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SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED PRODUCTS FOR CLIMATE

Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC"

September 2006

GCOS – 107

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Executive Summary

Global monitoring of climate requires products derived from satellite data records, as recognized by the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS-92, October 2004; the 'GIP'). The present document provides supplemental details to the GIP related to the generation of these products. It is intended mainly to assist Parties[1] that support Earth observation from space to respond to the requirements of the GIP. It also has relevance to all Parties that access satellite data records and/or use derived products for climate applications. Furthermore, a wide range of Parties can contribute to address the vital need for *in situ* data for the calibration and validation of satellite data and derived products.

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

The GIP, if fully implemented by the Parties both individually and collectively, will result in a system that provides global observations of the Essential Climate Variables[2] (ECVs) and their associated products that are needed to assist Parties in meeting their responsibilities under Articles 4 and 5 of the UNFCCC. In addition, it should provide the systematic and sustained observations needed by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC).

Specifically, the proposed system will 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 the assessment of risk and vulnerability.

The GIP describes a feasible and cost-effective path toward an integrated observing system that depends upon both *in situ* and satellite-based measurements. Both types of measurement are vital. The emphasis on satellite measurements given in the present report is not a reflection of priority, but rather a detailing of the opportunities to implement a major and important element of the GIP by meeting the specific needs for satellite observations and the products derived from them. Table 1, based on the GIP, provides the list of ECVs considered particularly feasible for sustained monitoring from satellites.

One of the issues identified in the GIP, and noted again in this report, is the need for all Parties to be able to benefit from the use of climate data records. This is an important issue in relation to products which depend primarily upon satellite observations: while Earth observation from satellites is a costly activity to which only a small number of Parties are currently able to contribute, the derived information is generally of global utility. To meet the needs of the UNFCCC, action needs to be taken to allow global access to these products, and to ensure their global utility. Detailed requirements to that effect are given in this report.

The analysis given in the GIP showed that many of the required data records that depend upon satellite observations could be obtained with existing technical capabilities of satellite instruments

[1] Parties in the context of this report are signatory countries of the UNFCCC.

[2] These are contained in Appendix 5 and were fully described in 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) and its Technical Annexes. Table 1 lists those ECVs that are largely dependent upon satellite observations.

Table 1: ECVs largely dependent upon satellite observations[3]

Domain	Essential Climate Variables
Atmospheric (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, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity), Sea state*, Ocean salinity*.
Terrestrial	Lakes*, Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI)*, Biomass*, Fire disturbance, Soil moisture*.

if extra attention were given to the GCOS Climate Monitoring Principles (GCMPs) in the use of such instruments. For the data records that cannot be generated in present circumstances, this report identifies additional research needs. Furthermore, it is noted that while existing data holdings generally do not meet the GCMPs, appropriate reanalysis efforts could provide improved records extending over the last two or three decades. This is true particularly for some of those ECVs that can be addressed with data from operational meteorological satellites. In other cases, a data record of some utility could be compiled with current capabilities or data holdings, notwithstanding possible deficiencies in length and/or accuracy.

This document does not reconsider the issue of costs. However, as noted in the GIP, most of the resources needed to achieve satellite-based monitoring of ECVs fall into two categories:

1. Resources needed to ensure that attention is given to the GCMPs in the sustained operation of the current and planned meteorological satellite instruments;

2. Resources needed to initiate and continue sustained observation capabilities not currently planned in future missions. The required instrument types are in most cases similar to satellite instruments on current research missions.

The actions falling under the first category have significant costs, but amount to only a fraction of the typical cost of a full satellite mission. The second category accounts for the major part of the total satellite-related costs estimated for the GIP. It includes some observational elements in the atmospheric domain, but addresses mainly the needs of the ocean and terrestrial domains. In addition to climate monitoring, meeting the needs in the second category would also bring substantial benefits to many other user communities, in particular those concerned with land surface and marine applications. (Note that in the GIP, for which total annual incremental costs were estimated in the order of USD 600 million, a roughly equal share of cost was attributed to *in situ* observations, systems and datasets on the one hand; and to satellite observations and datasets on the other hand)

The content of this report

This document provides additional technical detail to the actions and needs identified in the GIP related to satellite-based observations for climate, for each of the Essential Climate Variables listed in Table 1. In particular, it details the specific satellite data records that should be sustained in accordance with the GCMPs, as well as other important supplemental satellite observations that are needed on occasion or at regular intervals. Tables 2-4 provide an overview of the requirements for products and sustained satellite data records that are detailed in this document for the atmospheric, ocean and terrestrial domains, respectively.

[3] Based on the GIP and covering all ECVs considered in this report. ECVs denoted with an asterisk (*) were not included in the original table in the GIP. Note that soil moisture was not listed in the GIP as an ECV, but was recognized as an emerging ECV and has been included here.

While sustained climate products and data records are the focus of this document, the vital need for an active and continuing role for space agencies with remits solely for research is also emphasized. The need for research instruments on satellites relates to a number of issues, e.g.:

- Providing intermittent, supplemental detail to sustained observations through (often challenging) new measurements;
- Seeking improved and more effective ways of fully meeting observation targets and creating the required satellite data records;
- Developing new capabilities to cover some of the ECVs for which a data record cannot at present be initiated due to an absence of proven capability.

Along with scientific and technological progress, ECV product specifications (e.g., accuracy, stability), and associated requirements for satellite instruments and global sampling need to be maintained by expert groups. This document seeks to start this process by providing initial specifications of product needs and, where possible, by identifying expert groups that could have a role in maintaining these specifications. Note is also made of needs for data access and archiving, and issues related to calibration and validation. The key need for representative and high quality *in situ* data for calibration and validation is stressed throughout. All actions and recommendations have been made traceable to the GIP.

In addition to the details that apply to each ECV, the report gives an overview of generic, cross-cutting needs. In doing so, some of the recommended actions from the GIP are re-emphasized. These pertain to the need for institutional arrangements to ensure effective links between satellite agencies, end users and the scientific groups that should be involved in the creation of products. The report recommends that the establishment of these institutional arrangements be done in conjunction with existing international bodies such as WMO, IOC, ICSU, UNEP, and with other relevant bodies such as the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS) and the Group on Earth Observations (GEO).

Key recommendations

Action C10 of the GIP is of fundamental importance in the context of this report:

"Ensuring continuity and overlap of key satellite sensors; recording and archiving of all satellite meta-data; maintaining currently adopted data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses."

Breaking this action down in light of the details given in this report results in the following key recommendations for Parties that support space agencies. They should:

1. Ensure attention to the needs identified in this report related to the planning, initiation and continuity of satellite missions that are needed to provide satellite climate data records;

2. Ensure a systematic approach in applying, to the greatest extent possible, the GCOS Climate Monitoring Principles for the generation of satellite climate data records, recognizing in particular the need for overlaps in missions and for *in situ* measurements for calibration and validation purposes;

3. Ensure long-term custody of present and future satellite climate data records and their associated metadata, and provide open access to these records;

4. Ensure and encourage the generation of, and access to, products based on the satellite climate data records;

5. Ensure wide and continuing interaction among the international scientific, operational and end-user communities, to ensure effective feedback mechanisms and continuing advice on observation and product needs;

6. Sustain active research satellite programmes that address challenging measurement needs and that allow capabilities to advance and be more cost effective.

These key actions can be achieved only partly by space agencies within their current remits. Therefore, a key overarching need is that:

Parties supporting space agencies ensure that the remits of those agencies enable them to incorporate the needs for systematic observation of climate as identified in this report.

The future role of Earth Observation Satellites for Climate

Satellites now provide a vital means of obtaining observations of the climate system from a near-global perspective, and comparing the behaviour of different parts of the globe (GIP, p. 24). It is evident that the future of the global climate observing system depends critically upon a major satellite component. Nevertheless, while there are good expectations for the continuity of data records for some variables linked to meteorological satellites, there is a lack of plans for continuity of measurement of many of the key climate variables needed by the UNFCCC. Moreover, for satellite data to contribute fully and effectively to the determination of long-term records, they must be part of a system implemented and operated so as to ensure that these data are accurate and adequately homogeneous for climate. Finally, in addition to meeting the needs of the UNFCCC, the real-time and near-real-time information obtained through such a system would provide an equally large benefit to the needs of many other key societal benefit areas.

Table 2: Overview of Products – Atmosphere

ECVs / Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)
Surface Wind Speed and Direction Surface vector winds analyses, particularly from reanalysis	Passive microwave radiances and scatterometry
Upper-air Temperature Homogenized upper-air temperature analyses: Extended MSU-equivalent temperature record; New record for upper-troposphere and lower-stratosphere temperature using data from radio occultation; Temperature analyses obtained from reanalyses	Passive microwave radiances; GPS radio occultation; High-spectral resolution IR radiances for use in reanalysis
Water Vapour Total column water vapour over the ocean and over land; Troposphere and lower- stratosphere profiles of water vapour	Passive microwave radiances; UV/VIS radiances; IR imagery and soundings in the 6.7 μm band; Microwave soundings in the 183 GHz band
Cloud Properties Cloud radiative properties (initially key ISCCP products)	VIS/IR imagery; IR and microwave soundings
Precipitation Improved estimates of precipitation, both as derived from specific satellite instruments and as provided by composite products	Passive microwave radiances; High-frequency geostationary IR measurements; Active radar (for calibration)
Earth Radiation Budget Top-of-atmosphere Earth radiation budget on a continuous basis	Broadband radiances; Spectrally-resolved solar irradiances; Geostationary multispectral imagery
Ozone Profiles and total column of ozone	UV/VIS and IR/microwave radiances
Aerosol Properties Aerosol optical depth and other aerosol properties	VIS/NIR/SWIR radiances
Carbon Dioxide, Methane and other GHGs Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks	NIR/IR radiances
Upper-air Wind Upper-air wind analyses, particularly from reanalysis	VIS/IR imagery; Doppler wind lidar
Atmospheric Reanalyses	Key FCDRs and products identified in this report, and other data of value to the analyses

Table 3: Overview of Products – Oceans

ECVs / Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)
Sea Ice Sea-ice concentration	Microwave and visible imagery
Sea Level Sea level and variability of its global mean	Altimetry
Sea Surface Temperature Sea-surface temperature	Single and multi-view IR and microwave imagery
Ocean Colour Ocean colour and oceanic chlorophyll-a concentration derived from ocean colour	Multispectral VIS imagery
Sea State Wave height and other measures of sea state (wave direction, wavelength, time period)	Altimetry
Ocean Salinity Research towards the measurement of changes in sea-surface salinity	Microwave radiances
Ocean Reanalyses utilizing altimeter and ocean surface satellite measurements	Key FCDRs and products identified in this report, and other data of value to the analyses

Table 4: Overview of Products – Terrestrial

ECVs / Global Products requiring Satellite Observations	**Fundamental Climate Data Records required for Product Generation (from past, current and future missions)**
Lakes For lakes in the Global Terrestrial Network for Lakes: Maps of lakes; Lake levels; Surface temperatures of lakes	VIS/NIR imagery, and radar imagery; Altimetry; High-resolution IR imagery
Glaciers and Ice Caps Maps of the areas covered by glaciers other than ice sheets; Ice-sheet elevation changes for mass-balance determination	High-resolution VIS/NIR/SWIR optical imagery; Altimetry
Snow Cover Snow areal extent	Moderate-resolution VIS/NIR/IR and passive microwave imagery
Albedo Directional-hemispherical (black sky) albedo	Multispectral and broadband imagery
Land Cover Moderate-resolution maps of land-cover type; High-resolution maps of land-cover type, for the detection of land-cover change	Moderate-resolution multispectral VIS/NIR imagery; High-resolution multispectral VIS/NIR imagery
fAPAR Maps of fAPAR	VIS/NIR imagery
LAI Maps of LAI	VIS/NIR imagery
Biomass Research towards global, above-ground forest biomass and forest-biomass change	L band / P band SAR; Laser altimetry
Fire Disturbance Burnt area, supplemented by active-fire maps and fire-radiated power	VIS/NIR/SWIR/TIR moderate-resolution multispectral imagery
Soil Moisture[4] Research towards global near-surface soil-moisture map (up to 10cm soil depth)	Active and passive microwave

[4] Soil moisture was not listed in the GIP as an ECV, but was recognized as an emerging ECV and has been included here.

Systematic Observation Requirements for Satellite-based Products for Climate

Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC"

1. INTRODUCTION

1.1. Purpose of this Document

This document provides supplemental detail to the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS-92, October 2004, hereafter called the 'GCOS Implementation Plan' or 'GIP') related to the generation of global climate products derived from satellites. The detailed specifications, often in conjunction with the need for *in situ* data for calibration and validation, have been made traceable to the GCOS Implementation Plan. The document is intended to assist Parties[5] supporting Earth observation from space, and/or supporting the use of such observations in the generation of climate products, in responding to the requirements of the GCOS Implementation Plan[6]. Equally, all Parties can play an important role as users and potential generators of climate products derived from satellites, as well as through the vital contribution of *in situ* observations that are required for the derivation of the climate products specified in this report. Parties should respond to the needs expressed in the GCOS Implementation Plan, supplemented by this report. They should do so by working, as appropriate, with their space agencies, and in conjunction with international bodies such as WMO, IOC, ICSU, UNEP and other relevant bodies, such as the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS) and the Group on Earth Observations (GEO).

The GCOS Implementation Plan remains the consensus document of the international community regarding the global observing system for climate. It has found broad acceptance across a range of international bodies and national organizations, and meets the needs of the climate research community, e.g., those acting through WCRP[7] and IPCC, for sustained data and products for climate monitoring. While this particular document considers mainly the satellite-based observations, the GCOS Implementation Plan notes the equally vital roles of *in situ* and satellite-based observations, and seeks to balance these to form an effective integrated observing system. Notwithstanding the important needs for *in situ* observations, the actions related to satellite-based observations detailed in this supplement would provide a major enhancement to the capabilities for global monitoring of climate. In many cases, improved climate observations are also expected to be beneficial to other societal needs, for example to weather forecasting, oceanographic applications, agriculture, and land-use management.

This report also takes into account the important and evolving role of research-driven, more refined observations that aid interpretation and understanding of the sustained, systematic observational elements. This research component needs to be discussed on a continuous basis, especially for variables for which additional research is needed to pioneer future monitoring capabilities. In parts, these research components will also supplement the creation of climate data records for those variables that are practical and feasible for sustained monitoring today.

In the GCOS Implementation Plan, actions for implementation were assigned to groups with recognized expertise and responsibility, where possible. In other cases, needs for such institutional arrangements were identified. Consistent with this approach, the details provided in this report need to be regarded as guidance and subject to review and revision by such expert groups, to account for ongoing scientific and technological progress.

[5] Parties in the context of this report are signatory countries of the UNFCCC.

[6] Appendix 1 list all Actions from the GCOS Implementation Plan in which space agencies, CEOS and/or CGMS are listed as "Agents for Implementation".

[7] As described in: *The WCRP Strategic Framework 2005-2015: Coordinated Observation and Prediction of the Earth System (COPES)*. WCRP-123 (WMO/TD-No 1291), August 2005.

This document does not encompass all the ancillary data needed for derivation of end products from the noted satellite data records, e.g., data for the determination of the geoid, absolute geodetic reference frames or digital elevation models.

1.2. Basis provided by the GCOS Implementation Plan

[GIP][8] The Global Climate Observing System (GCOS), in consultation with its partners, developed, in 2004, the GCOS Implementation Plan that, if fully implemented by all nations, will provide those global observations of the Essential Climate Variables[9] (ECVs) and their associated products that are required by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The GCOS Implementation Plan draws on the views of the Parties on the 'Second Adequacy Report'[10] submitted by GCOS to SBSTA at its eighteenth session (June 2003). It specifically responds to the request of the Conference of the Parties (COP) to the UNFCCC in its decision 11/CP.9 to develop a 5- to 10-year implementation plan, and was strongly endorsed by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the COP at its 21st session in December 2004.

Specifically, the system proposed by the GCOS Implementation Plan will 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;
- Project the information provided by global climate models down to regional and national scales; and
- Characterize extreme events important in impact assessment and adaptation, and to assess risk and vulnerability.

At the same time, the GCOS Implementation Plan builds wherever possible on existing observing systems, datasets, infrastructure and institutional arrangements to achieve its goals. In its satellite component, the Plan considers both the

- Generation of fundamental climate data records of calibrated observations from satellites, and
- The generation of products for use in monitoring the global climate, derived from these data records.

Both of these needs are addressed in the present document.

In order to set priorities, criteria for placing items within the current or near-future implementation timeline of the GCOS Implementation Plan include:

- Clearly significant and demonstrable 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. Costs noted in the GCOS Implementation Plan for each action are indicative and need to be refined by those charged with executing the actions.

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8 Citations from existing documents are flagged: [GIP]: GCOS Implementation Plan, [2AR]: Second Adequacy Report.

9 These are contained in Appendix 5, were fully described in the Second Adequacy Report and its Technical Annexes. Table 2 lists those ECVs that are largely dependent upon satellite observations.

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

The critical high-priority issues thus identified that should be addressed by the Agents of Implementation, including the space agencies, are:

- Continuity and improvement of key satellite and *in situ* networks;
- Generation of high-quality global datasets for GCOS ECVs;
- Enhancement of the participation of least-developed countries and small island developing states;
- Improvement of access to high-quality global data for the ECVs;
- Strengthening of national and international infrastructure.

The specifications given in this report directly address these priorities as appropriate.

Furthermore, GCOS, consistent with its terms of reference, has been recognized by GEO as a lead group for the GEO climate "societal benefit area" and provides, through the GCOS Implementation Plan, a mature implementation document carried by a wide consensus of the climate community. GCOS has been closely involved in the development of the GEO work plan since its inception, and will continue to do so as GEO progresses.

1.3. Societal Benefits of Satellite-based Products

All societies and ecosystems are affected by climate change, including long-term climate trends, natural climate variability and extreme events. Improved knowledge of climate change underpins many other "societal benefit areas" (as defined by the GEOSS 10-year implementation plan[11]), such as Weather, Water, Agriculture, Health and Energy. In the same vein, if the satellite data records and products identified in this document were indeed obtained in conjunction with real-time and near-real-time applications, as largely the case with meteorology today, the resulting observing system would cover a major part of the satellite needs of all GEOSS societal benefit areas. For example, the value of a validated, routinely-produced global precipitation product would not be limited to weather and climate forecasts, but would also have a considerable impact on agricultural planning, forestry and water management.

For this reason, Parties and, if applicable, their space agencies need to follow a coordinated, systematic mission strategy in which particular instruments are cost effective and meet as many application needs as possible.

1.4. The Satellite Component of the GCOS Implementation Plan

As laid down in the GCOS Implementation Plan, satellites now provide a vital means of obtaining observations of the climate system from a global perspective and assessing the behaviour of different parts of the globe (see Table 5). A detailed global climate data record for the future will not be possible without a major satellite component. However, for satellite data to contribute fully and effectively to the determination of long-term records, they must be implemented and operated in an appropriate manner to ensure adequate stability, accuracy and homogeneity. To assist the space agencies, the GCOS Climate Monitoring Principles (GCMPs) have been extended, in consultation with CGMS, specifically for satellite observations, addressing the following satellite-specific key operational issues (see Appendix 4):

- Continuity, homogeneity and overlap of satellite observations;
- Enhanced orbit control;
- Calibration and instrument characterisation;
- Sampling strategy;
- Sustained generation of products, data analysis, and archiving.

[11] Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan and Reference Document, GEO-1000R, February 2005, 209pp.; http://earthobservations.org

Table 5: ECVs largely dependent upon satellite observations[12]

Domain	Essential Climate Variables
Atmospheric (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, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity), Sea state*, Ocean salinity*.
Terrestrial	Lakes*, Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI)*, Biomass*, Fire disturbance, Soil moisture*.

Recently, all space agencies have agreed to address the GCMPs for the relevant operational and research satellite systems. This is vital for the development of satellite data records for climate and will also greatly enhance the utility of satellite information for all applications. All of the points raised in the GCMPs are important and, as implied by the last bullet point above, sustained attention needs to be given by the space agencies to ensure that the accuracy and homogeneity of the satellite data records used to derive products are monitored. This will significantly enhance the value of satellite observations in the global observing system for climate. By virtue of committing to the requirements for satellite climate data records and products identified in this report (Sections 2 and 3), which each incorporate one or more GCMPs, a major step would be taken by the space agencies toward this end.

The list of ECVs in Table 5 is expected to evolve slowly as scientific knowledge and requirements extend, and as technological developments permit. A small number of variables, specifically soil moisture, ocean salinity and biomass, have been noted in this report as requiring further research for the development of routine monitoring capabilities. Land surface temperature has also been included, supporting derivation and analysis of the land-cover products.

The GCOS Implementation Plan contains many Actions which are specifically directed at space agencies, CGMS and CEOS (Appendix 1). In addition, the text of the GCOS Implementation Plan identifies several other needs that were not highlighted as specific Actions. The present report seeks to provide a consolidation of all the satellite-related requirements and Actions from the GCOS Implementation Plan, and in addition, adds more details to these requirements.

In the context of this document, the issue of costs is not being reconsidered. However, as the space-related Actions in the GCOS Implementation Plan show, most of the resources needed to achieve satellite-based monitoring of ECVs fall into two categories:

1. Resources needed to ensure that attention is given to the GCMPs in the sustained operation of the current and planned meteorological satellite instruments;

2. Resources needed to initiate and continue sustained observation capabilities not currently planned in future missions. The needed instrument types are in most cases comparable to satellite instruments on current research mission.

The actions falling under the first category have significant costs, but amount to only a fraction of the typical cost of a full satellite mission. The second category accounts for the major part of the total satellite-related costs estimated for the GIP. It includes some observational elements in the atmospheric domain, but mainly addresses the needs of the ocean and terrestrial domains. In addition to climate monitoring, meeting the needs in the second category would also bring substantial benefits to many other user

[12] Based on the GIP and covering all ECVs considered in this report. ECVs denoted with an asterisk (*) were not included in the original table in the GIP. Note that soil moisture was not listed in the GIP as an ECV, but was recognized as an emerging ECV and has been included here.

communities, in particular those concerned with land surface and marine applications. (Note that in the GIP, for which total annual incremental costs were estimated in the order of USD 600 million, a roughly equal share of cost was attributed to *in situ* observations, systems and datasets on the one hand; and to satellite observations and datasets on the other hand)

1.5. Scientific Coordination

Continuous scientific coordination and guidance related to the generation of required satellite climate data records and products are recommended to be assigned to scientific advisory groups, working in cooperation with GCOS, GOOS and GTOS Science Panels, the WCRP Observation and Assimilation Panel (WOAP), and other involved bodies. These groups should, in turn, advise CEOS and its working groups, and other involved bodies, such as the WMO Space Programme and CGMS. For all the products called for in this document, establishment of international working groups is recommended for the comparison and refinement of the products being generated routinely, ideally by independent teams. Wherever possible, existing activities, groups and linkages should be exploited to ensure effective scientific coordination.

1.6. The Nature of Requirements considered in this Report

1.6.1. Data Records and Products

As mentioned above, the focus of this report will be on actions related to the Essential Climate Variables (ECVs) for which monitoring is judged to be currently feasible with satellite observations (see Table 5).For each of these variables, the document focuses on the required satellite observations in terms of fundamental climate data records, and the need for products. The terms “fundamental climate data record” and “product” are defined as follows:

Fundamental Climate Data Record (FCDR):
In this document, the term “Fundamental Climate Data Record” (FCDR) is used to denote 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. For “one-off” research spacecraft, the principles of continuity obviously do not 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. Issues regarding spatial and temporal sampling, which depend on the number of satellites, their orbits, instruments and operating modes, are also mentioned. Although satellite observations provide the only technique to support truly global monitoring, they have limitations in this respect due to sampling issues.

Product:
The term “Product” denotes, in the context of this report, values or fields of geophysical variables derived from FCDRs, often generated by blending satellite observations and *in situ* data, and using physical model frameworks (other documents use the term “Thematic Climate Data Record” (TCDR)[13] for such products; in the GCOS Implementation Plan, the term “integrated climate product” was used). The development of products requires strong collaboration between space agencies and relevant research and operational groups, to ensure continuous refinement and extension. Adequate details of the product generation approach need to be documented and made available, along with the products, to ensure repeatability and incremental improvement of the products.

The following remarks apply to the definition of individual FCDRs and products in this document:

[13] 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.

- Specifications of required FCDRs are kept generic and given mostly in terms of "appropriate radiances" or spectral ranges of the data record (e.g., NIR, UV) that are, given current expertise, considered most relevant for the generation of the product;

- Mention of particular satellite instruments is for illustration only and by itself not meant to be exhaustive or an indication of preference;

- Analysis by relevant expert groups is necessary to determine the details of the generation of each product, and to ensure maximum synergy of the selected approaches, as some FCDRs can benefit more than one product;

- Independent products are usually required for cross-checking of uncertainties and trends; some of these products should be based on independent FCDRs to further enhance the independence in scientific judgment; past experience has also shown that complex climate products should be generated by independent teams in a collaborative manner;

- Note is also made of supplemental non-FCDR-type satellite data records and supplemental products, which add value to the FCDRs and products, e.g., with respect to interpretation and validation, , but need not necessarily be sustained according to the GCMPs.

1.6.2. Accuracy, Stability and Resolution

The accuracy and stability requirements on products are based on the expected variability of ECVs on diurnal, seasonal and decadal timescales. They are intended to be largely technology-free, i.e. irrespective of current observational capabilities. Setting these requirements is difficult, due to, in part, limited knowledge of the expected variability over time. Therefore, a number of caveats apply to the definition of requirements. For example,

- <u>Analysis Approach:</u> Although in some cases, the translation of product requirements into satellite mission specifications is fairly straightforward, this is usually a complex undertaking. It often depends on the particular approach taken in the analysis of products, for example, on the range and the exact characteristics of information available to a particular user. It is even possible that a combination of data records from two satellite instruments, neither of which meeting any of the requirements given in this report, could usefully meet the needs if applied together in careful analysis;

- <u>Sampling strategy:</u> As mentioned in the FCDR definition above, the suitability of a particular satellite instrument to ultimately contribute in a beneficial manner to a particular product also depends on the instrument sampling strategy, sometimes in connection with other relevant instruments in orbit.

In spite of these caveats, indicative product requirements are given in this report to provide a starting point for discussion, and a perspective of needed requirements. As mentioned above in section 1.5, these need to be maintained in consultation with GCOS and expert groups involved in the creation of end-to-end products.

The requirements are:

- **Requirements for accuracy and spatial and temporal resolution**, which depend on judgment of the scientific or other requirements to resolve variations on diurnal to decadal timescales, and the spatial scales characteristic of the variable (stated for each product explicitly, taking into account the report by Ohring et al. (2005)[14] on satellite instrument calibration to measure climate change, and the WMO/CEOS database requirements[15]);

- **Requirements for stability**, which do not refer to absolute accuracy, but to the ability of the data record to detect long-term trends of climate variables. Within limits, excellent accuracy is of secondary

[14] Ohring G., Wielicki B., Spencer R., Emery B., and Datla R. (2005): *Satellite Instrument Calibration for Measuring Global Climate Change – Report of a Workshop*. Bulletin of the American Meteorological Society, September 2005, 1303-1313.

