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 (GCOS-92)"

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Please refer to line numbers and/or table numbers when making comments.

GCOS Secretariat

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Editor's Note:

As the introduction to this document notes, the GCOS Implementation Plan (GIP) sought to have a careful judgment of the key elements that we considered practical to monitor on a global scale and were feasible within a decade. A focal concern in the GIP was supporting all aspects of the GCOS Climate Monitoring Principles (GCMP) for these key products so that they could really monitor climate change and climate variability according to UNFCCC needs. The GIP noted that there would remain, outside the Plan, a changing research-driven element of more refined observations that would aid interpretation and understanding of the elements that were included in the Plan. It was also assumed that this research component should be debated almost continuously in the light of scientific and technological progress. In this document, some mention is made of this vital and continuing research component, especially for variables for which further research is needed to allow more effective monitoring at a later time. However this report does not try to detail this research component as an additional requirement. Instead, the intention is to detail the monitoring requirements that we believe are practical and feasible, and to add, as in the GIP, only a few key emerging supplementary products of particular relevance to the needs of the UNFCCC.

Please review the present draft with this intended scope in mind.

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Executive Summary

This document provides supplemental detail to the requirements of the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* ('GCOS Implementation Plan', GCOS-92, October 2004) for climate products derived from satellites. The detailed specifications, often in conjunction with in-situ data for calibration and validation, have been made traceable to the GCOS Implementation Plan. The document is intended to assist Parties that support and/or use Earth observation from space in working with their Space Agencies to respond to the requirements of the GCOS Implementation Plan. This should be done 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 context of the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*

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

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

The GCOS Implementation Plan considers a balanced and integrated observing system that depends upon sustaining in-situ and satellite-based measurements. Both these systems are vital, and the emphasis given in this particular report to satellite measurements is not a reflection of priority, but a technical detailing of the opportunity to meet the implementation plan needs for satellite measurements and their derived products.

The role of Earth Observation Satellites

Satellites now provide a vital and important means of obtaining observations of the climate system from a near-global perspective and assessing the behaviour of different parts of the globe. A detailed global climate record for the future critically depends upon a major satellite component. However, for satellite data to contribute fully and effectively to the determination of long-term records, they must be part of a system implemented and operated in an appropriate manner to ensure that these data are accurate and homogeneous enough for climate.

The details relating to satellites in this document cover the GCOS Implementation Plan needs for many issues, including the 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; and undertaking reprocessing of all data relevant to climate for inclusion in integrated climate analyses and reanalyses.

In view of the increasing maturity and potential of current and future satellite measurements, this document details a clear and timely opportunity for those Parties that support Earth observation from space to provide all Parties, and their science communities involved in, e.g., WCRP and IPCC, with major advances in multi-decadal analyses of Essential Climate Variables. These should be linked with ongoing analysis and research activities, both of which would greatly improve our ability to support the needs of the UNFCCC and the needs of other key societal application areas.

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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 (GCOS-92)"

1. INTRODUCTION

1.1. Purpose of this document

This document provides supplemental detail to the requirements of 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') for climate products derived from satellites. The detailed specifications, often in conjunction with in-situ data for calibration and validation, have been made traceable to the GCOS Implementation Plan. The document is intended to assist Parties supporting Earth observation from space, and/or supporting the use of such observations in generation of climate products, working with their Space Agencies and in conjunction with the 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), in responding to the requirements of the GCOS Implementation Plan[1].

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, as well as covering the needs of the climate research community, mainly acting through WCRP, for sustained long-term climate monitoring. While this particular document considers mainly the satellite-based measurements, the GCOS Implementation Plan notes the equally vital roles of *in situ* and satellite-based measurements and seeks to balance these to form an effective integrated observing system. The GCOS Implementation Plan actions related to satellite-based observation detailed in this supplement would however provide a major enhancement to capabilities for global monitoring of climate and in many cases are expected to be linked to other societal needs as well, for example to weather forecasting, agriculture, and land use management.

Outside the GCOS Implementation Plan there remains an important changing research driven element of more refined observations that aid interpretation and understanding of the systematic elements sought here. This research component is to be debated on a continuous basis, as, with time, new research missions will be considered in relation to science needs. In places, in this report, possible components of these vital research missions are mentioned. They will also, in part, contribute to the creation of climate data records, and pioneer future monitoring capabilities.

Reviews of the specifications given in this report at regular intervals are crucial to account for ongoing scientific and technological progress.

1.2. Basis provided by the GCOS Implementation Plan

[GIP][2] 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[3] (ECVs) and their associated products that are required by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The GCOS

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

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

[3] 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.

Implementation Plan draws on the views of the Parties on the 'Second Adequacy Report'[4] 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 would provide information to:

- Characterize the state of the global climate system and its variability;
- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- 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 covers WCRP and IPCC needs for sustained data and products for climate monitoring, and meets many other sustained observational needs of the climate research community[5]. The Plan considers both the generation of fundamental climate data records of calibrated observations from satellites, and the equally challenging generation of products for use in monitoring global climate change.

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.

In order to set priorities, criteria for placing items within the current or near-future implementation time-line 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.

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 data sets 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.

[4] 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).

[5] 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.

1.3. Climate Variables, Datasets and Products considered in this Report

As noted, the focus of this report will be on actions related to the essential climate variables (ECVs) whose monitoring is judged to be currently feasible with satellite observations (see Table 2). In addition, and consistent with the GCOS Implementation Plan, attention is also given to some of the important variables for which it may prove after research to be possible to monitor with satellite observations. For each of these variables, the document focuses on the needed satellite measurements in term of fundamental climate data records and the need for products. The terms “fundamental climate data records” and “products” are defined as follows:

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 discussed in more detail for each variable considered in the main part of this report. This is important as while satellite observations provide the only technique to support truly global monitoring, they have limitations in this respect due to such sampling.

The term “Product” denotes, in the context of this report, geophysical variables derived from FCDRs, often generated by blending satellite observations, in-situ data and models (other documents use the term “Thematic Climate Data Record” (TCDR)[6] for such products). For FCDRs as well as products, their development requires strong collaboration between space agencies and relevant research and operational groups, to ensure that the climate products are continually being refined and extended. Experience has demonstrated that complex climate products should be generated by independent teams in a collaborative manner. Adequate meta-data are required along with the products to ensure repeatability and incremental improvement.

Table 2. [GIP] ECVs largely dependent upon satellite observations

Domain	Variables
Atmospheric (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction (especially over the oceans), Water vapour, Cloud properties, Carbon dioxide, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity).
Terrestrial	Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Fire disturbance.[7]

The list of ECVs is expected to evolve as scientific requirements change and as technological developments permit.

[6] 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.

[7] Soil Moisture and Biomass are variables recognized in the GCOS Implementation Plan, but needing further research before sustained monitoring can be considered.

1.4. The Satellite Component of the GCOS Implementation Plan

As noted in the GIP, 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 2). A detailed global climate 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 (see Appendix 4), addressing the following satellite-specific key operational issues

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

Recently, all space agencies have agreed to seek 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 ensuring that the accuracy and homogeneity of the FCDRs and derived products are monitored, which will significantly enhance the value of satellite observations to the global observing system for climate.

By virtue of committing to the recommendations for climate datasets and products provided 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 detailed specifications being developed in the context of this report will allow updates to the climate monitoring part of the CEOS/WMO database that GCOS maintains, and which contains summary requirements from different application areas and spaceborne instruments capabilities (see Appendix 2). 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.

1.5. Societal benefits of 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), such as Weather, Water, Agriculture, Health and Energy. For example, the value of a validated, routinely-produced global precipitation product would not be limited to weather and climate forecasts, but also have a high impact on agricultural planning, forestry and water management. Full implementation of the system as proposed by the GCOS Implementation Plan, including the refined products recommended in this report, would therefore not only benefit the systematic observation of climate, but also link with other application needs and have a much wider bearing on societies.

1.6. Scientific oversight

Continuous scientific oversight and priority advice for the FCDRs is recommended to be assigned to scientific advisory groups, working in cooperation with, GCOS, GOOS and GTOS Science Panels, the WCRP Observations and Assimilation Panel (WOAP), and other involved bodies and in turn advising CEOS and its working groups, and other involved bodies such as the WMO Space Programme and CGMS. These advisory groups should assigned or formed exploiting existing activities, groups and linkages. Where possible, existing appropriate groups are identified as agents for action in this report. For all the products called for in this document, establishment of working groups to compare and refine the climate products being generated routinely by independent teams is recommended.

1.7. Structure of this Document

This document identifies cross-cutting actions to be developed with space agencies and outlines the requirements from space agencies with respect to products for Essential Climate Variables as given in Table 2. For each domain (Atmosphere, Oceans, Terrestrial), a distinction is made between products that are feasible with today's capabilities, in some cases extended back to multi-decadal time scales, and products that are preliminary or as yet non-existent, requiring emerging capabilities and further research ("Emerging products"). For comprehensive reference and future guidance, reference should be made to the GCOS Implementation Plan and the actions therein where space agencies have been identified as 'Agents for Implementation' (see Appendix 1).

Section 2 elaborates on general needs that cut across the atmospheric, oceanic and terrestrial domains. Refined products for each of these domains are identified in the following Section 3. Due to the broad range of ECVs addressed, the nature of requirements differs depending on the domain and the variable in question.

Citations from existing documents are flagged throughout this document: [GIP] denotes the GCOS Implementation Plan, [2AR] the Second Adequacy Report, [2TS] the Second Adequacy Report Technical Supplement, respectively.

2. CROSS-CUTTING NEEDS

There are many common, cross-cutting needs for each of the essential climate variables considered, which include:

C.1 Generation of Fundamental Climate Data Records and Derived Products

C.1.1 Establish product analyses and provision of homogeneous Fundamental Climate Data Records, supported by periodic reprocessing

C.1.2 Maintain research efforts on global datasets and sustain the generation of independently-processed datasets as a means of determining the confidence that can be placed in estimated trends

C.1.3 Maintain strong links between reprocessing and calibration/validation activities to facilitate continuing improvement.

Remarks:

- While observations of the variables are an essential pre-requisite, users of climate information generally require analysed outputs and products
- Whenever possible the required data sets 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
- Operational[8] analysis centres for some atmospheric variables are in place, but additional operational analyses are required for these activities, especially for oceanic and terrestrial variables
- International coordination of activities under C.1 is highly desirable to take advantage of advances, , and promote efficiency, complementarity and cooperation rather than competition (see also C.3)
- In many climate applications, the assessment of the calibrated radiances, i.e. the FCDR, is the critical and required observable. This necessitates open access to those FCDRs along with comprehensive metadata. It is understood that the derivation of the FCDRs is generally the responsibility of the satellite instrument operators because the derivation of FCDRs requires substantial understanding of the instrument specific science
- Although satellite remotely-sensed data are a primary source for observing an ECV, *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
- Reference: GIP Action C8, C10, C11, C12, GIP Executive Summary Key Action 23

C.2 International Coordination of Reanalysis Activities

Strengthen links with and between the major reanalysis centres, through the GCOS Atmospheric Observing Panel for Climate and the WCRP Observations and Assimilation Panel, to ensure clear specification of current and developing needs for reprocessed satellite datasets, for example for use in reanalysis. The requirements for datasets for reanalysis specified below will be refined by this process.

Remarks:

- 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 observations (e.g., in-situ and remote sensing measurements)
- International 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 reanalysis systems and the ingested observational data
- The availability of national holdings of historical datasets, including comprehensive metadata, to International Data Centres is vital for the effective conduct of reanalysis.
- Reference: GIP Action C13

[8] "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.3 Detailed Specification of Fundamental Climate Data Records and Derived Products

Establish detailed specifications for each product in consultation with appropriate scientific advisory groups

Remarks:

- An initial set of requirements has been developed in the latter part of this report, with references given to other agents for action and consultation
- The specifications in this report build mainly on the GCOS Implementation Plan, but also have been cross-checked with the WMO/CEOS database[9] and the report by Ohring et al. (2005)[10] on satellite instrument calibration to measure climate change.

C.4 Emerging Products

Intensify efforts to further develop emerging operational[11] capabilities for research-based variables

Remarks:

- Research is needed to overcome a the current limitations of techniques for climate-quality measurements (in terms of e.g., instruments, algorithms, calibration/validation, resolution, cost) of some key and a few emerging potential ECVs (both *in-situ* and remotely-sensed observations)
- 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 climate data records.
- Reference: GIP Section 3.8

C.5 Archiving and Dissemination

C.5.1 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,
- enable reprocessing and reanalysis.

