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Guideline for the Generation of Datasets and Products Meeting GCOS Requirements*

*An update of the “Guideline for the Generation of Satellite-based Datasets and Products meeting GCOS Requirements” (GCOS-128, WMO/TD-No. 1488), including *in situ* datasets and amendments

May 2010

GCOS-143
(WMO/TD No. 1530)

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1. Purpose of this Document

This guideline is intended to **help all producers of climate-relevant datasets** (e.g., meteorological services, research institutions, oceanographic centres, environmental agencies, space agencies, universities) **in the way they document, assess the quality of, and publicize their work** related to the generation, processing and analysis of climate datasets and derived products (i.e. Fundamental Climate Data Records (FCDRs)² and Essential Climate Variable products (ECV, cf. Annex I)), **based on observations from surface-based, airborne and satellite-based instruments.**

Following this 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 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. Such guidance is provided by the internationally-adopted GCOS Climate Monitoring Principles, and adherence by observing system operators to these Principles greatly enhances the likelihood for obtaining climate-quality datasets from those systems (cf. Annex II);
- replace any obligations on data producers for quality assurance existing within their home institution, or for example within WMO or QA4EO guidelines (see section 3 for details).

2. Guideline

General guidance for the generation of FCDRs and derived ECV products based on surface-based, airborne and satellite-based observing systems, and subsequent quality assessment by providers as well as users, is given by the GCOS requirements³ (e.g., for accuracy, stability, temporal/spatial resolution) as recommended in the GCOS Implementation Plan (and its 2010 update) and the Satellite Supplement⁴; these requirements are based on a broad consensus by the international climate community; and are reviewed on a regular basis.

¹ An update of the *Guideline for the Generation of Satellite-Based Datasets and Products Meeting GCOS Requirements*, GCOS-128 (WMO/TD-No. 1488), including *in situ* datasets and amendments

² See section 4 for terminology.

³ The most recent version of the GCOS requirements can be found at <http://www.wmo.int/pages/prog/sat/Databases.html#UserRequirements> (WMO/CEOS database)

⁴ Overview of all documentation related to GCOS needs given at: <http://www.wmo.int/pages/prog/gcos/index.php?name=ClimateObservationNeeds> ; see 'Background' section for details

Specifically, to ensure full documentation, transparency and scientific stewardship in the generation (and update) of FCDRs and ECV products, the GCOS Steering Committee **recommends that data producers pay particular attention to the following 12 needs**⁵:

1. 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
2. Application of appropriate calibration/validation activities
3. Statement of expected accuracy ⁶ , stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements
4. Assessment of long-term stability and homogeneity of the product
5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications ⁷
6. Global coverage of FCDRs and products where possible
7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing
8. Arrangements for access to the FCDRs, products and all documentation
9. Timeliness of data release to the user community to enable monitoring activities
10. Facility for user feedback
11. Application of a quantitative maturity index if possible
12. Publication of a summary (a webpage or a peer-reviewed article) documenting point-by-point the extent to which this guideline has been followed

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.

3. Background: Requirements and Guidance

Formulation and regular review of requirements for observations-based climate datasets and products derived from those datasets in support of climate applications has been an ongoing activity under GCOS auspices⁸. In support of climate as well as of other application areas, the call has been repeatedly made by a number of international groups for adequate documentation, transparency and end-to-end scientific stewardship of observational datasets, ranging from their basic measurement to their use in analyses, reanalyses, models and other applications.

3.1. Background to GCOS Requirements

The 2004 *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*⁹ (GCOS-92, the 'GCOS Implementation Plan') identified 131 Actions required from many 'Agents for Implementation' to meet the needs for sustained, high-quality observations for the

⁵ These 12 needs should be addressed without prejudice to any other recommendations or obligations for quality assurance within data producers' home institutions or, for example, within WMO or QA4EO guidelines (see section 3 for details).

⁶ See section 4 for terminology.

⁷ This could be publications in peer-reviewed journals, or evaluations by independent, internationally-recognized science groups.

⁸ Overview of all documentation related to GCOS needs given at:

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

⁹ GCOS (2004): *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*, GCOS-92, October 2004, http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf

purposes of the Convention. This implies the provision of climate-quality datasets and derived products addressing the Essential Climate Variables, variables for which observation is both feasible and relevant to the work of the IPCC and the UNFCCC. The GCOS Implementation Plan:

- has led to the formulation of detailed observational requirements for all ECVs within the WMO Rolling Review of Requirements process¹⁰. The requirements are *inter alia* expected also to cover the requirements of the World Climate Research Programme for long-term sustained observations;
- identified the need for proper data management and stewardship as critical activities to be undertaken in order to ensure that high-quality climate datasets are collected, retained and made accessible for analysis and/or reanalysis by current and future generations of scientists;
- stressed the importance of data exchange and comprehensive metadata accompanying the data in order to provide transparency for quality assessments (see e.g. Action C11).

