Systematic Climate Monitoring from Space: the 2010 Global Climate Observing System Requirements

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Abstract

This paper introduces the updated 2010 Global Climate Observing System (GCOS) requirements for global and internationally coordinated climate monitoring from space, by way of a satellite-focussed summary of the 2010 Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (the ‘GCOS Implementation Plan’). User requirements for sustained, homogeneous and stable satellite-based datasets derived from a 2004 version of the Plan have been used in the past five years as the international reference by the satellite community worldwide, including by EUMETSAT, to address and coordinate systematic observation of GCOS Essential Climate Variables (ECVs) from space. The updated GCOS Plan builds on that legacy, and space agencies, research institutions, governments and other “agents for implementation” are invited to consider it for their planning over the coming years. Under leadership by the WMO/IOC-UNESCO/UNEP/ICSU-sponsored GCOS programme, finalizing the Plan involved a wide range of climate scientists and data users in the areas of meteorology, atmospheric chemistry, oceanography and land-based biogeochemistry. More detailed satellite-specific requirements for fundamental climate data records (FCDRs, usually calibrated radiances), derived ECV satellite products, and target accuracy, stability, and resolution of such products were developed back in 2006 (GCOS, 2006). Based on the 2010 GCOS Implementation Plan, those detailed requirements will be updated in the first half of 2011, involving a broad consultation process with the satellite and climate communities.

1. A 2010-2015 Roadmap for Systematic Observation of the Climate System

The Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC was updated and published on 31 August 2010 (GCOS, 2010a), including the revised list of GCOS Essential Climate Variables (ECVs). Focusing on the timeframe 2010-2015, the Implementation Plan replaces a similarly titled 10-year Plan published in 2004 and recommends a set of actions required to implement and maintain a comprehensive global observing system (based on satellites, aircraft and in situ measurements) for climate that will respond to the needs for systematic climate observation expressed in Articles 4 and 5 of the United Nations Framework Convention on Climate Change (UNFCCC).

Carrying out the 138 actions recommended in the document over the coming five years would ensure that countries have the observational information needed to understand, predict, and manage their response to, climate and climate change over the 21st century and beyond. It would also lead to a vastly improved observational basis in support of the emerging Global Framework for Climate Services and underpin all GEOSS Societal Benefit Areas (e.g., health, agriculture and energy), including climate.

The actions in the GCOS Implementation Plan call for sustained and global observations of ECVs in the atmosphere, in the world’s oceans, on land, and from space, needed to make significant progress in the generation of global climate datasets, products and derived information. Moreover, climate research, modelling, analysis and capacity building activities need to be strengthened to build and maintain a

1 The 2010 Implementation Plan is available for download from: http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf
global climate observing system, and observational records need to be improved to enable better seasonal-to-interannual climate predictions.

The basis of the Implementation Plan is provided by: its 2004 predecessor\(^2\) and a 2006 Satellite Supplement\(^3\); recognition of progress in the past five years in science (e.g., IPCC 4\(^{th}\) Assessment Report); advances in technology (e.g., satellite sensors, ocean in-situ platforms); evolving user needs (e.g., stronger focus on adaptation and mitigation options addressing climate change); and broader international coordination (e.g., Group on Earth Observations (GEO) / Global Earth Observation System of Systems (GEOSS), UN System “Delivering as One” on Climate Change). Furthermore, the GCOS-led writing team chaired by Prof. Paul Mason considered over 450 comments on the draft Implementation Plan received during an open community review between November 2009 and January 2010.

The Implementation Plan was submitted to the UNFCCC Secretariat on 31 August 2010, for consideration by Parties at the 33\(^{nd}\) session of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), which will be held in conjunction with the 16\(^{th}\) Conference of the Parties (COP 16) in Cancún, Mexico, in December 2010.