C.5.2 Ensure that data policies facilitate the exchange and archiving of all ECV data and associated metadata

Remarks:

- Implementation needs in this context involve archiving of all satellite metadata so that long-term sensor and platform performance is traceable
- The creation of Climate Data Records from all relevant satellite systems requires the organization of data service systems that ensures an on-going accessibility to the data into the future.
- Reference: GIP Actions C20, C21

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[9] As described in the *Manual of the CEOS/WMO Database on User Requirements and In-Situ and Space Capabilities* (Committee on Earth Observation Satellites, Issue 1.3, March 2001) and at http://alto-stratus.wmo.int/sat/stations/SatSystem.html

[10] 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.

[11] "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.6 Unique Fundamental Datasets

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

The needs expressed by C.1 to C.6 are general pre-requisites and accompanying measures for the generation of each of the products related to ECVs and are specified as appropriate in subsequent sections. However, some cross cutting actions span variables and are most easily presented here separately from the individual products. These common issues include:

C.7 Improved Community Awareness of Available and Planned Satellite Data Records

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

C.8 Exploiting Opportunities for Instrument Cross-Calibration

Satellite-to-satellite intercomparison and satellite fly-over of relevant in-situ sites provide an opportunity to improve satellite-based climate records. Such activities could be better coordinated by considering the concept of the Global Space-based Inter-Calibration System (GSICS), currently under development by CGMS and WMO. Maintaining a database of points of common satellite viewpoints, including designated radiosonde and surface-based measurement sites, and airborne measurements, is required to supplement this concept.

3. PRODUCTS

GCOS recommends the following products for priority action by the space agencies. 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.

GCOS also recommends several emerging products to be the focus of ongoing research and the future development of operational capabilities by the space agencies ("Emerging").

Table 3: Overview of Products – Atmosphere

Product No	Feasible Today or Emerging (F/E)	Product Specification	ECV(s) Addressed	Reference Action in GIP
A.1	F	Surface vector wind analyses, particularly from reanalysis, supported by satellite data over the oceans	Surface Wind Speed and Direction	A11
A.2	F	Homogenized upper-air temperature analyses: A.2.1 Extended MSU-equivalent temperature record A.2.2 New record for upper-troposphere and lower stratosphere temperature using data from radio occultation A.2.3 New record using high spectral resolution infrared soundings A.2.4 Detailed 3-D products obtained using reanalysis (see A.8), using all relevant available datasets	Upper-air Temperature	A19, A20
A.3	F	A.3.1 Total column water vapour over the ocean A.3.2 Total column water vapour over land A.3.3 Upper-tropospheric humidity A.3.4 Tropospheric profiles of water vapour	Water Vapour	A7, A21
A.4	F	Fields of cloud radiative properties (key ISCCP products in particular)	Cloud properties	A22, A23
A.5	F/E	Improved estimates of precipitation, both as derived from specific satellite instruments and as provided by composite products	Precipitation	A6, A7, A8, A9
A.6	F	Global estimate of top-of-atmosphere Earth radiation budget on a continuous basis at high spectral resolution and with adequate spatial and temporal sampling	Earth Radiation Budget	A24
A.7	F/E	A primary climate data record for profile and total column of ozone	Ozone	A25, A26
A.8	F	Atmospheric reanalyses supported by reprocessing of key satellite data streams		C13
A.9	E	Fields of aerosol optical depth, supported by single scattering albedo and phase function, and the sampling of vertical profiles of aerosol properties at regular time intervals	Aerosols	A31, A25, A26
A.10	E	Estimates of the global distribution of greenhouse gases, such as CO2 and CH4, of sufficient quality to estimate regional sources and sinks	Carbon dioxide, methane and other GHG	A25, A26, A27
A.11	E	Upper-air wind analyses, particularly from reanalysis, supported by additional emerging observation types: A.11.1 Atmospheric Motion Vectors in polar regions A.11.2 Satellite line-of-sight winds	Upper-air Wind	Section 4.2.2

Table 4: Overview of Products – Oceans

Product No	Feasible today or Emerging (F/E)	Product Specification	ECV(s) addressed	Reference Action in GIP
O.1	F	Continuous gridded sea-ice extent and concentration. Supplemental measurements of sea-ice concentration, thickness, drift, surface temperature and albedo from research missions and other operational missions	Sea Ice	O23, O24
O.2	F	Global sea-level maps and a record of global sea-level variability	Sea Level	O12
O.3	F	Global mapping of sea surface temperature	Sea Surface Temperature	O9, O10
O.4	F	Global gridded time series of ocean colour and oceanic chlorophyll-a concentration derived from ocean colour	Ocean colour	O18
O.5	F	Global gridded time series of wave height and other measures of sea state (wave direction, wavelength, time period)	Sea State	O19
O.6	F	Ocean reanalysis utilizing altimeter and ocean surface satellite measurements	Mainly subsurface variables	
O.7	E	Demonstrate capability to measure changes in sea surface salinity from space and develop plans for ongoing missions to maintain a continuous record of sea surface salinity over at least 20 years	Ocean salinity	

Table 5: Overview of Products – Terrestrial

Product No	Feasible today or Emerging (F/E)	Product Specification	ECV(s) addressed	Reference Action in GIP
T.1	F	T.1.1 Gridded map of the areas of lakes in the Global Terrestrial Network for Lakes (GTN-L) T.1.2 Regular estimates of lake level of all lakes in the Global Terrestrial Network for Lakes (GTN-L) T.1.3 Gridded map of surface temperature of lakes in the Global Terrestrial Network for Lakes (GTN-L)	Lakes	T5, T6, T8
T.2	F	T.2.1 Global, georeferenced map (2D outlines) of the areas covered by glaciers other than ice sheets T.2.2 Regular update of the World Glacier Inventory (including parameters such as glacier outlines, mass balance) T.2.3 Continuation of long-term measurements of ice sheet elevation changes for mass balance and estimates of consequent sea level change	Glaciers and Ice Caps	T13, T14
T.3	F	Continuous gridded datasets of snow areal extent	Snow Cover	T11
T.4	F	Retrieve daily global directional hemispherical (black sky) albedo	Albedo	T21
T.5	F	T.5.1 Global, georeferenced maps of land cover type. T.5.2 Global georeferenced map of changes in land cover type T.5.3 Global, georeferenced maps of historical changes in land cover type T.5.4 Global land surface temperature, in conjunction with land cover type	Land Cover	T24, T26, T27
T.6	F	Regular gridded georeferenced global maps of fAPAR	fAPAR	T28
T.7	F	Regular gridded georeferenced global maps of LAI	LAI	T28
T.8	E	Research towards global, above ground forest biomass map and forest biomass change	Biomass	T31
T.9	F	T.9.1 Georeferenced global maps of burnt area T.9.2 Global active fire maps (supplemental to burnt area) T.9.3 Fire radiated power (FRP) (supplemental to burnt area)	Fire disturbance	T33
T.10	E	Research towards global near-surface soil moisture map (up to 10cm soil depth)	(Soil moisture)	T37

3.1. ATMOSPHERE

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

3.1.1. ECV Surface Wind Speed and Direction

[2TS] The surface wind field is the primary driver of the ocean circulation, which transports important amounts of heat, freshwater and carbon globally. It 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.

The following is required for this ECV:

Product A.1 Surface vector wind analyses, particularly from reanalysis, supported by satellite data over the oceans

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

Required spatial and temporal resolution
Short-term accuracy: Mean and quadratic statistics to 10% of the mean speed or ~0.5 ms-1.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Wind vector over sea surface (horizontal):
10km horizontal resolution, 1-hourly observation cycle, 3h delay, 0.5m/s accuracy at 20deg resolution

[No long-term stability defined as yet]

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.
- Continuity currently expected from one satellite (ASCAT on METOP).
- QuikScat successor would provide required second satellite

Calibration, validation and data archiving needs
- Continuing requirement for ground-based transponder network for scatterometer calibration.
- Buoy data essential for calibration/validation.

Adequacy/inadequacy of current holdings
Scatterometer record largely based only on single-satellite coverage.

Immediate action, partnerships and advisory groups
- Implementation of two-satellite system of scatterometer measurements
- Maintenance of passive microwave measurements

- Reprocessing of ERS/QuikScat scatterometer record since 1991, and of SSM/I passive microwave record since 1987, supplemented by data from SMMR from 1979-1984

- CGMS/IWWG, WCRP/WOAP (for delegation as needed)

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

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

Products with Significant Overlap
A.8

3.1.2. ECV Upper-air Temperature

[2TS] Upper-air temperatures are a key dataset for detection and attribution of tropospheric and stratospheric climate change. Temperatures measured by radiosondes are a vital reference against which satellite-based measurements can be calibrated. Upper air temperatures are crucial for separating the various possible causes of global change, and 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, which will significantly improve the monitoring of temperature change. Other atmospheric temperature sounding data play an important role, along with many diverse data sources in reanalyses of all the upper-air variables.

[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 benchmark 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). Data need to be developed for real-time use and exchanged and implemented into operational meteorological data streams. Plans also need to be made to ensure future RO instruments and platforms, including on operational meteorological satellites. Some such plans already exist (such as on METOP).

The following is required for this ECV:

Homogenized upper-air temperature analyses:
Product A.2.1 Extended MSU-equivalent temperature record

Product A.2.2 New record for upper-troposphere and lower stratosphere using data from radio occultation

Product A.2.3 New record using high spectral resolution infrared soundings

Product A.2.4 Detailed 3-D products obtained using reanalysis (see A.8), using all relevant available datasets

Benefits
- Detection of temperature trends and variability in the troposphere and lower stratosphere
- Validation of climate models

- Linkage with trends in surface air temperature

Required spatial and temporal resolution
- Short-term accuracy (for low-frequency fluctuations): 0.5K for temperature variations on time- and space-scales of variations associated with El Nino and volcanic eruptions.
- Long-term stability: 0.04K/decade for troposphere, 0.08K/decade for lower stratosphere

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Atmospheric temperature profile – Lower troposphere up to lower stratosphere":
- *100km horizontal resolution, 0.1km vertical resolution (capturing the boundary layer and tropopause heights), 3-hourly observation cycle, 3h observation delay, 0.5K accuracy*

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Atmospheric temperature profile – Higher stratosphere & mesosphere":
- *100km horizontal resolution, 2km vertical resolution, 3-hourly observation cycle, 3h observation delay, 1K accuracy*

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 polar orbit using instruments with spectral and scanning characteristics, chosen to provide continuity with the past record

(A.2.2) FCDR of GPS radio occultation (RO) data record from past and current missions, for example through:
- RO, providing independent, self-calibrating temperature data in the upper troposphere and lower stratosphere with higher vertical resolution. A long-term network of RO measurements needs to be established, to continue the record established by CHAMP, COSMIC and GRAS

(A.2.3) FCDR of IR-based satellite inputs, 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 records (A.2.1)
- Support is required for activities to use data from RO (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 record (A.2.2)

Immediate action, partnerships and advisory groups
- Provision of the satellite measurements indicated above.
- Support for improvement and comparison of methodologies for 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 climate record of tropospheric and lower stratospheric temperature from RO data. Start with RO climate record from GPS/MET RO data from 1994 to1996, CHAMP RO data from 2001, and COSMIC and GRAS from 2006. (A.2.2)
- Construction of a climate record from high-resolution IR sounder data, from launch of AIRS in 2002 onwards, (A.2.3)
- ITWG, 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)

Products with Significant Overlap
A.8, A.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.

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
Product A.3.2 Total column water vapour over land
Product A.3.3 Upper-tropospheric humidity
Product A.3.4 Tropospheric 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, A.3.2, A.3.3, and A.3.4 , as appropriate

Required spatial and temporal resolution
- Short-term accuracy: 2% of absolute value, 1% for total column in tropics
- Long-term stability: 0.3% of absolute value of measurement per decade for both total column water vapour and upper-tropospheric humidity

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Specific humidity profile"":
- *Total column: 50km horizontal resolution, 1-day observation cycle, 7-day observation delay, 1% total RMS accuracy*
- *Total column in the Troposphere: 10km horizontal resolution, 1-hourly observation cycle, 7-day observation delay, 1% total RMS accuracy*
- *Lower Troposphere: 5km horizontal resolution, 0.1km vertical resolution, 1-hourly observation cycle, 7-day observation delay, 2% total RMS accuracy*
- *Higher Troposphere: 20km horizontal resolution, 0.5km vertical resolution, 1-hourly observation cycle, 7-day observation delay, 2% total RMS accuracy*
- *Lower Stratosphere: 50km horizontal resolution, 1km vertical resolution, daily observation cycle, 7-day observation delay, 2% total RMS accuracy*
- *Higher Stratosphere and Mesosphere: 50km horizontal resolution, 2km vertical resolution, daily observation cycle, 7-day observation delay, 5% total RMS accuracy*

Requirements for satellite instruments and satellite datasets
(A.3.1) FCDR of passive microwave 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 record

(A.3.2) FCDR of UV/VIS imagery, for example through:
- Polar-orbiting UV/VIS instruments to sustain and complement the record from e.g. MERIS.

