meet the total national and international needs for comprehensive, continuous, reliable climate and climate related data and information in support of:

- Climate system monitoring;
- Climate change detection and attribution;
- Operational climate prediction on seasonal-to-interannual timescales;
- Research to improve understanding, modelling and prediction of the climate system;
- Applications and services for sustainable economic development;
- Assessment of the impacts of, and vulnerability and adaptation to, natural climate variability and human-induced climate change;
- Formulation and implementation of global, regional, national and local policy response to climate change.

In particular, at the international level, GCOS is designed to support:

- The specific observational needs of the World Climate Programme and related earth system science and service programs;
- The climate change assessment role of the Intergovernmental Panel on Climate Change (IPCC); and
- The requirements of the UNFCCC and other international conventions and agreements.

### The concept of GCOS

The concept of GCOS is defined in terms of:

- Its goal;
- Its objectives;
- The component observing systems on which it is built; and
- The systems and programs through which its objectives should be met.

The goal of GCOS is to provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrologic, cryospheric and terrestrial processes.

The overall objective of GCOS is to support all aspects of the World Climate Programme and relevant aspects of other climate related global programmes. Its specific objectives are to provide the observations required to meet the needs for:

- Climate system monitoring and climate change detection;
- Research toward improving understanding, modelling and prediction of the climate system;
- Assessment of the impacts of climate variability and change;
- Climate information and prediction services and applications for sustainable economic development; and

- Climate change policy development and implementation.

GCOS is a system of observing systems built on the climate-relevant components of the established global observing systems for the atmosphere, ocean, land and surface water. The main component observing systems on which it is based are:

- WMO Integrated Global Observing System (WIGOS);
  - WWW Global Observing System (GOS) for atmospheric physical and dynamical properties;
  - Global Atmospheric Watch for atmospheric constituent and chemical properties; and
  - other WMO climate related observing systems;
- IOC/WMO/UNEP/ICSU Global Ocean Observing System (GOOS) for physical, chemical and biological properties of the ocean;
- FAO/UNEP/UNESCO/WMO/ICSU Global Terrestrial Observing System (GTOS) for land surface ecosystem, hydrosphere, and cryosphere measurements; and
- IGBP and WCRP and other research observing networks.

The international climate programs and mechanisms which it supports, and through which it meets its objectives, include:

- The World Climate Programme (WCP);
- The World Climate Research Programme (WCRP) and related earth system research programmes including the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and DIVERSITAS;
- The WMO-UNEP Intergovernmental Panel on Climate Change (IPCC); and
- The United Nations Framework Convention on Climate Change (UNFCCC) and other international environmental conventions and agreements.

### **Planning and implementation**

The planning, implementation and further development of GCOS are carried out by the sponsoring and participating organisations with scientific and technical advice and guidance from the joint WMO-IOC-UNEP-ICSU Steering Committee for GCOS. The Steering Committee carries out much of its work through three co-sponsored domain-based panels, the Atmospheric Observation Panel for Climate (AOPC), the Ocean Observations Panel for Climate (OOPC) and the Terrestrial Observation Panel for Climate (TOPC). The interface with the WMO-IOC-ICSU World Climate Research Programme (WCRP) is co-ordinated through the jointly-sponsored WCRP Observations and Assimilation Panel (WOAP). The Steering Committee is supported by the GCOS Secretariat located at WMO Headquarters in Geneva.

The initial plan for GCOS (GCOS-14), which was issued in 1995, set down the overall strategy and implementation framework. A series of Regional Action Plans for ten developing country regions provided guidance for key regional needs and a GCOS Co-operation Mechanism (GCM) was put in place to provide for a co-ordinated multi-government approach to funding the key implementation activities in developing countries.

### **The Implementation Plan for the Global Observing System for Climate In Support of the UNFCCC (IP-04)**

Through its Articles 4 and 5, the UNFCCC commits Parties to support international efforts to strengthen systematic observation capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analysis from areas beyond national jurisdictions. In 1997, the UNFCCC Conference of the Parties (COP) called for an assessment of the adequacy of global observations to meet the needs of the Convention. This led to the First (1998) and Second (2003) Adequacy Reports with the Second Adequacy Report (GCOS-82) identifying a set of "Essential Climate Variables" (ECVs) "that are both currently feasible for global implementation and have a high impact on UNFCCC requirements". Through its Decision 11, the Ninth (2003) Session of the COP requested 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”.