2. Satellite Community Action To Date

Publication of the updated 2010 version of the GCOS Implementation Plan marks five years of unprecedented action by space agencies, both collectively and individually, in support of climate observational needs. Reports to UNFCCC bodies by the international Committee on Earth Observation Satellites (CEOS) and GCOS give evidence of significant progress between 2004 and 2008 in generating satellite-based fundamental climate data records (FCDRs) and ECV products, reprocessing of past records, (inter)calibration and validation, improving data access and planning missions with attention to continuity and overlap (for the benefit of climate modelling), climate research and meteorology and oceanography in general. There have also been setbacks in ensuring mission continuity (e.g., NPOESS) but remedial action by agencies has been prompt to fill expected gaps between satellite missions.

For some ECVs, space agencies working through the CEOS and the Coordination Group on Meteorological Satellites (CGMS) have established mechanisms to ensure coordination in agencies’ operation and exploitation. The CEOS Virtual Constellations on Atmospheric Composition, Precipitation, Land Surface Imaging, Ocean Surface Topography, Ocean Colour Radiometry, and Ocean Surface Vector Winds have been put in place as one such coordination mechanism. The Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring initiative (SCOPE-CM) has been established with contributions from various space agencies. The SCOPE-CM pilot projects focus on the sustained generation of long-term ECV products, including regular reprocessing, addressing cloud and aerosol properties, water vapour, precipitation, surface albedo, atmospheric motion vectors and clear-sky radiance.

Other initiatives by agencies addressing their long-term records, such as those undertaken by ESA (through its Climate Change Initiative), EUMETSAT (through its Satellite Application Facilities), and corresponding efforts of JMA, NASA and NOAA should be fostered and continue as sustained activities.

\(^3\) [http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf](http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf)
3. Updated and New Requirements – the GCOS Essential Climate Variables (ECVs)

The GCOS ECVs as a concept were developed in the early 2000s to support the needs of the UNFCCC and most of the essential needs of the climate research community for systematic and sustained observations of the climate system (as articulated through the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC)). The ECVs have been selected, and updated in the 2010 GCOS Implementation Plan (see Table 1), based on the grounds of:

- Clearly significant and citable benefits toward meeting the needs for specific climate observations in support of prediction and attribution of climate change, impact assessment, and the amelioration of, and adaptation to, projected future changes (cf. Articles 4 and 5 of the UNFCCC);
- Feasibility of sustained global observation, as determined by the current availability of the technology and systems, or by knowledge of how to make an observation with acceptable accuracy, stability, and resolution in both space and time, and adequate cost-effectiveness;

Table 1: GCOS Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements (Source: 2010 GCOS Implementation Plan)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Essential Climate Variables</th>
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<tbody>
<tr>
<td>Atmospheric</td>
<td><strong>Surface:</strong> Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.**</td>
</tr>
<tr>
<td></td>
<td><strong>Upper-air:</strong> Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).**</td>
</tr>
<tr>
<td></td>
<td><strong>Composition:</strong> Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol, supported by their precursors.**</td>
</tr>
<tr>
<td>Oceanic</td>
<td><strong>Surface:</strong> Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton.**</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-surface:</strong> Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.**</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.**</td>
</tr>
</tbody>
</table>

As compared to its 2004 version, the updated list of ECVs now includes soil moisture, soil carbon, and ocean oxygen content. It also recommends global observations of precursors to ozone and aerosols (NO₂, SO₂, HCHO, CO in particular) in the years to come, given their importance in reducing uncertainty of emission databases, and their potential to lead to improved representation of ozone and aerosols from chemical data assimilation systems. Ocean acidity has been added as priority measurement to better quantify ocean carbon content. Additionally, for clarity, some variables have been given a different name: ‘ice sheets’ were previously included in ‘glaciers and ice caps’, and ‘ocean

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5 Including measurements at standardized, but globally varying heights in close proximity to the surface.

6 Up to the stratopause.

6 Including NO₂, CFCs, HCFCs, HFCs, SF₆ and PFCs.

7 In particular NO₂, SO₂, HCHO and CO.

8 Including measurements within the surface mixed layer, usually within the upper 15 m.
acidity’ and ‘carbon dioxide partial pressure,’ whose measurement allows characterisation of ocean carbon content, replace the ‘ocean carbon’ ECV.