(A.3.3) FCDRs of IR imagery and soundings in the 6.7um band, and microwave soundings in the 183 GHz band, for example through
- Polar-orbiting high spectral resolution infrared sounders 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.

(A.3.4) FCDR of ground-based measurements of GPS-delay

Calibration, validation and data archiving needs
- Calibration and characterization need continuing work to establish adequate coherence of all datasets, particularly for past data.
- Reference radiosonde profiles are needed for validation.
- Exchange, archive and access protocols need to be developed for ground-based GPS measurements

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

Immediate action, partnerships and advisory groups
- Maintain planned deployment of instruments to be consistent with above 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
- ITWG, GEWEX radiation panel
- CBS to lead development of protocols for ground-based GPS data exchange

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

Products with Significant Overlap

- A.5
- Occultation and limb-sounding missions to support A.9 and A.10 also provide information on stratospheric water vapour

3.1.4. ECV Cloud properties

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

The following is required for this ECV:

Product A.4 Fields of cloud radiative properties (key ISCCP products in particular)

Benefits

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

Required spatial and temporal resolution

- Ohring et al. (2005) listed requirements for different cloud properties for measuring climate change (base height, cover, particle size distribution, effective particle size, ice water path, liquid water path, optical thickness, top height, top pressure, top temperature). Current capability is far removed from this, though useful for model validation.
- High variability in time and space of cloud, including the diurnal cycle, needs to be resolved.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for Cloud properties:

- *Cloud cover: 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, 10% total RMS accuracy*
- *Cloud ice profile (total column): 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, no specs for accuracy*
- *Cloud top height: 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, 0.5km total RMS accuracy*
- *Cloud top temperature: 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, 0.3K total RMS accuracy*

- *Cloud water profile (<100um) (total column): 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, no specs for accuracy*
- *Cloud water profile (>100um) (total column): 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, no specs for accuracy*

Requirements for satellite instruments and satellite datasets
FCDRs of appropriate VIS/IR imagery, and IR and microwave soundings, for example through:

- Long-term products: combination of at least two stable-orbit LEO satellites, carrying VIS/IR imagers and infrared and microwave sounders, and five GEO satellites, carrying VIS/IR imagers and some infrared sounding capability,
- Ongoing programme of research missions using active instruments, to improve observation of cloud properties and to calibrate and characterize long-term products.

Calibration, validation and data archiving needs

- Good inter-satellite calibration, for example through WMO/GSICS, is a key requirement. GSICS will draw on current activities under the GEWEX radiation panel.
- 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 advisory groups

- Continuation and refinement of products, including reprocessing of the existing GEO and LEO satellite 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 records from enhanced instruments such as MODIS and SEVIRI
- 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

Products with Significant Overlap
Not yet specified

3.1.5. ECV Precipitation

[2TS] 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 and its change is crucial for the assessment of climate change and of the impact on nature, environment and human society. Changes in its timing (e.g. seasonality) have implications for water supplies and agriculture. In particular, the knowledge of surface precipitation resulting from rainfall and snowfall is important for assessment of global water resources and for 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).

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 for product formation.

The following is required for this ECV:

Product A.5 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 (see below)

Required spatial and temporal resolution
- Short-term accuracy: Owing to intermittency and disparate rates around the world, and distinctions between rain and snow, single values for accuracy are not very meaningful; an accuracy requirement of 0.125 mm h^{-1}, with a goal on amount at an accuracy of <10% of actual values on monthly time scales (consistent with Ohring et al., 2005).
- Long-term stability: A large-scale trend of order 0.6%/decade needs to be captured; 0.003 mm h^{-1} for stability per decade (consistent with Ohring et al., 2005)

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for Precipitation :
- *Precipitation index (daily cumulative): 100km horizontal resolution, 12-hour observation cycle, 1-day observation delay, 1% total RMS accuracy*
- *Precipitation rate (liquid & solid): 100km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, 0.6mm/h total RMS accuracy*

Requirements for satellite instruments and satellite datasets
FCDR of passive microwave imagery, for example through:
- Passive microwave instruments on a fleet of LEO satellites to provide adequate temporal coverage
- Active radar for calibration, complemented by high-frequency geostationary IR measurements.
- Microwave instrument accuracy to 1.25K brightness temperature and 0.03K for stability over a decade.
- Capability for enhanced detection of light rain and solid precipitation is a specific and important requirement, especially at high latitudes.
- Complementary measurements enabling retrieval of coincident temperature and humidity profiles are also needed

Calibration, validation and data archiving needs
- Calibration/validation of satellite measurements and products is major issue, especially as regards precipitation over the ocean and sparsely populated high-latitude regions.
- Regional validation is required on a continuous, long-term basis.

Adequacy/inadequacy of current holdings
Major biases and month-to-month variations over broad areas exist between existing products such as GPCP and CMAP.

Immediate action, partnerships and advisory groups
- 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 combine separate products from different types of observation.
- Deployment of the required satellite system, and support for the development of products from the data it provides.
- 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.
- CGMS IPWG, GEWEX

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 essential for managing water, flood and drought alerts
- Extreme values over short times (flash floods) and sustained extremes over longer times, as in tropical cyclones, can cause major devastation and loss of life unless warnings can be issued.
- Snow from storms may be extremely disruptive for travel and signal either potential value of a resource or danger when it melts.

Products with Significant Overlap
Not yet specified

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 (long wave) and reflected (short wave) 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 long-wave 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 estimates of the surface radiation budget.

The following is required for this ECV:

<u>Product A.6</u> Global estimate of top-of-atmosphere Earth radiation budget on a continuous basis at high spectral resolution and with adequate spatial and temporal sampling

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

Required spatial and temporal resolution
- Short-term accuracy: not yet specified
- Long-term stability: 1 Wm^{-2} over five years; decadal trends to 0.2 Wm^{-2}

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for Earth radiation budget:
- *Downwelling solar radiation at TOA: 3-hour observation cycle, 3-hour observation delay, 1 Wm-2 total RMS accuracy*
- *Outgoing SW/LW radiation at TOA: 200km horizontal resolution, 3-hour observation cycle, 3-hour observation delay, 5 Wm-2 total RMS accuracy*

Requirements for satellite instruments and satellite datasets
FCDR of appropriate radiances, for example through:
- At least one dedicated broadband instrument mission in polar orbit at any one time, together with at least one instrument providing spectrally resolved measurements of solar irradiance.
- Well-calibrated geostationary multi-spectral 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 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
- Updated and extended archive of BSRN measurements is needed to support and supplement the satellite-based measurements

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

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

Link to GCOS Implementation Plan
[GIP Action A24] Ensure continuation of Earth Radiation Budget observations.

Other applications
Validation of NWP models

Products with Significant Overlap
Not yet specified

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 A primary climate data record for 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 role of chemistry in the climate system.

Required spatial and temporal resolution
Short-term accuracy: Accuracy of 5% and a horizontal resolution of 50-100 km required for stratosphere/mesosphere, with vertical resolution ideally from 0.5 to 3km from upper troposphere to mesosphere; Tropospheric ozone is highly variable; the accuracy requirement is 10% with a horizontal resolution of 5–50 km.

- Long-term stability: Decadal stability requirements are 0.6% in the stratosphere and 1% in the troposphere (from WMO Report 140 and the IGOS IGACO Theme report as well as Ohring et al. (2005))

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for Ozone profile :

- *Total column: 10km horizontal resolution, daily observation cycle, 30-day observation delay, 2% total RMS accuracy*
- *Tropospheric column: 10km horizontal resolution, hourly observation cycle, 30-day observation delay, 5% total RMS accuracy*
- *Lower troposphere: 5km horizontal resolution, 0.5km vertical resolution, hourly observation cycle, 30-day observation delay, 5% total RMS accuracy*
- *Higher troposphere: 10km horizontal resolution, 0.5km vertical resolution, hourly observation cycle, 30-day observation delay, 5% total RMS accuracy*
- *Lower stratosphere: 50km horizontal resolution, 0.5km vertical resolution, daily observation cycle, 30-day observation delay, 5% total RMS accuracy*
- *Higher stratosphere and mesosphere: 50km horizontal resolution, 0.5km vertical resolution, daily observation cycle, 30-day observation delay, 5% total RMS accuracy*

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.

Supplemented at intervals or continuously with

- Limb sounding in IR/MW for profiles from upper troposphere to mesosphere.
- Fully achiving the target resolutions may require a combination of 2 LEO and ideally 3-5 GEO satellites

Calibration, validation and data archiving needs
Comprehensive ground, ship-board, aircraft and balloon-borne measurements are required for calibration/validation, for example through

- the NDAC (Network for the Detection of Atmospheric Change, formerly the NDSC (Network for the Detection of Stratospheric Change))
- the GAW network of ground-based total column ozone measurements and profile measurements from ozonesondes
- the GAW and NASA/SHADOZ ozonesonde global network
- the MOZAIC/IAGOS commercial aircraft programme

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

Immediate action, partnerships and advisory groups

- Continuation of the observational record using the evolving instrument types indicated above, coordinated and operated according to the GCOS Climate Monitoring Principles.
- Reprocessing of datasets when justified 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 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 records are provided by instruments such as GOME, MIPAS, OMI, SCIAMACHY and TES.
- 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 (reanalysis).
- WCRP-SPARC, IGBP-IGAC
- Specific advice may also be sought from satellite Instrument Advisory Groups and Science Teams.

Link to GCOS Implementation Plan
Activities identified here will contribute to *GIP Actions 25 and 26,* which call in general 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 attendant effects on human health and the biosphere;
- Monitoring and assessment of exposure to tropospheric ozone, with further effects on human health and agriculture

Products with Significant Overlap
Not yet specified

3.1.8. Atmospheric reanalysis (many ECVs)

Atmospheric reanalysis can potentially combine 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. At any instant of time, the renalysis techniques utilise observations in the immediate past and future to optimally judge the current analysis. As a technique, its use is in implied in many of the atmospheric products noted in this document. Used historically with satellite data, reanalysis makes use of a combination of Level-1 and Level-2 input satellite datasets based on measurements made over more than three decades. The quality of reanalysis products is strongly influenced by the quality of these datasets. Accordingly, there is a requirement for Level-1 datasets that are as free as possible of any errors in the original near-real-time data production, of Level-2 products that benefit from improvements in processing developed over the years since the first versions of these products were made, and of supporting metadata and processing software.

Almost all of the required Level-1 and Level-2 datasets can be obtained as a by-product of the derivation of the other atmospheric products identified in this document. Atmospheric Motion Vectors (AMVs) from geostationary satellites are an exception.

Production of reprocessed AMVs from geostationary satellites is a specific additional product required in support of reanalysis. The important need for improvement and need for international coordination of reanalysis are emphasized in the GCOS Implementation Plan (Key Actions 23 and 24, and Action C13). See also Cross-cutting Actions C.1 and C.2.

The following is required:

Product A.8 Atmospheric reanalyses supported by reprocessing of key satellite data streams

Benefits
- Reanalysis systems allow the assimilation of many different datasets to create integrated climate products
- Shortfalls would result in lower quality integrated products and reduced socio-economic benefits from the provision of such integrated products.

Required spatial and temporal resolution

- Requirements are stated in other sections for specific variables.
- Improvements in atmospheric motion vector (AMV) processing such as reduction in wind-speed biases introduce spurious trends in operational products, and reprocessing is needed to eliminate these (see A.11).

Requirements for satellite instruments and satellite datasets

- Relevant improved FCDRs and derived productsgenerated as a by-product of the generation of the other atmospheric products identified in this document should be made available to reanalysis centres by the data producers. Reanalysis centres should be partners in these activities through provision of information on known deficiencies in earlier datasets, through identification of the relevant datasets and through evaluation of trial versions of new datasets.
- Reprocessed AMVs from geostationary satellites

Calibration, validation and data archiving needs

Data are required in standard modern formats, with quality indicators as appropriate. Calibration/validation information will be provided by feedback from use of the data in reanalysis systems.

Adequacy/inadequacy of current holdings

Many of the comments on adequacy made for other atmospheric products apply also to the related FCDRs or derived products needed for reanalysis. 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.
In the particular case of AMV data:

- Meteosat and GMS data have been or are being reprocessed for ERA and JRA reanalyses;
- Data from other platforms, notably GOES, have not been similarly reprocessed;
- The case for repeated reprocessing in 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.

