Systematic Observation Requirements for Satellite-based Products for Climate[1]

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

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

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

Specifically, the proposed system will provide information to:

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

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

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

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

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature, Wind speed and direction, Water vapour, Cloud properties, Carbon dioxide, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity), Sea state*, Ocean salinity*.
Terrestrial	Lakes*, Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI)*, Biomass*, Fire disturbance, Soil moisture*.

***Table 1**: ECVs largely dependent upon satellite observations. This listing is based on the GIP and covering all ECVs considered in this report. ECVs denoted with an asterisk (*) were not included in the original table in the GIP. Note that soil moisture was not listed in the GIP as an ECV, but was recognized as an emerging ECV and has been included here.*

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

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

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

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

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

The content of this report

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

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

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

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

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

Key recommendations

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

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

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

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

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

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

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

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

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

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

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

The future role of Earth Observation Satellites for Climate

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

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

Table 2: *Overview of Products – Atmosphere*

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

Table 3: *Overview of Products – Oceans*

ECVs / Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)
Lakes For lakes in the Global Terrestrial Network for Lakes: Maps of lakes; Lake levels; Surface temperatures of lakes	VIS/NIR imagery, and radar imagery; Altimetry; High-resolution IR imagery
Glaciers and Ice Caps Maps of the areas covered by glaciers other than ice sheets; Ice-sheet elevation changes for mass-balance determination	High-resolution VIS/NIR/SWIR optical imagery; Altimetry
Snow Cover Snow areal extent	Moderate-resolution VIS/NIR/IR and passive microwave imagery
Albedo Directional-hemispherical (black sky) albedo	Multispectral and broadband imagery
Land Cover Moderate-resolution maps of land-cover type; High-resolution maps of land-cover type, for the detection of land-cover change	Moderate-resolution multispectral VIS/NIR imagery; High-resolution multispectral VIS/NIR imagery
fAPAR Maps of fAPAR	VIS/NIR imagery
LAI Maps of LAI	VIS/NIR imagery
Biomass Research towards global, above-ground forest biomass and forest-biomass change	L band / P band SAR; Laser altimetry
Fire Disturbance Burnt area, supplemented by active-fire maps and fire-radiated power	VIS/NIR/SWIR/TIR moderate-resolution multispectral imagery
Soil Moisture[3] Research towards global near-surface soil-moisture map (up to 10cm soil depth)	Active and passive microwave

Table 4: *Overview of Products – Terrestrial*

Endnotes/References:

[1] This paper is based on the Executive Summary of the report *Systematic Observation Requirements for Satellite-based Products for Climate*, GCOS-107, September 2006 (WMO/TD No. 1338), http://www.wmo.int/pages/prog/gcos

[2] These are fully described in the *Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC*, GCOS-82, April 2003 (WMO/TD No. 1143) and its Technical Annexes. Table 1 lists those ECVs that are largely dependent upon satellite observations.

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