[15] The WMO/CEOS database requirements for GCOS are tabulated in Appendix 2. Further information is available at http://www.wmo.int/web/sat/satsun.html.

importance to stability because a long-term trend can be determined as long as the dataset has the required stability (stated for each product explicitly, taking into account the report by Ohring et al. (2005) and the WMO/CEOS database requirements)).

Some **threshold requirements** for lower accuracy/resolution measurements, to provide potentially useful measurements of spatial and temporal variance, are contained in the WMO/CEOS database.

Full definitions of the terms used in the requirements (e.g., accuracy, stability, resolution) are given in Appendix 6.

In this context, GCOS has the responsibility for providing updates to the systematic climate observation elements of the WMO/CEOS database, in consultation with its partners and through continuing review. The requirements in this document are consistent with this process. Through the WMO Rolling Requirement Review process, this will directly influence the priorities to be agreed by WMO Members and their space agencies, for enhancing the space-based Global Observing System.

1.7. Structure of this Document

This document identifies cross-cutting needs for systematic climate monitoring that involve space agencies (section 2). Section 3 provides details of the satellite data records and products needed for each of the Essential Climate Variables given in Table 5. For each domain (Atmosphere, Oceans, Terrestrial), the focus is on the ECV product requirements, the FCDRs needed to sustain long-term records and, where appropriate, the research needs to establish such capabilities.

Citations from existing documents are denoted throughout this document as: [GIP] for the GCOS Implementation Plan, and [2AR] for the Second Adequacy Report.

2. CROSS-CUTTING NEEDS

There are many common, cross-cutting needs that pertain to each of the Essential Climate Variables considered in this report. As noted above, the GCOS Climate Monitoring Principles (GCMPs) provide an agreed statement of the main cross-cutting requirements on climate observations. The main cross-cutting need is therefore the following:

C.0 Systematic and continuous attention given to the GCMPs for each of designated Fundamental Climate Data Records

C.0.1 Ensure that remits of space agencies include the responsibility for maintaining Fundamental Climate Data Records, including past records

C.0.2 Establish structural arrangements and responsibilities (within space agencies) to ensure attention to the GCMPs

Remarks:

a. The GCOS Implementation Plan and this report provide a list of satellite data records (FCDRs and products) which need attention to the GCMPs with the highest priority;
b. While space agencies have recognised the GCMPs, and notwithstanding valuable and encouraging examples of best-endeavour practise within some space agencies, they have generally not built appropriate mechanisms into their planning and operating processes that are needed to ensure adequate adherence to the GCMPs;
c. Reference: GIP Action C10.

C.1 Comprehensive and routine calibration of satellite instruments

Remarks:

a. The raw digital counts recorded by a satellite instrument can only be converted into physical quantities (mostly radiance or reflectance), if instrument calibration coefficients are available. These physical quantities can then be used for the derivation of geophysical parameters. Because instrument characteristics can change with time, absolute calibration and radiometric stability must be determined at regular intervals; the accuracy of any such measurement defines how well a measurement is known compared to an internationally-agreed standard or scale, e.g., SI units. Consequently, well-defined accuracy and stability of individual data records are prerequisites for the generation of homogeneous satellite climate data records and products. They are also vital for consistent comparison and validation of these records with other data sources, such as *in situ* observations;
b. If the signal measured by a satellite instrument cannot be made traceable to an agreed standard, vicarious calibration methods can help specifying radiometric and spectral stability of an instrument over time. For that purpose, repeated satellite-based observations of radiometrically-stable calibration sites, typically salt pans and deserts, are compared with contemporaneous *in situ* radiometric measurements;
c. The Global Space-based Inter-Calibration System (GSICS), currently under development by CGMS and WMO, is a good example of a proposal expressing the needs for instrument calibration, and may be considered for wide adoption by space agencies. The GSICS proposal contains recommendations for:
    - Ensuring traceable pre-launch and on-board calibration;
    - Exploiting opportunities for calibration against external targets, e.g., Earth-based reference sites and the Moon;
    - Exploiting opportunities for instrument cross-calibration, e.g., by maintaining a database of common satellite viewpoints, including designated radiosonde and surface-based measurement sites, and airborne measurements.
d. The effectiveness of the *in situ* observations in this context would be improved by adopting the call in the GCOS Implementation Plan for:

- The establishment of a high-quality radiosonde network and associated ground-based measurements; and
- The provision of a set of key terrestrial reference sites, providing measurements of key biomes according to agreed standards.

e. See Appendix 6 for definitions;
f. Reference: GIP Action C10.

C.2 Archiving and Dissemination

C.2.1 Develop modern distributed data services that

- handle the increasing volumes of data
- allow timely feedback to observing network management (e.g., early detection of errors and biases)
- make access to increasingly large volumes of data more effective; this is especially important for countries with inadequate IT infrastructure or technical skills in using complex data
- provide access to metadata, as well as physical data
- maintain access to historic data

C.2.2 Ensure that data policies facilitate the exchange and archiving of all ECV products, FCDRs, associated metadata, and ancillary data

Remarks:

a. Implementation needs in this context involve archiving of all satellite metadata, so that long-term sensor and platform performance is traceable;
b. The creation of FCDRs from all relevant satellite systems requires the organization of data service systems that ensure ongoing accessibility to the data into the future;
c. Reference: GIP Actions C20, C21.

C.3 Detailed Specification of Fundamental Climate Data Records and Derived Products

Establish detailed specifications for each product in consultation with appropriate scientific and user advisory groups. This document provides a starting point for this ongoing process.

C.4 Generation of Fundamental Climate Data Records and Derived Products

C.4.1 Establish and ensure access to Fundamental Climate Data Records (FCDRs)

C.4.2 Update these FCDRs periodically by addition of new data or by reprocessing complete records when calibration methods or calibration data improve

C.4.3 Generate homogeneous derived products from the FCDRs

C.4.4 Sustain regeneration (or reprocessing) to derive improved products when FCDRs or generation methods improve

C.4.5 Sustain the independent generation of derived products as a means of determining the confidence that can be placed in products, in particular in trends estimated from these products

Remarks:

a. While observations of the variables are an essential pre-requisite, users of climate information generally require analysed outputs and products;
b. Whenever possible, the required data records for the generation of products, including historical data records, should cover as many years as possible (at least the most recent 30 years, if possible) in order to serve as a reference for climate variability and change studies;

c. Operational[16] analysis centres for some atmospheric variables are in place, but additional operational analyses are required for these activities, especially for oceanic and terrestrial variables;
d. International coordination of activities under C.4 is highly desirable, to take advantage of progress, and to promote efficiency, complementarity and cooperation while recognizing the value of independent product generation (see also C.3);
e. In many climate applications, the FCDRs themselves, mostly calibrated radiances, are the critical and required observables. This necessitates open access to those FCDRs, including their comprehensive metadata. It is understood that the derivation of the FCDRs is generally the responsibility of the satellite instrument operators, since in-depth knowledge of the instrument specifics is required;
f. Although satellite data are a primary source for observing many ECVs, *in situ* and/or other remotely-sensed data are generally needed to (inter-)calibrate, validate and assess the long-term stability of the satellite data;
g. See Appendix 6 for definitions;
h. Reference: GIP Action C8, C10, C11, C12, GIP Executive Summary Key Action 23.

Additionally, in the context of climate products, the following need has been identified:

C.5 International Coordination of Reanalysis Activities

Strengthen links between space agencies and the major reanalysis centres, e.g., through the GCOS Observing Panels for Climate and the WCRP Observations and Assimilation Panel, to ensure clear specification of current and future needs for reprocessed satellite datasets, and to feed experience back to space agencies on the quality of satellite datasets. The requirements for datasets for reanalysis specified below will be refined by this process.

Remarks:
a. Real-time data assimilation and reanalysis are increasingly powerful tools for generating integrated products which exploit the physical relationships among a number of the variables, and thus integrate many of the available types of observation (e.g., *in situ* and satellite-based measurements);
b. Coordination is vital, since the extension of data assimilation and reanalysis activities to the study of long-term climate trends places particular demands on the accurate calibration of key elements of the observational data used in reanalysis;
c. The availability of national holdings of historical datasets, including comprehensive metadata, to International Data Centres is vital for the effective conduct of reanalysis;
d. Reference: GIP Action C13.

C.6 Emerging Products

Intensify efforts to further develop emerging operational capabilities for research-based variables

Remarks:
a. Research is needed to overcome the current scientific and technical limitations to climate-quality measurements (in terms of, e.g., instruments, algorithms, calibration/validation, resolution, cost) of some key and a few emerging ECVs (including both *in situ* and satellite-based observations);
b. Many research satellites (mostly one-off, short-term missions) have demonstrated their potential to overcome these limitations and should therefore make a significant contribution to the improvements in the measurement of all ECVs and the creation of reliable FCDRs;
c. Ensure, through appropriate scientific coordination, the existence of strong links between research and operational communities;
d. Reference: GIP Action C7, GIP Section 3.8, GIP Executive Summary Section 6.

Finally, in addition to the needs noted above with direct connection to the GCMPs, two additional, more indirectly related, but nevertheless important needs are raised:

[16] "Operational" within the context of this report means observational activities that are undertaken according to internationally-agreed standards, on a routine and on-going basis, and with plans in place for continuity and homogeneity. It also implies compliance with the GCOS Climate Monitoring Principles

C.7 Unique Fundamental Datasets

Exploit the unique value of historical datasets through reprocessing to derive multi-decadal products, for example land cover, fire disturbance and aerosols from AVHRR

Reference: GIP Action C10, A31

C.8 Improved Community Awareness of Available and Planned Satellite Missions and Data Records

Maintaining a public domain database of past, current and planned satellite missions, including for each mission current status and information on data availability and access mechanisms

Reference: GIP Action C10

3. PRODUCTS

GCOS recommends the following products in the atmospheric, ocean and terrestrial domains for priority action by the space agencies (Tables 6-8; Tables 2-4 in the executive summary provide the same content in a more concise form). For all these products, routine creation and early delivery are feasible with today's capabilities, although a continuous research effort and subsequent reprocessing of data and regeneration of products are needed to ensure improving quality and consistency.

For some of the ECVs, in addition to the datasets and products listed here, supplemental observations and products have been identified in the actual text, which assist interpretation and analysis. Systematic adherence to the GCMPs is desirable for these supplemental datasets, but not as essential as in the case of the noted FCDRs.

Table 6: Overview of Products – Atmosphere

ECVs	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)	Product Numbers (GCOS IP Reference Actions)
Surface Wind Speed and Direction	Surface vector winds analyses, particularly from reanalysis	Passive microwave radiances and scatterometry	A.1 (A11)
Upper-air Temperature	Homogenized upper-air temperature analyses: Extended MSU-equivalent temperature record; New record for upper-troposphere and lower-stratosphere temperature using data from radio occultation; Temperature analyses obtained from reanalyses	Passive microwave radiances; GPS radio occultation; High-spectral resolution IR radiances for use in reanalysis	A.2.1 A.2.2 A.2.3 (A19, A20)
Water Vapour	Total column water vapour over the ocean and over land; Troposphere and lower- stratosphere profiles of water vapour	Passive microwave radiances; UV/VIS radiances; IR imagery and soundings in the 6.7 μm band; Microwave soundings in the 183 GHz band	A.3.1 A.3.2 (A7, A21)
Cloud Properties	Cloud radiative properties (initially key ISCCP products)	VIS/IR imagery; IR and microwave soundings	A.4 (A22, A23)
Precipitation	Improved estimates of precipitation, both as derived from specific satellite instruments and as provided by composite products	Passive microwave radiances; High-frequency geostationary IR measurements; Active radar (for calibration)	A.5 (A6, A7, A8, A9)
Earth Radiation Budget	Top-of-atmosphere Earth radiation budget on a continuous basis	Broadband radiances; Spectrally-resolved solar irradiances; Geostationary multispectral imagery	A.6 (A14, A24)
Ozone	Profile and total column of ozone	UV/VIS and IR/microwave radiances	A.7 (A25, A26)
Aerosol Properties	Aerosol optical depth and other aerosol properties	VIS/NIR/SWIR radiances	A.8 (A25, A26, A31)
Carbon Dioxide, Methane and other GHGs	Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks	NIR/IR radiances	A.9 (A25, A26, A27)
Upper-air Wind	Upper-air wind analyses, particularly from reanalysis	VIS/IR imagery; Doppler wind lidar	A.10 (Section 4.2.2)
Most upper-air and some surface ECVs	Atmospheric reanalyses	Key FCDRs and products identified in this report, and other data of value to the analyses	A.11 (C13)

Table 7: Overview of Products – Oceans

ECVs	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)	Product Numbers (GCOS IP Reference Actions)
Sea Ice	Sea-ice concentration	Microwave and visible imagery	O.1 (O23, O24)
Sea Level	Sea level and variability of its global mean	Altimetry	O.2 (O12)
Sea Surface Temperature	Sea-surface temperature	Single and multi-view IR and microwave imagery	O.3 (O9, O10)
Ocean Colour	Ocean colour and oceanic chlorophyll-a concentration derived from ocean colour	Multispectral VIS imagery	O.4 (O18)
Sea State	Wave height and other measures of sea state (wave direction, wavelength, time period)	Altimetry	O.5 (O19)
Ocean Salinity	Research towards the measurement of changes in sea-surface salinity	Microwave radiances	O.6 (O15)
Mainly sub-surface and some atmospheric ECVs	Ocean reanalyses utilizing altimeter and ocean surface satellite measurements	Key FCDRs and products identified in this report, and other data of value to the analyses	O.7 (C11, C12, C13)

Table 8: Overview of Products – Terrestrial

ECVs	Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)	Product Numbers (GCOS IP Reference Actions)
Lakes	For lakes in the Global Terrestrial Network for Lakes: Maps of lakes; lake levels; and surface temperatures of lakes	VIS/NIR imagery and radar imagery; Altimetry; High-resolution IR imagery	T.1.1, T.1.2, T.1.3 (T5, T6, T8)
Glaciers and Ice Caps	Maps of the areas covered by glaciers other than ice sheets; Ice-sheet elevation changes for mass-balance determination	High-resolution VIS/NIR/SWIR optical imagery; Altimetry	T.2.1, T.2.2 (T13, T14)
Snow Cover	Snow areal extent	Moderate-resolution VIS/NIR/IR and passive microwave imagery	T.3 (T11, T17)
Albedo	Directional-hemispherical (black sky) albedo	Multispectral and broadband imagery	T.4 (T21)
Land Cover	Moderate-resolution maps of land-cover type; High-resolution maps of land-cover type, for the detection of land-cover change	Moderate-resolution multispectral VIS/NIR imagery; High-resolution multispectral VIS/NIR imagery;	T.5.1, T.5.2 (T24, T26, T27)
fAPAR	Maps of fAPAR	VIS/NIR imagery	T.6 (T28)
LAI	Maps of LAI	VIS/NIR imagery	T.7 (T28)
Biomass	Research towards global, above-ground forest biomass and forest-biomass change	L band / P band SAR; Laser altimetry	T.8 (T31)
Fire Disturbance	Burnt area, supplemented by active-fire maps and fire-radiated power	VIS/NIR/SWIR/TIR moderate-resolution multispectral imagery	T.9 (T33)
Soil Moisture[17]	Research towards global near-surface soil-moisture (up to 10cm soil depth)	Active and passive microwave	T.10 (T37)

[17] Soil moisture was not listed in the GIP as an ECV, but was recognized as an emerging ECV and has been included here.

3.1. ATMOSPHERE

The following sections provide details of the required products and datasets primary derived from satellites in the atmospheric domain:

3.1.1. ECV Surface Wind Speed and Direction

The surface wind field is the primary driver of the ocean circulation, which is responsible for the global transport of important amounts of heat, freshwater and carbon. Surface drag and momentum exchanges, fluxes of sensible heat and moisture also depend on wind speed. The surface wind field is a sensitive measure of the state of the global coupled climate system and is very valuable for climate change detection and climate model evaluation. Over land, wind contributes to the surface heat balance influencing advective and turbulent heat fluxes.

[GIP] Spaceborne scatterometer and passive microwave radiometer data have been demonstrated to be valuable sources for wind field information over the ocean when coupled with the *in situ* observations (land: synoptic meteorological network; oceans: VOS, VOSClim, Tropical Mooring Network, Reference Buoy network) in an integrated analysis product. Systematic and sustained deployment of scatterometer or equivalent wind-measuring systems must be maintained. Scatterometers in particular provide large coverage and a spatial resolution of wind speed and direction that matches the scales of ocean variability.

Reanalysis approaches are of particular benefit to wind speed analyses, as wind is tightly coupled with atmospheric dynamics, and analysis benefits are obtained from observations of a wide range of other atmospheric variables that are involved in the dynamics (see A.11).

The following is required for this ECV:

<u>Product A.1</u> **Surface vector wind analyses, particularly from reanalysis**

Benefits
- Forcing of ocean-wave and ocean-circulation models, through improved estimation of air-sea fluxes
- Climate monitoring
- Climatological information in support of marine operations (e.g., ship design and oil exploration)

Target requirements
- Accuracy: Mean and quadratic statistics to 10% of the mean speed, or ~0.5 ms^{-1} at 10°
- Spatial and temporal resolution: 10 km horizontal resolution, hourly observing cycle
- Stability: ~0.1 ms^{-1}/decade

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate passive microwave radiances and of scatterometry, for example through:
- Continuity of passive microwave radiometric measurements
- Scatterometers on two (AM and PM) polar-orbiting satellites

Calibration, validation and data archiving needs
Buoy data essential

Adequacy/inadequacy of current holdings
- Scatterometer data record largely based only on single-satellite coverage
- Continuity is currently expected from only one satellite (ASCAT on METOP)

Immediate action, partnerships and international coordination
- Implementation of two-satellite system of scatterometer measurements; a QuikScat successor would provide the required second satellite
- Maintenance of passive microwave measurements
- Reprocessing of ERS/QuikScat scatterometer data record since 1991, and of SSM/I passive microwave record since 1987, supplemented by data from SMMR from 1979-1984

- Coordination by CGMS/IWWG, GCOS and WCRP Panels

Link to GCOS Implementation Plan
[GIP Action A11] Ensure continuous operation of AM and PM satellite scatterometer or equivalent observations.

Other applications
- Assimilation for NWP and ocean forecasting
- Transport sector, construction sector, energy production, air quality management, human health, marine safety and pollution response

3.1.2. ECV Upper-air Temperature

Upper-air temperatures are a key dataset for detection and attribution of tropospheric and stratospheric climate change, measured both by radiosondes and satellite instruments. Temperatures measured by high-quality radiosondes are an important reference against which satellite-based measurements can be calibrated. Upper-air temperatures are crucial for separating the various possible causes of global change, and are vital for the validation of climate models.

[GIP] Specific microwave radiance data have become key elements of the historical climate record and need to be continued into the future to sustain a long-term record. The MSU radiance record is a primary resource for this, providing essential coverage over the oceans and data for comparison and combination with radiosonde data over land. It should be noted that new high-resolution infrared sounders will improve the vertical resolution of satellite-derived temperature soundings by a factor of three, and will significantly improve the monitoring of temperature change. Other atmospheric temperature sounding data play an important role, along with many diverse data sources in reanalyses of all the upper-air variables.

[GIP] 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 independent observations that are likely to be utilized to calibrate all other data (sondes, IR and microwave soundings). Instruments are being flown on multiple low Earth orbiting satellites (such as during the CHAMP and SAC-C projects) and further research missions are planned (such as the COSMIC fleet of 6 satellites due for launch in 2006[18]). Systems need to be developed for real-time data exchange and use, implemented into operational meteorological data streams. Plans also need to be made to ensure future RO instruments and platforms, including on operational meteorological satellites. Some such plans already exist, such as for METOP.

Recent research has shown that the RO technique also has the potential to provide, in the middle to lower troposphere, high-resolution profiles of atmospheric refractive index, combining the effects of temperature and water vapour in this region of the atmosphere (see A.2.2 and A.3.1).

The following is required for this ECV:

Homogenized upper-air temperature analyses:

<u>Product A.2.1</u> Extended MSU-equivalent temperature record
<u>Product A.2.2</u> New record for upper-troposphere and lower-stratosphere temperature using data from radio occultation
<u>Product A.2.3</u> Temperature analyses obtained from reanalysis (see A.11)

Benefits
- Monitoring and detection of temperature trends and variability in the troposphere and lower stratosphere
- Validation of climate models
- Linkage with trends in surface air temperature

[18] Successfully launched 14 April 2006.

Target requirements
- Accuracy: 0.5 K
- Spatial and temporal resolution: 100 km horizontal resolution, 0.1 km vertical resolution for planetary boundary layer and tropopause heights, 2 km vertical resolution elsewhere; 3-hourly observing cycle
- Stability: 0.05 K/decade for troposphere, 0.1 K/decade for lower stratosphere

Requirements for satellite instruments and satellite datasets
(A.2.1) FCDR of past and future data records from passive microwave sounding, for example through:
- Passive microwave sounding from at least two satellites in low Earth orbit using instruments with spectral and scanning characteristics, able to provide continuity with the past record

(A.2.2) FCDR of GPS radio occultation (RO) data record, for example through:
- A long-term network of RO measurements to continue the limited record established by past and present missions (e.g., GPS/MET, CHAMP, COSMIC and GRAS)

(A.2.3) FCDR of IR-based satellite inputs for use in reanalysis, for example through:
- Ongoing provision of high-resolution IR sounder capability, such as AIRS, IASI and CrIS

Calibration, validation and data archiving needs
- Differences in trends estimated from MSU radiances point to the need for improved adjustments for effects of instrumental and orbital drifts and inter-satellite differences (A.2.1)
- Support is required for reference radiosonde and other ground-based observations for calibration/validation of future satellite data records (A.2.1)
- Support is required for activities to use data from RO and demonstrate their value for calibration (A.2.2)

Adequacy/inadequacy of current holdings
- The accuracy of tropospheric trend estimates is inadequate as judged by differences between different MSU-based trends (A.2.1)
- Lower stratospheric trends are barely adequate as judged by differences between different MSU-based trends and between MSU- and reanalysis-based trends; differences between MSU-based and radiosonde-based trends are larger. Accuracy is generally adequate for large-scale low-frequency fluctuations (A.2.1)
- The RO data have yet to be put together as a climate data record (A.2.2)

Immediate action, partnerships and international coordination
- Support for improvement and comparison of methodologies for the construction of homogenized MSU-equivalent radiance datasets, including provision of metadata for instrument characterization, to address inconsistencies in trend analyses. Start with improved processing of MSU record from 1979 onwards (A.2.1)
- Construction of an FCDR of tropospheric and lower stratospheric temperature from RO data. Start with RO climate data record from GPS/MET RO data from 1994 to 1996, CHAMP RO data from 2001, and COSMIC and GRAS from 2006 (A.2.2)
- Ensure utilization of new global positioning technologies
- Construction of an FCDR from high-resolution IR sounder data, from launch of AIRS in 2002 onwards (A.2.3)
- Coordination by SPARC, AOPC WGARO

Link to GCOS Implementation Plan
[GIP Action A19] Continue the system of satellites following the GCMPs to enable the continuation of MSU-like radiance data (A.2.1)
[GIP Action A20] GPS RO measurements should be made available in real time, incorporated into operational data streams, and sustained over the long-term. Protocols need to be developed for exchange and distribution of data (A.2.2)

Other applications
- Microwave, high-resolution IR and RO data are valuable for NWP

- RO and IR sounder data have potential for climate monitoring of lower tropospheric water vapour. (A.2.2 and A.2.3)

3.1.3. ECV Water Vapour

Water vapour is the primary natural greenhouse gas and intimately linked to cloud formation and precipitation, as well as to the understanding of the global water and energy cycles.

[GIP] Information on tropospheric water vapour is provided by operational passive microwave and infrared satellite instruments whose data are generally used to provide precipitation products (see Product A.5). Data assimilation can be used to improve the consistency of water vapour, cloud and precipitation estimates, and the combination of passive microwave and precipitation radar measurements from space (as in the Tropical Rainfall Measurement Mission and the proposed Global Precipitation Mission) has an important role to play in this regard.

[GIP] Water vapour also is an important product and reactant in the chemistry of the upper troposphere and stratosphere, influencing methane, ozone and halogenated greenhouse gases. Here it can be measured using the limb-sounding and occultation techniques employed for other trace constituents. Calibration of the data from the various sensors is a very important issue, and for this the implementation of the proposed reference network of high-quality radiosondes (GIP Action A16) would provide invaluable data.

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

Recent research has shown that the GPS-based RO technique also has the potential to provide, in the middle to lower troposphere, high-resolution profiles of atmospheric refractivity, combining the effects of temperature and water vapour in this region of the atmosphere (see A.2.2 and A.3.1).

The current requirements largely apply to the troposphere, noting that the capability for provision of analysis of stratospheric water vapour products for climate studies is much less well-developed.

The following is required for this ECV:

Product A.3.1 Total column water vapour over the ocean and over land
Product A.3.2 Troposphere and lower-stratosphere profiles of water vapour

Benefits
- Determine radiative forcing due to water vapour and the nature of the water vapour feedback as greenhouse gases increase
- Better understanding of precipitation
- Greater structural information on water vapour distribution will be obtained from 3-D fields derived from reanalysis, which will utilize products A.3.1 and A.3.2, as appropriate

Target requirements
- Accuracy: 2% of local value; 1% for total column
- Spatial and temporal resolution: 10-50 km horizontal resolution, varying between the lower troposphere and the stratosphere; 0.1 km vertical resolution for planetary boundary layer, 2 km vertical resolution elsewhere, 3-hourly observing cycle
- Stability: 0.3%/decade for both total column water vapour and upper-tropospheric humidity

Requirements for satellite instruments and satellite datasets
(A.3.1) FCDR of passive microwave imagery, UV/VIS imagery, for example through:
- Continuity of microwave imagery on at least two polar-orbiting satellites
- SSMIS, CMIS and similar microwave imagers to extend the SSM/I data record
- Polar-orbiting UV/VIS instruments to sustain and complement the data record from e.g. MERIS.