Immediate action, partnerships and advisory groups

- Production of reprocessed AMV data is sought from the agencies responsible for near-real-time AMV production.
- The first round of actions needs to be completed by 2009 for the improved datasets to be used in the next generation of reanalyses.
- An immediate opportunity is for GOES reprocessing 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.
- A further opportunity is for the production of improved FCDRs for VTPR and TOVS based on quality-monitoring and analysis-feedback results from recent reanalyses.
- CGMS/IWWG, WCRP/WOAP

Link to GCOS Implementation Plan

[GIP Action C13] Establish a sustained capacity for global climate reanalysis and ensure coordination and collaboration between reanalysis centres.

Other applications

- Application of reanalysis data for testing and calibration of medium-range, monthly and seasonal forecasting systems will give more representative results if input observations are as close as possible in quality to those currently available.
- 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).

Products with Significant Overlap

A.11

3.1.9. ECV Aerosols

[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:

Emerging Product A.9 Fields of aerosol optical depth, supported by single scattering albedo and phase function, and the sampling of vertical profiles of aerosol properties at regular time intervals.

Benefits
- Better aerosol products will lead to 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.

Required spatial and temporal resolution
- Stability requirement per decade of 0.005 for aerosol optical depth and .015 for single scattering albedo (consistent with Ohring et al., 2005).
- 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 are clearly less stringent for climate monitoring, for example of fluctuations in stratospheric aerosol due to volcanic eruptions.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for aerosol parameters:
- *AOD: 1km horizontal resolution, 1-day observation cycle, 7-day observation delay, total rms accuracy 0.01*
- *Extinction coefficient: 10km horizontal resolution, 7-day observation cycle, 7-day observation delay, total rms accuracy 0.01km-1*
- *Absorption optical depth: 1km horizontal resolution, 1-day observation cycle, 7-day observation delay, total rms accuracy 0.004*

Requirements for satellite instruments and satellite datasets FCDR of selected wavelengths in VIS/NIR, for example through
- An operational configuration, extending the current research-based demonstration instruments, comprising primary VIS/NIR instruments on two or more LEO satellites (e.g., equivalent to MODIS), with complementary observations from the GEO constellation, and supplemented by specialized missions
- Continuity of records from future missions, through AVHRR-3 (NOAA-N'), VIIRS (NPP, NPOESS) and MTG
- Reprocessing of full AVHRR dataset back to 1979 with respect to total column aerosol optical depth over the sea, which has the best prospect to provide a long-term record by using better calibration, cloud screening and aerosol microphysics.
- Reprocessing of full GOES dataset with respect to aerosol optical properties
- Research studies of more refined measurement of aerosols, for example with active instruments, are very important in view of the difficulties of fully interpreting optical depth as a measure of all aerosol components. They are critical to 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 requires very accurate calibration. Comprehensive ground-based independent validation measurements are required. These can be provided by existing networks or extension of the NDAC 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 with capability for aerosol measurement.

Immediate action, partnerships and advisory groups
- 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 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 polar orbit and from the operational imagers in geostationary orbit.
- The opportunity exists for the formation of comprehensive single-instrument and composite products from current observations, with some extension back in time using calibrated data from the long-term instruments.
- There is also an emerging opportunity to provide products through data assimilation. Lidar capability can be explored with data from GLAS and from the future ADM/Aeolus.
- Other instrument records can improve the AVHRR record and extend it over land
- WCRP-SPARC, IGBP-IGAC, WMO-GAW
- Specific advice may also be sought from satellite Instrument Advisory Groups and Science Teams.

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 2.5um (PM2.5) on human health
- Future benefit to NWP
- Improve understanding of role of aerosols in cloud chemistry, gas-to-particle reactions and precipitation processes
- Monitor aerosol impact on stratospheric ozone layer chemistry

Products with Significant Overlap
Not yet specified

3.1.10. ECV Carbon Dioxide, Methane and other Greenhouse Gases

[2TS] 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.

[2TS] 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 Climate Convention includes future restrictions on the release of the following types 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 the CFCs and HCFCs for individual countries that are also GHGs. The above trace gas measurements are vital to international and national regulatory agencies, climate models, and scientists interested in atmospheric chemistry and transport.

There is an emerging capability for the following for these ECVs:

<u>Emerging Product A.10</u> Estimates of the global distribution of greenhouse gases such as CO2 and CH4, of sufficient quality to estimate regional sources and sinks.

Benefits
- Data products will allow the spatial distribution and change over time of the key greenhouse gases to be monitored.
- 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 to be made of regional emissions, such as 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, total dry column and vertical profile of mixing ratio of carbon dioxide, methane and nitrous oxide, when coupled with reanalysis, may provide monitoring of sources and sinks of greenhouse gases, especially CO2 and CH4.

Required spatial and temporal resolution
Research use and demonstration of currently available measurements in reanalysis is needed to provide clear statement of essential data needs, and in particular on the extent of needed detail to vertical sounding. Initial estimates are based on resolving the values of observed column fluctuations.
- Short-term accuracy: For carbon dioxide, 10 ppmv for both climate forcing and the detection of sources and sinks (consistent with Ohring et al., 2005).
- Short-term accuracy: For methane and N2O: not yet specified, but 20 ppb for methane would be useful
- Long-term stability: For carbon dioxide, 2.8 ppmv for climate forcing and 1 ppmv for source/sinks (consistent with Ohring et al., 2005). Spatial stability of 1ppmv is also required for source/sinks. This is considered to be a minimum requirement.
- Time scales that extend from the diurnal through the synoptic, monthly, seasonal, yearly to the decadal need to be resolved for a complete description of the processes determining the distribution of these 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 without resolving the shortest space and time scales.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for CO2 profile:
- *Total column: 50km horizontal resolution, 1-day observation cycle, 30-day observation delay, accuracy 1%*
- *Tropospheric column: 10km horizontal resolution, 2-hour observation cycle, 7-day observation delay, accuracy 1%*
- *Lower troposphere: 10km horizontal resolution, 0.5km vertical resolution, 2-hour observation cycle, 7-day observation delay, accuracy 1%*
- *Higher troposphere: 50km horizontal resolution, 1km vertical resolution, 2-hour observation cycle, 7-day observation delay, accuracy 1%*
- *Lower stratosphere: 250km horizontal resolution, 1km vertical resolution, 1-day observation cycle, 30-day observation delay, accuracy 1%*
- *Higher stratosphere & mesosphere: 100km horizontal resolution, 2km vertical resolution, 1-day observation cycle, 30-day observation delay, accuracy 1%*

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for CH4 profile:
- *Total column: 10km horizontal resolution, 12-hour observation cycle, 30-day observation delay, accuracy 2%*
- *Tropospheric column: 10km horizontal resolution, 2-hour observation cycle, 30-day observation delay, accuracy 2%*
- *Lower troposphere: 10km horizontal resolution, 2km vertical resolution, 2-hour observation cycle, 30-day observation delay, accuracy 2%*
- *Higher troposphere: 50km horizontal resolution, 2km vertical resolution, 2-hour observation cycle, 30-day observation delay, accuracy 1%*
- *Lower stratosphere: 50km horizontal resolution, 2km vertical resolution, 6-hour observation cycle, 30-day observation delay, accuracy 5%*

- *Higher stratosphere & mesosphere: 50km horizontal resolution, 2km vertical resolution, 1-day observation cycle, 30-day observation delay, accuracy 5%*

Requirements for satellite instruments and satellite datasets
(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
- For the upper troposphere and stratosphere, general-purpose high spectral resolution IR sounding for long-term operational continuity, 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.
- Specialised passive NIR operational missons for CO_2 and CH_4 building on the experience with the general purpose SCIAMACHY, and the specialized missions GOSAT and OCO. Simultaneous total column CO, such as provided by SCIAMACHY, adds much value for CO2 source characterization

Calibration, validation and data archiving needs
- The required comprehensive independent ground-based validation measurements can be provided by the GAW Global CO_2 and CH_4 Monitoring Network (both GCOS Comprehensive Networks), including ship and dedicated light aircraft profiles up to 8 km.
- A baseline network of surface based total column CO2 and CH4 instruments, and continued routine commercial aircraft observations and those 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 advisory groups
- 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/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 additionally provides data for retrieval of tropospheric CH_4.
- WCRP-SPARC, IGBP-IGAC
- Specific advice may also be sought from satellite Instrument Advisory Groups and Science Teams

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.

Products with Significant Overlap
Not yet specified

3.1.11. 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.

In addition to the requirement for reprocessed Atmospheric Motion Vectors (AMV) data from geostationary satellites for use in reanalysis (Product A.8), there are emerging possibilities, which require ongoing research and development of operational capabilities. These are included in the following product:

Upper-air wind analyses, particularly from reanalysis, supported by additional emerging observation types:
Emerging Product A.11.1 Atmospheric Motion Vectors in polar regions
Emerging Product A.11.2 Satellite line-of-sight winds

Benefits
- Direct observations of upper-air wind contribute to a reliable upper-air wind climate data record derived mostly from reanalysis
- The resulting wind products are essential for monitoring fluxes of heat, momentum, moisture and other variables within the climate system, including the long-range transport of pollutants.

Required spatial and temporal resolution
- Short-term accuracy: Estimates of required short-term wind accuracies need to be provided by Expert Group.
- Long-term stability: Estimates of required long-term wind accuracies need to be determined by Expert Group.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Wind profile (horizontal component)":
Higher stratosphere & mesosphere: 100km horizontal resolution, 2km vertical resolution, 3-hourly observation cycle, 3h delay, 3m/s total RMS accuracy
Lower stratosphere: 100km horizontal resolution, 0.5km vertical resolution, 3-hourly observation cycle, 3h delay, 2m/s total RMS accuracy
Higher troposphere: 100km horizontal resolution, 0.5km vertical resolution, 3-hourly observation cycle, 3h delay, 2m/s total RMS accuracy
Lower troposphere: 100km horizontal resolution, 0.1km vertical resolution, 3-hourly observation cycle, 3h delay, 2m/s total RMS accuracy

Requirements for satellite instruments and satellite datasets
(A.11.1) FCDR of appropriate imagery, for example through
- Successive, overlapping swaths of imagery from at least one, preferably two polar-orbiting satellites
- Reprocessing of wind products from MODIS, already used operationally in data assimilation for NWP, for the lifetimes of TERRA/AQUA instruments

(A.11.2) FCDR from Doppler wind lidars, for example through
- Demonstration product from ESA ADM/Aeolus mission
- Data from Doppler wind lidar instruments flown on operational basis, subject to successful demonstration of ESA ADM/Aelus

FCDRs of appropriate imagery and specific wind datasets (see A.11.1, A.11.2), for example from polar-orbiting and geostationary satellites, with capability for reprocessing as data analysis and assimilation methods improve.

Calibration, validation and data archiving needs
Validation opportunities are provided by co-located radiosondes and by data assimilation feedback statistics.

Adequacy/inadequacy of current holdings
The MODIS polar AMV record is incomplete.

Immediate action, partnerships and advisory groups:

- Investigation of utility of AVHRR polar winds (since 1980) for reanalysis.
- Assessment of impact of ADM/Aeolus, and preparation for operational follow-on.
- CGMS/IWWG

Link to GCOS Implementation Plan

Section 4.2.2

Other applications

Use in data assimilation for NWP

Products with Significant Overlap

Not yet specified

3.2. OCEANS

The following list provides 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. [2TS] 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 mapped from visible, passive and active microwave data. The information is important for modelling sea ice and validating coupled ocean-atmosphere GCMs. Ice concentrations by ice type are determined by the operational sea ice agencies. These can be used to provide rough estimates of ice volume.

The following product is required for this ECV:

Product O.1 Continuous gridded sea-ice extent and concentration. Supplemental measurements of sea-ice concentration, thickness, drift, surface temperature and albedo from research missions and other operational missions.

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

Required spatial and temporal resolution
- Sea-ice extent (passive microwave):
  Short-term accuracy: 5%; Long-term stability: 4% stability per decade, 12km horizontal resolution, 0.5d observation cycle; seasonal-to-interannual resolution on a spatial scale of the order of 10^6 km^2
- Simultaneous to sea-ice extent: Daily, gridded sea-ice concentration, drift, thickness, temperature and albedo
- Sea-ice temperature, sea-ice albedo (VIS/IR): 1-4 km horizontal resolution, 0.5d observation cycle

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Sea-ice cover":
30km horizontal resolution, 1d observation cycle, 3h delay, total RMS accuracy 2%

Requirements for satellite instruments and satellite datasets
Primary measurements
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 MWR instruments, with AMSR on GCOM-W in 2009/10 and CMIS on NPOESS C-2 in approx. 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

Supporting measurements:
- CryoSat2 recovery action for the development of an all-weather, ice thickness derivation capability
- Consideration of operationalisation of the sea-ice thickness measurement as a high priority requirement for GMES Sentinel-3 altimetry
- IceSat follow-on mission to supplement the all-weather 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 record, in conjunction with altimetry-derived ice thickness

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

Adequacy/inadequacy of current holdings
Sea-ice extent and concentration is the only sea-ice product which can be derived uniformly over the existing 25 year record, but is not accompanied by sufficient information on uncertainties. Future products need to take this into account.