In response to the UNFCCC request, the GCOS Steering Committee and Secretariat produced the “Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC” (GCOS-92). The GCOS-92 Implementation Plan identified 24 ‘Key needs’ and 131 ‘Actions’ required to implement a comprehensive observing system for the ECVs that would address Articles 4 and 5 of the UNFCCC and, if fully implemented, would:

- 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; and
- Enable the characterisation of extreme events important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

The 2004 Implementation Plan (IP-04) was endorsed by the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) and the GCOS sponsors and referred to the various identified ‘Agents of Implementation’ including the Committee on Earth Observation Satellites (CEOS) which requested elaboration of the space-based observational requirements to assist in the formulation of the space agencies’ response. The resulting “Satellite Supplement” (GCOS-107) to IP-04 provided the basis for the October 2006 “Satellite Observation of the Climate System – The CEOS Response to the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC”.

The IP-04 was explicitly focussed on assisting Parties to the UNFCCC in meeting their responsibilities under the Convention while also providing many of the essential observations required by the WCRP and the IPCC. It did not explicitly address the full purpose of GCOS as noted above, but contained most of the needed component observations.

Through SBSTA/2005/10 paragraph 94, the 23<sup>rd</sup> (Montreal) session of SBSTA called for a “comprehensive report at its thirtieth session (June 2009) on progress with the GCOS Implementation Plan” and at its 27<sup>th</sup> Session (Bali, 2007), SBSTA approved a set of guidelines based on the ECVs and IP-04 as a basis for Parties’ reports on progress. Consequently, the *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008* (GCOS-129) was reviewed by SBSTA-30 which invited the GCOS sponsors to arrange for the update of the IP-04 in the light of the progress achieved and other relevant developments since 2004.

### **Major developments since 2004**

The most significant international developments since 2004 bearing on the updating of the GCOS-92 Implementation Plan have included:

- Establishment of GEO (Group on Earth Observations) and its preparation of the 10-year Implementation Plan for the Global Earth Observation System of Systems (GEOSS);
- Completion of the IPCC Fourth Assessment Report (AR4) in 2007 and initiation of preparations for the Fifth Assessment Report (AR5);
- Increased emphasis on adaptation to climate change under the UNFCCC Nairobi Work Programme;
- Planning for a UN System Coordinated Action on Climate Change.

#### *The Global Earth Observation System of Systems (GEOSS)*

With the principal objective to enhance international coordination of Earth observation and to emphasize the importance of Earth observation for decision-making, the 1<sup>st</sup> Earth Observation Summit in 2003 established the Group on Earth Observations (GEO), with the aim to implement the Global Earth Observation System of Systems (GEOSS) within ten years. The GEOSS 10-Year

Implementation Plan,<sup>78</sup> adopted by GEO members in February 2005 and organized along nine 'Societal Benefit Areas' (SBAs), describes a strategy for coordinated comprehensive and sustained observations of the Earth system in order to improve monitoring of the changing state of the planet, increase understanding of complex Earth processes, and enhance the prediction of the impacts of environmental change, including climate change. Implementation of GEOSS also includes end-user products for nine SBAs – weather, climate, water, agriculture, disasters, biodiversity, ecosystems, energy, and health. Further, the GEOSS strategy foresees building a comprehensive data architecture for a system of observing systems. GEO has been established outside the UN system; its membership includes 79 member nations and the European Commission as of 31 July 2009. It also has the participation of a number of other organizations. GEO 'Communities of Practice' have been established for Societal Benefit Areas. The Integrated Global Observing Strategy (IGOS) Themes and their reports, which have provided valuable community statements of needs, have been incorporated into GEO and most of them continue to inform the process as GEO Communities of Practice. Provisions for enhanced coordination of data exchange and access are being put in place. GCOS has been identified as the climate observing component of GEOSS.

#### *The Intergovernmental Panel on Climate Change (IPCC) AR4 and AR5*

The publication of the IPCC Fourth Assessment Report (AR4) in 2007, together with widespread acknowledgment of the issue of climate change and the need to respond to its impacts, has emphasized and strengthened national engagement on climate-related issues. In particular, the AR4 highlighted the inevitability of significant climate change at the regional level and hence the need for a greatly-strengthened information base for impact and vulnerability assessments, adaptation planning and support to mitigation measures that are being considered "post Kyoto". To ensure that the GCOS, WCRP and IGBP benefited from the insights gained from the AR4, the three international programmes organized a joint workshop with 66 AR4 lead authors in Sydney, Australia, in October 2007.<sup>79</sup> In terms of observational needs, this workshop, and a survey preceding the event, provided strong support for the requirements and targets set in the IP-04. In addition, participants raised a number of areas which needed additional emphasis or new measurements. These needs will be considered in detail in updates of the IP-04.