<u>Supplemented by:</u>
Continuous ground-based measurements of GPS-delay

(A.3.2) FCDRs of IR imagery and soundings in the 6.7 μm band, and microwave soundings in the 183 GHz band, for example through:
- Low Earth orbiting high-spectral resolution IR sounders (e.g., AIRS and IASI) and geostationary water-vapour imagery, to extend and improve HIRS data record for upper-tropospheric humidity, and establish a tropospheric profile record
- Continuity of microwave sounders on at least two polar-orbiting satellites

Calibration, validation and data archiving needs
- Reference radiosonde profiles are particularly important for the calibration and validation of water vapour profiles
- Exchange, archive and access protocols need to be developed for ground-based GPS data

Adequacy/inadequacy of current holdings
- Total column water vapour over oceans from SSM/I is considered to be of good quality
- HIRS products are useful for model validation, but not yet well-established for trend identification

Immediate action, partnerships and international coordination
- Maintain planned deployment of instruments to be consistent with existing capabilities/datasets, and improve pre-launch characterization of IR instruments
- Construction of improved products from HIRS data from 1979 to present; SSM/I from 1987, with earlier data from SMMR (1979-1984) and from SSM/T2+AMSU-B+MHS from 1993
- Research toward derivation of water vapour profiles from radio occultation and the development of a strategy for systematic measurement of lower stratosphere water vapour, building on experience already obtained from limb-sounding and solar occultation
- WMO CBS to lead development of protocols for ground-based GPS data exchange
- Coordination by ITWG, GEWEX radiation panel

Link to GCOS Implementation Plan
[GIP Action A7] Ensure stable operation and processing of relevant operational satellite instruments for precipitation and the continuity of associated products.
[GIP Action A21] Develop standards and protocols for exchange of data from the networks of ground-based GPS receivers.

Other applications
- Assimilation in and validation of NWP models
- Hydrology: surface humidity important in the calculation of potential evapotranspiration
- Oceans: surface humidity determines the latent heat flux, i.e., the energy exchange between ocean and atmosphere

3.1.4. ECV Cloud Properties

[GIP] Cloud feedback is considered to be one of the most uncertain aspects of projections of future climate, and is responsible for much of the wide range of estimates of climate sensitivity in climate models. The accurate measurement of cloud properties is exceedingly difficult. The WCRP International Satellite Cloud Climatology Project (ISCCP) has developed a continuous data record of infrared and visible radiances since 1983 utilizing both geostationary and low Earth 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 datasets of the NOAA Advanced Very High Resolution Radiometer (AVHRR) and HIRS (for cirrus clouds) should be reprocessed to obtain data records of cloud microphysics. Because of the importance of the observation of cloud amount, microphysical characteristics and radiative properties, and their variation in time, continued research on improving the observational system is required, and an overall strategy needs to be devised to provide systematic cloud observations. Gaps in the future data record should be avoided.

The following is required for this ECV:

Product A.4 Cloud radiative properties (initially key ISCCP products)

Benefits
- Reduce uncertainty in projections of future climate
- Improve climate monitoring and model/reanalysis validation
- Improve knowledge about the interaction between clouds, aerosols and atmospheric gases

Target requirements
Although clouds are one of the most critical factors in the climate system, a precise strategy for monitoring their properties has yet to be developed. The ISCCP products provide a valuable heritage. As noted in the GIP, research needs to continue in order to refine the strategy and the needed products.

Inevitably, cloud properties involve a complex set of variables, with many target requirements remaining under development. They need active consultation with expert groups. The current content of the WMO/CEOS database (quoted for illustration below) and Ohring et al. (2005) provide two sets of judgements on these needs. Requirements for FCDR stability are yet to be established.

Cloud cover:
Accuracy: 10%
Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle

Cloud ice profile (total column):
Accuracy: -
Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle

Cloud water profile (total column):
Accuracy: -
Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle

Cloud top height:
Accuracy: 0.5 km
Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle

Cloud top temperature:
Accuracy: 0.3 K
Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate VIS/IR imagery, and IR and microwave soundings, for example through:
- Long-term products: exploiting the operational meteorological satellites, combining at least two stable-low Earth orbit satellites, carrying VIS/IR imagers and infrared and microwave sounders, and five geostationary satellites, carrying VIS/IR imagers and some infrared sounding capability

Supplemented by:
- Ongoing programme of research missions using active and passive instruments, to improve observation of cloud properties and to calibrate and characterize long-term products

Calibration, validation and data archiving needs
- Validation against active ground-based and space-based observations is needed

Adequacy/inadequacy of current holdings
- Current products are barely adequate for monitoring large-scale spatial structure and regional variability such as ENSO, and for aspects of model validation
- Current products are far from adequate for monitoring climate change, as evidenced by difference in time series from different products, and from discontinuities in single products

Immediate action, partnerships and international coordination
- Continuation and refinement of products, including reprocessing of the existing geostationary and low Earth orbit satellite data record from the early 1980s onwards
- The product set should at least include the ISCCP products; additional long-term products may be developed from combined analysis of AVHRR and HIRS; new more detailed products may be based on the shorter-term data records from enhanced instruments such as MODIS and SEVIRI
- Research using CLOUDSAT and CALIPSO, and other available instruments towards an improved strategy for monitoring clouds
- Coordination by GEWEX radiation panel, ITWG

Link to GCOS Implementation Plan
[GIP Action A22] Ensure continuation of a climate data record of visible and infrared radiances, e.g., from the International Satellite Cloud Climatology Project, and include additional data streams as they become available.
[GIP Action A23] Research to improve cloud property observations in three dimensions.

Other applications
- Useful for NWP model validation
- Assessment of surface UV-B irradiance, with implications on health, biodiversity, and agriculture

3.1.5. ECV Precipitation

Precipitation (frequency, intensity, quantity and type) is a key variable for specifying the state of the climate system. It varies considerably in space and time and requires a high-density network to observe its variability and extremes on regional scales. Analysis of precipitation variability and change is crucial for the assessment of climate change and of the impact on nature, environment and human society. Changes in timing of precipitation (e.g., seasonality) can have implications for water supplies and agriculture. In particular, knowledge of surface precipitation (rainfall, snowfall) is important for the assessment of global water resources and for better understanding of the interaction between the energy and water cycle, as well as for the assessment of climate impact on ecosystems. Aspects are climate change impact on vegetation, desertification (duration of droughts, shift of climate zones), water resources, river runoff and floods (intensity and duration of extreme events), snow cover and ice sheet balance.

A gridded long-term product of hourly accumulated precipitation at 0.5º resolution, or finer in some areas, would be needed to satisfy directly the full range of requirements. Currently feasible products of lower temporal and spatial resolution may nevertheless satisfy some of the important requirements for monitoring climate fluctuations and change, for validating climate models and for input data to or validation of reanalyses. Over land, ground-based *in situ* measurements form the backbone network, complemented by ground-based radar, with satellite observations used to provide estimates where ground-based measurements are lacking. Over the oceans, satellite observations provide the primary data basis for the generation of products.

The following is required for this ECV:

<u>Product A.5</u> Improved estimates of precipitation, both as derived from specific satellite instruments and as provided by composite products

Benefits
- Monitor long-term fluctuations and change in precipitation
- Improve the representation of precipitation in climate simulation and prediction models, and in reanalyses

- Improve the validation of climate models
- Precipitation is perhaps the single most important climate variable for societal use

Target requirements
Precipitation rates and spatial scales have a very large dynamic range, and extreme events, which may occur rarely, are of overall significance for monthly and seasonal means. Precise accuracy requirements are therefore hard to set, except for within the context of specific applications and approaches to deriving products. The requirements given here should therefore be taken as broadly indicative.

- Accuracy: Single values for accuracy are not very meaningful, but a typical accuracy requirement of 0.1 mm h^{-1}, with total amount at an accuracy of <10% of actual values on monthly time scales, appears reasonable
- Spatial and temporal resolution: 100 km horizontal resolution and 3-hourly observing cycles; 1 km horizontal resolution and 10 minutes observing cycle for extreme events
- Stability: 0.6%/decade (large-scale trend)

Requirements for satellite instruments and satellite datasets
FCDR of passive microwave imagery, for example through:
- Passive microwave instruments on a constellation of low Earth orbit satellites to provide adequate temporal coverage
- Microwave instrument accuracy to 1.25 K brightness temperature and 0.03 K for stability over a decade.

FCDR of active radar (for calibration), and high-frequency geostationary IR measurements.

<u>Supplemented by:</u>
- Capability for enhanced detection of light rain and solid precipitation as a specific and important requirement, especially at high latitudes
- Complementary measurements enabling retrieval of coincident temperature and humidity profiles (such complementarity would in turn benefit the generation of temperature and water vapour products A.2 and A.3, respectively, which may otherwise have some errors due to uncertain liquid water contaminations of their FCDRs)

Calibration, validation and data archiving needs
- Calibration and validation of satellite measurements and related products by high-quality surface-based instruments is a major issue, not only with regard to the capability of the *in situ* instruments, but especially as regards regional variations in precipitation characteristics, and data coverage over the oceans and in high-latitude regions
- Such validation is required on a continuous, long-term basis, and needs improved data exchange by all countries

Adequacy/inadequacy of current holdings
- Major biases and month-to-month variations over broad areas exist between existing products such as GPCP and CMAP
- Current products have been designed for investigation of the global water cycle, but not for monitoring climate variability and change. They are not yet adequate for monitoring climate change, as demonstrated by differences in time series from different products, and from discontinuities in single products

Immediate action, partnerships and international coordination
- Support for the improvement of products through reprocessing of past data
- New products, including error estimates, should be developed, making physically synergistic use of the various available observations, rather than simply combining separate products from different types of observation
- Arrange for a TRMM-type passive microwave instrument follow-on mission, to mitigate the likely gap in these measurements
- Reprocessing of the data records from specific instruments, such as SSM/I (from 1987 onwards), and of composite products, such as GPCP and CMAP (from 1979 onwards)

- Development of new products with higher temporal and spatial resolution, such as the new pentad (5-daily) GPCP product and the 0.25^0 six-hourly Persiann product
- Coordination by CGMS IPWG, GEWEX Hydrometeorology Panel

Link to GCOS Implementation Plan
[GIP Action A6] Submit precipitation data from national networks to the International Data Centres.
[GIP Action A7] Ensure stable operation and processing of relevant operational satellite instruments for precipitation and the continuity of associated products.
[GIP Action A8] Develop and deploy precipitation-measuring instruments on the Ocean Reference Mooring Network.
[GIP Action A9] Develop and implement improved methods for observing precipitation that take into account advances in technology and fulfil GCOS requirements.

Other applications
- Numerical Weather Prediction
- Precipitation monitoring essential for use in agriculture, forestry and water resource management (under GWSP and GEOSS)
- Precipitation monitoring and analyses (including snow) essential for managing water, flood and drought alerts
- Extreme precipitation events over short times (flash floods) and sustained extremes over longer times, as in tropical cyclones, can cause major devastation and loss of life
- Heavy snowfall can be extremely disruptive for societies, both during the event and when melting

3.1.6. ECV Earth Radiation Budget

[GIP] The Earth Radiation Budget (ERB) measures the overall balance between the incoming energy from the sun and the outgoing thermal (longwave) and reflected (shortwave) energy from the Earth. It can only be measured from space, thus continuity of observations is an essential issue. The radiation balance at the top of the atmosphere is the basic radiative forcing of the climate system. Measuring its variability in space and time over the globe provides insight into the overall response of the system to this forcing. The satellite measurements include solar irradiance observations as well as the broadband measurements of reflected solar and outgoing longwave radiation. At least one dedicated satellite ERB mission should be operating at any one time. Satellite observations should be continued without interruption, and operational plans should provide for overlap, so that accuracy and resolution issues are resolved to meet climate requirements. Satellite measurements are also needed to provide a global estimate of the surface radiation budget. The Baseline Surface Radiation Network (BSRN) has been established to provide high-quality *in situ* data for calibration and validation of global satellite-based estimates of the surface radiation budget.

The following is required for this ECV:

Product A.6 Top-of-atmosphere Earth radiation budget on a continuous basis

Benefits
- Improved knowledge of basic radiative forcing of the climate system
- Insight into the response of the system to changes in its forcing and feedbacks (due to changes in greenhouse gases and other factors)

Target requirements
- Accuracy: 1 Wm^{-2} for downwelling solar radiation at TOA; 5 Wm^{-2} for outgoing SW/LW radiation at TOA
- Spatial and temporal resolution: 100 km horizontal resolution, 3-hourly observing cycle
- Stability: 1 Wm^{-2} over five years; 0.2 Wm^{-2}/decade

Requirements for satellite instruments and satellite datasets
FCDR of appropriate radiances, for example through:
- At least one dedicated broadband instrument mission in low Earth orbit at any one time, together with at least one instrument providing spectrally resolved measurements of solar irradiance

- Well-calibrated geostationary multispectral imagery to provide global fields resolving the diurnal cycle

Calibration, validation and data archiving needs
- Because the stability of the instruments employed is often greater than the accuracy of the absolute calibration, it is vital to have overlapping data records from instruments on different satellites in order to create a continuous time series with the highest relative accuracy
- The consistency of global budgets provides gross validation
- An updated and extended archive of BSRN measurements is needed to support and supplement the satellite-based measurements, e.g. with spectral irradiance measurements at the surface

Adequacy/inadequacy of current holdings
Absolute calibration of past multi-satellite data record is inadequate

Immediate action, partnerships and international coordination
- Ensure continuity of satellite data records, and ensure reference to a calibration standard for future satellites. Support processing of past data records to improve adequacy
- Reprocess past data record that extends back to 1985
- Extend BSRN measurements and update archive
- Coordination by GEWEX Radiation panel

Link to GCOS Implementation Plan
[GIP Action A14] Expand the BSRN network to obtain global coverage and establish formal analysis infrastructure.
[GIP Action A24] Ensure continuation of Earth Radiation Budget observations.

Other applications
Validation of NWP models

3.1.7. ECV Ozone

Ozone is the most important radiatively active trace gas in the stratosphere and essentially determines the vertical temperature profile in that region. The ozone layer protects the Earth's surface from harmful levels of UV radiation. Since the 1960s, stratospheric ozone has been monitored *in situ* by wet-chemical ozone sondes, and remotely by ground-based spectrometers. Since the late 1970s and 1980s, ozone has also been monitored by optical and microwave techniques from various satellites and ground-based stations. Ozone has been declining in the upper and lower stratosphere over the last decades, largely due to anthropogenic chlorine.

The following is required for this ECV:

Product A.7 Profile and total column of ozone

Benefits
Products will support monitoring and assessment of:
- the impact of the Montreal Protocol and its amendments on the anthropogenically-induced removal of stratospheric ozone
- the expected radiative influence of ozone on the climate system, and its role in the chemistry of the climate system

Target requirements
- Accuracy: 10% (troposphere), 5% (stratosphere)
- Spatial and temporal resolution: Horizontal: 5-50 km (troposphere), 50-100 km (stratosphere); Vertical: 0.5 km (troposphere), 0.5-3 km (stratosphere); 3-hourly observing cycle everywhere
- Stability: 1% (troposphere), 0.6% (stratosphere)

Requirements for satellite instruments and satellite datasets
FCDR of appropriate UV/VIS and IR/microwave radiances, for example through:
- Nadir UV/VIS instruments for total column and limited profile information

- Nadir IR sounding for profiles from lower troposphere to stratosphere

Supplemented by:
- Limb sounding in IR/MW for profiles from upper troposphere to mesosphere
- Limb sounding in UV/VIS from solar occultation

Fully achieving the target resolutions will require 2 low Earth orbit satellites, ideally in combination with 5 geostationary satellites.

Calibration, validation and data archiving needs
Comprehensive ground, ship-board, aircraft and balloon-borne measurements are required for calibration and validation, for example through:
- the NDACC (Network for the Detection of Atmospheric Change)
- the WMO GAW network of ground-based total column ozone measurements and profile measurements from ozonesondes
- the WMO GAW and NASA/SHADOZ ozonesonde global network
- the MOZAIC/IAGOS commercial aircraft programme

Adequacy/inadequacy of current holdings
- Total column measurements provide largely adequate data record of gross change and fluctuations
- Profile information is of limited resolution and mostly lacking in long-term continuity

Immediate action, partnerships and international coordination
- Reprocessing of identified datasets by improved retrieval algorithms, especially with regard to instrumental biases, including effects of ageing in orbit
- TOMS and (S)BUV provide an established data record from the late 1970s onward. HIRS provides an additional possible long-term record, to be supplemented by present and future data from high-spectral resolution IR sounders. IR data from operational geostationary satellites are also available. Shorter-term data records are provided by instruments such as GOME, MIPAS, OMI, SCIAMACHY and TES
- Reprocessing of occultation datasets, such as from SAGE and HALOE
- In addition to the opportunity for reprocessed products from particular instruments or series of instruments, there is an emerging opportunity for provision of integrated products through data assimilation
- Continuous research and related intermittent observations are necessary to fully understand ozone chemistry in the troposphere and the stratosphere, including precursor trace gases
- Coordination by WCRP SPARC, IGBP IGAC, IGACO Ozone

Link to GCOS Implementation Plan
Activities identified here will contribute to *GIP Actions 25 and 26,* which call for the development and implementation of a plan for a comprehensive system for observing key atmospheric constituents, including their vertical profiles.

Other applications
- Use in NWP and air-quality forecasting
- Monitoring and assessment of UV-B exposure at the surface, with its effects on human health and the biosphere
- Monitoring and assessment of exposure to tropospheric ozone, with further effects on human health and agriculture

3.1.8. ECV Aerosol Properties

[GIP] Atmospheric aerosols are minor constituents of the atmosphere by mass, but a critical component in terms of impacts on climate and especially climate change. Aerosols influence the global radiation balance directly by scattering and absorbing radiation, and indirectly through influencing cloud reflectivity, cloud cover and cloud lifetime. The IPCC has identified anthropogenic aerosols as the most uncertain climate forcing constituent.

The following is required for this ECV:

<u>Product A.8</u> Aerosol optical depth and other aerosol properties

Benefits
- Better aerosol products will lead to a reduction in the uncertainty as to the quantitative role of aerosols in climate forcing identified by the IPCC
- Better products are also needed to validate and improve the capability of climate simulation models and reanalyses to represent aerosol effects

Target requirements (for aerosol optical depth)
- Accuracy: 0.01
- Spatial and temporal resolution: 1 km horizontal resolution, daily observing cycle
- Stability: 0.005/decade

A global aerosol optical depth product would ideally be supplemented by other aerosol properties, such as single-scattering albedo. For the latter, a target accuracy of 0.02, and target stability of 0.015/decade are recommended.

Tropospheric aerosol is highly variable in time and space. Requirements for air-quality applications are hourly measurements with 0.5-100 km horizontal resolution and 1-2 km for vertical resolution.

Requirements for satellite instruments and satellite datasets
FCDR of selected wavelengths in VIS/NIR/SWIR, for example through:
- An operational configuration, extending the current research-based demonstration instruments, comprising primary VIS/NIR/SWIR instruments on two or more low Earth orbit satellites (e.g., equivalent to MODIS), with complementary observations from geostationary satellites

<u>Supplemented by:</u>
- Specialized missions, e.g. with multi-view VIS/NIR/SWIR capabilities
- Research studies of more refined measurement of aerosols, for example with active or polarimetric instruments; these are very important in view of the difficulties of fully interpreting aerosol optical depth as a measure of all aerosol properties, such as single-scattering albedo or phase function. They are also critical to address the need for the sampling of vertical profiles of aerosol properties at regular time intervals

Calibration, validation and data archiving needs
Satellite measurements of back-scattered solar radiation require very accurate calibration. Comprehensive ground-based independent validation measurements are required. These can be provided by existing networks or extensions of the NDACC and GAW networks, the NASA AERONET observations and other lidar networks, with quality assurance coordinated by WMO GAW.

Adequacy/inadequacy of current holdings
- Long-term holdings are limited by the capability of the instruments deployed, and there is a lack of integrated products from the many recent instruments, which have a capability for aerosol parameter measurements
- No operational aerosol instruments measuring particle composition and size/shape (phase function) have been flown to date

Immediate action, partnerships and international coordination
- Long-term datasets are available from SAGE (from 1979), TOMS (from 1979) and AVHRR (from 1981); MODIS has provided measurements from one satellite since 2000 and from two since 2002, with derived products available from both; MERIS has also taken measurements since 2002. Aerosol data are also available for earlier or shorter periods from the MISR, POLDER, ATSR-2, AATSR, PARASOL and SCIAMACHY instruments in low Earth orbit, and from operational imagers in geostationary orbit
- Reprocessing of: full AVHRR dataset with respect to total column aerosol optical depth over the sea; full GOES dataset with respect to aerosol optical properties; full (A)ATSR dataset

- The opportunity exists for the formation of composite products from current observations, with some extension back in time using calibrated data from the long-term instruments
- There is an emerging opportunity to provide products through data assimilation
- Lidar capability can be explored with data from GLAS and from planned missions such as ADM/Aeolus
- Other instrument data records can improve the AVHRR record and extend it over land
- Coordination by WCRP SPARC, IGBP IGAC, WMO GAW

Link to GCOS Implementation Plan
[GIP Action A31] Develop and implement a coordinated strategy to monitor and analyze the distribution of aerosols and aerosol properties.
[GIP Actions 25 and 26] call for development and implementation of a comprehensive plan for consistent measurement of atmospheric composition based on a combination of satellite and other observing systems.

Other applications
- Air quality forecasting, in particular the effect of anthropogenic particulate matter smaller than 2.5 μm (PM2.5) on human health
- Future benefit to NWP
- Improve understanding of the role of aerosols in cloud chemistry, gas-to-particle reactions and precipitation processes
- Monitor aerosol impact on stratospheric ozone layer chemistry

3.1.9. ECV Carbon Dioxide, Methane and other Greenhouse Gases

Carbon dioxide is the most important of the greenhouse gases emitted by anthropogenic activities. The atmospheric build-up is caused mostly by the combustion of coal, oil, and natural gas, and reflects to a significant extent the cumulative anthropogenic emissions, rather than the current rate of emissions, due to its very long lifetime (up to thousands of years) in the atmosphere-ocean-terrestrial biosphere system.

Methane (CH_4) is the second most significant greenhouse gas, and its level has been increasing since the beginning of the 19th century. In addition to methane, other long-lived greenhouse gases (GHGs) include nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs). The current direct radiative forcing from CH_4 is 20% of the total from all of the long-lived and globally-mixed greenhouse gases, and the other trace gases contribute another 20% of the changes in climate forcing since the start of the industrial revolution (IPCC, 2001). The Kyoto Protocol of the UN Climate Convention includes future restrictions on the release of GHGs, including CO_2, CH_4, N_2O, HFCs, SF_6, and PFCs. The Montreal Protocol on Substances that Deplete the Ozone Layer includes mandatory restrictions on the production and consumption of those CFCs and HCFCs that are also GHGs for individual countries. Trace gas measurements are vital to international and national regulatory agencies, climate models, and scientists interested in atmospheric chemistry and transport.

The following is needed for these ECVs:

<u>Product A.9</u> Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks

Benefits
- Data products will allow monitoring of the spatial distribution and change over time of the key greenhouse gases
- Stabilization of the concentrations of these gases at a level that would prevent dangerous anthropogenic interference with the climate system is the ultimate objective of the UNFCCC
- Data products of sufficient accuracy would allow estimates of regional emissions, such as those related to wetlands and rice fields, land-use change and missing-sink processes
- Improved detection of global mean and meridional concentrations, as well as deduction of carbon sources and sinks on a regional or continental scale

- Satellite-based observations of total column values and vertical profiles of the mixing ratio of carbon dioxide, methane and nitrous oxide, when coupled with reanalysis, may provide a capability for monitoring of sources and sinks of greenhouse gases, especially CO_2 and CH_4

Target requirements
Research use and demonstration of currently available measurements in reanalysis is needed to provide a clear statement of essential data needs, in particular on the extent of needed detail to vertical sounding. Initial estimates are based on resolving the values of observed column fluctuations. Time scales that extend from the diurnal through the synoptic, monthly, seasonal, yearly to the decadal need to be resolved, to allow for a complete description of the processes determining the distribution of these atmospheric species. Spatial variability can be substantial in the planetary boundary layer, reflecting the variability of sources and sinks. Products can be useful for monitoring and source-sink inversion even without resolving the shortest space and time scales.

- Accuracy: CO_2: 3 ppm; CH_4: 20 ppb
- Spatial and temporal resolution: CO_2, CH_4: from 10-250 km horizontal resolution from troposphere to stratosphere; 3-hourly observing cycle
- Stability: CO_2: 3 ppm (climate forcing) and 1 ppm (sources and sinks)

Requirements for satellite instruments and satellite datasets
A research study is needed to establish the minimum needs for monitoring sources and sinks of these gases. At this stage note is made of immediate data needs.

FCDR of appropriate NIR/IR radiances, for example through:
- High spectral resolution IR sounding for the upper troposphere and stratosphere, as provided initially by AIRS and IASI
- Limb-sounding in IR and MW for distributions from upper troposphere to mesosphere
- Active NIR systems to obtain tropospheric vertical profiles
- Passive NIR operational missions for CO_2 and CH_4, building on the experience with SCIAMACHY, and the specialized missions GOSAT and OCO. Simultaneous total column CO, such as provided by SCIAMACHY, adds much value for CO_2 source characterization

Calibration, validation and data archiving needs
- The required comprehensive independent ground-based validation measurements can be provided by the WMO GAW Global CO_2 and CH_4 Monitoring Networks (both GCOS Comprehensive Networks), including ship and dedicated light aircraft profiles up to 8 km.
- A baseline network of surface-based total column CO_2 and CH_4 instruments, continued routine commercial aircraft observations, and observations planned by IAGOS/MOZAIC, are needed for validation of products

Adequacy/inadequacy of current holdings
- Satellite data are available for only recent years, and provision of products is a developmental activity
- An adequate measure of global values of these long-lived gases can be obtained from *in situ* data

Immediate action, partnerships and international coordination
- Support for the generation of products through retrieval or, in appropriate cases, data assimilation
- Execution of planned missions and development and implementation of a plan for sustained operational measurements sufficient to deliver products of the required accuracy
- Support for the surface and free-tropospheric measurements needed for calibration and validation.
- Products may be derived from AIRS and SCIAMACHY from 2002 onwards
- Limb-sounding data for retrieval of stratospheric profiles from current instruments include those from HIRDLS (CH_4, N_2O), MIPAS (CH_4, N_2O) and MLS (N_2O)
- TES provides additional data for the retrieval of tropospheric CH_4
- Research towards improved future capabilities, including long-term monitoring of CO_2, CH_4 and other GHG, such as N_2O
- Coordination by WCRP SPARC, IGBP IGAC

Link to GCOS Implementation Plan
[GIP Action A25] Establish a plan for and implement a consistent surface- and satellite-based global observing system for the atmospheric composition ECVs, based on common standards and procedures, and encourage data submission to WDCs.
[GIP Action A26] Develop and implement a comprehensive plan to observe the vertical profiles of GHGs, ozone and aerosols utilizing commercial and research aircraft, pilotless aircraft, balloon systems, kites, ground-based lidars and satellites.
[GIP Action A27] Establish the GCOS/GAW baseline network for CO_2 and CH_4, and fill the gaps.

Other applications
Carbon dioxide fields may allow improved extraction of the temperature information from IR sounders for NWP and reanalysis

3.1.10. ECV Upper-air Wind

Upper-air wind speed and direction is a basic element of the climate system that influences many other variables. It is designated an Essential Climate Variable, but one for which no specific action other than engagement via reanalysis is identified in the GCOS Implementation Plan. Here, attention is given to the provision of FCDRs and products needed to support future improvements in atmospheric reanalysis (see A.11).

The following is required:

Product A.10 Upper-air wind analyses, particularly from reanalysis

Benefits
Monitoring fluxes of heat, momentum, moisture and other variables within the climate system, including the long-range transport of pollutants.