Immediate action, partnerships and advisory groups
- Obtain estimates of uncertainties in sea-ice concentration retrievals, together with accompanying quality control information for facilitated assimilation in models (WCRP CliC, OOPC Sea-ice and surface temperature expert group).
- Consistent bi-polar sea-ice drift records should be developed from the combination of Global Synthetic Aperture Radar (Envisat ASAR GMM), Passive microwave (SSMI; AMSR, CMIS) and radar scatterometer (QuikScat, METOP) datasets, accompanied by uncertainty estimates, provided via intercomparison with WCRP IBAP (Arctic) and IPAB (Antarctic) buoy data
- Quantify the degree to which this impacts the ability to derive accurate/unbiased seasonal cycle in sea-ice thickness.
- Further opportunities exist for combining in-situ records from Upward Looking Sonars, together with the satellite thickness and extent/coverage for quantifying 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 and due to short-term weather driven snow emissivity variations and summer season meltponding.
- WCRP CliC, IGOS Cryosphere, CEOS WGCV, 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.
- Used in NWP data assimilation

Products with Significant Overlap
Not yet specified

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 and attribution 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.

Product O.2 Global sea-level maps and a record of global sea-level variability

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

Required spatial and temporal resolution

- Maintain the 25km horizontal resolution, monthly temporal resolution, 1cm rms total accuracy goal for ocean surface topography estimation along the ground tracks established by the TOPEX and Jason precision altimetry missions.
- Requirements of interannual basin/gyre-scale variation of O(1 cm) and global sea level rise estimates with uncertainty estimate better than 1 mm rms need to be maintained. The challenge here is to maintain the highest possible measurement and instrumentation standards AND maintain the scientifically critical TOPEX ground track (to eliminate factors related to the marine geoid) along with millimeter level precision orbit determination.
- A 25 km spatial resolution product in the open ocean is the norm and data are not usually available within about 50 km of coasts. Obtaining higher resolution data, closer to coasts would improve the climate record because altimetry data are used to improve tidal models. Improved tidal models can be used in the reprocessing of the entire satellite altimetry record to reduce uncertainty estimates, thus improving the climate record for sea level. Methods to obtain high-quality altimetric data in coastal, lake, and riverine environments would be important to the climate record.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for “Coastal sea-level change”:*

100km horizontal resolution, 1h observation cycle, 1h delay, accuracy 0.01mm

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 low 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 (AKA 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 and wide-swath 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 for the climate observing system.
- 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 record length.

Adequacy/inadequacy of current holdings
Not yet specified

Immediate action, partnerships and advisory groups
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 record, when compared with 20th century tide gauge data and ice/land 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

Products with Significant Overlap
Not yet specified

3.2.3. ECV Sea Surface Temperature

Together with air temperature over land, 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>26C) SST appears a strong and sensitive factor for hurricane formation and (T>28C) for coral reef bleaching. SST is important also for operational oceanography, fisheries management, human health, transport of invasive species, weather (including tropical cyclones) forecasting, seasonal-interannual climate forecasting, ecosystem dynamics, recreational opportunities, hazardous material spill impacts, the net air-sea flux of carbon and other socially relevant activities.

While noting the modern perspective that there are three distinct 'surface' temperatures, the traditional in situ 'bulk' SST, the 'sub-skin' SST and 'skin' SST, nonetheless the climate "SST" 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.

Product O.3 Global mapping of sea surface temperature

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

Required spatial and temporal resolution
Known patterns of interannual and longer 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 1km 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 0.5C over 100years.

Short-term accuracy 0.25°C total rms accuracy, horizontal resolution 4 km, daily repeat cycle or better to meet needs for determining
- Inter-annual and long-term variability
- Coastal variability
- Diurnal cycle.

Long-term stability: 0.1°C

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Sea-surface temperature":*

1km horizontal resolution, 1h observation cycle, 3h delay, accuracy 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. Immediate action is needed to sustain the quality of the satellite-era SST record.
- Filling IR gap between MODIS and VIIRS.
- Extending AATSR post-ENVISAT ('09)
- Maintaining post-'09 the global all-weather capability currently provided by TMI and AMSR-E.
- Maintaining high frequency observations provided at present by GEO equipped with infrared imagers with split-window channels (e.g., GOES-10, FY2-C, MSG, MTSat) in order to resolve diurnal variability.
- Maintaining an instrument of the ATSR-class for high-accuracy and temporal stability observations, which can tie together general SST coverage by LEO and GEO instruments in the IR and microwave
- Ensuring seamless follow-on of AATSR by Sentinel-3

Calibration, validation and data archiving needs
Not yet specified

Adequacy/inadequacy of current holdings
Not yet specified

Immediate action, partnerships and advisory groups
- Expand in situ network of appropriate ship borne radiometers for calibration.
- Sustain the in situ observing system described in the GCOS IP, 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).
- Maintain ongoing reprocessing of satellite data for providing a homogeneous global SST climate data record, e.g. from the (A)ATSR series from 1991 to 2010
- 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 socially relevant activities

Products with Significant Overlap
Not yet specified

3.2.4. ECV Ocean Colour

Chlorophyll-a concentration is a measure of phytoplankton biomass: it is the fundamental basis of biological production in the oceans. It is a critical for property of 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 have broader application for climate monitoring than just the calculation of chlorophyll-a, e.g. for calculating ocean particulate carbon and other emerging products (see below).

Ocean colour is the normalised water leaving radiance (nL_w, [W m^{-2} sr^{-1}]) or reflectance (R, [sr-1]) in the visible spectrum (350-700 nm); satellite-derived Chlorophyll-a concentration ([mg m^{-3}]) is calculated from ocean colour data. Products are required in the form of global, gridded time series.

<u>Product O.4</u> Global gridded time series of 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

Required spatial and temporal resolution
- Ocean colour; Short-term accuracy: 5% on nL_w/R; Long-term stability: decadal stability of 1%
- Chlorophyll-a short-term accuracy of 0.1 mg m^{-3}
- Horizontal resolution of 25km globally, but 1km resolution globally is desirable
- Daily observational cycle (overcome cloud cover issues by producing daily merged composites from different sensors with different local overpass times)
- Error estimates should be produced alongside both ocean colour and chlorophyll-a

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Ocean chlorophyll":*

25km horizontal resolution, 1-day observation cycle, 1-day delay, accuracy 0.1mg m^{-3}

Requirements for satellite instruments and satellite datasets
FCDR of appropriate multispectral imagery, for example through

- Sustaining multiple MERIS-class instruments in orbit, with SeaWiFS-class as a minimum requirement
- Maintaining continuous ocean colour observations, especially between 2007-2009, when MERIS will probably be the only ocean colour sensor, and this reaches critical level in 2009 with a potential data gap of several years if NPP is not launched before MERIS ends, or if VIIRS is not included in the payload
- Maintaining multiple sensors in orbit and avoid gaps in the data record

Adequacy/inadequacy of current holdings

- Much useful work in using current holdings is ongoing in the development of new products such as Total Suspended Material (TSM)/Suspended Particulate Matter (SPM) and Coloured dissolved organic matter (CDOM) from ocean colour data. Such products can in turn be used to improve the chlorophyll-a record. Intercomparison studies of global **primary production** estimates (PPAR experiments) have been made comparing a number of different models, using both EO and process modelling approaches. **Particulate ocean carbon** products are also being developed. Bio-optical radiative transfer models provide the **inherent optical properties** (IOPs) of **absorption** (a), **backscatter** (b_b) and **volume scattering function** (VSF) from water leaving radiances/reflectances.
- Research is ongoing into assimilation of ocean colour products into ocean climate models. These may provide us with improved carbon cycle products, such as **pCO_2** and **air-sea CO_2**

Calibration, validation and data archiving needs

- Access to ocean colour data products is an issue. These should be freely available internationally through ftp/web service. This exists for NASA data and is improving in Europe, but needs to be addressed globally
- Improve the network of in situ measurements (e.g. MOBY) for vicarious calibration of instruments

Immediate action, partnerships and advisory groups

- The most immediate issue is for sustaining ocean colour observations in the near-term: although the long-term commitments to ocean colour remain, the implementation status has dropped below the 100% reported in the GCOS Implementation Plan.
- IOCCG is responsible for specifying chlorophyll-a and ocean colour product requirements. IOCCG was established in 1996 following a resolution endorsed by CEOS and is an affiliated programme of SCOR.
- Greater representation of ocean colour in the OOPC would be useful, to be discussed with IOCCG.
- User groups of ocean colour data include IOCCG, IOCCP, CASIX, and CARBOOCEAN

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

Products with Significant Overlap
Not yet specified

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 systems, making best use of point measurements from the moored network of buoys, sparse along-track significant wave height measurements made by existing conventional altimeters, as well as spectral band-limited directional wave measurements by Synthetic Aperture Radars.

Product O.5 Global gridded time series of 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 a 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.

Required spatial and temporal resolution
Use of sea-state information in ocean-atmosphere coupling schemes used in climate models is still an evolving area of research and so there are presently no well-specified requirements concerning the desired magnitude of decadal variation or the space 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:

- Of order decimetres change in SWH over decade (ref: Wolf – SOC for NAO signal in SWH and trends).
- Space scales achieved from 1Hz altimeter data are (~10km), whilst 10Hz (~1 km) conventional altimetry data or SAR altimetry would facilitate higher spatial resolutions (250m) in coastal zones.

Requirements for satellite instruments and satellite datasets
FCDR of appropriate altimetry, ideally complemented with additional SAR measurements, for example through
- Continuity in existing altimetric SWH measurements. Future GNSS based L-band bistatic techniques appear promising for supplementary sea-state derivation, and efforts should be made to exploit the addition directional spectral information provided by these data. Currently, the CHAMP and DMC satellites carry reverse circularly polarised GPS antennas and receivers capable of making such demonstration measurements, and GPS receiver technology would be a relatively cheap addition to future polar orbiters for the purpose of making global L-band bistatic sea-state measurements. The UK DMC satellite has recently demonstrated promise in this area, and proposals have been made for similar space-based observing system for extreme waves.
- New SAR altimeter (Sentinel-3) and swath altimeter technologies (WSOA), which will allow advances in near-shore SWH measurement, and their combination with global SAR wave spectral estimates, which would 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.

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.
- 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, resulting in a minimum detectable wavelength of about 150-200 m.
- Current sea-state records exist from ERS-1, T/P, ERS-2, ENVISAT, Geosat

Calibration, validation and data archiving needs
Not yet specified

Immediate action, partnerships and advisory groups
- Efforts should be made 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 records.

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

Other applications
NRT (<3hr) altimetric sea-state information is presently delivered routinely to operational oceanography users (comprising navies and ocean forecast modellers).

Products with Significant Overlap
Not yet specified

3.2.6. Ocean Reanalysis

Product O.6 Ocean reanalysis utilizing altimeter and ocean surface satellite measurements

Ocean reanalyses of the 4D ocean circulation, including biogeochemical and ecosystem variables as feasible, 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 kilometers/few hours. The GODAE pilot project provides international coordination of these products. The second is the 'ocean state estimation' space/time scale of about 100km/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.

The noted ocean surface variables derived from satellites are vital elements for ocean reanalysis. Subsurface measurements are of insufficient resolution to define most ocean eddies and any construction or de-aliasing of theeddies depends on detection of their surface characteristics. No additional requirements other than data availability to reanalysis centres are raised.

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

3.2.7. Ocean Salinity

Sea-Surface Salinity is important because it provides insight into changes in the planetary hydrological cycle, influences upper-ocean mixing (of heat and gases) and, in some regions, controls the formation of intermediate, deep and bottom waters. Global ocean climatologies of both temperature and salinity are thus the basic dataset for ocean model evaluation At present, global knowledge of sea-surface salinity (SSS) is not adequate for these purposes. If practical a global satellite system is needed to provide surface salinity at a time/space appropriate to its principal scales of variability. Microwave sensing of large amplitude SSS variability has been proven in concept, and several research satellite missions (e.g., SMOS and Aquarius) are planned in the next decade. Such new satellite sensors hold promise of improved global coverage, although special *in situ* observing efforts will be needed to evaluate sustained sensor performance.