#### *The UNFCCC Nairobi Work Programme*

The Twelfth (Nairobi, 2006) Session of the UNFCCC COP initiated the Nairobi Work Programme (NWP) to improve understanding and assessment of impacts, vulnerability and adaptation to climate change with a focus on developing countries. The enhanced focus on adaptation, vis-à-vis mitigation, under the NWP has greatly increased the importance, for the purposes of the UNFCCC, of observations and information on climate at the national and local level and on observations of all the various impact variables needed to document, understand and plan for more effective adaptation.

The emphasis on adaptation is of particular importance for the terrestrial (GTOS) and ocean (GOOS) components of GCOS and substantial efforts have been got underway through the GCOS sponsors, FAO and other organisations and mechanisms to identify and address the future needs for observations in support of adaptation to climate change. At its Sixteenth (Geneva, 2008) Session, the GCOS Steering Committee made recommendations regarding planning for future observations in support of the UNFCCC adaptation agenda.

#### *Coordinated UN Action on Climate Change*

Following the December 2007 adoption of the Bali Action Plan and a series of meetings, including the UN General Assembly, the UN Secretary General in May 2008, through the UN Chief Executives Board for Coordination and its High Level Committee on Programmes, initiated a process to ensure a coherent and coordinated UN system response to the challenge of climate change. In the first instance, this involved the identification of five focus areas:

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<sup>78</sup> GEO (2005): *Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan and Reference Document*, GEO-1000R, February 2005, 209pp, <http://earthobservations.org>.

<sup>79</sup> 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>.

1. Adaptation;
2. Capacity building;
3. Finance (mitigation, adaptation);
4. Reducing emissions from deforestation and forest degradation in developing countries (REDD);  
and
5. Technology Transfer;

and four cross-cutting areas of UN system activity:

7. Science, assessment, monitoring and early warning;
8. Supporting global, regional and national action;
9. Public awareness; and
10. Climate-neutral UN;

with one or more of the UN system agencies and programmes assigned convening/facilitating roles for developing a coordinated UN-wide approach for each. Most activities in the cross-cutting area of 'science, assessment, monitoring and early warning' ('climate knowledge') will, of necessity, rely heavily on observational support from the GCOS.

#### *World Climate Conference-3 and Ocean Obs'09*

The Conference Statement and Ministerial Declaration of the August-September 2009 World Climate Conference-3 (WCC-3) underscore the essential role of a fully implemented GCOS in underpinning the future Global Framework for Climate Services through which all countries will be enabled to more effectively use climate prediction and information for decision-making in order to better manage climate related risks and opportunities in support of adaptation to climate variability and change. Implementation of this Framework over the next few years should significantly enhance the prospects for full implementation of this IP-10.

Another key development bearing on the updating of IP-04 was the Ocean Obs'09 Conference held in Venice in September 2009. The planning for Ocean Obs'09 proceeded in parallel with the updating of GCOS-92 and the conclusions from the conference are incorporated in this Plan.

#### **The 2009 Progress Report**

As requested by SBSTA 23 in 2005, the GCOS Steering Committee and Secretariat compiled a comprehensive report on progress with the implementation of IP-04 for consideration by SBSTA-30 in June 2009. The *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008* (GCOS-129) provided both a general overview of progress with implementation of GCOS and a specific assessment of achievements under each of the cross-cutting and domain-based actions set down in IP-04. The Progress Report was based, inter alia, on:

- Detailed assessments from each of the GCOS Panels and WMO, GOOS and GTOS Secretariats;
- The report of the October 2007 Sydney Workshop on Future Climate Change Research and Observations (GCOS-117);

- National reports<sup>80</sup> on progress against the 2007 Reporting Guidelines provided to the UNFCCC Secretariat up to March 2009;
- Reports from a number of GCOS National Coordinators and Focal Points and other IP-04 Agents of Implementation;
- The December 2008 CEOS Report to SBSTA<sup>81</sup> on progress with implementation of the space-based components of IP-04.