Target requirements
Being data records for reanalysis, accuracy requirements for upper-air wind need to be set in conjunction with the experience gained at reanalysis centres. Values given here are merely indicative.

- Accuracy: 2 m/s
- Spatial and temporal resolution: 100 km horizontal resolution, typically 0.5 km vertical; 3-hourly observing cycle
- Stability: 2 m/s

Requirements for satellite instruments and satellite datasets
FCDR of appropriate VIS/IR imagery from geostationary satellites, to enable winds (Atmospheric Motion Vectors – AMVs) to be derived from successive images, with capability for reprocessing as wind-derivation techniques improve

FCDR of appropriate VIS/IR imagery from low Earth orbit satellites, to enable AMVs to be derived from successive, overlapping swaths from at least one, preferably two satellites, with capability for reprocessing as wind-derivation techniques improve

FCDR from Doppler wind lidars, for example through:

- Demonstration data records from the ESA ADM/Aeolus mission
- Data from Doppler wind lidar instruments flown on an operational basis, subject to successful demonstration of ESA ADM/Aeolus

Calibration, validation and data archiving needs
Validation opportunities are provided by collocated radiosonde and aircraft data, and by data assimilation feedback statistics.

Adequacy/inadequacy of current holdings

- Improvements in AMV processing, such as reduction in wind-speed biases, have introduced spurious trends in operational products. Reprocessing is needed to eliminate these

- Meteosat and GMS data have been reprocessed for ERA and JRA reanalyses, but data from other platforms, notably GOES, have not been similarly reprocessed
- The MODIS polar AMV data record is incomplete

Immediate action, partnerships and international coordination
- Reprocessing of AMV products from geostationary and low Earth orbits should be done by the agencies responsible for near-real-time AMV production. The case for repeated reprocessing in the future will depend on the extent of future improvements in AMV production techniques, and the extent to which these improvements are applicable to data from older instruments
- Reprocessing of GOES data records, to supplement the initial reprocessing of data from the series of Meteosat and GMS satellites. Temporal coverage should start from as early a date as possible and stop when data quality does not improve significantly upon that produced in near-real-time operations
- Reprocessing of wind products from MODIS for the lifetimes of the TERRA/AQUA instruments
- Investigation of the utility of AVHRR polar winds (since 1980) for reanalysis
- Assessment of the impact of ADM/Aeolus, and preparation for operational follow-on
- Research towards improved measurement capabilities
- Coordination by CGMS/IWWG

Link to GCOS Implementation Plan
Section 4.2.2

Other applications
- Use of new data sources in data assimilation for NWP
- The reprocessing chain for AMV production may enable production of other climate data products or data for reanalysis from geostationary satellite systems (clear-sky water vapour radiances, ocean and terrestrial products).

3.1.11. Atmospheric Reanalysis

Atmospheric reanalysis combines a wide range of *in situ* and satellite data measured over time to form optimal analyses of all dynamically-related atmospheric variables for which measurements are available. For any instant of time, reanalysis techniques utilise observations from the immediate past and future to determine the current analysis. As a technique, its use is implied in many of the atmospheric products noted in this document. Reanalysis makes use of all datasets that provide useful information, usually a combination of FCDRs and products derived from satellite observations. The quality of reanalysis products is strongly influenced by the quality of these datasets. For climate analyses, this means that a significant number of the datasets need to be consistent over long periods of time, ideally over decades, to ensure homogeneous reanalysis products as a result. These datasets should include FCDRs provided in good accord with the GCMPs, and products derived with the latest scientific approach applied consistently over the whole data record.

Reanalysis can in principle make use of most of the FCDRs and some of the products identified in this document, encompassing the atmosphere, ocean and terrestrial domains. Many of these datasets have been specified primarily because of other applications, but a number of FCDRs and products specifically for use in reanalysis are identified in Products A.1, A.2 and A.10.

The following is required:

<u>Product A.11</u> Atmospheric reanalyses, supported by key FCDRs and products identified in this report, and other data of value to the analyses

Benefits
- Widespread availability of sets of comprehensive integrated climate products that should provide the most comprehensive view of climate change in the full 3-D atmospheric system
- Creation of many products addressing atmospheric ECVs

Target requirements
Requirements are stated in other sections for specific FCDRs and products

Requirements for satellite instruments and satellite datasets
- Relevant improved FCDRs and products identified in this document should be made available to reanalysis centres by the data providers
- Reanalysis centres should be partners in these activities through the provision of comprehensive information on known deficiencies in earlier datasets (including, e.g., metadata, processing algorithms, radiative transfer codes), through identification of the relevant datasets and through evaluation of trial versions of new datasets

Calibration, validation and data archiving needs
- Data need to be stored and maintained in standard modern formats, with quality indicators as appropriate
- Calibration and validation information will be provided by feedback from using the data in reanalysis systems

Adequacy/inadequacy of current holdings
- Inadequacies in input data and in NWP-based data assimilation systems limit the reliability of trends, low frequency variability, and hydrological and other budgets derived from existing reanalysis products
- Many of the comments on adequacy made for the other atmospheric products identified in this document apply also to the related FCDRs or derived products needed for input to new reanalyses
- Past reanalysis efforts have resulted in identification of specific data deficiencies, for example in the TOVS datasets, that are a key input to both reanalysis and the production of many of the other atmospheric products

Immediate action, partnerships and international coordination
- Most immediate opportunities for action are as identified for the specific FCDRs and products given elsewhere in this report. The first round of actions needs to be completed by 2009, for the improved datasets to be available for use in the next generation of reanalyses
- A further opportunity is for use of quality-monitoring and analysis-feedback results from recent reanalyses, to assist the production of improved FCDRs and products
- Coordination by CGMS/IWWG, WCRP/WOAP, GCOS/AOPC and the expert groups identified for each set of FCDRs and products

Link to GCOS Implementation Plan
The important need for improved international coordination of reanalysis is emphasized in the GCOS Implementation Plan (Key Actions 23 and 24, and Action C13). See also cross-cutting needs C.4 and C.5.

Other applications
- Improved reanalyses will provide data for improved testing and calibration of medium-range, monthly and seasonal forecasting systems

3.2. OCEANS

The following sections provide details of the required products and datasets primarily derived from satellites in the ocean domain:

3.2.1. ECV Sea Ice

[GIP] Sea-ice variability is a key indicator of climate variability and change, and there are a number of parameters characterizing it.
Sea ice extent and concentration play a major role in ice albedo feedback, energy and moisture fluxes between the ocean and atmosphere, and in the temperature and salinity of high-latitude oceans. Ice volume is an important component of high-latitude heat and is needed to characterise the seasonal to interannual variability in freshwater export (in the form of sea ice) from the polar oceans. Ice volume estimates require estimates of ice thickness in combination with ice concentrations. Ice motion can be determined from drifting buoys and can be mapped using visible, passive and active microwave data. All this information is important for modelling sea ice and validating coupled ocean-atmosphere GCMs. Sea-ice concentrations by ice type are determined by operational agencies. They can be used to provide rough estimates of ice volume.

The following is required for this ECV:

Product O.1 Sea-ice concentration

Benefits
- Long-term sea-ice climate data record represents a fundamental indicator of high-latitude climate change
- Information on sea-ice concentration, extent, volume and spatio-temporal variation is required to assess impact on climate forcing, ocean-atmosphere fluxes and the global thermohaline circulation

Target requirements (for sea-ice concentration):
- Accuracy: 5%
- Spatial and temporal resolution: 12 km horizontal resolution, daily observing cycle
- Stability: 5%/decade

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate microwave imagery and visible imagery, for example through:
- Sustaining existing and planned passive microwave and VIS/IR instruments (DMSP SSM/I-class series of multi-frequency, dual polarisation microwave radiometer instruments, with AMSR on GCOM-W in 2009/10 and CMIS on NPOESS C-2 in approximately 2011; SSMI/S)
- Consolidation of existing sea-ice products (1978 – present), given the broad range of algorithms being applied to microwave brightness temperatures for derivation of sea-ice extent and concentration

Supplemented by:
Measurements of sea-ice thickness, drift, surface temperature from research missions and other operational missions, for example through:
- CryoSat2 recovery action, for the development of an all-weather ice thickness derivation capability
- Consideration of operationalization of the sea-ice thickness measurement as a high-priority requirement for GMES Sentinel-3 altimetry
- IceSat follow-on mission, to supplement the data delivered by an all-weather SAR altimeter of the CryoSat SIRAL instrument class
- To assess ice volume and freshwater (i.e., advective) flux, supplemental measurements are needed to derive a global SAR-derived ice-drift data record, in conjunction with altimetry-derived ice thickness

Calibration, validation and data archiving needs
- Rigorous validation of sea-ice products
- Inter-sensor calibration to ensure uniform data records

Adequacy/inadequacy of current holdings
Sea-ice concentration is the only sea-ice product that can be derived uniformly over the existing 25-year data record. It needs to be accompanied by the comparison and verification of data records derived from different algorithms, to provide sufficient information on uncertainties.

Immediate action, partnerships and international coordination
- Obtain estimates of uncertainties in sea-ice concentration retrievals, together with accompanying quality control information, to facilitate assimilation in models
- Consistent polar sea-ice drift data records should be developed from the combination of Global Synthetic Aperture Radar (Envisat ASAR), passive microwave (SSM/I; AMSR, CMIS) and radar scatterometer (QuikScat, METOP) datasets, accompanied by uncertainty estimates, provided by intercomparison with WCRP IBAP (Arctic) and IPAB (Antarctic) buoy data
- Quantify the degree to which the above points impact the ability to derive accurate and unbiased seasonal cycles in sea-ice thickness
- Further opportunities exist for combining *in situ* data records from Upward Looking Sonars, together with the satellite-derived values of thickness and coverage, so as to quantify estimates of volume and mass variability and fluxes. Similar opportunities exist to combine high-resolution VIS/IR image data, SAR and passive microwave data to reduce uncertainties caused by short-term weather-driven snow emissivity variations and summer season meltwater ponding.
- Coordination by WCRP CliC, IGOS Cryosphere, CEOS WGCV, GCOS OOPC Sea-ice and surface temperature expert group

Link to GCOS Implementation Plan
[GIP Action O23] Ensure sustained satellite (microwave, SAR, visible and IR) operations: improve the *in situ* observations from sea-ice buoys, visual surveys (SOOP and Aircraft), and ULS. Implement observations in the Arctic and Antarctic.
[GIP Action O24] Promote development of integrated analysis products and reanalysis using historical data archives.

Other applications
- Operational ice forecasting services supporting ship routing, offshore oil/gas operations, and polar logistics.
- Use in NWP data assimilation

3.2.2. ECV Sea Level

Sea-level rise, including the changing frequency and intensity of extreme events, is one of the main impacts of anthropogenic climate change, and is particularly important to all low-lying land regions, including many small-island states. Changes in sea level are a significant parameter in the detection of climate change and an indicator of our ability to model the climate system adequately. Sea level is also an indicator of ocean circulation and is an important component in initializing ocean models for seasonal-to-interannual and possibly decadal climate prediction.

The following is required for this ECV:

Product O.2 Sea level and variability of its global mean

Benefits
- Estimates of state of the global ocean
- Evaluation of skill of climate change projections
- Critical information to coastal communities

Target requirements
- Accuracy: 1 cm
- Spatial and temporal resolution: 25 km horizontal resolution, daily observing cycle
- Stability: 0.5 mm/decade

Requirements for satellite instruments and satellite datasets
FCDR of appropriate satellite altimetry, for example through:

- One high-precision altimeter operating at all times, with planned extensive overlaps between successive missions, and two lower-precision but high-resolution altimeters to provide needed sampling. (GIP Action O12)
- Precision altimetry, started by TOPEX (launched August 1992, ended October 2005) and continued by Jason (launched December 2001, currently in service), and then to be followed by the Ocean Surface Topography Mission (Jason-2, launch mid-2008); requires urgently the establishment of an ongoing series of follow-on missions in the same orbit
- Planning for launch of lower-precision altimetry missions for necessary coverage and real-time applications, such as Envisat or the Geosat follow-on missions

Calibration, validation and data archiving needs

- Jason and Envisat-class mission continuity is necessary
- Ancillary systems, such as tide gauges, calibration sites, precision orbit determination, path length corrections, including best estimates of the marine geoid, must also be considered part of these missions
- Complete reprocessing of altimetry data on a regular basis is a necessary climate system function because continuous improvement in orbit determination and tidal models provide improvements to the entire data record length

Adequacy/inadequacy of current holdings
Satellite altimetry, supplemented with tide gauges, has proved adequate to revolutionize the view of global sea-level variability. Current analysis efforts should be maintained and strengthened.

Immediate action, partnerships and international coordination
Continue the precision altimetry satellite time series through 2020. This is an opportunity to provide the data to unambiguously determine if global sea-level rise is accelerating. The present >13-year satellite data record, when compared with 20th century tide-gauge data and ice/land data records, suggest that the rate of sea-level rise may have doubled in the most recent decade.

Link to GCOS Implementation Plan
[GIP Action O12] Ensure continuous coverage from one high-precision altimeter and two lower-precision but higher-resolution altimeters.

Other applications

- Ocean surface topography data provide the core data that enable ocean state estimates from global ocean data assimilation activities
- Critical information to coastal communities

3.2.3. ECV Sea Surface Temperature

Together with air temperature over land, sea-surface temperature (SST) is a fundamental indicator of the state of the climate system on all time scales. It is also critical for weather forecasting under certain conditions. In warm-water regions (T>26°C), SST appears to be a strong and sensitive factor for the formation of tropical cyclones, and (T>28°C) for coral-reef bleaching. SST is also important for operational oceanography, for the estimation of net air-sea flux of carbon, and many other marine applications.

While noting the modern perspective that there are three distinct sea-‘surface’ temperatures (the traditional *in situ* ‘bulk’ SST, the ‘sub-skin’ SST and ‘skin’ SST), the climate “SST” data record has been based upon *in situ* (‘bulk’) and IR ‘skin’ SST observations blended together. Climate-quality blended analyses that make use of *in situ*, IR and microwave observations will be needed to meet GCOS ‘bulk’ SST requirements.

The following is required for this ECV:

Product O.3 Sea-surface temperature

Benefits
- Fundamental indicator for the state of the climate system
- Input parameter for seasonal-to-interannual climate forecasting

Target requirements
Known patterns of interannual and longer-term climate variability have amplitudes of several degrees C over basin scales. Coastal variability has comparable or larger amplitudes and occurs on scales as small as 1 km over multi-day periods. The diurnal cycle can be of comparable magnitude under certain conditions and can be aliased into lower frequencies if not sampled properly. Global-average warming trends are estimated to be about 0.5°C over 100 years.

- Accuracy: 0.25°C
- Spatial and temporal resolution: 1 km horizontal resolution, 3-hourly observing cycle
- Stability: 0.1°C

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate IR and microwave imagery, for example through:
- Sustained IR and microwave sensors, capable of supporting climate accuracy global SST analyses.
- AATSR-class capability for high-accuracy and high temporal stability observations, which can tie together general SST coverage by low Earth orbit and geostationary instruments in the IR and microwave, to provide for an all-weather diurnal and high spatial resolution capability

Calibration, validation and data archiving needs
- Work needs to continue on the use of *in situ* observations for product calibration and validation, as well as for cloud and aerosol characterization. Comparison of products from independent analyses remains a priority
- Expand *in situ* network of appropriate shipborne surface-viewing radiometers for calibration

Adequacy/inadequacy of current holdings
There are opportunities for additional reprocessing of AVHRR, and improved access to (A)ATSR data.

Immediate action, partnerships and international coordination
- Immediate action is needed to sustain the quality of the satellite-era SST data record
- Sustain the *in situ* observing system described in the GIP, namely sustain the global array of surface drifting buoys, Volunteer Observing Ships (and the VOSClim subset of them) and time series mooring sites (tropical moored arrays and OceanSites reference array)
- Continue reprocessing of satellite data for providing a homogeneous global SST climate data record, in particular from AVHRR and the (A)ATSR series, from 1991 to 2010
- Maintain both the high frequency observations sufficient to resolve diurnal variability, provided at present by geostationary instruments, together with more limited coverage AATSR-class capability
- Support national participation in GCOS SST/Sea Ice Working Group and SST activities recommended by WOAP

Link to GCOS Implementation Plan
[GIP Action O9] Ensure a continuous mix of polar orbiting and geostationary IR measurements combined with passive microwave coverage. To link with the comprehensive *in situ* networks noted in O10.
[GIP Action O10] Obtain global coverage, via an enhanced drifting buoy array (total array of 1250 drifting buoys equipped with atmospheric pressure sensors as well as ocean temperature sensors), a complete Tropical Moored Buoy network (~120 moorings) and the improved VOSClim ship fleet.

Other applications
Operational oceanography, weather forecasting (including tropical cyclones), fisheries management, human health, transport of invasive species, ecosystem dynamics, recreational opportunities, hazardous material spill impacts, the net air-sea flux of carbon, and other marine applications.

3.2.4. ECV Ocean Colour

Ocean colour is the normalised water-leaving radiance or reflectance in the visible spectrum, as measured by a satellite instrument. Chlorophyll-a concentration, which can be calculated from ocean-colour data, is a measure of phytoplankton biomass: it is the fundamental basis of biological production in the oceans. Chlorophyll-a is a critical parameter to characterize the ecosystem and as such represents essential information for natural living-resource management and monitoring of the health of coastal seas. At a global level, chlorophyll-a relates to cycling of carbon between the ocean and atmosphere. Ocean colour data also have broader application for climate monitoring than just the calculation of chlorophyll-a, e.g., for calculating ocean particulate carbon and other emerging marine products.

The following is required for this ECV:

Product O.4 Ocean colour, and oceanic chlorophyll-a concentration derived from ocean colour

Benefits
- Climate monitoring
- Chlorophyll-a linked to carbon-cycling, including between the ocean and the atmosphere
- Ocean particulate carbon estimated from ocean colour

Target requirements (for ocean colour)
- Accuracy: 5%
- Spatial and temporal resolution: 1 km horizontal resolution, daily observing cycle
- Stability: 1%/decade

Requirements for satellite instruments and satellite datasets
FCDR of appropriate multispectral VIS imagery, for example through:
- Extension of current provision of MODIS and MERIS-class, followed by development of a strategy based on advances beyond MODIS, MERIS and SeaWiFS-class capabilities

Adequacy/inadequacy of current holdings
There is no current consolidation of a global FCDR based on existing data from SeaWiFS, MODIS and MERIS, and activities to address this need and to derive products should be encouraged

Calibration, validation and data archiving needs
- Improved access to ocean colour data is required
- Improve the network of *in situ* measurements for calibration purposes

Immediate action, partnerships and international coordination
- Coordination through user groups of ocean-colour data, such as IOCCG, IOCCP, CASIX, CARBOOCEAN and GLOBCOLOUR
- Research should continue in the development of new products, making use of water-leaving radiances
- Research should continue in assimilation of ocean-colour products into ocean climate models, in order to improve carbon-cycle products, such as pCO_2 and air-sea CO_2 fluxes

Link to GCOS Implementation Plan
[GIP Action O18] Implement plans for a sustained and continuous deployment of ocean colour satellite sensors together with research and analysis.

Other applications
- Essential information for natural living-resource management
- Monitoring of the health of coastal seas

3.2.5. ECV Sea State

Sea-state governs air-sea fluxes of momentum, heat, water vapour and gas transfer, as well as being of high societal relevance in terms of safety at sea and coastal impact (e.g., extreme events). Despite its fundamental significance, there is presently no coordinated, sustained effort to deliver global, high-quality sea-state information for climate. Present best estimates are provided via NWP model analysis and reanalysis systems, making best use of sparse along-track significant wave height measurements made by existing conventional altimeters, spectral band-limited directional wave measurements by Synthetic Aperture Radars, and point measurements from the network of moored buoys. Sea-state is, however, a complex variable, and an exact strategy for monitoring particular aspects of sea state has yet to be established.

The following is required for this ECV:

Product O.5 Wave height and other measures of sea state (wave direction, wavelength, time period)

Benefits
- Required input parameters to ocean-atmosphere coupling schemes of climate models
- Sea state is fundamental to the corrections required to derive climate-quality sea-surface topography. As such, it is an essential by-product of the spaceborne contribution to sea-level derivation

Target requirements
Noting that the end products are derived from NWP or reanalysis, the requirements here relate to FCDRs for use in data assimilation into these systems. Statements of requirements for spatial and temporal resolution need to be developed in collaboration with these activities.

In addition, the use of sea-state information in ocean-atmosphere coupling schemes that are used in climate models is still an evolving area of research. For this reason, there are presently no well-specified requirements concerning the desired magnitude of decadal variation or the spatial scales that will need to be resolved over the full spectrum. Existing statistics from records of change in significant wave height (SWH) can initially be used to provide indicative requirements for stability.

For significant wave height, target requirements are:
- Accuracy: 10 cm
- Spatial and temporal resolution: 25 km horizontal resolution, with higher resolution needs in coastal regions, 3-hourly observing cycle
- Stability: 5 cm/decade

Wave direction and spectrum are also significant parameters, but more work is needed to specify requirements.

Requirements for satellite instruments and satellite datasets
FCDR of appropriate altimetry, ideally complemented with SAR measurements, for example through a strategy for continuing the current data records of those measurements.

Adequacy/inadequacy of current holdings
- Accuracy of the present NWP estimates is known to vary considerably geographically, as well as being of limited utility in shallower coastal regions. Knowledge of the uncertainties is limited as a function of both the availability of calibration and validation data, and the geographic distribution of reference datasets
- Reanalyses currently underestimate extreme sea states due to their limited horizontal resolution, but statistical corrections have been developed making use of altimetric wave-height data
- The altimeters on board of past, present and planned missions only provide the integrated wave energy, while the SAR data estimate the spectral properties of the ocean waves. However, the SAR has the disadvantage of a strongly distorted image spectrum, caused by the motion of the ocean surface, thereby resulting in a minimum detectable wavelength of about 150-200 m
- Sea-state data records exist from ERS-1, ERS-2, TOPEX/POSEIDON, ERS-2, ENVISAT, Geosat, GFO and Jason-1, but homogenisation is needed if data records from different instruments are to be used together

Calibration, validation and data archiving needs
- It is of the utmost importance to have and maintain a high-quality buoy network for calibration and validation purposes
- It is desirable that data be archived in a common format, such as the BUFR format in which they are ingested into NWP analysis/reanalysis systems

Immediate action, partnerships and international coordination
- Reprocessing and promotion of use of existing sea-state data records, such as from ERS, Envisat, and Jason
- Efforts to make comprehensive use of planned altimeter and SAR bearing satellites, in order to ensure the continuity of the existing sea-state information, and to build on the existing altimeter and SAR-based decade-long satellite data records
- New SAR altimeter (Sentinel-3) and swath-altimeter technologies (WSOA) will allow advances in near-shore SWH measurement, and their combination with global SAR wave spectral estimates, will allow more effective coastal zone retrievals of sea-state. Conventional polar-orbiting altimeters are presently unable to make effective sea-state retrievals in near-shore regions

Link to GCOS Implementation Plan
[GIP Action O19] Implement a wave measurement component as part of the Surface Reference Mooring Network.

Other applications
- Near-real-time (<3hr) altimetric sea-state information is presently delivered routinely to operational oceanography users (comprising navies and ocean forecast modellers)
- Near-real-time altimetric and SAR data are used in operational NWP, using coupled atmosphere/ocean-wave models

3.2.6. Ocean Salinity

Sea-surface salinity (SSS) is emerging as a new research product from satellite measurements of ocean brightness temperature at L-band (microwave) frequencies. This measurement is important for a number of reasons: in the oceans, sea-surface salinity and sea-surface temperature control the density and stability of surface water. Thus, ocean mixing (of heat and gases) and water-mass formation processes are intimately related to variations of surface salinity. Ocean modelling and analysis of water-mass ventilation should be enabled by new knowledge of surface-density fields, which are again enabled by knowledge of surface salinity. The importance of the ocean in the global hydrological cycle also cannot be overstated. Some ocean models show that sufficient surface freshening results in slowing down the meridional overturning circulation and thereby affecting the meridional oceanic transport of heat. The monitoring of surface salinity from space, combined with the provision of regular surface and sub-surface salinity profiles from *in situ* observing systems, such as surface ships and buoys, and the Argo array, provide a key constraint on the balance of freshwater input over the ocean. This allows for better determination of the marine aspects of the planetary hydrological cycle and the possibility of important ocean circulation changes.

The following is required for this ECV:

Product O.6 Research towards the measurement of changes in sea-surface salinity

Benefits
The importance of the sea-surface salinity field has been demonstrated in the prediction of El Niño (because of the changes in salinity in the West Pacific Warm Pool region) as well as the climate of the high-latitude North Atlantic (with respect to the Great Salinity Anomaly and possible implication in the strength of the Atlantic Meridional Overturning Circulation), and by improving estimates of precipitation over the ocean.

Target requirements
- Accuracy: 0.05 psu

- Spatial and temporal resolution: 100 km horizontal resolution, weekly observing cycle
- Stability: 0.05 psu/decade

Requirements for satellite instruments and satellite datasets
- Research satellite missions (e.g., SMOS and Aquarius/SAC-D) should be supported to enable development and demonstration of sea-surface salinity measurements from space
- Consistent with demonstrated levels of accuracy, an optimal balance of *in situ* and satellite instruments should be sustained in the future (e.g., an integrated sea-surface salinity observing and analysis system)

Calibration, validation and data archiving needs
Sea-surface salinity will be calibrated primarily using surface-salinity measurements obtained from the installation of sensors on surface drifters, salinity profiles from Argo floats, and thermosalinograph measurements from ships. Production of salinity requires a simultaneous estimate of sea-surface temperature and surface roughness.

Immediate action, partnerships, and international coordination
- Coordination by science teams for SMOS (ESA) and Aquarius/SAC-D (NASA/CONAE)
- Salinity Working Group under WCRP

Link to GCOS Implementation Plan
[GIP Action O15] Develop a robust programme to observe SSS, including surface ships and buoys.

Other applications
Hydrological studies

3.2.7. Ocean Reanalysis

Ocean reanalyses of the 4D ocean circulation, including biogeochemical and ecosystem variables, will be necessary to provide dynamically-constrained syntheses of ocean temperature, salinity, current and sea-level variability and change, and to explore their relationships with ecosystem and biogeochemical variability and change. Ocean reanalysis is in its infancy, and the primary requirements now are that it be supported, that the results be evaluated by its various user communities, and that plans for both evaluation and future reanalyses be coordinated internationally.

Ocean reanalysis is being done on two different space/time scales. The first is the ‘operational oceanography’ space/time scale of a few kilometres/few hours. The GODAE pilot project provides international coordination of these products. The second is the ‘ocean state estimation’ space/time scale of about 100 km/few days at present. The WCRP WOAP and CLIVAR GSOP provide coordination of these efforts. Some groups (e.g., CASIX) are developing biogeochemical ocean model analysis and reanalysis products using assimilation of ocean colour and derived variables. These are used to produce fields of primary production and air-sea CO_2 fluxes. IOCCG and IOCCP have an overview of these biogeochemical reanalysis activities. In any case, it is imperative that at least two independently-produced analyses are available for each space/time scale.