Emerging Product O.7 Demonstrate capability to measure changes in sea surface salinity from space and develop plans for ongoing missions to maintain a continuous record of sea surface salinity over at least 20 years

Benefits
The much-improved full global coverage that satellite allow would greatly assist detection, understanding and predictions of climate.

Required spatial and temporal resolution
Short-term accuracy: 0.2 psu rms; Horizontal resolution 150km, monthly repeat cycle

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Ocean surface salinity":*

200km horizontal resolution, 1-day observation cycle, 10-day delay, accuracy 0.1psu

Requirements for satellite instruments and satellite datasets
Research satellite missions (e.g., SMOS and Aquarius) should be supported to enable the development and demonstration of salinity measurements from space. Consistent with of the levels of accuracy that are practically achievable, an optimal balance of in situ and satellite instruments should be sustained in the future. Links with activities considering the derivation of soil moisture from the same or comparable instruments should be sustained.

Product validation
Noting the limits of currently available *in situ* observations special *in situ* observing efforts will be needed to evaluate sustained sensor performance.

3.3. TERRESTRIAL

The following list provides details of the required products and datasets primarily derived from satellites for the terrestrial domain:

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 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. (This section does not cover water bodies such as reservoirs that are primarily controlled by human activities. Wetlands are treated under land cover, and are therefore not considered here.)

The following products are required for this ECV:

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

Benefits
- Assessment of changes in regional climate and better knowledge of 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 hydrologic (surface water recharge, discharge and ground water tables) conditions.

Required spatial and temporal resolution
- Gridded, georeferenced maps covering, as a minimum requirement, all GTN-L lake areas with a minimum mapping unit of 250 by 250 metres through the annual cycle, preferably monthly. Global all-weather coverage should be a target.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for “Lake level/area”:*

10m horizontal resolution, 1cm vertical resolution, 7-day observation cycle, 30-day delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
FCDR of appropriate VIS/NIR imagery,radar imagery, for example through
- Moderate resolution optical instruments (MERIS/MODIS class)

Data archiving
- No current capability for global data archiving is established
- Proposals for a future International Lake Data Centre have been received in the context of the Global Terrestrial Network for Hydrology (GTN-H)
- Data documentation, availability and distribution by such a centre needs to be established with high priority

Calibration Will be required against in situ measurements

Product validation Very High Resolution imagery (60 cm – 1 m) from sample sites and in situ measurements

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

Immediate action, partnerships, and advisory groups
- Initiate the generation of lake area products using available optical and radar satellite imagery, and laser altimetry data
- Advice and coordination through GCOS TOPC, WMO CHy and WHYCOS, WaTER mission stakeholders
- GTN-H (through GTN-L) to coordinate creation of International Lake Data Centre, to be responsible for archiving

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

Products with Significant Overlap
T.1.2

Product T.1.2 Regular estimates of 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 hydrologic (surface water recharge, discharge and ground water tables) conditions.

Required spatial and temporal resolution
Vertical resolution of lake level of at least 1 cm with respect to reference geoid on a weekly basis at better than 4km spatial resolution. Spatial and temporal scales should match with requirements for T.1.1.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Lake level/area":*

10m horizontal resolution, 1cm vertical resolution, 7-day observation cycle, 30-day delay, accuracy 5%

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

Data archiving
- No current for global data archiving capability established
- Proposals for a future International Lake Data Centre are solicited in the context of the Global Terrestrial Network for Hydrology (GTN-H)

Calibration Ensure calibration of altimeter to achieve required accuracy

Product validation
- None from satellite agencies
- In-situ GPS measurements

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

Immediate action, partnerships and advisory groups
- Reprocessing of satellite altimeter data to retrieve lake area
- WaTER mission stakeholders, GCOS TOPC

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

Products with Significant Overlap
T.1.1

Product T.1.3 Gridded map of 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

Required spatial and temporal resolution
Gridded, georeferenced map on at least 1km resolution, daily, at an accuracy of 0.2°C

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

Data archiving
- No current capability for global data archiving established
- Proposals for a future International Lake Data Centre are solicited in the context of the Global Terrestrial Network for Hydrology (GTN-H)
- Freeze-up and break-up data should also be submitted to NSIDC to accompany existing historical records archived by them

Calibration
- Climate quality SST (and thus, lake temperature) requires active absolute instrument calibration and long-term instrument stability monitoring using vicarious calibration methods.
- A satellite intercalibration strategy must be developed to characterize the biases in each satellite instrument record.

Product validation
Use very accurate long term in-situ measurement data, in order to establish biases and drifts (see Product O.3)

Adequacy/inadequacy of current holdings
- Current accuracy limited by stability and accuracy of most infrared sensors.

- ATSR and A-ATSR meet the resolution and accuracy requirements, but neither has the swath width to obtain a global daily record

Immediate action, partnerships and advisory groups
- Need for flight 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 A-ATSR records spanning the period 1991 – present.
- Advice and coordination through GCOS TOPC, WMO CHy and WHYCOS, WaTER mission stakeholders
- GTN-H (through GTN-L) to coordinate creation of International Lake Data Centre, to be responsible for archiving
- NSIDC for archiving of freeze-up and break-up data

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, such as GMES Sentinel-3)
- Assessment of aquatic ecosystem functiuon and biodiversity

Products with Significant Overlap
O.3, T.1.1, T.1.2

3.3.2. ECV Glaciers and Ice Caps, and Ice Sheets

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 melt water. The GLIMS project at NSIDC is compiling a global baseline data set (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 (melt and dynamic thinning) and 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.

After failure of Landsat 7 ETM+ global glacier mapping from space relies solely on data from the ASTER sensor, which will pass its expected lifetime in 2006. Data from other multispectral sensors are not practically available for global scientific applications due to their commercial distribution. A Landsat or ASTER type of sensor is required to ensure continued glacier measurements. After failure of the CryoSat mission and end of ICESat's lifetime in the coming years, measurement of ice sheet elevation changes, one of the most relevant factors to determine the pace of sea-level change, is not assured.

The ice sheets of Antarctica and Greenland are growing at higher elevations and losing significant mass at lower elevations (melt and dynamic thinning) and hence accelerating the hydrological cycle (Greenland) under a warming climate. The state and balance of the Greenland and Antarctic ice sheets is, among others, the most relevant yet unknown factor determining the pace of sea level change.

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

- Global glacier outlines from historical air photo and satellite data (e.g., data from Landsat 5 and other programmes) (T.2.1)
- Continuation of a Landsat or ASTER-type sensor for frequent update of the World Glacier Inventory (WGI) and the GLIMS database (T.2.2)
- Ice sheet elevation changes from ICESat type sensors for mass balance determination (T.2.3)

Product T.2.1 Global, georeferenced map (2D outlines) of the areas covered by glaciers, other than ice sheets

Benefits
- Support early-detection strategies in global climate-related observations
- Support the instrumental 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

Required spatial resolution and temporal frame
The historic Landsat 4/5 TM data set (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.

Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Glaciers and ice caps (topography, extent)":
10m horizontal resolution, 10cm vertical resolution, 1-year observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
FCDR of historical archived Landsat-4/5 Thematic Mapper data and other historical satellite datasets.

Data archiving
- 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 (snow conditions).
- Suitable scenes should be provided at [reproduction] cost
- A standard format for satellite data, consistent with existing holdings, needs to be determined with high prioritsy
- The continuity of existing archives (WGMS, USGS, NSIDC) of in-situ glacial data (for validation) and satellite data needs to be maintained

Calibration
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).

Product validation
- Field verification and archived in situ observations / topographic maps will be used where available.

Adequacy/inadequacy of current holdings
- Currently, the World Glacier Inventory (WGI) (see Product T.2.2) 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) and the Global Land Cover Facility (GLCF) offer scenes 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.

Immediate action, partnerships and advisory groups
- The organisations 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 remote-sensed products, including mapped glacier outlines

- The existing National Snow and Ice Data Center (NSIDC) supports archiving and long-term availability of the products.
- World Glacier Monitoring Service (WGMS) and GTN-G provide strategic guidance

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 hydrologic regime, with impact on energy production and agriculture
- Risk assessment of glacier-related natural hazards
- Contribution of glacier melt to global sea level rise.

Products with Significant Overlap
T.2.2

Product T.2.2 Regular update of the World Glacier Inventory (including glacier outlines, mass balance) at time intervals of a few decades from satellite data

Benefits
- Support of early-detection strategies in global climate-related observations
- For detection of climate change related impacts, long-term records obtained from the same sensor should be used.

Required spatial and temporal resolution
- Same specifications as Landsat7 ETM+,
- Based on a 16 day repeat cycle, several years of observation are required to build up an updated inventory in regions with frequent cloud cover.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Glaciers and ice caps (topography, extent)":*

10m horizontal resolution, 10cm vertical resolution, 1-year observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
- FCDR of appropriate imagery, ideally combined with stereo imaging capabilities, for example through: Continuity of the Landsat TM/ETM+ class, ideally combined with an along-track stereo imaging capability (backward/forward) for generation of glacier mass balance through glacier digital elevation models (DEMs)
- Suitable future stereo imaging measurements, with capabilities similar or better than current systems

Data archiving
- Global archive held by USGS and others must be maintained and access to system corrected data and the associated metadata needed for reprocessing should be assured.
- Archiving modalities as for Landsat 5/7
- System corrected (or pre-processed Geo-Tiff [TBD]) should be made available for the purpose of this product at reproduction costs.

Calibration Same as for Landsat 5/7.

Product validation Very high-resolution optical imagery (about 1 m) from selected sample sites are needed.

Adequacy/inadequacy of current holdings
- Currently, the World Glacier Inventory (WGI) provides data of about 40% of the estimated 160'000 glaciers worldwide, but only as point information with limited use for assessment of changes. As simple and robust semi-automatic methods for delineation of debris-free glaciers from multispectral Landsat Thematic Mapper (TM) data are readily available, regular updating of the Inventory in the future is readily feasible.

- Landsat 7 failed in 2003; Landsat 5 has been in operation since 1984 and might fail soon; ASTER is already beyond its lifetime.

Immediate action, partnerships and advisory groups

- GTN-G is responsible for developing the integrated strategy for merging in situ and satellite information
- The National Snow and Ice Data Center (NSIDC) supports archiving and long-term availability of the products
- World Glacier Monitoring Service (WGMS) provides strategic guidance

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.

Non climate applications

- Assessment of freshwater resources (particularly critical e.g. in Central Asia)
- Overall assessment of the hydrologic regime, with impact on energy production and agriculture
- Risk assessment of glacier-related natural hazards
- Contribution of glacier melt to global sea level rise.
- Broad range of applications for Landsat-type data, e.g. for land cover change detection (see Product T.5.2)

Products with Significant Overlap

T.2.1

Product T.2.3 Continuation of long-term measurements of ice sheet elevation changes: for mass balance and estimates of consequent sea level changes

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 the most relevant yet unknown factor in determining the pace of sea-level change

Required spatial and temporal resolution

- Spatially resolved at 10m with 10 cm vertical resolution
- Measurements for the seasonal cycle
- Repeat missions every decade

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Glaciers and ice caps (topography, extent)":*

10m horizontal resolution, 10cm vertical resolution, 1-year observation cycle, 1-year delay, total RMS accuracy 5%

Requirements for satellite instruments and satellite datasets

FCDR of appropriate altimetry (e.g., laser altimetry from ICESat),, 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 (e.g., ice motion)

Data archiving

Data archiving through the World Data Center for Glaciology (NSIDC)

Calibration

Needs for calibration should be identified by the CEOS WGCV working with involved partners

Product validation

- 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)

Adequacy/inadequacy of current holdings
- Coastal regions of certain outlet glaciers in Greenland are not adequately covered by current satellite data but surface height changes in these regions are alarming (>25 m/year).
- Data by PARCA, ITASE, a 5-km resolution bed topography, DEMs with appropriate spatial resolution are available, and will be enhanced in the future.

Immediate action, partnerships and advisory groups
- The remote-sensing community should develop an instrument capable of replacing the failed CRYOSAT.
- There is a need to exploit the knowledge base of several research programmes and organisations, including e.g. PARCA, CliC, IGOS-Cryo, 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)

Products with Significant Overlap
Not yet specified

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 affecting 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 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. Synthetic Aperture Radar (SAR)and improved resolution passive microwave sensors arerequired 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 record of snow cover.