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

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

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

Over time, the ECVs have been increasingly accepted, and are now being widely used, by the climate community, meteorological services, space agencies, and policymakers for framing priority action in support of climate observations. Established for a scientific, programmatic as well as policy-level audience, the list of ECVs is partly uneven: some variables in the list are rigorously defined physical properties, such as ‘surface air temperature’, ‘sea level’ or ‘albedo’, for which requirements on accuracy etc. can be directly established. Others, such as ‘precipitation’, ‘cloud properties’, ‘ocean acidity’ or ‘glacier and ice caps’ serve as placeholders for an array of geophysical measurands (for example, ‘rainfall intensity’, ‘monthly rainfall amount’ are associated with ‘precipitation’).

To achieve systematic monitoring of Essential Climate Variables, it is essential that the related satellite-derived FCDRs and products meet requirements for resolution, accuracy, and stability (GCOS, 2006); an update to those detailed requirements, based on the 2010 GCOS Implementation Plan, is planned for the first half of 2011, involving a broad consultation process with the satellite and climate communities). Due attention should further be given to proper quality analysis of FCDRs and ECV satellite products (e.g., through the application of a maturity index or the QA4EO guidelines) and associated documentation. The latter is essential to meet the increasing demand for transparency and traceability of all climate-related datasets, and guidance material has been developed to assist research groups, agencies and other institutions generating datasets in efficiently meet that demand (see section 7).

4. The Role of Satellites

Satellites now provide a vital means of obtaining observations of the climate system from a global perspective and comparing the behaviour of different parts of the globe. Addressing the updated set of GCOS requirements in the 2010 GCOS Implementation Plan and the upcoming ‘Satellite Supplement'
to that Plan (in 2011) relies on space agency action in the period 2010-2015 and beyond, with particular emphasis on:

- Ensuring continuity and over-lap of key satellite sensors, in adherence to the GCOS Climate Monitoring Principles (i.e., basic principles of continuity and sustainability, mission overlap, orbit control, calibration);
- Recording and archiving of all satellite metadata;
- Maintaining appropriate 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; and
- Undertaking sustained generation of satellite-based ECV products.

### Table 2: GCOS Essential Climate Variables for which satellite observations make a significant contribution.

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

The 2010 GCOS Implementation Plan identifies the ECVs to which observations from space make a significant contribution (cf. Table 2). Those ECVs should be used to guide priority action by space agencies in mission planning and the generation of FCDRs and derived ECV satellite products. The global climate observing system relies on all satellite systems that are relevant for climate, but that often have not been designed with a primary focus on ‘climate’ requirement (e.g., in the case of AVHRR or MSU units). In addition, the Plan calls explicitly for missions, datasets, products and calibration/validation activities which have climate requirements as a primary driver (e.g., a CLARREO-type mission as an absolute calibration standard in orbit; continuity of instruments for the calculation of Earth radiation budget; continuity of altimeters to continue the sea-level record; laser, altimetry and gravity missions for the monitoring of ice masses).

Missions targeted on observation of a particular ECV or domain (atmosphere, oceans, land) may additionally provide valuable information in another domain, as in the case of ocean colour and atmospheric aerosol, for example. Space agencies should ensure that they retrieve information in a scientifically sound, mutually consistent and beneficial cross-domain manner, thereby maximising the use of their data across the domains.

The 2010 GCOS Plan also notes many other valuable observations from satellites which, although ideally measured in the same sustained way, are, for reasons of priority and cost, suggested to be made
at intervals of time, with a view to assisting in the interpretation of changes in the climate system. While indicative details of the satellite observation requirements are given, the process of finalizing detailed specifications for satellite instruments is a very complex issue, which depends on the various approaches taken in generating end products. For this reason the Plan stresses the need to ensure appropriate structural arrangements to ensure links between space agencies, end users and scientific groups involved in the creation of products. For example, the EUMETSAT Satellite Application Facilities for Climate Monitoring, as well as for Ocean/Sea Ice, benefit from effective linkages between EUMETSAT as the data provider on the one hand, and the user community on the other. In some cases, this linkage also includes near-real time use of the satellite data. At the same time, independent data processing and product generation are essential to allow reliable estimates of errors, and to help continuous improvement of product quality.