The noted ocean surface variables derived from satellites are vital elements for ocean reanalysis. Sub-surface measurements are of insufficient resolution to define most ocean eddies, and any construction or de-aliasing of these eddies depends on the detection of their surface characteristics.

The following is required:

Product O.7 Ocean reanalyses utilizing altimeter and ocean surface satellite measurements, supported by key FCDRs and products identified in this report, and other data of value to the analyses

Benefits
- Dynamically-constrained syntheses of ocean temperature, salinity, current and sea-level variability and change

- Explore the relationship of these parameters with ecosystem and biogeochemical variability and change

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate altimetry and ocean-surface measurements consistent with those designated in this report.

Space agencies need to enable the provision of homogeneous datasets, with associated uncertainty estimates, to reanalysis centres.

Adequacy/inadequacy of current holdings
See individual ECVs for details.

Calibration, validation and data archiving needs
See individual ECVs for details. Uncertainty estimates are essential.

Immediate action, partnerships and international coordination
- Ensure progress on reprocessing and ensure data availability
- International planning and coordination required, as current reanalysis is only done in an ad-hoc fashion

Link to GCOS Implementation Plan
Cross-cutting actions C11, C12 and C13, as they pertain to ocean and coupled reanalysis

Other applications
- Development of climate information products and regional products
- Assist in interpretation of individual ECV analyses

3.3. TERRESTRIAL

The following sections provide details of the required products primarily derived from satellites for the terrestrial domain.

An overarching issue in this section concerns the lack of standards for many of the terrestrial observation types. The GCOS Implementation Plan (Action T1) calls for the establishment of mechanisms to develop these standards. One component of these mechanisms needs to engage the issue of standards for the *in situ* data used in the calibration and validation of terrestrial products that are based on satellite data. At the same time, the algorithms and approaches used in deriving terrestrial products from satellite observations are highly variable. While it is essential to maintain independent analyses of the terrestrial variables, it is vital that the use of intercomparisons and collaboration leads to progressive improvements.

A key action for the terrestrial domain as a whole will be to ensure that institutional arrangements exist to coordinate activities related to the generation of satellite products. Space agencies may wish to consider contributing to such institutional arrangements.

3.3.1. ECV Lakes

Large open lakes have a regional impact on climate through albedo and evaporation. In some regions (e.g., the semi-arid interior of Australia or the Great Basin of the USA) highly-ephemeral lakes provide a data record of extreme events and also have potential feedback effect on regional climate. Closed-basin lakes are more sensitive to changes in regional water balance and therefore better sensors of changes in regional climate. The Global Terrestrial Network for Lakes (GTN-L) focuses on the largest lakes, primarily closed-basin lakes that include major ephemeral lakes, and a selection of the largest open lakes. The GTN-L will evolve during implementation, taking into account other lakes indicative of climate change, including non-permanent water bodies, such as the seasonal lakes appearing with the onset of the rainy seasons throughout the tropics. Although of undoubted importance in terms of determining terrestrial water storage, fluctuations of the area and level of reservoirs are largely controlled by human activities, rather than climate alone, and are invariably being monitored by good *in situ* facilities. (Wetlands are treated under land cover, and are therefore not considered here.)

The following is required for this ECV:

Product T.1.1 Maps of lakes in the Global Terrestrial Network for Lakes (GTN-L)

Benefits
- Assessment of changes in regional climate and better knowledge of the regional water balance, which is an important issue for sustainable development
- Lake area, combined with lake level, gives indication of the volume of the lake-water body, which is an integrator variable, reflecting both atmospheric (precipitation, evaporation-energy) and hydrological (surface-water recharge, discharge and ground-water tables) conditions.

Target requirements
Gridded, georeferenced maps covering, as a minimum requirement, all GTN-L lake areas, with the following characteristics:
- Accuracy: 5% (maximum error of omission and commission in lake area maps); location accuracy better than 1/3 of instantaneous field-of-view (IFOV) with 250 m target IFOV
- Spatial and temporal resolution: 250 m horizontal resolution, monthly observing cycle, global all-weather coverage
- Stability: 5% (maximum error of omission and commission in lake area maps); location accuracy better than 1/3 of instantaneous field-of-view (IFOV) with 250 m target IFOV

Requirements for satellite instruments and satellite datasets
FCDR of appropriate VIS/NIR imagery and radar imagery, for example through:
- Moderate-resolution optical instruments (MERIS/MODIS-class)
- ALOS L-band in ScanSAR mode

Calibration, validation and data archiving needs
- Calibration will be required against *in situ* measurements
- Validation by high-resolution imagery (10-30 m) from sample sites and *in situ* measurements
- No current capability for global data archiving is established; data documentation, availability and distribution by such a centre needs to be established with high priority

Adequacy/inadequacy of current holdings
Current holdings are fragmented; data holdings are not accessible; research databases are no longer supported.

Immediate action, partnerships, and international coordination
- Initiate the generation of lake-area products using available optical and radar satellite imagery, and laser altimetry data
- Arrangements for a future International Lake Data Centre are under development in the context of the Global Terrestrial Network for Hydrology (GTN-H)
- Coordination by GCOS TOPC, GTN-H, WMO CHy, WCRP GEWEX

Link to GCOS Implementation Plan
[GIP Action T5] Create a lake information data centre.
[GIP Action T6] Submit weekly/monthly lake level/area data for the 150 GTN-L lakes to the International Data Centre; submission of weekly/monthly altimeter-derived lake levels by space agencies to the International Data Centre.

Other applications
- Monitoring of lakes allows the prediction of freshwater supplies through the assessment of the regional water cycle
- Assessment of changes in the regional water cycle and their impact on water quality, biodiversity, and health

Product T.1.2 Lake level of all lakes in the Global Terrestrial Network for Lakes (GTN-L)

Benefits
- Assessment of changes in regional climate, better knowledge of regional water balance
- Lake area, combined with lake level, gives indication of the volume of the lake-water body, which is an integrator variable, reflecting both atmospheric (precipitation, evaporation-energy) and hydrological (surface-water recharge, discharge and ground-water tables) conditions

Target requirements
- Accuracy: 10 cm with respect to reference geoid
- Spatial and temporal resolution: <4 km horizontal resolution, monthly observing cycle
- Stability: 10 cm with respect to reference geoid

Requirements for satellite instruments and satellite datasets
- FCDR of appropriate satellite altimetry able to meet measurement requirements
- Use of laser altimetry instruments, if available

Calibration, validation and data archiving needs
- Ensure calibration of altimeters to achieve required accuracy
- No validation from satellite agencies; *in situ* GPS measurements required
- No current global data archiving capability established, although around 1000 lakes have been monitored by Topex/Poseidon (1992-2006) and Jason-1 (since 2001); data documentation, availability and distribution by such a centre need to be established with high priority

Adequacy/inadequacy of current holdings
- Current holdings fragmented
- Global all-weather coverage missing

Immediate action, partnerships and international coordination
- Reprocessing of satellite-altimeter data to retrieve lake level
- Arrangements for a future International Lake Data Centre are under development in the context of the Global Terrestrial Network for Hydrology (GTN-H)
- Coordination by GCOS TOPC, GTN-H, WMO CHy, WaTER mission stakeholders

Link to GCOS Implementation Plan
[GIP Action T5] Create a lake information data centre.
[GIP Action T6] Submit weekly/monthly lake level/area data for the 150 GTN-L lakes to the International Data Centre; submission of weekly/monthly altimeter-derived lake levels by space agencies to the International Data Centre.

Other applications
- Monitoring of lakes allows prediction of freshwater supplies through the assessment of the regional water cycle
- Assessment of changes in the regional water cycle and their impact on water quality, biodiversity, and health

<u>Product T.1.3</u> Surface temperature of lakes in the Global Terrestrial Network for Lakes (GTN-L)

Benefits
- Lake temperature is linked to lake freeze-up and break-up dates, which serve as an indicator for regional climate monitoring purposes
- Improved regional representation of surface temperature distribution
- Climate modelling input

Target requirements
- Accuracy: 0.2°C
- Spatial and temporal resolution: 1 km horizontal resolution, daily observing cycle
- Stability: 0.1 °C

Requirements for satellite instruments and satellite datasets
- FCDR of appropriate IR imagery, for example through high-resolution, high-fidelity IR instruments (e.g., of the AATSR-type), with appropriate capability for cloud clearing and aerosol correction
- Analysis of FCDRs used for sea-surface temperature mapping (see O.3)

Calibration, validation and data archiving needs
- Use very accurate long-term *in situ* observations for validation, in order to establish biases and drifts (see Product O.3)
- No current capability for global data archiving is established; data documentation, availability and distribution by such a centre needs to be established with high priority
- Freeze-up and break-up data should be submitted to the World Data Centre for Glaciology at the National Snow and Ice Data Center (NSIDC), to accompany existing historical data records archived there

Adequacy/inadequacy of current holdings
- Current accuracy limited by stability and accuracy of most infrared sensors
- ATSR and AATSR meet the resolution and accuracy requirements, but neither has the swath width to obtain a global daily data record
- A single polar-orbiting satellite is unlikely to be capable of meeting the requirement
- Potential value of: GMES Sentinel-3 Land and Ocean Surface Temperature sensor, VIIRS (on NPP, NPOESS)

Immediate action, partnerships and international coordination
- Need for space agencies to uphold commitments to fly VIS/IR sensors with the necessary calibration to meet the required accuracy

- Uniform reprocessing of global ERS ATSR and Envisat AATSR data records spanning the period 1991 – present
- Arrangements for a future International Lake Data Centre are under development in the context of the Global Terrestrial Network for Hydrology (GTN-H)
- Coordination by GCOS TOPC, GTN-H, WMO CHy, WaTER mission stakeholders

Link to GCOS Implementation Plan
[GIP Action T8] Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of 150 priority lakes in GTN-L.

Other applications
- Water quality assessment (requires combination with VIS data from hyperspectral sensors)
- Assessment of aquatic ecosystem function and biodiversity

3.3.2. ECV Glaciers and Ice Caps

Glacier changes provide some of the clearest evidence of climate change. Their decline will cause serious impacts on the terrestrial water cycle, since many societies are dependent on glacial meltwater. The GLIMS project at NSIDC is compiling a global baseline dataset (2D glacier outlines, outside the major ice sheets) to provide an accurate baseline estimate of global land ice and to facilitate assessment of the ongoing global glacier decline. The ice sheets of Antarctica and Greenland are growing at higher elevations and losing significant mass at lower elevations (through melting and dynamic thinning); this has the potential to affect ocean salinity and circulation. The land-ice cover is a primary determinant of sea level, and imperfect knowledge of its state and balance is the principal source of uncertainty about the rate of sea-level change.

Based on these considerations, the following needs have been identified:

- Maps of the areas covered by glaciers, other than ice sheets (T.2.1)
- Ice sheet elevation changes, for mass balance determination (T.2.2)

Product T.2.1 Maps of the areas covered by glaciers, other than ice sheets

Benefits
- Support early-detection strategies in global climate-related observations
- Support the instrumental data record of climate by providing climate-related information, going further back in time, in remote areas and at higher altitude than meteorological stations.
- Input to regional climate models, and for the validation of impact assessment and climate scenarios at a regional scale

Target requirements
- Accuracy: 5% (maximum error of omission and commission in glacier area maps); location accuracy better than 1/3 IFOV of sensor with target IFOV 30 m
- Spatial and temporal resolution: 30 m horizontal resolution, 1-year observing cycle; for the historical perspective, several years of observations are required to build up an inventory in regions with frequent cloud cover
- Stability: 5% (maximum error of omission and commission in glacier area maps); location accuracy better than 1/3 IFOV of sensor with target IFOV 30 m

The historic Landsat 4/5 TM dataset (at 30 m resolution) covering the period 1982-2003 should include at least one cloud-free image from the end of the ablation period (autumn) of each glacier in the world. The entire archive can then be used to create a global dataset.

Requirements for satellite instruments and satellite datasets
FCDR of appropriate VIS/NIR/SWIR multispectral imagery, for example through:
- Historical archived Landsat-4/5 Thematic Mapper data and other historical satellite datasets.
- Continuity of the Landsat TM/ETM+-class

<u>Supplemented by:</u> (for the determination of glacier mass balance)
- Along-track stereo imaging capability (backward/forward)

Calibration, validation and data archiving needs
- For calibration, image processing and validation, a network for ground-control points needs to be established. Although existing information can be used in some areas, this will require the insertion of new ground-control points in many remote areas (e.g. Asia)
- For the historical data, field verification and archived *in situ* observations/topographic maps will be used where available
- For validation, very high-resolution optical imagery (at spatial resolution of about 1 m) from selected sample sites is needed
- Global archives held by USGS/DAAC/ESA should provide access to previously selected scenes at original sensor resolution, for assessment of their suitability for glacier mapping
- Suitable data records (system-corrected or pre-processed Geo-TIFF, if available) should be provided at reproduction cost
- A standard format for satellite data, consistent with existing holdings, needs to be determined with high priority
- The continuity of existing archives (WGMS, USGS, NSIDC) of *in situ* glacial data (for validation) and, for reprocessing, satellite data including metadata needs to be maintained

Adequacy/inadequacy of current holdings
- Currently, the World Glacier Inventory provides data of about 40% of the estimated 160'000 glaciers worldwide, but only as point information with limited use for assessment of changes. Simple and robust semi-automatic methods for delineation of debris-free glaciers from multispectral Landsat Thematic Mapper (TM) and ASTER data are readily available; thus, it is feasible to generate the above global product
- Archived Landsat 4/5 Thematic Mapper data exist, but appropriate arrangements for data discovery and access should be made (marginal cost of reproduction); the Global Land Cover Facility (GLCF) offer scenes for free
- Satellite images can only be used for glacier mapping under snow-free conditions. Debris-covered glaciers and small glaciers in dark shadow need special treatment and ground-truthing. The pre-processing (to geocoded TIFF images) is a hindrance in regions where high-resolution DEMs are available for proper orthorectification, but not for other regions in the world where continental-scale block-bundle adjustment provides sufficient accuracy and accelerates data processing
- Landsat 7 lost its scan line corrector in 2003, which reduced the quality of single images at the outer edges of the swath; Landsat 5 has been in operation since 1984 and might fail soon; ASTER is already beyond its expected lifetime

Immediate action, partnerships and international coordination
- The generation of a consistent historical data record spanning the Landsat 4/5 TM data record would provide major advancement in global monitoring of glaciers
- The organizations holding Landsat archived data (USGS, GLCF, ESA and the Oak Ridge DAAC) to make data available
- The Global Land Ice Measurements from Space (GLIMS) provides support for analysis of remotely-sensed products, including mapped glacier outlines
- The existing National Snow and Ice Data Center (NSIDC) supports archiving and long-term availability of the products
- Coordination and guidance by the World Glacier Monitoring Service (WGMS), GTN-G, GCOS TOPC

Link to GCOS Implementation Plan
[GIP Action T13] Maintain current glacier observing sites and add additional sites and infrastructure in South America, Africa, the Himalayas and New Zealand; ensure continued functioning of WGMS.

Other applications
- Assessment of freshwater resources (particularly critical, e.g., in Central Asia)
- Overall assessment of the hydrological regime, with impact on energy production and agriculture
- Risk assessment of glacier-related natural hazards
- Contribution of glacier melt to global sea-level rise

Product T.2.2 Ice-sheet elevation changes, for mass-balance determination

Benefits
- Existing estimates of Antarctic and Greenland mass balance are prone to significant errors. Some parts of Antarctica and Greenland ice sheets are subject to rapid change, especially the Antarctic Peninsula and coastal regions in west and east Greenland
- State of the ice sheet is a major unknown factor in determining the pace of sea-level change

Target requirements (for ice sheet elevation change)
- Accuracy: 0.1 m
- Spatial and temporal resolution: 100 m horizontal resolution, 1-year observing cycle
- Stability: 0.1 m

Requirements for satellite instruments and satellite datasets
FCDR of appropriate altimetry, for example through laser altimetry (ICESat-type sensor)

Supplemented by:
- Radar measurements, for example through consideration of the use of SAR, especially interferometric SAR, to provide intermittent sampling of more detailed ice-field properties (surface-height change, densification, vertical ice velocity, rates of flow from outlet glaciers)

Calibration, validation and data archiving needs
- Needs for calibration should be identified by the CEOS WGCV, working with involved partners
- Validation through mass-balance closure estimates, reference point surveys, airborne laser altimetry, use of other sensors (optical, microwave, etc.)
- Aircraft laser altimeter (NASA ATM) missions are required for validation as well as *in situ* ground observations by automatic stations (surface height change, densification, vertical ice velocity)
- Product archiving by the World Data Center for Glaciology (NSIDC)

Adequacy/inadequacy of current holdings
- Coastal regions of certain outlet glaciers in Greenland are not adequately covered by current satellite data, although surface-height changes in these regions are dramatic (>25 m/year)
- 5-km resolution bed topography data by PARCA, ITASE, and DEMs with appropriate spatial resolution are available, and will be enhanced in the future
- GRACE offers a potential that should be explored for time-varying changes in mass of water and ice on land through gravity measurements
- Replacement of the failed Cryosat is underway (ESA Cryosat-2)

Immediate action, partnerships and international coordination
- There is a need to exploit the knowledge base of several research programmes and organisations, including PARCA, CliC, IGOS Cryosphere, SCAR, ICESat
- There is a need to identify the body that will coordinate this activity and develop a strategy for archiving data

Link to GCOS Implementation Plan
[GIP Action T14] Ensure continuity of current spaceborne cryosphere missions.

Other applications
- Estimate of biomass production on seasonal time scales by measuring vegetation canopy
- Laser altimeter missions have proven very useful for near-real-time monitoring of major rivers (e.g., of the Mississippi during flooding events)

3.3.3. ECV Snow Cover

The high sensitivity of terrestrial snow properties to changes in temperature and precipitation regimes is recognized as a fundamental indication of climate variability and change. Projected loss of seasonal snow water storage will strongly affect planetary albedo, soil moisture, growth conditions for vegetation and other parameters that influence surface water and energy balance. Moreover, changes in the timing, rate and magnitude of snowfall can indicate changing climate conditions, and will modify land-atmosphere fluxes through changes in albedo, latent energy sinks, surface roughness, boundary layer stability, and other processes. Snow depth and snow-water equivalent also affect permafrost thermal state, soil temperatures, and other characteristics of the ground.

The primary monitoring product is a continuous data record of snow areal extent. It is also highly desirable to have supplemental global information of three additional terrestrial snow properties: 1) snow depth, 2) snow water equivalent, and 3) the presence of water in the liquid phase (i.e., wet snow). Combined integrated products linking the four snow products have been generated by space agencies and research groups on a prototype basis, and these activities must continue. Improved resolution passive microwave sensors are able to provide observations of snow depth, water equivalent and wetness in mountainous areas. Research-mode missions to address these have been proposed and should be supported over the coming years; the immediate focus should be to develop reliable capacity to measure global snow areal extent and snow water equivalent. Such measurements need to be maintained in order to provide a climate data record of snow cover.

The following is required for this ECV:

Product T.3 Snow areal extent

Benefits:
- Better estimate of planetary albedo
- Indicator of changes in precipitation and temperature regimes
- Assessment and improvement of regional and global climate model performance
- Provision of a key indicator of climate change in cold seasons/regions
- Assessment of changes in seasonally-frozen ground

Target requirements
- Accuracy: 5% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100 m in areas of complex terrain, 1 km elsewhere
- Spatial and temporal resolution: 100 m horizontal resolution (for areas of complex terrain), 1 km elsewhere, daily observing cycle
- Stability: 5% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100 m in areas of complex terrain, 1 km elsewhere

Requirements for satellite instruments and satellite datasets
FCDR of appropriate moderate-resolution VIS/NIR/IR and passive microwave imagery, for example through:
- Current and planned moderate-resolution, multispectral optical sensors in polar-orbiting (e.g., MODIS) and geostationary (e.g., SEVIRI) mode, which are generally sufficient for observing the areal extent of snow cover and snow albedo; continuation of their capability should be ensured
- Improvements in spectral resolution, calibration and dynamic range, which are important considerations for future sensors. More, narrower, and better-calibrated bands would help improve observation accuracy and improve snow-cloud discrimination. Greater dynamic range is needed to avoid sensor saturation

Current and planned low-resolution passive microwave sensors are adequate to provide an estimate of snow-water equivalent for shallow snow packs in simple terrain, and their continuation is desirable.

Calibration, validation and data archiving needs
- Instrument and algorithm calibration is required, to account for changes in sensor characteristics
- Continuing research, surface observations and field verifications are needed to validate algorithms and satellite products for snow cover, snow extent and snow water equivalent; *In situ* observations can provide long time series of these variables
- National Snow and Ice Data Center (NSIDC) provides product archiving facilities

Adequacy/Inadequacy of Current Holdings

- Current holdings of historical remote sensing and *in situ* observations are adequate to generate a global reanalysis product for the past 20-30 years, if national archives are made freely available
- Current holdings are inadequate to overcome limitations of low-resolution passive microwave observations and sparse *in situ* observations in areas of complex terrain and deep snow. NSIDC produces global snow-cover products from MODIS at 500 m resolution and global monthly snow water equivalent from passive microwave data at 25 km resolution; NOAA produces daily snow-cover products at 4 km resolution
- SMMR and SSM/I (version 2) provide soil freeze/thaw states on a daily basis for the Arctic at 25 x 25 km resolution, from 1978 to 2004

Immediate action, partnerships and international coordination

- NCDC archives NOAA snow-cover products; NSIDC archives snow-cover and SWE products and should continue with this activity
- An immediate need exists for continuity and reanalysis of historical areal extent of snow-cover observation datasets that must be maintained for the Northern Hemisphere, and extended to the Southern Hemisphere. NOAA/NESDIS has produced daily Northern Hemisphere maps since 1999 and weekly maps since 1966. Comparable map products for the Southern Hemisphere are required
- Multi-sensor (optical, microwave, *in situ*) observations should be integrated to ensure spatial and temporal consistency for the snow areal extent product and the supplemental snow variable datasets. The NOAA/NWS National Operational Hydrologic Remote Sensing Center has demonstrated a multi-sensor snow analysis prototype for the conterminous U.S. since 2003. Comparable products are required globally
- The near-real-time accessibility of *in situ* observations of snow depth, water equivalent and seasonal frost depth needs to be improved. A central archive for these observations needs to be identified. Protocols need to be developed for comparing *in situ* observations with satellite derived information
- Coordination by WCRP CliC, GTN-H (through NCDC, NSIDC, GTN-P), NOAA/NWS

Link to GCOS Implementation Plan

[GIP Action T11] Obtain integrated analyses of snow cover over both hemispheres.
[GIP Action T17] Implement operational mapping of seasonal soil freeze/thaw.

Other Applications

- Provision of surface boundary condition for numerical weather prediction
- Assessment of freshwater resources needed as initial conditions for hydrological forecasts and flood predictions
- Changes in snow water storage affect water availability in many mountainous areas, and surrounding lowlands in the dry season.

3.3.4. ECV Albedo

Surface albedo generally refers to the (non-dimensional) ratio of the radiation reflected by a surface and the incoming irradiance. Albedo is highly variable in space and time, both as a result of changes in surface properties (snow deposition or sea-ice growth and melting, changes in soil moisture and vegetation cover, etc.) and as a function of changes in the illumination conditions (solar angular position, atmospheric and cloud properties, etc.).

Albedo can be defined spectrally or for spectral bands of finite width. However, since the scattering of light by typical terrestrial surfaces depends not only on the properties of that surface (notably its spectrally dependent anisotropy) but also on the direction of the incoming radiation and on the direction of observation, various theoretical concepts have been introduced, including the directional hemispherical reflectance factor (sometimes referred to as the black sky albedo) and the bi-hemispherical reflectance factor (also referred to as the white sky albedo). None of these albedo-related factors are directly measurable, in the field or otherwise. Instead, reflectance measurements must be interpreted with the help of radiation transfer models that can help retrieve the desired variables from the actual observations. Significant progress has taken place: The issue of angular integration of directional reflectances into hemispherical values is well-understood, and various approaches are currently applied to deliver a range of related products.

The following is required for this ECV:

<u>Product T.4</u> Directional-hemispherical (black sky) albedo

Benefits
- Black sky albedo offers improvements to climate modelling over the currently-used white sky albedo, because this solves the sun-angle dependency
- It is a critical variable required by climate models, as it directly controls the amount of solar radiation absorbed at the Earth's surface
- Future improvements in forecasting skills are largely dependent on the validity and accuracy of parameterizations of physical processes in climate models. For example, radiation exchanges between the Earth's surface and the atmosphere could be much better parameterized using observations of albedo which properly describe the anisotropy of reflectance.

Target requirements
- Accuracy: 5%
- Spatial and temporal resolution: 1 km horizontal resolution, daily observing cycle
- Stability: 1%

Requirements for satellite instruments and satellite datasets
FCDR of appropriate multispectral and broadband imagery with appropriate global and diurnal coverage, for example through:
- Geostationary platforms, which allow wide coverage and good time resolution, but are hard to correct for atmospheric effects or to characterize angular reflectance factors (BRDF) required to convert directional radiance to albedo; they are also inadequate to observe polar regions
- Polar-orbiting satellites, which can provide observations for all regions, but only acquire data for more or less narrow swaths during each orbit. Also, multiple observations are ideally made quasi-simultaneously from different observation angles (e.g., with instruments such as MISR or POLDER), but good results have also been derived from mono-directional, near-nadir observing instruments, such as MODIS and MERIS, through an analysis of data accumulated over time periods of days to weeks. As a precondition, surface and atmospheric conditions had to be reasonably stable during these periods

Calibration, validation, and data archiving needs
- Calibration is critical: for a global and annual average, an error of 1 percent in surface albedo would correspond to a change in surface energy balance of some 35 Wm^{-2}. This calls not only for both pre-launch characterization, on-board calibration devices and vicarious calibration campaigns, i.e. where the relative degradation of the instrument in orbit is determined using repeated observations of radiometrically-stable calibration sites, typically salt pans and deserts over land, which can then be compared with contemporaneous *in situ* radiometric measurements
- For validation, vicarious calibration campaigns and *in situ* radiometric measurements are important, as well as inter-comparisons of results between different sensors (especially across different space agencies).
- Benchmark the products retrieved from different sensors and platforms before they are merged spatially and temporally
- Encourage operational weather satellite operators (e.g., EUMETSAT and NOAA) to reprocess their archives of geostationary and sun-synchronous sensor measurements in a compatible way (i.e., using the same or similar, internationally agreed-upon algorithms) to generate a coherent integrated global surface albedo product, with a suitable temporal resolution, and over extended periods of time (e.g., decades)

Adequacy/inadequacy of current holdings
- Databases of hemispherical-conical spectral reflectance measurements have been made by space agencies since the early 1980's. Some of these data have been analyzed to estimate surface albedo, but a much more coherent, integrated, systematic effort should be conducted to ensure consistent accuracy and temporal coverage. In particular, the historical AVHRR data cannot readily be made consistent with more recent albedo data products, because of the inadequate angular sampling of this

instrument class. This issue could be addressed by exploiting the more recent measurements and understanding to reprocess past archives (see also C.7)

- EUMETSAT have generated around one year of data over Africa, and, in coordination with CGMS, a one day global demonstration product
- Albedo products are also being generated by NASA from MODIS and MISR, but the adequacy for use in GCMs is only now being investigated
- There are significant differences between the currently-available albedo products, and an international exercise is needed to fully characterise these differences

Immediate action, partnerships and international coordination

- Vicarious calibration campaigns, sensor intercomparisons, and product validation should be coordinated and executed by existing international mechanisms, such as the AERONET programme, CEOS WGCV and the CGMS
- A long-term series of global albedo estimates should be created by reprocessing the AVHRR data base in such a way that consistency can be guaranteed with products generated from recent sensors (see also C.7)

Link to GCOS Implementation Plan

[GIP Action T21] Implement globally coordinated and linked data processing to retrieve the directional hemispherical reflectance factor (or black sky albedo) from geostationary satellites on a daily and global basis from archived (and current) satellite data.