Product T.3 Continuous gridded datasets of snow areal extent

Benefits:
- Better estimate of planetary albedo
- Indicator of changes in precipitation and temperature regimes
- Assess and improve 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

Required spatial and temporal resolution
- Gridded, daily products of continuous snow areal extent at 1-km or higher resolution, consistent with current moderate-resolution optical remote sensing capabilities. Higher resolution (100-500 m) is desired for areas of complex terrain.
- Short-term accuracy (RMS): 5%
- Gridded daily products of SWE at 25km or higher resolution for regional and global assessments. Accuracy (RMS) at 10% or better

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Snow cover":*

250m horizontal resolution, 10cm vertical resolution, 1-day observation cycle, 30-day delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
- FCDR of appropriate moderate resolution VIS/NIR/IR and microwave imagery, for example through current and planned moderate-resolution, multi-spectral optical sensors such as MODIS and VIIRS are generally sufficient for observing the areal extent of snow cover and snow albedo, and their continuation should be ensured. Improvements in spectral resolution, calibration and dynamic range 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 for shallow snowpacks in simple terrain, and their continuation should be ensured.

Data Archiving
National Snow and Ice Data Center (NSIDC) provides archiving facilities.

Calibration
Instrument and algorithm calibration is required to account for sensor and channel changes.

Product Validation
- Continuing research, surface observations and field verification 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

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 snowNSIDC produces global snow cover products from MODIS at 500m resolution and global monthly SWE 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 advisory groups
- Continuation of snow cover and SWE products globally
- NCDC archives NOAA's snow cover products; NSIDC archives snow cover and SWE products and will continue to provide this facility
- An immediate need exists for continuity and reanalysis of historical areal extent of snow cover observation data sets that must be maintained for the Northern Hemisphere and extended to the Southern Hemisphere. The National Environmental Satellite and Data Information Service (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 (NOHRSC) 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.
- GTN-H (through NCDC, NSIDC, GTN-P) should provide strategic guidance. Other partners include WCRP CliC and 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.

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

Products with Significant Overlap
T.4 (partial overlap)

3.3.4. ECV Albedo

Surface albedo generally refers to the (non-dimensional) ratio of the radiation reflected by a surface over the incoming irradiance. Albedo is highly variable in space and time, both as a result of changes 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 dependentanisotropy) 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.

Product T.4 Retrieve daily global directional hemispherical (black sky) albedo

Benefits
- 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.

Required spatial and temporal resolution:
- Spatial resolution of most current and planned space-borne sensors is more than satisfactory for climate and weather applications, and adequate for other environmental monitoring applications
- Temporal resolution remains an issue, as surface albedo changes significantly over periods ranging from hours to years and beyond
- Ensure long-term stability of 1%

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Albedo":*

250m horizontal resolution, 1-day observation cycle, 30-day delay, accuracy 5%

Requirements for satellite instruments and satellite datasets

- FCDR of appropriate multispectral and broadband imagery with appropriate global and diurnal coverage, for example through Space-borne sensors, that are useful for albedo have been placed on both geostationary and polar-orbiting platforms. Geostationary platforms have the major advantage of allowing frequent observations of locations within their field of view many times a day (e.g., every 15 minutes for MSG), from a fixed observation geometry, but with the relative solar position changing each time. They are inadequate to observe polar regions.
- Sun-synchronous satellites, which can provide observations for all regions but only acquire data for more or less narrow swaths during each orbit. Ideally, multiple observations are made quasi-simultaneously at different observation angles (e.g., with instruments such as MISR or POLDER), but good results have also been derived from an analysis of data accumulated over time periods of days to weeks with mono-directional, near-nadir observing instruments, such as MODIS and MERIS, at least when the surface and atmospheric conditions are 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, but also for inter-comparisons 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 hemispheric 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.6).
- EUMETSAT have generated around one year's data over Africa, and in coordination with CGMS one day's 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.

Actions and partnership:

- 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.
- 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.6)

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 burned areas
- Indicates trends in desertification

Products with Significant Overlap
C.6

3.3.5. ECV Land Cover

Land cover forces 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. 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 models' cells. Land-cover distributions are linked to the regional climate, so changes in cover can indicate climate change.

Moderate resolution measurements of land cover are needed to quantify changes in the area covered by specific land cover type. For example Brazil routinely maps the whole of legal Amazonia at these resolutions to quantify their rates of deforestation; the European Union uses data at these resolutions to monitor agricultural production, urbanization, and other land change processes. Moderate resolution measurements provide a key intermediary level of information that is necessary to integrate in-situ and global scale land cover observations.

Moderate resolution measurements of land cover change would provide significant support for national reporting under many chapters of the GHG inventories called for by the Convention (especially those linked to agriculture, grasslands, wetlands, forestry). They would also offer a neutral basis for verification of carbon trading linked to aforestation and reforestation projects, and provide accurate measures of processes such as deforestation and conversion of land to agriculture. Moderate resolution land cover mapping could also be linked to other climate products such as maps of glaciers and ice caps

Creation of improved records of historical changes in natural land cover and land use, as stated in the GCOS Implementation Plan section 3.6.1, is also required. Historical land cover change would provide key support for national reporting under many chapters of the GHG inventories called for by the Convention (especially those linked to agriculture, grasslands, wetlands, forestry), in particular in establishing baselines (e.g. pre/1990 for a/reforestation or the degree of averted tropical deforestation) and to understand long term land change and their link to climate processes.

In close relation to land cover, land surface temperature (LST) is one of the key subsidiary variables to 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.

Four products are required for this ECV:
- Global, georeferenced map of land cover type (T.5.1)
- Global, georeferenced map of changes in land cover type (T.5.2)
- Global, georeferenced maps of historical changes in land cover types (T.5.3)
- Global land surface temperature (T.5.1), in conjunction with land cover type (T.5.4)

Product T.5.1 Global georeferenced map 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 the implementation and monitoring of various UNFCCC Convention Articles, especially those linked to reducing uncertainties related to the climate system

Required spatial, temporal and thematic characteristics

Global land-cover maps should be produced annually, documenting the spatial distribution of land-cover characteristics with attributes suitable for climate, carbon and ecosystem models, and using a common language for class definitions, at 250m-1km resolution. The thematic detail should be regionally adapted in order to satisfy requirements of international conventions and as far as possible harmonised with regional classifications schemes presently in use.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Land cover":*

10m horizontal resolution, 1-year observation cycle, 1-year delay, accuracy 5%

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.

Data archiving

- Global archives of daily observations held by NASA, ESA, VITO must be maintained and access to daily geo-corrected data provided.
- Image to image registration needs to be with an RMS error of 1/3 of a pixel or better.

Calibration

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)).

Product validation

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 (1-30m) satellite imagery, itself validated by *in situ* observations wherever possible.

Adequacy/inadequacy of current holdings

- Global land-cover products at 250 – 500 m resolution are currently being generated in the US (MODLAND) and Europe (GLOBCOVER). The classification systems and therefore map legends should adhere to internationally-agreed standards. The UN's Land Cover Classification System (LCCS) for legend harmonization and translation provide a means for developing and comparing legends.
- 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 advisory groups

- The GTOS' GOFC-GOLD panel working with the CEOS WGCV has established validation protocols.
- UN's 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 250m and 1km, 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.

Products with Significant Overlap
T.5.2, T.5.3

Product T.5.2 Global georeferenced map of changes in land cover type:

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 higher resolution information.

Benefits
- Required to quantify changes in the area covered by specific land cover types (see T.5.1)
- Moderate 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 aforestation and reforestation projects

Required spatial, temporal and thematic characteristics
Global land-cover change maps at 10 – 30 metre resolution should be produced at five-year intervals, synchronised with UNFCCC reporting requirements. In high latitudes, a 3-day revisit interval is required during growing season.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Land cover":*

10m horizontal resolution, 1-year observation cycle, 1-year delay, accuracy 5%

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
- Requirements in this regard are operational and hence extend beyond existing and past strategies in the Landsat program. Consistent viewing and illumination geometry and seasons of acquisition are required for global land cover mapping. It is important to recognize that acquisition strategies, imaging capacity and archiving are significant elements of the satellite programs that support this effort. Only in the Landsat 7 era have requirements in this domain been achieved.

Data archiving
- Global data sets of satellite imagery at 30 m resolution have been assembled for 1990 and 2000, and some regional land-cover maps have been generated from these.
- No global maps at this scale exist.

Calibration
Best possibleabsolute calibration is a requirement for global mapping of land cover at these resolutions..

Product validation
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.

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 Amazon, 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 advisory groups
The 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 10-30m 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 10m and 30m 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 etc are a key factor in sustainable development of many regions and can be a major driver of land use conflicts.
- Land cover distributions are also required for studying changes in biodiversity and land degradation.
- Land cover change, if monitored on moderate resolutions, such as 30 metre 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

Products with Significant Overlap
T.5.1, T.5.3

Product T 5.3 Global, georeferenced maps of historical changes in land cover types

For clarity the actions needed to consider historical changes in land cover type as detailed as a separate product.

Benefits
- Key support for national reporting under many chapters of the GHG inventories called for by the UNFCCC (especially those linked to agriculture, grasslands, wetlands, forestry), in particular in establishing baselines (e.g. pre 1990 for a/reforestation or avoided tropical deforestation)
- Understand long-term land change and its link to climate processes.

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

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Land cover":*

10m horizontal resolution, 1-year observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
- FCDR of appropriate historical imagery, for example through Reprocessing of historical Landsat MSS, TM, ETM, SPOT HRV, in comparison to historical NOAA AVHRR and other coarse resolution sensors.

Data archiving
Access to the global archives of relevant satellite data etc held by relevant space agencies and land cover facilities.

Calibration
Best possible absolute calibration is a requirement for global change monitoring

Product validation
The global historical land-cover change database must use internationally agreed validation protocol that needs to be developed.

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 even Argos/Corona archives would need to be systematically accessed and suitable images identified in order to reconstruct early land cover maps.

Immediate action, partnerships and advisory groups
The GTOS' GOFC-GOLD and the UN Global Land Cover Network provide an institutional framework on which to launch such an activity, providing space agencies are able to provide appropriate data

Link to GCOS Implementation Plan
[GIP Action 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.

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 etc are a key factor in sustainable development of many regions.
- Land cover change history distributions are also required for studying changes in biodiversity, ecosystem functioning, and land degradation.

Products with Significant Overlap
T.5.1, T.5.2

Supporting Product T.5.4 Global land surface temperature, in conjunction with land cover type

For clarity the need this supporting product that assists the identification of land cover type is noted separately.

Benefits
- Relevant to detailed observations of TOA LW upwelling radiance (atmosphere);
- Added value from radiometric data collected to observe SST;
- Synergistic with making observations of lake surface temperature (see T.1.3);
- 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 hydrologic conditions;
- Early and sensitive indicator of drought conditions;

Required spatial and temporal resolution:
- Spatial resolution (1 km – 2 km) of most current and planned space-borne 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. Geo-stationary provide very adequate temporal resolution.
- Short-term accuracy: 1%

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Land cover":*

10m horizontal resolution, 1-year observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
Continuity of AATSR-class of instruments;

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

Adequacy/inadequacy of current holdings
Global data sets based on AVHRR Ch4, Ch5 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
AVHRR: The atmospheric window in 8-13 μm spectral region is wide enough to permit observations in two channels. The Split Window Method uses observations at two different wavelength intervals within this window to eliminate the influence of the atmosphere and solve for Ts (channels 4 and 5 of AVHRR and channels 3 and 4 of ATSR).
MODIS: The coefficients used in the split window algorithm are given by interpolation on a set of multi-dimensional look-up tables (LUT). The LUTs were obtained by linear regression of the MODIS simulation data from radiative transfer calculations over wide ranges of surface and atmospheric conditions. Improvements for the generalized split-window LST algorithm incorporated in the establishment of the LUTs include: 1) view-angle dependence, 2) column water vapor dependence, and 3) dependence on the atmospheric lower boundary temperature.
(A)ATSR: bi-angular observations provide improved account for atmospheric effects by means of estimates of column water vapour and aerosols optical depth. With the launch of ATSR on-board the European Remote Sensing Satellite (ERS-1) in July 1991, the first sensor operating in biangular-mode was available. ATSR measures at nadir and at forward view under 55º. The second Along-Track Scanning Radiometer (ATSR-2) on board the EuropeanRemote Sensing (ERS) and AATSR onboard the ENVISAT satellite is currently the only observing system able to provide quasi-simultaneous multispectral (from visible to TIR) measurements at two view angles (approximately 0‡ and 53‡ at surface). In addition to three thermal infrared channels centred at 3.7 mm, 11 mm and 12 mm and one short wave infrared (SWIR) channel at 1.6 mm, ATSR-2 and AATSR have three visible-near infrared channels centred at 0.56 mm, 0.67 mm and 0.87 mm intended for vegetation analysis.