In addition to global observations of the ECVs, the Plan notes the need, and identifies Actions, for detailed in-situ measurements at a range of global sites of atmosphere, ocean, and terrestrial ECVs (preferably collocated) serving as reference for the climate records obtained from other, more comprehensive observing systems, such as satellites. Both for the calibration of satellite instruments pre-launch and during operations, as well as for regular and independent ground-based validation and benchmarking, high-quality in situ observations from reference sites are indispensable. The emerging GCOS Reference Upper Air Network (GRUAN) is one example for a network of such reference sites. One application is to use the atmospheric profiles (e.g., of temperature, water vapour) obtained at GRUAN sites along with radiation models for comparison with satellite radiance measurements. To make the climate observing system more resilient, GRUAN observations can also be used as a transfer standard from one satellite to another especially if there is a gap due to an instrument failure.

Implementation of the GCOS satellite component will also involve collecting and archiving all satellite metadata so that long-term sensor and platform performance is accessible. The creation of consistent data records from all relevant satellite systems (so that optimum use can be made of the satellite data in the integrated global analyses and reanalyses, for example through reprocessing of past records) requires the organization of data service systems that ensures an on-going accessibility to the data into the future.

5. Observational Datasets and ECV Products Needed for Many Purposes

Observations of the ECVs are required for the purposes of monitoring and understanding climatic variations (for example, monitoring seasonal variation of sea-surface temperature and surface pressure in order to distinguish between natural and human-induced variability in the Pacific), detecting and attributing trends (for example, decadal trends in upper air temperature and attributing them to changes in radiative forcing and circulation patterns), and validating and improving the models used for climate prediction (for example, using a long-term precipitation dataset to test rainfall output from a GCM run in hindcast mode; providing initial conditions for an atmosphere-ocean coupled model used for seasonal prediction; comparing observed and modelled decadal variability to test forecast skill (Meehl et al., 2009, Trenberth, 2008). Other, and in particular surface, variables (e.g., surface air temperature, solar irradiance, wind speed, precipitation, river discharge, sea level) are needed to assess possible climate change impacts and to guide adaptation and mitigation actions, for example, in guiding the design of renewable energy systems, which include wind and solar farms and hydroelectric systems.

Vertical profile information up to the stratopause is required for most of the upper-air meteorological and atmospheric composition variables, mainly for monitoring and understanding trends in the concentration of climate forcing agents. Regions of key interest differ from variable to variable (e.g., water vapour trends are weakly established in the UT/LS; variations in GHG concentrations are most uncertain in the lower troposphere). Vertical depth profiles in the oceans, ranging from the skin and
surface mixed layer ("surface" – usually within the upper 15m) to deeper layers and the deep oceans ("sub-surface") are required for a range of ocean ECVs.

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

It cannot be stressed enough that investigators and programme managers should take an integrated view on observing the climate system even though the domain and ECV-based approach to priority-setting has been useful. For example, estimating fluxes within and across domains (e.g., atmosphere-ocean coupling and exchange; atmospheric energy and water fluxes, land-ocean interactions, terrestrial carbon fluxes etc.) is essential for our understanding of the underlying processes that drive climate variability and change, and for closing the budgets in question (e.g., carbon, energy, water). Generally, only high-quality and sustained observations of several ECVs will support calculation and interpretation of flux estimates. The 2010 GCOS Implementation Plan emphasizes the importance of providing supporting observations for monitoring Earth system cycles.

Data assimilation is a technique that adds considerable value to global observing systems by combining heterogeneous sets of observations (e.g., in situ and remotely-sensed measurements) as well as using global numerical models to incorporate other ECVs into consistent analyses. Direct assimilation of satellite-based FCDRs in modelling frameworks circumvents the need to retrieve geophysical fields, avoiding issues related to ill-posed mathematical inversion problems and the possible introduction of artificial trends in the error characteristics of the retrieved fields (Eyre, 1987). These analyses recognize the inter-relationships between variables and the errors associated with each variable. Diagnostic data produced during the assimilation process provide information on the overall quality of the analyses, including information on model biases, and can be used to identify questionable data. At the same time, the production of more simple analyses from single-source climate data records remains critical to ensuring or confirming the reliability of conclusions regarding climate change over time.