The outcome of SBSTA-30 consideration of the 2009 Progress Report included an invitation to the GCOS Steering Committee and Secretariat to produce an update of 2004 Plan which would reflect both the progress since 2004 and the new developments, requirements and perspectives that emerged during the preparation of the Progress Report.

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<sup>80</sup> Such reports were provided by: Australia, Belgium, Belize, Canada, Denmark, European Community, Finland, France, Germany, Greece, Ireland, Italy, Japan, Lithuania, Netherlands, Poland, Portugal, Russia, Slovakia, Spain, Sri Lanka, Sweden, Switzerland, United Kingdom, United States; All reports are available at [http://unfccc.int/methods\\_and\\_science/research\\_and\\_systematic\\_observations/items/4499.php](http://unfccc.int/methods_and_science/research_and_systematic_observations/items/4499.php) , and a synthesis of the reports, prepared by the GCOS Secretariat, is available at <http://www.wmo.int/pages/prog/gcos/Publications/gcos-130.pdf> .

<sup>81</sup> FCCC/SBSTA/2008/MISC.11; <http://unfccc.int/resource/docs/2008/sbsta/eng/misc11.pdf>

## Appendix 4

# GCOS Climate Monitoring Principles

*Effective monitoring systems for climate should adhere to the following principles<sup>82</sup>:*

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.

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<sup>82</sup>The ten basic principles were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. The complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17<sup>th</sup> Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

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.
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, metadata 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 5

# 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 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.
- Germany, DLR – Research and development environmental satellite systems.
- Brazil, INPE - Research and development environmental satellite systems.

### **National GCOS Implementation Mechanisms:**

7. GCOS National Coordinators and Coordinating Committees.
8. National Meteorological Services (NMSs).
9. National Hydrological Services (NHSs).
10. National Ocean Services and Research Institutions.
11. National Environmental Agencies.

### **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 CCI) – 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, in particular through the WCRP/GCOS Observation and Assimilation Panel (WOAP)
- 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 Integrated Global Observing System (WIGOS);
  - World Weather Watch Global Observing System (GOS) - comprehensive system for observing meteorological variables used in weather forecasting and other related applications;
  - Global Atmospheric Watch comprehensive observations of atmospheric constituent and chemical properties on global and regional scales; and
  - other WMO climate related observing systems;
- IOC/WMO/UNEP/ICSU Global Ocean Observing System (GOOS) – permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide.
- FAO/UNEP/UNESCO/WMO/ICSU 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.
- IGBP and WCRP and other research observing networks.

**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.
- Group on Earth Observations (GEO) – international framework on a voluntary basis working towards coordinated comprehensive and sustained observations of the Earth system within the Global Earth Observation System of Systems (GEOSS) in order to improve monitoring of the changing state of the planet, increase understanding of complex Earth processes, and enhance the prediction of the impacts of environmental change, including climate change.
- Integrated Global Observing System-Partnership (IGOS-P) – merged into the GEO structure and 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.



## Appendix 6

### List of Annex-I and non-Annex-I Parties to the UNFCCC<sup>83</sup>

Annex-I Parties to the UNFCCC include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. The Annex-I Parties are (41):

Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America.

Non-Annex I Parties are mostly developing countries. Certain groups of developing countries are recognized by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought. Others (such as countries that rely heavily on income from fossil fuel production and commerce) feel more vulnerable to the potential economic impacts of climate change response measures. The Convention emphasizes activities that promise to answer the special needs and concerns of these vulnerable countries, such as investment, insurance and technology transfer. The non-Annex-I Parties are (151):

Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Cuba, Cyprus, Côte d'Ivoire, Democratic People's Republic of Korea, Democratic Republic of the Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, The former Yugoslav Republic of Macedonia, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran (Islamic Republic of), Israel, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia (Federated States of), Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Nicaragua, Niger, Nigeria, Niue, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Qatar, Republic of Korea, Republic of Moldova, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Solomon Islands, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Syrian Arab Republic, Tajikistan, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Tuvalu, Uganda, United Arab Emirates, United Republic of Tanzania, Uruguay, Uzbekistan, Vanuatu, Venezuela (Bolivarian Republic of), Viet Nam, Yemen, Zambia, Zimbabwe.

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<sup>83</sup> [http://unfccc.int/parties\\_and\\_observers/items/2704.php](http://unfccc.int/parties_and_observers/items/2704.php)

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## 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)
CCI	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
GEOS	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)
GTSP	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)
ICODS	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	VOLUNTARY 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

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