Other applications

- Critical variable for NWP
- Useful as an environmental indicator
- Changes in albedo can be used to assess the extent of burnt areas
- Indicates trends in desertification

3.3.5. ECV Land Cover

Land cover influences climate by modifying water and energy exchanges with the atmosphere, and changes greenhouse gas and aerosol sources and sinks. Many climatically-relevant variables that are difficult to measure at a global scale (e.g., surface roughness) can be inferred in part from vegetation and land-surface types. Thus, land cover can be a surrogate for other important climate variables. Land-cover distributions are linked to the regional climate, so changes in cover can indicate climate change on a regional scale. Current climate models operate on resolutions of 0.5° to 1°, but land-cover information at moderate resolution (250 m – 1 km) is needed to correctly describe the spatial heterogeneity of the land surface within the model cells.

Although moderate-resolution land cover can meet most science needs and detect intrinsically large-scale land-cover changes, it is not sufficient in resolution to deal with all land-cover changes, e.g., involving agriculture or forestry, deforestation in particular. High-resolution measurements of land cover are needed to quantify changes in the area covered by a specific land-cover type. For example, Brazil routinely maps the whole of legal Amazonia at high resolutions to quantify the rate of deforestation; the European Union uses data at these resolutions to monitor agricultural production, urbanization, and other land change processes. High-resolution measurements provide a key intermediary level of information that is necessary to integrate *in situ* and global-scale land-cover observations.

High-resolution measurements of land-cover change would provide significant support for national reporting under many chapters of the GHG inventories called for by the UNFCCC (especially those linked to agriculture, grasslands, wetlands, forestry). Including historical datasets of land cover, they would allow the establishment of neutral baselines for verification of carbon trading, e.g., pre-1990 for a/reforestation, or the degree of avoided deforestation. They would also contribute to the understanding of long-term land-cover change and its link to climate processes. High-resolution land-cover mapping could also be linked to other climate products, such as maps of lake area (T.1.1), and glaciers (T.2.1).

Historical land-cover datasets could be generated on a decadal scale from the 1970s to 2000 using available Landsat-type data (high resolution), and by comparing recent 1 km-resolution global land cover datasets with sampled historical high-resolution imagery from the Landsat and SPOT archives to reconstruct land cover. Given limited compatibility between existing land cover databases, some should be reprocessed to ensure the consistency of observations.

In close relation to land cover, land-surface temperature (LST) is one of the key subsidiary variables used to observe, identify and understand land-surface climate processes at regional and global scales. Because of the strong heterogeneity in land-surface characteristics, such as vegetation, topography and soil physical properties, LST changes rapidly in space as well as in time. An adequate characterization of LST distribution and its temporal evolution therefore requires measurements with detailed spatial and temporal frequencies, which can only be provided by satellite remote sensing.

Two products are required for this ECV:
- Moderate-resolution maps of land-cover type (T.5.1)
- High-resolution maps of land-cover type, for the detection of land-cover change (T.5.2)

Product T.5.1 Moderate-resolution maps of land-cover type

Benefits
- Improving predictability and accuracy of vegetation and climate models by improved land-surface parameterisation
- Help reduce uncertainty in factors having influence on key climate processes such as deforestation rates and conversion to agriculture
- Assist in meeting the science-based monitoring needs of various UNFCCC Convention Articles, especially those linked to reducing uncertainties related to the climate system
- Understand long-term land-cover change and its link to climate processes

Target requirements
A common language for class definitions in land-cover maps should be used. The thematic detail should be regionally adapted in order to satisfy requirements of international conventions, and as far as possible be harmonised with regional classification schemes presently in use.

- Accuracy: 15% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 250 m
- Spatial and temporal resolution: 250 m-1 km horizontal resolution, 1-year observing cycle
- Stability: 15% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 250 m

Requirements for satellite instruments and satellite datasets
FCDR of appropriate moderate-resolution multispectral VIS/NIR imagery, for example through:
- Continuity of moderate-resolution optical data, such as the MODIS/MERIS/SPOT VGT-class
- Appropriate historical imagery, for example through reprocessing of historical Landsat MSS, TM, ETM, SPOT HRV, air photo archives and declassified Argon/Corona imagery in comparison to historical NOAA AVHRR and other coarse-resolution sensors

Supplemented by:
Radar measurements, for example through SAR, e.g. from the current ALOS sensor and the planned TerraSAR and ESA Sentinel missions.

Calibration, validation, and data archiving needs
- Stringent instrument calibration is essential for land cover mapping, where globally and regionally-tuned approaches are used, and for automated approaches (see for example requirements for fAPAR (T.6))
- For validation purposes, the global land-cover databases must be accompanied by a regional and quantitative robust description of by-class thematic/spatial accuracy. Internationally-agreed validation protocols should be used. The current protocols base accuracy assessment on a sample of high-resolution (1-30 m) satellite imagery, itself validated by *in situ* observations wherever possible
- Access to the global archives of relevant satellite data and metadata held by relevant space agencies (e.g., daily geo-corrected observations held by NOAA, NASA, ESA, VITO) and land-cover facilities must be maintained (see also C.7)

Adequacy/inadequacy of current holdings

- The early IGBP-sponsored DISCover land-cover map from 1992 could be revisited and reworked alongside historical Landsat/SPOT-class data. The Landsat, SPOT and Argos/Corona archives would need to be systematically accessed and suitable images identified in order to reconstruct early land-cover maps
- Global land-cover products at 250-500 m resolution are currently being generated in the US (MODLAND) and Europe (GLOBCOVER), and a pan-global partnership created a 1 km resolution dataset for the year 2000 (GLC2000). The classification systems and therefore map legends should adhere to internationally-agreed standards. The UN Land Cover Classification System (LCCS) for legend harmonization and translation provide a means for developing and comparing legends, though MODLAND products do not currently use LCCS
- Synergy among existing data sources and integration of continuous land-cover observations from *in situ* to global scales must be ensured

Immediate action, partnerships and international coordination

- The GTOS GOFC-GOLD and the UN Global Land Cover Network provides an institutional framework on which an activity to generate historical land cover could be launched, providing space agencies are able to provide appropriate data
- The GTOS GOFC-GOLD panel working with the CEOS WGCV has established validation protocols
- The UN LCCS provides legend compatibility checks and frameworks for standardized development of land cover data
- ESA and NASA currently support global data acquisitions and pre-processing
- The GOFC-GOLD panel can ensure processing, product archiving and distribution

Link to GCOS Implementation Plan

[GIP Action T26] Generate annual products documenting global land-cover characteristics at resolutions between 250 m and 1 km, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.
[GIP Action T27] Generate maps documenting global land cover at resolutions between 10 m and 30 m every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.

Other applications

- Land cover and the change of land cover affect the services provided to human society (e.g., provision of food, fibre, shelter etc.)
- Changes in land availability for agriculture, forestry as well as urbanization are key factors in sustainable development of many regions, and a major driver of land use conflicts
- Land-cover distributions are intrinsically linked to biodiversity, land degradation, and ecosystem functioning and services

<u>Product T.5.2</u> High-resolution maps of land-cover type, for the detection of land-cover change

Detailed and reliable monitoring of changes in land-cover areas requires very high-resolution land-cover information, and it is therefore suggested that the annual land-cover type maps noted above are supplemented at intervals with measurements of change made using higher-resolution data.

Benefits

- Required to quantify changes in the area covered by specific land-cover types (see T.5.1)
- High-resolution measurements of changes in land-cover type provide a key level of information that is necessary to integrate *in situ* and global-scale land-cover observations
- Significant support for national reporting under many chapters of the GHG inventories called for by the UNFCCC (especially those linked to agriculture, grasslands, wetlands, forestry)
- Providing a neutral basis for verification of carbon trading linked to afforestation, reforestation and eventually also avoided-deforestation projects

Target requirements

- Accuracy: 5% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 10-30 m
- Spatial and temporal resolution: 10-30 m horizontal resolution, 5-year observing cycle
- Stability: 5% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 10-30 m

Global land-cover change maps at 10-30 m resolution should be produced at five-year intervals, synchronised with UNFCCC reporting requirements, although it should be noted that non-climate applications, such as agricultural yield estimations, would require annual observation at these spatial resolution scales.

Requirements for satellite instruments and satellite datasets

FCDR of appropriate high-resolution multispectral VIS/NIR imagery, for example through continuity of the Landsat ETM-class

Consistent viewing and illumination geometry and seasons of acquisition are required for measuring land-cover changes. It is important to recognize that data acquisition strategies and archiving are significant elements of the satellite programmes that support this effort. A data acquisition/archiving strategy designed to achieve cloud-free coverage of the global landmass at least once per year is essential. Only in the Landsat 7 era have requirements in this domain been achieved in an operational manner.

Supplemented by:

Radar measurements, for example through SAR, e.g. from the current ALOS sensor and the planned TerraSAR and ESA Sentinel missions.

Calibration, validation, and data archiving needs

- Best possible absolute calibration is a requirement for global mapping of land cover at these resolutions
- The global land-cover databases must also be accompanied by a description of by-class thematic/spatial accuracy. Internationally-agreed validation protocols should be used and a protocol for long-term validation should be elaborated. CEOS WGCV working with the GTOS GOFC-GOLD are developing suitable validation guidelines
- Global datasets of satellite imagery at 30 m resolution have been assembled and archived for 1990 and 2000, and some regional land-cover maps have been generated from these. No global land-cover maps at this scale exist

Adequacy/inadequacy of current holdings

- Current collection of satellite imagery is not sufficient to meet the requirements for this action
- Scattered regional maps at 30 m resolution exist (e.g., CORINE for Europe, Africover for Eastern Africa, PRODES for the Brazilian Amazonia, EOSD for Canada), but institutional arrangements to ensure operational generation of global land cover maps at these resolutions are not yet in place

Immediate action, partnerships and international coordination

GTOS GOFC-GOLD and the UN Global Land Cover Network provide an institutional framework on which to launch such an activity, providing that space agencies are able to provide suitable data. Research is needed to develop feasible operational solutions, including the possibility to use moderate-resolution imagery as gap filler and appropriate orthorectification methods. Methods based on post-classification are not appropriate.

Link to GCOS Implementation Plan

[GIP Action T24] Commit to continuous 10-30 m resolution optical satellite systems with data acquisition strategies at least equivalent to the Landsat 7 mission for land cover.

[GIP Action T27] Generate maps documenting global land cover at resolutions between 10 m and 30 m every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.

Other applications

- Changes in land availability for agriculture, forestry, etc. are a key factor in sustainable development of many regions, and can be a major driver of societal conflicts

- Land-cover distributions are also required for studying changes in biodiversity and land degradation
- Land-cover change, if monitored on high resolutions, such as 30 m, would support many local/national scale land-management and resource-management activities with respect to monitoring of ecosystems, biodiversity, water resources, disasters, and public health
- Non-climate applications, such as agricultural yield forecasting and production monitoring (already well-established in parts of the world) would be possible if annual coverage at 10-30 m resolution was available

<u>Supporting Product to T.5.1, T.5.2</u> Land-surface temperature, in conjunction with land-cover type

For clarity, the need for this supporting product is noted separately. It is not considered an ECV, as it constitutes a very dynamic variable that responds to both the land surface and to changes in surface radiation. In addition, land-surface temperature is hard to relate reliably to other *in situ* surface-temperature measurements. Although this product is not well-suited for long-term monitoring of land cover, it has a number of clear benefits, such as assisting interpretation of land cover maps.

Benefits
- Relevant to detailed observations of TOA longwave upwelling radiance (see A.6)
- Added value from radiometric data collected to observe SST
- Synergistic with making observations of lake surface temperature and SST (see T.1.3 and O.3)
- Relevant to spatial and temporal characterization of freeze-thaw cycle
- Land-surface temperature is a driver of vegetation phenology
- Response of the land surface to radiative and boundary layer forcing, modulated by hydrological conditions
- Early and sensitive indicator of drought conditions

Target requirements
- Accuracy: 1%
- Spatial and temporal resolution: 1 km horizontal resolution, daily
- Stability: n/a in the context of a supplementary variable

Requirements for satellite instruments and satellite datasets
A data record of appropriate high-resolution IR radiances, for example through:
- Continuity of AATSR-class of instruments
- See requirements for sea-surface temperature (O.3)

Calibration, validation, and data archiving needs
Older AVHRR data should be reprocessed to guarantee consistency with MODIS and (A)ATSR-derived LST

Adequacy/inadequacy of current holdings
- Spatial resolution (1-2 km) of most current and planned spaceborne sensors is more than satisfactory for climate and weather applications, and adequate for other environmental monitoring applications
- Temporal resolution remains an issue, as surface-temperature changes significantly over periods ranging from hours to years and beyond; Geostationary satellites provide very adequate temporal resolution
- Global datasets based on AVHRR radiometric data are available since 1982
- Global LST maps with an accuracy of 1ºC and emissivity maps with an accuracy of 0.005 will be available from AATSR, MODIS and ASTER data for many surface types

Immediate action, partnerships and international coordination
Vicarious calibration campaigns, sensor intercomparisons, and product validation should be coordinated and executed by existing international mechanisms, such as the CEOS WGCV and the CGMS

Link to GCOS Implementation Plan
[GIP Action T 17] Implement operational mapping of seasonal soil freeze/thaw.

Other applications
- Useful as an environmental indicator

- Necessary to detect fires (low intensity) and to determine fire radiative power
- Indicator of water availability
- Indicator of trends in desertification

3.3.6. ECV fAPAR

Land vegetation and plankton in the ocean exploit the process of photosynthesis to gather the solar energy required to assemble organic materials from mineral components. A limited spectral range of solar irradiance is useful for this purpose, nominally between 400 and 700 nm, known as Photosynthetically Active Radiation (PAR). The fraction of Absorbed Photosynthetically Active Radiation (fAPAR) is a non-dimensional ECV that estimates the proportion of the incoming PAR that is effectively absorbed by plants. fAPAR varies between 0 (e.g., over deserts) and 1, although such high values are never witnessed in practice. This variable plays a critical role in the energy balance of the surface ecosystems and, in particular, in the calculation of their productivity and assimilation of atmospheric carbon. fAPAR is thus a physically-based, quantitative variable with a clear, unambiguous meaning, directly related to the maintenance of life systems on the planet. Although fAPAR is difficult to measure in the field, it can be inferred from models describing the transfer of solar radiation in plant canopies, using remote sensing observations as constraints.

Currently, global, gridded fAPAR products are routinely generated by various space agencies at a typical spatial resolution of 1 km; regional products are available on finer scales of 250-300 m. The satellite data are typically collected on a daily basis and composited over longer periods, e.g., weeks, 10 day periods or months, to reduce the masking effect of clouds. In the future, a higher spatial resolution, such as 100-300 m, may be desirable to enable more regional or local applications.

The fAPAR of crops and other seasonally-variable ecosystems may vary from very low values (0.1 or less outside the growing period) to values of 0.7 or more at the peak of the growing season. Observations are required every 7 to 10 days to properly track the phenology of vegetation systems.

The following is required for this ECV:

Product T.6 Maps of fAPAR

Benefits
- Assess the strength of carbon assimilation and the productivity of ecosystems, in combination with vegetation models and other sources of data
- Indicate the presence and health of live green vegetation at the land surface, as well as characterize the variability of phenology in space and time
- Contribute to the monitoring of terrestrial carbon sinks and in particular to carbon sequestration, hence be relevant to the science underpinning the Kyoto Protocol

Target requirements
Accuracy: 0.05 (between measurements of the same target from different sensors)
Spatial and temporal resolution: 250 m horizontal resolution, daily observing cycle
Stability: 0.05 (over the lifetime of each satellite)

Requirements for satellite instruments and satellite datasets
FCDR of appropriate multispectral imagery, for example through:
- Sustaining multispectral instruments, if possible with multi-angular viewing capability
- Medium spatial resolution (e.g., 300 m) optical instruments (such as ESA MERIS, or NASA MODIS and SeaWiFS), with at least a blue spectral band to allow for scene-specific atmospheric corrections, as well as narrow red and near-infrared spectral bands, required to monitor the state of the biosphere over land

Calibration, validation, and data archiving needs
- Radiometric and spectral calibration as well as directional accuracy of the sensors is essential to the generation of accurate products

- Strong requirement on the co-location of the spectral measurements and the pointing accuracy of the sensors. Image to image registration of 1/3 or better of the instantaneous field of view is required
- fAPAR estimates derived from space instruments must be evaluated against *in situ* measurements to determine their reliability and accuracy
- Space agencies and other data providers routinely generate fAPAR datasets at regional, continental or global scales

Adequacy/inadequacy of current holdings
Global fAPAR products from 1997 onwards have been generated by space agencies and other data providers (e.g., ESA, NASA, European Commission JRC). These products are typically available at a spatial resolution of 1–2 km, daily, weekly or monthly. Limited inter-comparisons have indicated large differences between the products. Higher-resolution products at 250 – 300 m resolutions can be generated, but are not available operationally on a global and sustained basis. The latter would offer significant improvements in terms of national or regional scale reporting on the terrestrial carbon sink, or as one input to the generation of land cover maps. The higher-resolution products are also easier to compare with the point measurements made at reference sites than the moderate-resolution products.

Immediate action, partnerships and international coordination
- Space agencies and data providers should continue to generate gridded fAPAR
- Reprocessing of available archives of fAPAR to generate and deliver global, coherent and internationally-agreed values
- Further efforts should also be made to re-analyze the historical archives of the NOAA AVHRR instrument, ensuring the long-term consistency of the product with current estimates throughout the entire period (see also C.7)
- CEOS WGCV should continue to lead international benchmarking and product intercomparison and validation exercises including fAPAR. These efforts should take full advantage of existing networks of reference sites for *in situ* measurements whenever possible

Link to GCOS Implementation Plan
[GIP Action T28] Make fAPAR and LAI products available as gridded products at 250m to 1 km resolution.

Other applications
fAPAR is useful in a number of applications, ranging from agriculture (e.g., crop-yield forecasting) and forestry to environmental stress and sustainability monitoring; it has potential impact in the areas of food security, land degradation (e.g., desertification), and land-cover mapping

3.3.7. ECV LAI

Leaf Area Index (LAI) measures the amount of leaf material in an ecosystem, which imposes important controls on processes, such as photosynthesis, respiration and rain interception, that couple vegetation to climate. Hence, LAI appears as a key variable in many models describing vegetation-atmosphere interactions, particularly with respect to the carbon and water cycles. Satellites can only provide indirect measures of LAI, but are nevertheless vital, as *in situ* measurements provide very limited coverage.

The following is required for this ECV:

Product T.7 Maps of LAI

Benefits
- Key parameter in atmosphere-vegetation interactions
- Improved land-surface parameterization in models

Target requirements
- Accuracy: 0.5 (average as per IFOV)
- Spatial and temporal resolution: 250 m horizontal resolution, daily observing cycle
- Stability: 0.5

Requirements for satellite instruments and satellite datasets

FCDR of appropriate multispectral imagery, for example through:

- Medium-resolution optical instruments with a blue band for atmospheric correction (MODIS/MERIS/ SeaWiFS-class)
- Multi-angular spectral measurements should be continued
- Use of historical archives of AVHRR, albeit at lower accuracies than from current MODIS/MERIS/SeaWiFS-class instruments (see C.7)

Calibration, validation, and data archiving needs

- A network of reference sites for *in situ* measurements should support overall product validation
- Space agencies and other data providers routinely generate LAI datasets at regional, continental or global scales

Adequacy/inadequacy of current holdings

The retrieval of reliable LAI estimates from space is still difficult: when the canopy cover is sparse, reflectance measurements are dominated by soil properties and the accuracy of the LAI is low; for LAI values exceeding 3-4 on average, at typical instantaneous fields of view of around 250 m, the measurements generally saturate. Also, since LAI measured by satellites is inferred from reflectance, it is tightly coupled to fAPAR. The accuracy of LAI estimates and the separation of LAI from fAPAR improve significantly with multi-angular measurements. Regular global LAI estimates from space are currently being produced and should be continued. Limited inter-comparisons of these have indicated large differences. These estimates have the same spatial resolutions (250 m-1 km) and temporal frequencies (7 to 10 days) as the fAPAR products (see T.6).

Immediate action, partnerships and international coordination

- The detection of trends in the presence of interannual variability requires long time series, hence the full existing archive of satellite data for which consistent correction for the atmosphere is possible (i.e., those having at least the blue channel in their spectral coverage) should be processed. NASA should continue to generate gridded LAI
- Generation of global LAI using NASA satellite measurements has recently commenced on a regular basis, but has been funded under research budgets, as are archiving and distribution. Intercomparison of the different products is essential
- The CEOS WGCV should continue to lead product intercomparison and validation exercises

Link to GCOS Implementation Plan

[GIP Action T28] Make fAPAR and LAI products available as gridded products at 250m to 1 km resolution.

Other applications

- Forestry, agricultural crop yield forecasting
- Estimates on land degradation and desertification
- Useful for the monitoring of phenology and the seasonal evolution of productivity
- Hydrology and hydrogeology monitoring and assessment

3.3.8. ECV Biomass

Biomass (in this context, phytomass), herein defined as above-ground mass per unit area of living plant material, is an essential product for determining stored CO_2 in the terrestrial domain, and has two major roles in the climate system:

- Photosynthesis withdraws CO_2 from the atmosphere and stores it as biomass
- The quantity of biomass consumed by fire affects emissions of CO_2, and of other trace gases and aerosols

Most nations have schemes to estimate woody biomass through forest inventories, which form the basis for reporting their forest resources to the UNFCCC. Above-ground biomass can be measured with an accuracy of 10% to 20% using *in situ* methods; satellite estimates of comparable accuracy are desirable.

The research studies mentioned below are aimed at both demonstrating a capability suitable for climate use, and defining the necessary satellite characteristics.

The following is required for biomass:

<u>Product T.8</u> Research towards global, above-ground forest biomass and forest-biomass change

Benefits
- Biomass change is a direct measurement of carbon sequestration or loss
- Biomass information can help to validate carbon-cycle models
- Biomass provides an estimate of carbon stocks for terrestrial ecosystems

Target requirements
- Accuracy: 5%
- Spatial and temporal resolution: 10-30 m horizontal resolution, 1-year observing cycle
- Stability: 5%

Requirements for satellite instruments and satellite datasets
Two approaches are available for estimating biomass from space. The direct approach infers biomass directly from the signal, while the indirect approach measures forest height, from which biomass is recovered using regionally-dependent allometric relations:
- <u>Direct Approach:</u> The ALOS L-band SAR (launched in January 2006) should provide the first systematic global observations for generating biomass maps. Longer wavelengths (P-band) should also be considered for future missions
- <u>Indirect Approach:</u> Two techniques are able to retrieve forest heights from space: interferometric polarimetric SAR (Pol-InSAR), and lidar. For continuous wide area coverage, the Pol-InSAR technology seems able to provide the requested accuracy, and the ALOS system will be used to test the viability of this approach

Calibration, validation, and data archiving needs
- Direct Approach: Absolute radiometric calibration to 1dB is needed
- Indirect Approach: Precise control of the interferometric baseline is needed, and polarimetric cross-talk of about 25 dB is required
- For validation, ground-based biomass and height measurements are needed at a range of sites
- Under the Kyoto Protocol and Carbon Initiative of JAXA, systematic global measurements of backscatter (with a limited amount of polarimetry) will be acquired for the Earth's forest biomes, from which biomass could be derived

Adequacy/inadequacy of current holdings
- Direct Approach: Although historical JERS data are available through JAXA and ESA, calibration issues and lack of systematic coverage prevent their use for global biomass mapping
- Indirect Approach: Experimental airborne data are available (INDREX-II for tropical forests, TreeSAR for temperate forests)

Immediate action, partnerships and international coordination
- Actions need to be taken by the space agencies to develop a concept for above-ground biomass product estimation, for example based on low frequency (L- and P-band) SAR for both direct and indirect approaches
- The Kyoto and Carbon Initiative of JAXA needs to be maintained and developed

Link to GCOS Implementation Plan
[GIP Action T31] Develop methodology for forest inventory information and begin acquisition of data.

Other applications
- Dataset valuable for forest management but only at coarse resolution
- Consistent input for the FAO Forest Resource Assessment Updates

3.3.9. ECV Fire Disturbance

The emissions of greenhouse gases (GHGs) and aerosols from fires are important climate forcing factors, contributing on average between 25-35% of total CO_2 emissions to the atmosphere, as well as CO, methane and aerosols. Hence, estimates of GHG emissions due to fire are essential for realistic modelling of climate and its critical component, the global carbon cycle. Fires caused deliberately for land clearance (agriculture and ranching) or accidentally (lightning strikes, human error) are a major factor in land-cover changes, and hence affect fluxes of energy and water to the atmosphere.

Fires are expected to become more severe under a warmer climate (depending on changes in precipitation), giving a positive feedback. Observations suggest that this is occurring in the boreal zone, but long-term trends are hard to detect, because the area burnt in boreal forests is episodic; major burn years occur every 5-10 years, causing an order of magnitude more destruction than the mean rate of burn.

Spatially and temporally-resolved trace gas emissions from fires are the main target quantities. These can be inferred using both land-surface and atmospheric measurements, preferably in combination (the latter are dealt with in the atmospheric domain, e.g. in A.9).

Burnt area, as derived from satellites, is considered as the primary variable that requires climate-standard continuity. It can be combined with information on burn efficiency and available fuel load to estimate emissions of trace gases and aerosols. Measurements of burnt area can be used as a direct input (driver) to climate and carbon cycle models, or, when long time series of data are available, to parameterize climate-driven models for burnt area.

Satellite monitoring can also provide supplemental variables to support emission estimates based on burnt area. These are “global active fire maps” and “fire radiated power” data (an estimate of the rate of thermal energy emission from actively burning fires).