6. Cost Estimations

The 2010 GCOS Implementation Plan also contains cost estimates for turning the recommended actions into reality over the next five years. The total estimated global costs of US$2.5 billion annually for implementing all Actions in this Plan are additional annual costs over and above the costs of existing networks, systems, and activities that are required to address climate needs but that are in many cases not specifically designed for climate purposes. Fig. 1 gives an overview of cost estimates within four categories (satellite-related, open-ocean related, related to enhancements in developing countries, and related to enhancements in developed countries), where roughly US$1 billion annually is needed in addition to current expenditure for climate-specific satellite missions and the generation of climate datasets and products.

The Plan includes costs for augmenting existing systems in support of climate needs, for continuing some existing networks, systems, and activities undertaken for research purposes with no plans for continuity, for the transition of systems from research to operations, and for new systems needed to satisfy climate needs. For example, the cost for a weather satellite and its ground segment are not

\footnote{Funding for these existing networks, systems, and activities is not necessarily secured in the future.}
considered; only the extra cost to make this satellite ‘climate-worthy’ is estimated. The cost for something entirely new required for climate that is not within current plans or budgets is fully counted (this applies to many of the necessary actions addressing systematic observation of the oceans and of the Earth’s land surface).

7. Ensuring Transparency, Traceability and Quality of Climate Datasets

As indicated in section 5, there is an unprecedented demand in many socio-economic sectors for relevant climate information for climate change adaptation, mitigation and risk management. Decision-makers expect this information, including related uncertainties, to be based on sound science and trustworthy data. Ensuring transparency, traceability and good scientific judgment in the generation of data records that underpin climate research and climate change monitoring has therefore become imperative. This has been recognized as a requirement in the 2010 GCOS Implementation Plan (in Action C9) and includes the satellite-based climate data record.

All producers of (e.g., space agencies, satellite data users) climate-relevant datasets (e.g., FCDRs, ECV satellite products) should document, assess the quality of, and publicize their work related to the generation, processing and analysis of climate datasets and derived products in a structured and systematic way. A short guideline was published earlier in 2010 to assist in that process. (GCOS, 2010b). Following the guideline would help to:

- Facilitate the self-assessment of quality by data producers;
- Ensure transparency in the generation of climate datasets and products; and thereby
- Enable users to judge the quality and fitness for purpose (“peer review”) of climate datasets and products.
In addition, complying with this guideline can help producers of climate datasets and products to demonstrate that they aspire to address GCOS requirements for data quality, completeness and transparency.

Nevertheless, following this guideline does **not**:

- imply that those datasets and products necessarily attain climate standards for accuracy, resolution and stability as stipulated by GCOS;
- guide the operation of the observing networks and systems themselves that are the original source of datasets in support of climate applications.
- replace any obligations on data producers for quality assurance existing within their home institution, or for example within WMO or QA4EO guidelines.

In the generation (and update) of FCDRs and ECV products, it is recommended that data producers pay particular attention to the following 12 needs:

<table>
<thead>
<tr>
<th>1.</th>
<th>Full description of all steps taken in the generation of FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities</th>
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<tbody>
<tr>
<td>2.</td>
<td>Application of appropriate calibration/validation activities</td>
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<tr>
<td>3.</td>
<td>Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements</td>
</tr>
<tr>
<td>4.</td>
<td>Assessment of long-term stability and homogeneity of the product</td>
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<tr>
<td>5.</td>
<td>Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality, and applications (e.g., publications in peer-reviewed journals, or evaluations by independent, internationally-recognized science groups)</td>
</tr>
<tr>
<td>6.</td>
<td>Global coverage of FCDRs and products where possible</td>
</tr>
<tr>
<td>7.</td>
<td>Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing</td>
</tr>
<tr>
<td>8.</td>
<td>Arrangements for access to the FCDRs, products and all documentation</td>
</tr>
<tr>
<td>9.</td>
<td>Timeliness of data release to the user community to enable monitoring activities</td>
</tr>
<tr>
<td>10.</td>
<td>Facility for user feedback</td>
</tr>
<tr>
<td>11.</td>
<td>Application of a quantitative maturity index if possible</td>
</tr>
<tr>
<td>12.</td>
<td>Publication of a summary (a webpage or a peer-reviewed article) documenting point-by-point the extent to which this guideline has been followed</td>
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</table>