Immediate action, partnerships and advisory groups:
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;
- Indicates trends in desertification

Products with Significant Overlap
T.1.3. (Lake surface temperature), O.3 (SST), A.6 (ERB)

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: this is 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.

The following is required for this ECV:

Product T.6 Regular gridded georeferenced global 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.
- Contribution to the monitoring of terrestrial carbon sinks and in particular to carbon sequestration. Hence it is relevant to the science underpinning the Kyoto Protocol.

Required spatial and temporal resolution
- Global, gridded fAPAR products are routinely generated by various space agencies at a typical spatial resolution of 1 km or better. 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 to 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

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "fAPAR":*

0.1km horizontal resolution, 10-day observation cycle, 10-day delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
FCDR of appropriate multispectral imagery, for example through
- Sustaining multispectral instruments, if possible with multiangular viewing capability.
- Medium spatial resolution (e.g., 300 m) optical instruments (such as ESA's MERIS, or NASA's 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

Data archiving
Space agencies and other data providers routinely generate fAPAR data sets at regional, continental or global scales. Limited inter-comparisons of these have indicated large differences

Calibration
- 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.

Product validation
fAPAR estimates derived from space instruments must be evaluated against alternative methods of measurement to determine their reliability and accuracy.

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, EC's JRC, etc). These products are typically available at a spatial resolution of 1–2 km, daily, weekly or monthly. Finer resolution products, at 250 – 300 meters 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

in the generation of land cover maps. The higher resolution products are also easier to compare with the point measurements made at reference sites.

Immediate action, partnerships and advisory groups

- 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 NOAA's AVHRR instrument, ensuring the long-term consistency of the product with current estimates throughout the entire period (see also C.6)
- 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 1km 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, with potential impacts in such fields as food security, land degradation (e.g., desertification), and land cover mapping

Products with Significant Overlap

T.5.1, T.5.2, T.5.3, T.7

3.3.7. ECV LAI

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 and but are nevertheless vital as *in situ* measurements have very limited coverage.

The following is required for this ECV:

Product T.7 Regular gridded georeferenced global maps of LAI

Benefits

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

Required spatial and temporal resolution

- Daily gridded, georeferenced maps with a minimum mapping unit of 250m – 1km horizontal resolution; daily data can subsequently be composited at weekly to 10-day intervals as required to avoid cloud cover.
- Short-term accuracy: 3% (consistent with Ohring et al., 2005)
- Long-term accuracy: Estimated decadal change of 5-10% (at high latitudes) leads to estimated requirements on decadal sensor stability of 1% (consistent with Ohring et al., 2005)

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "LAI":*

250m horizontal resolution, 1-day observation cycle, 30-day delay, accuracy 5%

Requirements for satellite instruments and satellite datasets

FCDR of appropriate multispectral imagery, for example through

- Medium-resolution optical instruments with blue band for atmospheric correction (MODIS/MERIS/SeaWiFS class)
- Multiangular spectral measurements should be continued.

- Reprocessing of historical archives of AVHRR, albeit at lower accuracies than from current MODIS/MERIS/SeaWiFS class instruments.

Data archiving
Space agencies and other data providers routinely generate LAI data sets at regional, continental or global scales. Limited inter-comparisons of these have indicated large differences.

Calibration/Product validation
A network of reference sites for in-situ measurements should support overall product validation.

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 or 4, the measurements saturate. Also, since the 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 multiangular measurements.Regular global LAI estimates from space are currently being produced and should be continued. These have the same spatial resolutions (250m-1km) and temporal frequencies (7 to 10 days) as the fAPAR products.

Immediate action, partnerships and advisory groups
- To detect trends in the presence of interannual variability requires long time series, hence the full existing archive of satellite data for which consistent correction for the atmosphere is possible (i.e., those having at least the blue channel in their spectral coverage) should be processed. 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 1km 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.

Products with Significant Overlap
T.6

3.3.8. ECV Biomass

Biomass is an essential product for the above ground stored CO2 and has two major roles in the climate system:

- Photosynthesis withdraws CO2 from the atmosphere and stores it as biomass
- The quantity of biomass consumed by fire affects emissions of CO2, 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 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>Emerging Product T.8</u> Research towards global, above ground forest biomass map 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

Required spatial and temporal resolution
- For climate purposes, annual estimates in the tropics (in order to measure biomass change) and five to ten years in temperate and boreal forests. A spatial resolution of 250 m to 1 km is adequate.
- To meet the Kyoto protocol, requirements: annual temporal resolution, with spatial resolution of 70 m

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Biomass":*

250m horizontal resolution, 1-day observation cycle, 30-day delay, accuracy 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.

Data archiving
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.

Calibration
- 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.

Product validation
Ground based biomass and height measurements are needed at a range of sites.

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 advisory groups
- 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's Forest Resource Assessment Updates.

Products with Significant Overlap
A.10 (for global carbon budget calculations), T.9 (biomass conversion to gas and particulate emissions)

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 modifying land cover and hence affecting 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 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 under the atmospheric domain).

Burnt area as derived from satellites is considered as the primary variable needing 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 parameterise 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).

Three products are therefore required for this ECV:

- Georeferenced global maps of burnt area (T.9.1)
- Global active fire maps (T.9.2, supplemental to T.9.1)
- Fire radiated power (FRP) (T.9.3, supplemental to T.9.1)

Product T.9.1 Georeferenced global maps of burnt area

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 (the latter approach is how fire is dealt with in many climate and biospheric models).
- Fire-induced emissions are a significant terrestrial source of GHGs, with large spatial and inter-annual variability

Required spatial and temporal resolution
- Gridded, geo-referenced maps with a mapping unit of 250 m X 250 m to 1 x 1 km.
- Daily observations are required, typically amalgamated to 5-10 day products.

Required/observed magnitude of fluctuations
- The Historical AVHRR archive offers the potential to extend the burnt area record back to 1982. Calibration, especially of the SWIR channel is not good enough in the currently available 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.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for “Fire disturbance”:*

250m horizontal resolution, 30-day observation cycle, 1-year delay, accuracy 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.

Data archiving
Burnt area products are held by ESA and NASA

Calibration
Relative calibration of VIS, NIR and SWIR channels to within 2% over the full lifetime of each sensor. Either overlapping periods of operation or absolute calibration is needed to provide continuity from sensor to sensor. Orbital overpass time drifts should be minimized (GCOS recommendations).

Product validation
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.

Immediate action, partnerships, and advisory groups
- 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 outlets should be maintained.
- The CEOS WGCV, working with GOFC-GOLD, is establishing internationally-agreed validation protocols, which should be applied to all data sets 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, and human health and safety
- They also cause changes to ecosystem boundaries, sometimes permanently, with associated consequences for biodiversity.

Products with Significant Overlap
T.9.2, T.9.3

Product T.9.2 Global active fire maps (supplemental to burnt area)

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 inter-annual variability in fire activity.

Required spatial and temporal resolution
- Gridded, geo-referenced daily maps with a mapping unit of a 1 x 1 km.
- Long time-series, over the full ATSR-2 data record and extended into the future, are needed to quantify the link between climate and fire frequency and shifts in geographic location and timing of fire events.

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Fire disturbance":*

250m horizontal resolution, 30-day observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
FCDR of 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
- Absolute instrument calibration is important here.
- Even vicarious calibration to within 1 – 2% would be good.
- Past experience with post launch calibration drift causes significant problems as many fire detection algorithms rely on fixed thresholds.

Product validation
The ephemeral nature of active fires makes this 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.

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 advisory groups
- 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 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

Products with Significant Overlap
T.15, T.17

Other applications
- Extreme wildfire events have adverse impacts on economies, livelihoods, and 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 estimate of direct smoke emission rates.

Product T.9.3 Fire radiated power (FRP) (supplemental to burnt area)

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 CO2 emissions estimate from remotely-sensed observations without relying on difficult-to-acquire ancillary data on fuel load and combustion completeness factors

Required spatial and temporal resolution

- Geostationary products at high temporal resolution, stored at the native spatial resolution and with ancillary data on cloud-cover and ideally burned area for each image scene (to adjust FRP measures for cloud-obscuration).
- Orbital (?) and gridded, geo-referenced maps from polar orbiting imagers, with a mapping unit of 1 x 1 km.
- Observations are required from each satellite overpass (polar orbiter) or image scene (geostationary).
- Long time-series, over the full satellite data record and extended into the future, are needed to quantify the link between climate, FRP and carbon emissions, and to identify possible shifts in fire intensity.
- Low spatial resolution systems fail to detect the weakest burning fires, so a multi resolution approach is desirable

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Fire disturbance":*

250m horizontal resolution, 30-day observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets

FCDR 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.

Data archiving

- MODIS FRP archive to be extended into the future through follow-on instruments.
- Geostationary satellite operators to commence archiving of FRP products.

Calibration

- 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).

Product validation

- 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.

Adequacy/inadequacy of current holdings

- NASA distributes MODIS derived daytime and night-time FRP beginning in late 2001, continuity of which is needed into the VIIRS era
- Experimental geostationary FRP product being generated from SEVIRI (Meteosat-8), based on observations every 15 minutes over Africa and Europe, must be continued. This activity should be expanded to other geostationary sensors covering the Americas and Australasia
- Isolated BIRD records exist for ~ 3 years and a replacement system is required.

Immediate action, partnership, and advisory groups

- Operational production of geostationary FRP should begin, led by geostationary satellite operators or cooperating agencies, such as National Meteorological Services: e.g., the exploitation of the MSG archive helped by EUMETSAT
- NASA should maintain FRP production capability from MODIS and follow-on sensors.
- SEVIRI, MODIS existing; and GOES/MTSAT in near future subject to funding.

Link to GCOS Implementation Plan
A more direct estimator of emissions than from 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, and 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.

Products with Significant Overlap
T.9.1, T.9.2

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. It should be developed in proper coordination with other land surface variables. The soil moisture activities can build on the soil-moisture data archive at Rutgers University, national networks (Russian Federation, China, USA) and the potential of new satellite missions including SMOS and Hydros. The various ways of representing soil moisture from satellite and *in situ* measurements needs rationalization.

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

The following is needed for soil moisture:

Emerging 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 global climate 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, which can grow in a region.
- Soil moisture estimates assist gas flux estimates in permafrost regions.

Required spatial and temporal resolution
Minimum temporal resolution of 3-4 days (preferably daily), with a moderate spatial resolution (global maps have been produced with a spatial resolution of 50 km)

- *Target general spatial and temporal resolution and short-term accuracy (as in WMO/CEOS database) for "Soil Moisture":*

25km horizontal resolution, 7-day observation cycle, 1-year delay, accuracy 5%

Requirements for satellite instruments and satellite datasets
- ENVISAT is operating the ASAR C-band radar system, which could possibly contribute to the derivation of a global soil moisture map. A fully polarimetric SAR system may be needed in order to exploit soil moisture -vegetation interfaces

- The SMOS radiometer is in its phase B development at ESA and due to launch some time 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 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 record of the scatterometers on ERS-1 and –2 and provide a possible continuous and homogenous record for the foreseeable future
- 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
Absolute radiometric calibration will be needed

Product validation
- *In-situ* methods are not general 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
- No current data available

Immediate action, partnerships and advisory groups
- Data management organisations need to be identified to ensure provision of soil moisture products from the current and forthcoming satellite microwave data (ALOS, SMOS, ASAR, etc).

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, ground water management, agricultural management and hazard forecasting (soil erosion, land slides, flooding, debris flow etc.)
- Human health is affected through lack of fresh water, impacts on farming (FAO) and ground water recharge.

Products with Significant Overlap
Not yet specified

4. CONCLUSIONS

A clear opportunity is at hand to provide both GCOS, WCRP, IPCC and the wider GEOSS community with multi-decadal analyses of essential climate variables, linked with ongoing analysis and research activities, both of which would greatly improve our ability to support the needs of the UNFCCC and the needs of other application areas. This does not preclude necessary adaptations after further dialogue with partner agencies or programmes. [TO BE REVISED]

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 CO2 and CH4, 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 data set 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.

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	ol 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	osorption 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	2 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 deg	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	km along tr	km along t	2 m	2 m	30 d	10 y	60 d	1 y	)2 C / 0.001	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%

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.

Appendix 4

GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles[12]:

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

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

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

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

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

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

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

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

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

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

Furthermore, satellite systems for monitoring climate need to:

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

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

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

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

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

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

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, meta-data and raw data, including key data for delayed-mode analysis, should be established and maintained.

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

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

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

Appendix 5

GCOS Essential Climate Variables[13]

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[14], 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[15]	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.	

[13] 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).

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

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

Appendix 6

List of Acronyms

(To be added)

GCOS Secretariat
Global Climate Observing System
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7 *bis,* Avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland
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