The products required for this ECV are:

- Burnt area (T.9)
- Active-fire maps (supplemental to T.9)
- Fire-radiated power (FRP) (supplemental to T.9)

Product T.9 Maps of burnt area, supplemented by active-fire maps and fire-radiated power (FRP)

Benefits
- Burnt area, combined with other information (burn efficiency and available fuel load) provides estimates of emissions of trace gases and aerosols
- Measurements of burnt area can be used as a direct input (driver) to climate and carbon-cycle models, or, when long time series of data are available, to parameterise climate-driven models for burnt area (fire is dealt with in many climate and biospheric models using the latter approach)
- Fire-induced emissions are a significant terrestrial source of GHGs, with large spatial and interannual variability

Target requirements
- Accuracy: 5% (maximum error of omission and commission)
- Spatial and temporal resolution: 250 m horizontal resolution, daily observing cycle
- Stability: 5%

Requirements for satellite instruments and satellite datasets
FCDR of moderate-resolution multispectral imagery, for example through:
- Sustained moderate-resolution optical data of the MODIS/MERIS-class
- Reprocessing of the AVHRR archive held by NOAA (and NASA), with correction for known deficiencies in sensor calibration, and also for known directional/atmospheric problems (see C.7)

Calibration, validation, and data archiving needs
- Relative calibration of VIS, NIR and SWIR channels to within 2% over the full lifetime of each instrument. Either overlapping periods of operation or absolute calibration is needed to provide continuity from instrument to instrument. Orbital overpass time drifts should be minimized.
- The 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 collaboration with local fire management organizations and the research community. High-resolution imagery (Landsat ETM-class) is needed for sample sites.

Adequacy/inadequacy of current holdings
- The historical AVHRR archive offers the potential to extend the burnt-area data record back to 1982. Calibration, especially of the SWIR channel, is not good enough in most currently available global processed time series
- Long time-series are needed to quantify the link between climate and burnt area, and to detect climate change effects on burnt area
- Burnt-area products are held by ESA and NASA

Immediate action, partnerships, and international coordination
- Current global burnt-area products as generated by ESA and NASA should be maintained
- These data are held by and distributed by these agencies, and the Global Land Cover Facility (GLCF), and these data distribution channels should be maintained
- The CEOS WGCV, working with GOFC-GOLD, is establishing internationally-agreed validation protocols, which should be applied to all datasets before their release
- Community consensus on regionally-applicable algorithms needs to be developed. GOFC-GOLD can coordinate this with the CEOS WGCV

Link to GCOS Implementation Plan
[GIP Action T33] Continue the generation of active fire and burnt area products

Other applications
- Extreme wildfire events have adverse impacts on economies, livelihoods, human health and safety
- They also cause changes to ecosystem boundaries, sometimes permanently, with associated consequences for biodiversity

Supplemental Product to T.9 Active fire maps

Benefits
- Detection of active fires serves as part of the validation process for burnt area (i.e., is the burnt area associated with previous observations of active fire)
- Detection of active fires provides an indicator of seasonal, regional and interannual variability in fire frequency and shifts in geographic location and timing of fire events

Target requirements
- Accuracy: 5% (maximum error of omission and commission)
- Spatial and temporal resolution: 250 m horizontal resolution, daily observing cycle
- Stability: n/a in the context of a supplementary variable

Requirements for satellite instruments and satellite datasets
A data record of appropriate moderate-resolution multispectral imagery, for example through sustained moderate-resolution radiometer data from the ATSR-2/MODIS-class instruments

Data archiving
Global archives held by ESA and NASA must be maintained.

Calibration, validation, and data archiving needs
- Absolute instrument calibration is important; vicarious calibration to within 1-2% accuracy satisfactory

- Past experience with post-launch calibration drift causes significant problems, as many fire detection algorithms rely on fixed thresholds
- The ephemeral nature of active fires makes validation a real challenge. Controlled burns coinciding with satellite overpass have been used to check detection algorithms, and should be periodically repeated - amongst other benefits, this acts as input for vicarious calibration
- Existing archives (e.g., by ESA, NASA) must be maintained

Adequacy/inadequacy of current holdings
- ESA hold a full, readily-available archive beginning in 1995
- NASA also distribute MODIS derived active fire counts

Immediate action, partnerships and international coordination
- ESA has produced the World Fire Atlas, giving global maps of fire counts from 1995 to 2005; this is being continually rolled forward and should be maintained
- NASA maintains the near-real-time fire detection data record from MODIS
- GTOS GOFC-GOLD provides coordination and scientific direction

Link to GCOS Implementation Plan
[GIP Action T33] Continue the generation of active fire and burnt area products

Other applications
- Extreme wildfire events have adverse impacts on economies, livelihoods, human health and safety
- Wildfire events cause changes to ecosystem boundaries, sometimes permanently, with associated consequences for biodiversity
- Rapid detection of active fires forms part of the remit for natural-hazards monitoring in the US and Europe
- Rapid detection of active fires can feed directly into near-real-time assessments of air quality via an estimate of direct smoke emission rates

Supplemental Product to T.9 Fire radiated power (FRP)

Benefits
- Strong empirical relations exist between FRP and rates of combustion, allowing CO_2 emission rates from a fire to be estimated from FRP observations
- Using multiple FRP observations to integrate over the lifetime of the fire provides an estimate of the total CO_2 emitted
- FRP provides a means to derive a CO_2 emissions estimate from remotely-sensed observations without relying on difficult-to-acquire ancillary data on fuel load and combustion completeness factors

Target requirements
- Accuracy: 5%
- Spatial and temporal resolution: 1 km horizontal resolution, daily observing cycle
- Stability: n/a in the context of a supplementary variable

Requirements for satellite instruments and satellite datasets
A data record of appropriate multispectral imagery, for example through:
- SEVIRI-class instruments, to be extended to the full set of geostationary meteorological satellites
- MODIS-class observations, to be extended post-Aqua and Terra through VIIRS
- Future BIRD (Bi-Spectral Infrared Detection)-type instrument, required for high-spatial resolution acquisitions with reduced spatial coverage, to allow the more frequent but lower spatial resolution datasets to be adjusted for missing smaller and weaker fires

Calibration, validation, and data archiving needs
- Absolute calibration is important across the entire dynamic range of the sensor
- High sensor saturation is needed, in both the mid-infrared and the thermal infrared spectral bands
- Preferably the mid-infrared channel will be narrow band, avoiding the effects of CO_2 and water vapour (following design of MODIS 3.9 µm narrowband channel)

- Validation is challenging due to the ephemeral nature of active fires; method validation is still ongoing and is currently limited to relatively small scales
- Coincident and near-coincident multi-spatial resolution observations (such as BIRD-type sensors, MODIS and geostationary) are needed to determine differences between sensors
- *In situ* observations should be periodically repeated
- Near-ground and top-of-atmosphere FRP measures should be compared to ensure consistency
- MODIS FRP archive to be extended into the future through follow-on instruments
- Geostationary satellite operators need to commence archiving of FRP products

Adequacy/inadequacy of current holdings
- NASA distributes MODIS-derived daytime and night-time FRP, beginning in late 2001; the continuity of this product is needed into the VIIRS era
- Experimental geostationary FRP product being generated from SEVIRI, based on observations every 15 minutes over Africa and Europe, should be continued. This activity should be expanded to other geostationary sensors covering the Americas and Australasia
- Isolated BIRD data records exist for ~3 years, and a replacement system is required

Immediate action, partnerships, and international coordination
- Operational production of geostationary FRP should begin, led by geostationary satellite operators or cooperating agencies, such as National Meteorological Services, for example through the exploitation of the MSG archive with EUMETSAT assistance
- NASA should maintain the FRP production capability from MODIS and follow-on sensors
- SEVIRI, MODIS instrument currently existing; GOES/MTSAT in the near future, subject to funding

Link to GCOS Implementation Plan
This product provides a more direct estimation of emissions than the burnt area product noted in the GIP.
[GIP Action T33]: Continue the generation of active fire and burnt area products

Other applications
- Extreme wildfire events have adverse impacts on economies, livelihoods, human health and safety
- Wildfire events cause changes to ecosystem boundaries, sometimes permanently, with associated consequences for biodiversity
- Rapid detection of active fires forms part of the natural-hazards monitoring in the US and Europe
- Rapid detection of active fires can feed directly into near-real-time assessments of air quality via estimates of smoke emission rates

3.3.10. Soil Moisture

Soil moisture is an emerging ECV, which has an important influence on land-atmosphere feedbacks at climate time scales, because it has a major effect on the partitioning of incoming radiation into latent and sensible heat, and on the allocation of precipitation into runoff and infiltration. Changes in soil moisture have a serious impact on agricultural productivity, forestry and ecosystem health. Monitoring soil moisture is critical for managing these resources and understanding long-term changes, such as desertification, and should be developed in proper coordination with other land surface variables. The soil-moisture-related activities can build on the soil-moisture data archive at Rutgers University, national networks (Russian Federation, China, USA) and the potential of new satellite missions, such as SMOS. The various ways of representing soil moisture from satellite and *in situ* measurements need rationalization.

Information on soil-moisture changes and its statistics will help reduce process uncertainties and improve climate models. On seasonal timescales, improved initial conditions for soil moisture in models should increase the model prediction accuracy. The details noted here refer to research studies aimed at both demonstrating a capability suitable for climate use, and at offering guidance for later operations.

The following is needed for soil moisture:

Product T.10 Research towards global near-surface soil-moisture map (up to 10cm soil depth)

Benefits
- Improve accuracy of and reduce process uncertainties in general circulation models (GCMs) and soil-vegetation-atmosphere transfer schemes by including surface soil moisture
- Soil moisture is intimately involved in the feedback between climate and vegetation, since local climate and vegetation both influence soil moisture through evapotranspiration, while soil moisture and climate determine the type of vegetation in a region
- Soil moisture estimates assist gas flux estimates in permafrost regions

Target requirements
- Accuracy: 5%
- Spatial and temporal resolution: 50 km horizontal resolution, daily observing cycle
- Stability: 5%

Requirements for satellite instruments and satellite datasets
- The SMOS radiometer is in its phase B development at ESA, and due to launch sometime after 2007; it is expected to provide surface soil moisture with 30 - 50 km spatial resolution. The 3-day temporal resolution would be sufficient. For the detection of regional soil-moisture variations, the spatial resolution is not sufficient. The JAXA ALOS active microwave sensor is now an additional potential source of data. ASCAT on METOP (2006-2018?) will continue the data record of the scatterometers on ERS-1 and -2, and possibly provide a continuous and homogenous data record for the foreseeable future
- ENVISAT is operating the ASAR C-band radar system, which could possibly contribute to the derivation of a global soil-moisture map, though accurate retrieval of soil moisture from these measurements is still a research topic. A fully polarimetric SAR system may be needed in order to exploit interfaces between soil moisture and vegetation
- NASA operates the JAXA-provided AMSR-E on Aqua, which uses X-band to derive soil moisture over sparsely-vegetated land surfaces. C-band capability is limited due to radio frequency interference in many populated regions of the world (e.g., US, Europe, Japan)
- Space agencies may need to maintain active long-wavelength microwave observation systems with a high temporal and reasonable spatial resolution, possibly with a polarimetric capability, to measure soil moisture and soil-moisture change

Calibration, validation, and data archiving needs
- Absolute radiometric calibration will be needed
- *In situ* methods for validation are not generally applicable at the spatial scale of 50 km, but verification campaigns could be considered at some sites with multiple *in situ* instruments
- Limited validation is possible using meteorological models or comparing the soil-moisture estimates with precipitation events

Adequacy/inadequacy of current holdings
- ERS Scatterometer data have been used for global soil-moisture estimation on a scale of 50 km, but are no longer available
- AMSR-E-derived soil-moisture results are currently available from NASA for the Aqua time period (2002-present)

Immediate action, partnerships and international coordination
- Research to blend surface soil-moisture observations with satellite observations remains a key challenge
- Robust and reliable algorithms for retrieval of soil moisture are still lacking, especially over densely-vegetated surfaces

Link to GCOS Implementation Plan
[GIP Action T37] Develop an experimental soil-moisture product from existing networks and satellite observations.

Other applications
- Soil moisture is of major importance for hydrological modelling, groundwater management, agricultural management and hazard forecasting (soil erosion, land slides, flooding, debris flow etc.)
- Human health is affected through lack of freshwater, impacts on farming (FAO) and groundwater recharge

4. ACKNOWLEDGEMENTS

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Appendix 1

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

List of Actions (left column) and 'Agents for Implementation' (right column) for which 'Agents' are Space Agencies/CGMS/CEOS

(Total: 42)

C10

Ensure continuity and over-lap of key satellite sensors; recording and archiving of all satellite meta-data; maintaining currently adopted data formats for all archived data; providing data service systems that ensure accessibility; undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses.	Parties operating satellite systems.

C21

Develop modern distributed data services that can handle the increasing volumes of data and which can allow feedback to observing network management.	Parties' national services committing to International Data Centre operation and high data volume providers such as Space Agencies through appropriate technical commissions and international programmes.

A7

Ensure stable operation and processing of relevant operational satellite instruments for precipitation and the continuity of associated products.	Space Agencies through CGMS and CEOS with WMO Space Programme and GCOS.

A11

Ensure continuous operation of AM and PM satellite scatterometer or equivalent observations.	Space Agencies through CGMS and CEOS with WMO Space Programme and GCOS.

A19

Continue the system of satellites following the GCMPs to enable the continuation of MSU-like radiance data.	Space Agencies.

A20

GPS RO measurements should be made available in real time, incorporated into operational data streams, and sustained over the long-term. Protocols need to be developed for exchange and distribution of data.	Space Agencies, in cooperation with CGMS, WMO CBS, the WMO Space Programme and AOPC.

A22

Ensure continuation of a climate data record of visible and infrared radiances, e.g., from the International Satellite Cloud Climatology Project, and include additional data streams as they become available.	Space Agencies, for processing.

A23

Research to improve cloud property observations in three dimensions.	Parties' national research and Space Agencies in cooperation with the WCRP.

A24

Ensure continuation of Earth Radiation Budget observations.	Space Agencies, coordinated through WMO Space Programme, CEOS and CGMS.

A25

Establish a plan for and implement a consistent surface- and satellite-based global observing system for the atmospheric composition ECVs, based on common standards and procedures, and encourage data submission to WDCs.	Parties' national services, research agencies and Space Agencies, under the guidance of WMO GAW in coordination with AOPC.

A26

Develop and implement a comprehensive plan to observe the vertical profiles of GHGs, ozone and aerosols utilizing commercial and research aircraft, pilotless aircraft, balloon systems, kites, ground-based lidars and satellites.	Parties' national services, research agencies and Space Agencies, under the guidance of WMO GAW in coordination with AOPC.

A27

Establish the GCOS/GAW baseline network for CO_2 and CH_4, and fill the gaps.	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.

A31

Develop and implement a coordinated strategy to monitor and analyze the distribution of aerosols and aerosol properties.	Parties' national services, research agencies and Space Agencies, with guidance from AOPC in cooperation with WMO GAW, WCRP, IGBP.

A32

Develop and implement a strategy to enable use of satellite data on atmospheric composition for climate by scientific users, regardless of source.	Space Agencies, in conjunction with CEOS and CGMS, IGOS-P, and WMO Space Programme.

O3

Promote and facilitate research and development (new improved technologies in particular), in support of the global ocean observing system for climate.	Parties' national ocean research programmes and Space Agencies, in cooperation with GOOS, GCOS, and WCRP.

O7

IGOS-P Ocean Theme Team to publish update of the Ocean Theme and, as appropriate, restating the satellite requirements and explicitly noting requirements for climate.	IGOS-P through WMO Space Programme, CGMS, CEOS in consultation with OOPC and GCOS.

O9

Ensure a continuous mix of polar orbiting and geostationary IR measurements combined with passive microwave coverage. To link with the comprehensive *in situ* networks noted in O10.	Space Agencies coordinated through CGMS, CEOS, and WMO Space Programme.

O12	
Ensure continuous coverage from one high-precision altimeter and two lower-precision but higher-resolution altimeters.	Space Agencies with coordination through CGMS, CEOS, and WMO Space Programme.
O16	
Research programmes to demonstrate feasibility of utilizing satellite data to help resolve global fields of SSS.	Space Agencies in collaboration with the ocean research community.
O18	
Implement plans for a sustained and continuous deployment of ocean colour satellite sensors together with research and analysis.	Space Agencies through the IGOS-P and in consultation with the IOCCG.
O23	
Ensure sustained satellite (microwave, SAR, visible and IR) operations: improve the *in situ* observations from sea-ice buoys, visual surveys (SOOP and Aircraft), and ULS. Implement observations in the Arctic and Antarctic.	Parties' national services, research programmes and Space Agencies, coordinated through the WMO Space Programme, IGOS-P Cryosphere Theme, CGMS, and CEOS; National services for *in situ* systems coordinated through JCOMM.
O29	
Develop and implement a pilot project designed to assemble the *in situ* and satellite altimetry data into a composite dataset and to assimilate the data into models and to create climate variability and trend analyses.	Parties' national ocean research programmes and space programmes through GODAE.
T6	
Submit weekly/monthly lake level/area data for the 150 GTN-L lakes to the International Data Centre; submission of weekly/monthly altimeter-derived lake levels by Space Agencies to the International Data Centre.	National Hydrological Services, through WMO CHy; Space Agencies; the new global lake information data centre.
T8	
Submit weekly surface and sub-surface water temperature, date of freeze-up and date of break-up of 150 priority lakes in GTN-L.	National Hydrological Services; Space Agencies in response to request from TOPC through the WMO.
T11	
Obtain integrated analyses of snow cover over both hemispheres.	Space Agencies through CliC and IGOS–P Cryosphere, with advice from TOPC and AOPC.
T14	
Ensure continuity of current spaceborne cryosphere missions.	Space agencies, in cooperation with IGOS-P Cryosphere.
T18	
Test prototype algorithms to retrieve the directional hemispherical reflectance factor (or black sky albedo) from geostationary satellites on a daily and global basis.	Space Agencies, especially EUMETSAT, in cooperation with the algorithm developers and the CEOS WGCV.

T19	
Obtain *in situ* calibration/validation measurements and collocated albedo products from all Space Agencies generating such products.	Space Agencies in cooperation with CEOS/WGCV.
T20	
Identify the most appropriate satellite derived albedo for specific climate models.	CEOS WGCV, in cooperation with GEWEX and the Project for Intercomparison of Land-surface Parameterization Schemes.
T21	
Implement globally coordinated and linked data processing to retrieve the directional hemispherical reflectance factor (or black sky albedo) from geostationary satellites on a daily and global basis from archived (and current) satellite data.	Space Agencies, through the CGMS and WMO Space Programme.
T23	
Produce reliable accepted methods for land-cover map accuracy assessment.	CEOS WGCV, in collaboration with GOFC-GOLD and GLCN.
T24	
Commit to continuous 10-30m resolution optical satellite systems with data acquisition strategies at least equivalent to the Landsat 7 mission for land cover.	Space Agencies.
T25	
Develop an *in situ* reference network and apply CEOS WGCV validation protocols for land cover.	Parties' national services, research institutes and Space Agencies, in cooperation with GOFC-GOLD, CEOS/WGCV, FAO GLCN and the GTOS web-based data system TEMS.
T26	
Generate annual products documenting global land-cover characteristics at resolutions between 250m and 1km, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.	Parties' national services, research institutes and Space Agencies through GLCN in collaboration with GOFC-GOLD research partners, and the IGOS land theme (IGOL).
T27	
Generate maps documenting global land cover at resolutions between 10m and 30m every 5 years, according to internationally-agreed standards and accompanied by statistical descriptions of the maps' accuracy.	Space Agencies, in cooperation with GCOS, GTOS, GLCN and other members of CEOS.
T28	
Make fAPAR and LAI products available as gridded products at 250m to 1km resolution.	Space Agencies, coordinated through CEOS WGCV, with advice from GCOS/GTOS.
T29	
Establish a calibration/validation network of *in situ* observing sites for fAPAR and LAI (reference sites).	Parties' national and regional research centres, in cooperation with Space Agencies coordinated by CEOS WGCV, GCOS and GTOS.

T30 Evaluate the various LAI satellite products and benchmark against ground truth to arrive at an agreed operational product.	Parties' national and regional research centres, in cooperation with Space Agencies and CEOS WGCV and TOPC.
T32 Reanalyze the historical fire disturbance satellite data (1982 to present).	Space Agencies, working with research groups coordinated by GOFC-GOLD.
T33 Continue the generation of active fire and burnt area products.	Space Agencies, in collaboration with GOFC-GOLD.
T34 Apply CEOS WGCV and GOFC-GOLD validation protocol to fire disturbance data.	Space Agencies and research organizations.
T37 Develop an experimental soil-moisture product from existing networks and satellite observations.	Parties' national services and research programmes, through IGWCO and TOPC in collaboration with Space Agencies.

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Appendix 2

GCOS requirements in WMO/CEOS Database (13 July 2004)

		Observation Requirement	Hor Res	HR min	Vert Res	VR min	Obs Cycle	OC min	Delay	D min	Acc-RMS	Acc min
1	AOPC	ɔl optical depth (VIS+IR) - Higher stratosphere & mesosphere (H	1 km	10 km			1 d		7 d	60 d	0.01	0.02
2	AOPC	Aerosol optical depth (VIS+IR) - Higher troposphere (HT)	1 km	10 km			1 d		7 d	60 d	0.01	0.02
3	AOPC	Aerosol optical depth (VIS+IR) - Lower stratosphere (LS)	1 km	10 km			1 d		7 d	60 d	0.01	0.02
4	AOPC	Aerosol optical depth (VIS+IR) - Lower troposphere (LT)	1 km	10 km			1 d		7 d	60 d	0.01	0.02
5	AOPC	extinction coefficient (VIS) - Higher stratosphere & mesosphere (	10 km	100 km	0.5 km	1 km	7 d		7 d	60 d	0.01 km-1	0.02 km-1
6	AOPC	Aerosol extinction coefficient (VIS) - Higher troposphere (HT)	10 km	100 km	0.5 km	1 km	7 d		7 d	60 d	0.01 km-1	0.02 km-1
7	AOPC	Aerosol extinction coefficient (VIS) - Lower stratosphere (LS)	10 km	100 km	0.5 km	1 km	7 d		7 d	60 d	0.01 km-1	0.02 km-1
8	AOPC	Aerosol extinction coefficient (VIS) - Lower troposphere (LT)	10 km	100 km	0.5 km	1 km	7 d		7 d	60 d	0.01 km-1	0.02 km-1
9	AOPC	ɔsorption optical depth (VIS) - Higher stratosphere & mesospher	1 km	10 km			1 d		7 d	60 d	0.004	0.02
10	AOPC	Aerosol absorption optical depth (VIS) - Higher troposphere (HT	1 km	10 km			1 d		7 d	60 d	0.004	0.02
11	AOPC	Aerosol absorption optical depth (VIS) - Lower stratosphere (LS)	1 km	10 km			1 d		7 d	60 d	0.004	0.02
12	AOPC	Aerosol absorption optical depth (VIS) - Lower troposphere (LT)	1 km	10 km			1 d		7 d	60 d	0.004	0.02
13	AOPC	Air specific humidity (at surface)	25 km	100 km			3 h	6 h	1 d	3 d	1 %	2 %
14	AOPC	Air temperature (at surface)	25 km	100 km			3 h	12 h	1 d	2 d	0.1 K	0.3 K
15	AOPC	Air pressure (at surface)	200 km	500 km			3h	1 d	3 h	12h	0.5hPa	1hPa
16	AOPC	Atmospheric temperature profile - Higher strat & mes (HS & M)	100 km	500 km	2 km	3 km	3 h	6 h	3 h	12 h	1 K	3 K
17	AOPC	Atmospheric temperature profile - Higher troposphere (HT)	100 km	500 km	0.1 km	0.5 km	3 h	6 h	3 h	12 h	0.5 K	2 K
18	AOPC	Atmospheric temperature profile - Lower stratosphere (LS)	100 km	500 km	0.1 km	0.5 km	3 h	6 h	3 h	12 h	0.5 K	2 K
19	AOPC	Atmospheric temperature profile - Lower troposphere (LT)	100 km	500 km	0.1 km	2 km	3 h	6 h	3 h	12 h	0.5 K	2 K
20	AOPC	Cloud cover	100 km	500 km			3 h	6 h	3 h	12 h	10 %	20 %
21	AOPC	Cloud ice profile - Total column	100 km	500 km			3 h	6 h	3 h	12 h		
22	AOPC	Cloud top height	100 km	500 km			3 h	6 h	3 h	12 h	0.5 km	2 km
23	AOPC	Cloud top temperature	100 km	500 km			3 h	6 h	3 h	12 h	0.3 K	0.6 K
24	AOPC	Cloud water profile (< 100 µm) - Total column	100 km	500 km			3 h	6 h	3 h	12 h		
25	AOPC	Cloud water profile (> 100 µm) - Total column	100 km	500 km			3 h	6 h	3 h	12 h		
26	AOPC	Downwelling long-wave radiation at the Earth surface	25 km	100 km			3 h	6 h	1 d	5 d	5 W/m2	10 W/m2
27	AOPC	Downwelling short-wave radiation at the Earth surface	25 km	100 km			1 d	5 d	1 d	30 d	5 W/m2	10 W/m2
28	AOPC	Downwelling solar radiation at TOA					3 h	7 d	3 h	1 d	1 W/m2	2 W/m2
29	AOPC	Land surface temperature	100 km	500 km			3 h	6 h	3 h	6 h	1 K	3 K
30	AOPC	Outgoing long-wave Earth surface	25 km	100 km			3 h	6 h	1 d	5 d	5 W/m2	10 W/m2
31	AOPC	Outgoing long-wave radiation at TOA	200 km	500 km			3 h	6 h	3 h	1 d	5 W/m2	10 W/m2
32	AOPC	Outgoing short-wave radiation at TOA	200 km	500 km			3 h	6 h	3 h	1 d	5 W/m2	10 W/m2
33	AOPC	Ozone profile - Higher stratosphere & mesosphere (HS & M)	50 km	100 km	0.5 km	3 km	1 d		30 d	0.5 y	5 %	20%
34	AOPC	Ozone profile - Higher troposphere (HT)	10 km	100 km	0.5 km	2 km	1 h		30 d	0.5 y	5%	30%
35	AOPC	Ozone profile - Lower stratosphere (LS)	50 km	100 km	0.5 km	3 km	1 d		30 d	0.5 y	5%	20 %
36	AOPC	Ozone profile - Lower troposphere (LT)	5 km	50 km	0.5 km	2 km	1 h		30 d	0.5 y	5%	20 %
37	AOPC	Ozone profile - Total column	10 km	50 km			1 d		30 d	0.5 y	2%	5%
38	AOPC	Ozone profile - Tropospheric column	10 km	50 km			1 h		30 d	0.5 y	5%	15%