Experience with historical climate data records has shown that continuous, cyclical improvement of the quality of datasets and product is generally needed, since historical records usually have challenges in terms of homogeneity. An audit trail associated with climate data records is needed to document how such challenges have been met. A one-time assessment of quality/maturity of datasets and products must not preclude this improvement over time.
8. Strengthening Peer Review of Climate Datasets

The need for well-supported and systematic scientific data stewardship for climate data records, e.g., through advocating the provision of sufficient documentation and metadata (cf. section 7) and the publication of analyses using climate data records in the open literature has been widely recognized. A number of international scientific groups, some associated with the international GCOS and WCRP programmes, have been working for years on the intercomparison and effective peer review of such records, many of them with an excellent track record.

However, there is currently no systematic international approach to ensure transparency, traceability and sound scientific judgment in the generation of FCDRs and ECV products across all fields of climate science and related Earth observations, and there are no dedicated sustained resources in place to support such an objective. For example, there are currently eight sea-ice concentration products produced by different organizations globally that differ significantly in providing an estimate of sea-ice extent and concentrations, mostly due to differences in methodology and not the variability or dynamics of the underlying phenomenon. It is very confusing and frustrating for the non-experts as to which one of these products they can use in their research and analysis, and the necessary documents to describe their attributes in a comparative manner akin to the global climate model inter-comparison projects (CMIP) under WCRP auspices do not exist.

In a joint May 2010 letter, the programme directors of GCOS and WCRP have called upon space agencies, research institutions, modelling centres and other relevant institutions to:

1. empower existing international scientific working groups to carry out, on a regular basis, expert reviews of FCDRs and derived products, through appropriate mandates and with adequate resources;

2. instigate such groups in areas where they do not currently exist;

3. raise awareness that agencies must promote – through appropriate documentation – transparency, traceability and scientific judgment of climate data records.

Several proposals on how to move this initiative forward have been received in response to this call, and they are currently being evaluated. In the spirit of the 2010 GCOS Implementation Plan, climate science and climate change monitoring could be significantly advanced by the relatively modest investments associated with strengthening international scientific peer review of climate datasets.

9. Concluding Remarks – Improving the Global Climate Observing System

The 2010 GCOS requirements encompass a wide range of needs related to climate observation from space. Those needs are epitomized by the updated list of 50 Essential Climate Variables, to over half of which satellite-based measurements are making a significant contribution. Setting those requirements is the beginning of a (roughly quintennial) assessment cycle on whether the global observing systems for climate are meeting the needs of the times for high-quality and sustained, climate-related data and information (see Fig. 2). Implementation of the actions proposed in the 2010 GCOS Implementation Plan will lead to significant improvement in the system and its satellite component. Our current ability to measure some key and emerging ECVs from \textit{in situ} and remote-sensing systems (both surface- and satellite-based) is limited by the lack of suitable instruments and techniques. The limitation can vary all the way from difficulties with the fundamental observing technique to those associated with instrumentation, measurement methodology, suitable calibration/validation techniques, spatial and temporal resolution, ease of operation, and cost.
The development, demonstration, and validation of existing and new techniques are vital to the future success of the global observing system for climate in support of the UNFCCC. It is critically important that as new global satellite-based observations of environmental variables are made, the validation of both the measurements themselves (e.g., radiances) and the retrieval algorithms be carried out under a sufficiently broad range of conditions that they can be confidently applied in the creation of global datasets.

Research is needed to improve the ability to blend different datasets and/or data sources into integrated products. As new types of data are assimilated into models, it will also be important to understand the error characteristics of the new data and of the models used. Data assimilation for climate purposes is still in an early stage of development and requires continued research support. As these developments occur, reprocessing of data to take advantage of the new knowledge will be vital to sustained long-term records.

References


GCOS (2010b): *Guideline for the Generation of Datasets and Products Meeting GCOS Requirements*, GCOS-143 (WMO/TD-No. 1530), May 2010