39	AOPC	Precipitation index (daily cumulative)	100 km	500 km			12 h	1 d	1 d	12 d	1%	2%
40	AOPC	Precipitation rate (liquid) at the surface	100 km	500 km			3 h	6 h	3 h	12 h	0.6 mm/h	2 mm/h
41	AOPC	Precipitation rate (solid) at the surface	100 km	500 km			3 h	6 h	3 h	12 h	0.6 mm/h	2 mm/h
42	AOPC	Sea surface bulk temperature	100 km	500 km			1 d	3 d	3 h	12 h	0.3 K	1 K
43	AOPC	Short-wave Earth surface bi-directional reflectance	25 km	100 km			3 h	6 h	1 d	5 d	5 % (Max)	10 % (Max)
44	AOPC	Significant wave height	100 km	250 km			3 h	6 h	3 h	12 h	0.5 m	2 m
45	AOPC	Snow cover (for model assimilation)	100 km	500 km			1 d	7 d	6 h	1 d	10 % (Max)	20 % (Max)
46	AOPC	Snow water equivalent	100 km	500 km			1 d	7 d	6 h	1 d	5 mm	10 mm
47	AOPC	Specific humidity profile - Higher strat & mes (HS & M)	50 km	200 km	2 km	5 km	1 d		7 d	60 d	5%	20%
48	AOPC	Specific humidity profile - Higher troposphere (HT)	20 km	100 km	0.5 km	2 km	1 h		7 d	60 d	2%	20%
49	AOPC	Specific humidity profile - Lower stratosphere (LS)	50 km	200 km	1 km	3 km	1 d		7 d	60 d	5%	20%
50	AOPC	Specific humidity profile - Lower troposphere (LT)	5 km	25 km	0.1 km	1 km	1 h		7 d	60 d	2%	15%
51	AOPC	Specific humidity profile - Total column	50 km	200 km			1 d		7 d	60 d	1%	3%
52	AOPC	Specific humidity profile - Tropospheric column	10 km	200 km			1 h		7 d	60 d	1%	3%
53	AOPC	Trace gas profile CH4 - Higher strat & mesosphere (HS & M)	50 km	250 km	2 km	4 km	1 d		30 d	0.5 y	5%	30%
54	AOPC	Trace gas profile CH4 - Higher troposphere (HT)	50 km	250 km	2 km	4 km	2 h		30 d	0.5 y	2 %	20%
55	AOPC	Trace gas profile CH4 - Lower stratosphere (LS)	50 km	250 km	2 km	4 km	6 h		30 d	0.5 y	5%	30%
56	AOPC	Trace gas profile CH4 - Lower troposphere (LT)	10 km	50 km	2 km	3 km	2 h		30 d	0.5 y	2 %	10 %
57	AOPC	Trace gas profile CH4 - Total column	10 km	250 km			12 h		30 d	0.5 y	2%	10%
58	AOPC	Trace gas profile CH4 - Tropospheric column	10 km	50 km			2 h		30 d	0.5 y	2%	10%
59	AOPC	Trace gas profile CO2 - Higher strat & mesosphere (HS & M)	250 km	500 km	2 km	4 km	1 d		30 d	0.5 y	1%	2%
60	AOPC	Trace gas profile CO2 - Higher troposphere (HT)	50 km	500 km	1 km	2 km	2 h		7 d	60 d	1%	2%
61	AOPC	Trace gas profile CO2 - Lower stratosphere (LS)	250 km	500 km	1 km	4 km	1 d		30 d	0.5 y	1%	2%
62	AOPC	Trace gas profile CO2 - Lower troposphere (LT)	10 km	500 km	0.5 km	2 km	2 h		7 d	60 d	1%	2%
63	AOPC	Trace gas profile CO2 - Total column	50 km	500 km			1 d		30 d	0.5 y	1%	2%
64	AOPC	Trace gas profile CO2 - Tropospheric column	10 km	500 km			2 h		7 d	60 d	1%	2%
65	AOPC	Wind profile (horizontal component) - Higher strat & mes (HS & M	100 km	500 km	2 km	3 km	3 h	6 h	3 h	12 h	3 m/s	7 m/s
66	AOPC	Wind profile (horizontal component) - Higher troposphere (HT)	100 km	500 km	0.5 km	1 km	3 h	6 h	3 h	12 h	2 m/s	5 m/s
67	AOPC	Wind profile (horizontal component) - Lower stratosphere (LS)	100 km	500 km	0.5 km	1 km	3 h	6 h	3 h	12 h	2 m/s	5 m/s
68	AOPC	Wind profile (horizontal component) - Lower troposphere (LT)	100 km	500 km	0.1 km	2 km	3 h	6 h	3 h	12 h	2 m/s	5 m/s
69	AOPC	Wind vector over sea surface (horizontal)	100 km	500 km			3 h	6 h	3 h	12 h	m/s, 20 deg	m/s,20 deg
70	OOPC	Ocean chlorophyll	25 km	100 km			1 d	3 d	1 d	3 d	0.1mg/m3	0.5mg/m3
71	OOPC	Ocean dynamic topography	25 km	250 km			1 d	30 d	3 h	1 d	1 cm	5 cm
72	OOPC	Ocean surface salinity	200 km	500 km			1 d	30 d	10 d	30 d	0.1 psu	0.3 psu
73	OOPC	Sea-ice cover	30 km	100 km			1 d	7 d	3 h	1 d	2 % (Max)	10 % (Max)
74	OOPC	Wind vector over sea surface (horizontal)	10 km	100 km			1 h	1 d	3 h	12 h	.5 m/s,20 de	m/s,20 deg
75	OOPC	Wind speed	10 km	500 km			1 h	1 d	1 h	12 h	0.25 m/s	1 m/s
76	OOPC	Upper ocean temperature	1 km	300 km	1 m	10 m	1 d	10 d	12 h	1 d	0.001 C	0.01 C

77	OOPC	Upper ocean salinity	15 km	300 km	1 m	10 m	1 d	10 d	12 h	1 d	0.001 psu	0.01 psu
78	OOPC	Coastal sea level change	100 km	1000 km			1 h	10 d	1 h	1 d	0.01 mm	0.1 mm
79	OOPC	Sea surface temperature	1 km	500 km			1 h	1 d	3 h	12 h	0.1 C	0.2 C
80	OOPC	Sea-ice thickness	100 km	500 km			1 h	7 d	1 h	1 d	0.1 cm	1 cm
81	OOPC	Ocean carbon content change	50 km	100 km	10 m	10 m	10 y	5 y	1 y	2 y	)IC/1 umol/k	IC/2 umol/k
82	OOPC	Air-sea delta pCO2	5 km	50 km			1 h	30 d	30 d	1 y	1 microatm	3 microatm
83	OOPC	Full depth temperature / salinity	<m along tr	km along tı	2 m	2 m	30 d	10 y	60 d	1 y	)2 C / 0.001 ı	5 C / 0.003
84	TOPC	Fire disturbance (area, location)	250m	10km			30 d	5y	1y	1y	5%	10%
85	TOPC	raction of Absorbed Photosynthetically Active Radiation (FAPAF	0.1 km	2 km			10 d	30 d	10 d	30 d	5 %	10 %
86	TOPC	Glaciers and ice caps (topography, extent)	10 m	100 m	0.1m	1m	1y	5y	1y	1y	5%	10%
87	TOPC	Land cover (incl vegetation type)	10 m	1 km			1 y	5y	1y	1y	5%	10%
88	TOPC	Land surface topography	250m	10km	1m	10m	5y		1y	1y	5%	10%
89	TOPC	Leaf Area Index (LAI)	250m	10km			1d	30d	30d	90d	5%	10%
90	TOPC	Permafrost and seasonally-frozen ground	250m	10km	1m	10m	1y	5y	1y	1y	5%	10%
91	TOPC	Snow cover (for impact and hydrological cycle studies)	250m	10km	0.1m	1m	1 d	30d	30d	1y	5%	10%
92	TOPC	Soil moisture	25 km	50km			7d	30d	1y	1y	5%	10%
93	TOPC	Biomass	250m	10km			1 d	30d	30 d	90 d	5%	10%
94	TOPC	River discharge					1d	7d	30d	90d	5%	10%
95	TOPC	Lake level/area	10m	100m	0.01m	1m	7d	30d	30d	90d	5%	10%
96	TOPC	Groundwater	1km	10km	0.05m	1m	30 d	1y	30d	90d	5%	10%
97	TOPC	Water use	1km	10km			7d	30d	30d	90d	5%	10%
98	TOPC	Albedo	250m	10km			1d	30d	30d	90d	5%	10%
99	TOPC	Wetland extent	250m	10km			7d	30d	30d	90d	5%	10%

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Appendix 3

UNFCCC Conference of the Parties (COP-10)

Decision 5/CP.10

Implementation of the global observing system for climate

The Conference of the Parties,

Having considered the recommendations of the Subsidiary Body for Scientific and Technological Advice at its twenty-first-session,

1. *Expresses its appreciation* to the Global Climate Observing System for preparing the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (hereinafter referred to as the implementation plan);

2. *Welcomes* the emphasis given in the implementation plan to enhancing the participation of developing countries, in particular the least developed countries and small island developing States, in the global observing system for climate;

3. *Encourages* Parties to strengthen their efforts to address the priorities identified in the implementation plan, and to implement the priority elements in the regional action plans relating to the global observing systems for climate;

4. *Encourages* Parties to enhance their work and collaboration on observation of the essential climate variables and on development of climate products to support the needs of the Convention, including through participation in the Global Climate Observing System cooperation mechanism;

5. *Invites Parties* that support space agencies involved in global observations to request these agencies to provide a coordinated response to the needs expressed in the implementation plan;

6. *Requests* the secretariat of the Global Climate Observing System to provide information to the Subsidiary Body for Scientific and Technological Advice at its twenty-third session (November 2005) and, as required, at subsequent sessions, on how the actions identified in the implementation plan are being implemented.

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Appendix 4

GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles[19]:

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 is required.

3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.

4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.

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

6. Operation of historically-uninterrupted stations and observing systems should be maintained.

7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.

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

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

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

Furthermore, operators of 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.

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[19] The 10 basic principles (in paraphrased form) 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. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

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

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

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

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

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

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

GCOS Essential Climate Variables[20]

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

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **Upper-air:** Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. **Composition:** Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[21], Aerosol properties.
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial[22]	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance.

[20] 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).

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

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

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Appendix 6

Definition of Requirement Categories

Accuracy:
Measured by the bias or systematic error of the data, i.e. the difference between the short-term average measured value of a variable and the truth. The short-term average is the average of a sufficient number of successive measurements of the variable under identical conditions, such that the random error is negligible relative to the systematic error.

Stability:
The extent to which accuracy remains constant with time. Stability is measured by the maximum excursion of the short-term average (e.g., daily, monthly, seasonal) measured value of a variable under identical conditions over the long term, e.g. a decade. The smaller the maximum excursion, the greater the stability of the dataset.

Horizontal resolution:
Usually means sampling distance. In the case of images, horizontal resolution means the image resolution.

Vertical resolution:
Means vertical sampling distance or average spacing of independent pieces of information.

Observing cycle:
The required interval between two successive observations. For applications of global nature, this is the time needed for the whole Earth surface to be observed at least once within each grid square of size equal to the horizontal resolution and with the specified accuracy.

Calibration:
The process of quantitatively defining system responses to known, controlled signal inputs. Thus, a calibrated product is the output from the complete calibrated data generation chain. Vicarious calibration is indirect calibration achieved by simulating the signal at the satellite sensor input based on independently measured geophysical parameters, and comparing it to the actual signal measured by the sensor. The outcome of the comparison can be used to calibrate the sensor output.

Validation:
The process of assessing, by independent means, the quality of the data products derived from system outputs. Validation ensures that the quality of the products is properly assessed, via quantification of the uncertainties in Level 1b and Level 2 products. Thus, a validated product is the output from the complete validated data generation chain. Geophysical validation is the process of assessing, by independent means, the quality of geophysical data products derived from the system.

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Appendix 7

Glossary of Acronyms

2AR	GCOS SECOND ADEQUACY REPORT (THE SECOND REPORT ON THE ADEQUACY OF THE GLOBAL OBSERVING SYSTEMS FOR CLIMATE IN SUPPORT OF THE UNFCCC (GCOS-82))
AATSR	ADVANCED ALONG TRACK SCANNING RADIOMETER
ADM/AEOLUS	ATMOSPHERIC DYNAMICS MISSION AEOLUS (ESA)
AERONET	AEROSOL ROBOTIC NETWORK
AIRS	ATMOSPHERIC INFRARED SOUNDER (NASA)
ALOS	ADVANCED LAND OBSERVING SATELLITE (JAXA)
AMSR	ADVANCED MICROWAVE SCANNING RADIOMETER (JAXA)
AMSU	ADVANCED MICROWAVE SOUNDING UNIT (NOAA)
AMV	ATMOSPHERIC MOTION VECTOR
AOPC	ATMOSPHERIC OBSERVATION PANEL FOR CLIMATE
ASAR	ADVANCED SYNTHETIC APERTURE RADAR (ESA)
ASCAT	ADVANCED SCATTEROMETER (EUMETSAT)
ASTER	ADVANCED SPACEBORNE THERMAL EMISSION AND REFLECTION RADIOMETER (NASA)
ATSR	ALONG TRACK SCANNING RADIOMETER
AVHRR	ADVANCED VERY HIGH RESOLUTION RADIOMETER (NOAA)
BRDF	BIDIRECTIONAL REFLECTION DISTRIBUTION FUNCTION
BIRD	BI-SPECTRAL INFRARED DETECTION INSTRUMENT
BSRN	BASELINE SURFACE RADIATION NETWORK
BUFR	BINARY UNIVERSAL FORM FOR THE REPRESENTATION OF METEOROLOGICAL DATA
CALIPSO	CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATIONS
CASIX	CENTRE FOR OBSERVATION OF AIR-SEA INTERACTIONS AND FLUXES
CBS	COMMISSION FOR BASIC SYSTEMS (WMO)
CEOS	COMMITTEE ON EARTH OBSERVATION SATELLITES
CIMO	COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION (WMO)
CFC	CHLOROFLUOROCARBON
CGMS	COORDINATION GROUP FOR METEOROLOGICAL SATELLITES
CHAMP	CHALLENGING MINISATELLITE PAYLOAD (GERMANY)
CHy	COMMISSION FOR HYDROLOGY (WMO)
CliC	CLIMATE AND CRYOSPHERE PROJECT (WCRP)
CLIVAR	CLIMATE VARIABILITY AND PREDICTABILITY PROJECT (WCRP)
CMAP	CLIMATE MODELING, ANALYSIS AND PREDICTION PROGRAM (US NSF)
CMIS	CONICAL SCANNING MICROWAVE IMAGER/SOUNDER (NOAA)
CONAE	COMISION NACIONAL DE ACTIVIDADES ESPACIALES (ARGENTINA)
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)
DAAC	DISTRIBUTED ACTIVE ARCHIVE CENTER (NASA)
DEM	DIGITAL ELEVATION MODEL
DMSP	DEFENSE METEOROLOGICAL SATELLITE PROGRAM (USA)
ECV	ESSENTIAL CLIMATE VARIABLE (AS DEFINED BY GCOS SECOND ADEQUACY REPORT (GCOS-82))
ENSO	EL NINO SOUTHERN OSCILLATION
ENVISAT	ENVIRONMENTAL SATELLITE (ESA)
ERA	ECMWF RE-ANALYSIS PROJECT
ERB	EARTH RADIATION BUDGET
ERS	EUROPEAN REMOTE SENSING SATELLITE (ESA)
ESA	EUROPEAN SPACE AGENCY

ETM	ENHANCED THEMATIC MAPPER (USGS LANDSAT)
EUMETSAT	EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FAPAR	FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION
FCDR	FUNDAMENTAL CLIMATE DATA RECORD
FRP	FIRE RADIATED POWER
GAW	GLOBAL ATMOSPHERE WATCH (WMO)
GCM	GENERAL CIRCULATION MODEL
GCMP	GCOS CLIMATE MONITORING PRINCIPLE
GCOM	GLOBAL CHANGE OBSERVATION MISSION (JAXA)
GCOS	GLOBAL CLIMATE OBSERVING SYSTEM
GEO	GROUP ON EARTH OBSERVATIONS
GEOSAT	GEODETIC SATELLITE (US NAVY)
GEOSS	GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS
GEWEX	GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (WCRP)
GFO	GEOSAT FOLLOW-ON
GHG	GREENHOUSE GAS
GIP	GCOS IMPLEMENTATION PLAN (IMPLEMENTATION PLAN FOR THE GLOBAL OBSERVING SYSTEM FOR CLIMATE IN SUPPORT OF THE UNFCCC (GCOS-92))
GLAS	GEOSCIENCE LASER ALTIMETER SYSTEM (NASA)
GLFC	GLOBAL LAND COVER FACILITY
GLIMS	GLOBAL LAND ICE MEASUREMENTS FROM SPACE
GMES	GLOBAL MONITORING FOR ENVIRONMENT AND SECURITY
GMS	GEOSTATIONARY METEOROLOGICAL SATELLITE (JMA)
GODAE	GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT
GOES	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE (NOAA)
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)
GPCP	GLOBAL PRECIPITATION CLIMATOLOGY PROJECT
GPS	GLOBAL POSITIONING SYSTEM
GPS/MET	GLOBAL POSITIONING SYSTEM METEOROLOGY
GRACE	GRAVITY RECOVERY AND CLIMATE EXPERIMENT
GRAS	GLOBAL NAVIGATION SATELLITE SYSTEM RECEIVER FOR ATMOSPHERIC SOUNDING
GSICS	GLOBAL SPACE-BASED INTERCALIBRATION SYSTEM
GSN	GCOS SURFACE NETWORK
GSOP	GLOBAL OBSERVATIONS AND SYNTHESIS PANEL (WCRP CLIVAR)
GTN-G	GLOBAL TERRESTRIAL NETWORK FOR GLACIERS
GTN-H	GLOBAL TERRESTRIAL NETWORK FOR HYDROLOGY
GTN-L	GLOBAL TERRESTRIAL NETWORK FOR LAKES
GTN-P	GLOBAL TERRESTRIAL NETWORK FOR PERMAFROST
GTOS	GLOBAL TERRESTRIAL OBSERVING SYSTEM
GUAN	GCOS UPPER-AIR NETWORK
GWSP	GLOBAL WATER SYSTEM PROJECT
HALOE	HALOGEN OCCULTATION EXPERIMENT
HCFC	HYDROCHLOROFLUOROCARBONS
HFC	HYDROFLUOROCARBONS
HIRDLS	HIGH RESOLUTION DYNAMICS LIMB SOUNDER
HIRS	HIGH RESOLUTION INFRARED RADIATION SOUNDER (NOAA)
IAGOS	INTEGRATION OF ROUTINE AIRCRAFT MEASUREMENTS INTO A GLOBAL OBSERVING SYSTEM
IASI	INFRARED ATMOSPHERIC SOUNDING INTERFEROMETER (EUMETSAT)
IPAB	INTERNATIONAL PROGRAMME FOR ANTARCTIC BUOYS
IPAP	ICE PILOT APPLICATIONS PROJECT

ICESat	ICE, CLOUD AND LAND ELEVATION SATELLITE (NASA)
ICSU	INTERNATIONAL COUNCIL FOR SCIENCE
IFOV	INSTANTANEOUS FIELD OF VIEW
IGAC	INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY PROGRAM (IGBP)
IGACO	INTEGRATED GLOBAL ATMOSPHERIC CHEMISTRY OBSERVATIONS
IGBP	INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME
IGOS	INTEGRATED GLOBAL OBSERVING STRATEGY
IGOS-P	INTEGRATED GLOBAL OBSERVING STRATEGY PARTNERSHIP
INDREX	INDONESIAN RADAR EXPERIMENT
IOC	INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)
IOCCG	INTERNATIONAL OCEAN COLOUR COORDINATING GROUP
IOCCP	INTERNATIONAL OCEAN CARBON COORDINATION PROJECT
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IP	IMPLEMENTATION PLAN
IR	INFRARED SPECTRAL RANGE
ISCCP	INTERNATIONAL SATELLITE CLOUD CLIMATOLOGY PROJECT
ITASE	INTERNATIONAL TRANS-ANTARCTIC SCIENTIFIC EXPEDITION
ITWG	INTERNATIONAL TOVS WORKING GROUP
IWWG	INTERNATIONAL WINDS WORKING GROUP (CGMS)
JAXA	JAPAN AEROSPACE EXPLORATION AGENCY
JERS	JAPAN EARTH RESOURCES SATELLITE (JAXA)
JRA	JAPANESE RE-ANALYSIS PROJECT
JRC	JOINT RESEARCH CENTRE (EUROPEAN COMMISSION)
LAI	LEAF AREA INDEX
LCCS	UN LAND COVER CLASSIFICATION SYSTEM
LST	LAND SURFACE TEMPERATURE
LW	LONGWAVE SPECTRAL RANGE
MERIS	MEDIUM RESOLUTION IMAGING SPECTROMETER (ESA)
METOP	METEOROLOGICAL OPERATIONAL POLAR SATELLITE
MHS	MICROWAVE HUMIDITY SOUNDER (EUMETSAT)
MIPAS	MICHELSON INTERFEROMETER FOR PASSIVE ATMOSPHERIC SOUNDING
MISR	MULTIANGLE IMAGING SPECTRORADIOMETER
MLS	MICROWAVE LIMB SOUNDER (NASA)
MODIS	MODERATE RESOLUTION IMAGING SPECTRORADIOMETER (NASA)
MOZAIC	MEASUREMENT OF OZONE ON AIRBUS IN-SERVICE AIRCRAFT
MSG	METEOSAT SECOND GENERATION
MSS	MULTISPECTRAL SCANNER (LANDSAT)
MSU	MICROWAVE SOUNDING UNIT (NOAA)
MTSAT	MULTI-FUNCTIONAL TRANSPORT SATELLITE (JMA)
MW	MICROWAVE SPECTRAL RANGE
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (USA)
NCDC	NATIONAL CLIMATIC DATA CENTER (NOAA)
NDACC	NETWORK FOR THE DETECTION OF ATMOSPHERIC COMPOSITION CHANGE (FORMERLY: NDSC – NETWORK FOR THE DETECTION OF STRATOSPHERIC CHANGE)
NESDIS	NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE (NOAA)
NIR	NEAR INFRARED SPECTRAL RANGE
NOAA	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (USA)
NPOESS	NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM
NPP	NPOESS PREPARATORY PROJECT
NSIDC	NATIONAL SNOW AND ICE DATA CENTER (USA)
NWP	NUMERICAL WEATHER PREDICTION
NWS	NATIONAL WEATHER SERVICE (USA)
OCO	ORBITING CARBON OBSERVATIONS
OMI	OZONE MONITORING INSTRUMENT
OOPC	OCEAN OBSERVATIONS PANEL FOR CLIMATE
PAR	PHOTOSYNTHETICALLY ACTIVE RADIATION

PARASOL	POLARIZATION AND ANISOTROPY OF REFLECTANCES FOR ATMOSPHERIC SCIENCES COUPLED WITH OBSERVATIONS FROM A LIDAR (CNES)
PARCA	PROGRAM FOR ARCTIC REGIONAL CLIMATE ASSESSMENT
PFC	PERFLUOROCARBONS
POLDER	POLARIZATION AND DIRECTIONALITY OF THE EARTH'S REFLECTANCES (CNES)
QUIKSCAT	QUICK SCATTEROMETER (NASA)
RO	RADIO OCCULTATION
SAC	ARGENTINE SATELITE DE APLICACIONES CIENTIFICAS (ARGENTINA)
SAGE	STRATOSPHERIC AEROSOL AND GAS EXPERIMENT
SAR	SYNTHETIC APERTURE RADAR
SBSTA	SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE (UNFCCC/COP)
SBUV	SOLAR BACKSCATTER ULTRAVIOLET RADIOMETER
SCAR	SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH
SCIAMACHY	SCANNING IMAGING ABSORPTION SPECTROMETER FOR ATMOSPHERIC CARTOGRAPHY
SEAWIFS	SEA-VIEWING WIDE FIELD-OF-VIEW SENSOR (NASA)
SEVIRI	SPINNING ENHANCED VISIBLE AND INFRARED IMAGER (EUMETSAT)
SHADOZ	SOUTHERN HEMISPHERE ADDITIONAL OZONESONDES
SIRAL	SAR INTERFEROMETRIC RADAR ALTIMETER
SMMR	SCANNING MULTICHANNEL MICROWAVE RADIOMETER
SMOS	SOIL MOISTURE AND OCEAN SALINITY MISSION
SOOP	SHIP OF OPPORTUNITY PROGRAMME
SPARC	STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE CHANGE (WCRP)
SPOT (VGT, HRV)	SATELLITE POUR L'OBSERVATION DE LA TERRE (VEGETATION, HIGH RESOLUTION)
SSM/I	SPECIAL SENSOR MICROWAVE/IMAGER
SSMIS	SPECIAL SENSOR MICROWAVE IMAGER/SOUNDER
SSM/T2	SPECIAL SENSOR MICROWAVE TEMPERATURE/HUMIDITY SOUNDER
SSS	SEA-SURFACE SALINITY
SST	SEA-SURFACE TEMPERATURE
SW	SHORTWAVE SPECTRAL RANGE
SWE	SNOW WATER EQUIVALENT
SWH	SIGNIFICANT WAVE HEIGHT
SWIR	SHORTWAVE INFRARED SPECTRAL RANGE
TCDR	THEMATIC CLIMATE DATA RECORD
TES	TROPOSPHERIC EMISSION SPECTROMETER
TIR	THERMAL INFRARED SPECTRAL RANGE
TIROS	TELEVISION INFRARED OBSERVATION SATELLITE (NOAA)
TM	THEMATIC MAPPER (USGS LANDSAT)
TOA	TOP OF ATMOSPHERE
TOMS	TOTAL OZONE MAPPING SPECTROMETER (NASA)
TOPC	TERRESTRIAL OBSERVATION PANEL FOR CLIMATE
TOPEX/POSEIDON	OCEAN SURFACE TOPOGRAPHY ALTIMETER EXPERIMENT (NASA/CNES)
TOVS	TIROS OPERATIONAL VERTICAL SOUNDER (NOAA)
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 SPECTRAL RANGE
VIIRS	VISIBLE/INFRARED IMAGER RADIOMETER SUITE (NPOESS)
VIS	VISIBLE SPECTRAL RANGE

VITO	VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (FLEMISH INSTITUTE FOR TECHNOLOGICAL RESEARCH, BELGIUM)
VOS	V OLUNTARY OBSERVING SHIP
VOSCLIM	VOLUNTARY OBSERVING SHIP CLIMATE PROJECT
WaTER	THE WATER ELEVATION RECOVERY SATELLITE MISSION
WCRP	WORLD CLIMATE RESEARCH PROGRAMME
WDC	WORLD DATA CENTRE
WGARO	WORKING GROUP ON ATMOSPHERIC REFERENCE OBSERVATIONS (AOPC)
WGCV	WORKING GROUP ON CALIBRATION AND VALIDATION (CEOS)
WGMS	WORLD GLACIER MONITORING SERVICE
WMO	WORLD METEOROLOGICAL ORGANIZATION
WOAP	WCRP OBSERVATION AND ASSIMILATION PANEL
WSOA	WIDE SWATH OCEAN ALTIMETER (NASA)

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