In 2006, GCOS provided supplemental detail on the space-based requirements of the ‘GCOS Implementation Plan’) by issuing the document *Systematic Observation Requirements for Satellite-based Products for Climate*¹¹ (GCOS-107, September 2006, hereafter called the ‘Satellite Supplement’). The Satellite Supplement stated requirements for datasets and products addressing 26 ECVs for which there is a major satellite observing component, as well as nine cross-cutting needs related to systematic observation of climate from space. The document indicated expected target accuracy, stability and resolution of ECV satellite products. It also included indications for the FCDRs required for the generation of products, relevant satellite instruments, necessary involvement of expert groups, supplemental needs for non-FCDR-type data records, and other application areas of ECV satellite products.

As such, the Satellite Supplement by itself provides a substantial body of guidance for the generation of datasets and products that meet GCOS requirements. These requirements are reviewed by GCOS science panels on a regular basis, with involvement of relevant expert groups as appropriate. In addition, given the complexity of climate variability and, in part, limited knowledge of the expected variability of ECVs over space and time, several caveats apply to the use of requirements as such. For example, it is possible that a combination of data records from two satellite instruments, neither of which separately meet any of the requirements given in the Satellite Supplement, could usefully meet the needs for climate monitoring if applied together in careful analysis.

The 2010 update of the GCOS Implementation Plan¹² re-iterates and updates, as appropriate, the needs identified in the 2004 Plan.

3.2. Background to the Development of this Guideline

The GCOS/WCRP Atmospheric Observation Panel for Climate, at its 13th session in April 2007, recognized that “it could be beneficial for GCOS to develop a process through which it might formally or informally recognize products that meet the requirements expressed in the Second Adequacy Report and the [GCOS] Implementation Plan. As an example, it was suggested that a data set might be formally recognized once it had been described in the peer-reviewed literature and made freely available to users.”

The GCOS Steering Committee, at its 15th session in October 2007, requested “the GCOS Secretariat, in collaboration with the GCOS science panels, to develop guidelines for datasets and products meeting GCOS requirements, in response to the needs of [...] space agencies.” In October 2008, the Committee “endorsed the approach taken in developing the guidelines [and] encouraged their use [...]. It also requested the GCOS Secretariat to expand the scope of the guidelines to *in situ* observations.” Based on the above requests, in March 2009, the GCOS Secretariat published the

¹⁰ The GCOS requirements in the WMO/CEOS database can be found at <http://www.wmo.int/pages/prog/sat/Databases.html#UserRequirements> (February 2010)

¹¹ GCOS (2006): *Systematic Observation Requirements for Satellite-based Products for Climate* – Supplemental details to the satellite-based component of the GCOS Implementation Plan, GCOS-107, September 2006, <http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf>

¹² Draft at the time of writing; Final version to be published on <http://gcos.wmo.int> by August 2010

*Guideline for the Generation of Satellite-Based Datasets and Products Meeting GCOS Requirements (GCOS-128)*¹³ which provides the basis for this expanded guideline.

The need for guidelines to support a recognition process has been identified by space agencies, for example, in the context of the SCOPE-CM initiative (Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring). It has also been expressed by producers of *in situ* datasets for climate, e.g. the scientific group maintaining the International Surface Pressure Databank.

The 'CIMO Guide' (WMO, 2007a)¹⁴ provides guidance to measurement techniques for a range of meteorological variables from ground-based, airborne and space-based observing systems, and contains recommendations for quality management of observing systems, including metadata documentation. As noted in the GCOS Implementation Plan and the Satellite Supplement, observing systems should, for the purpose of climate monitoring and other climate applications, adhere to the GCOS Climate Monitoring Principles (see Annex II) to the greatest extent possible. Datasets obtained from such systems (ultimately, FCDRs) will be of enhanced value for monitoring the state of the Earth's climate, through, for example, trend analyses, assimilation in climate models, use in reanalyses, and validation of model outputs.

Observations coordinated by the WMO Global Atmosphere Watch programme address key ECVs related to atmospheric composition and fall under the WMO GAW quality assurance system¹⁵. The system has been set up to ensure that the data in the GAW World Data Centres are consistent, of known and adequate quality (including adherence to the GCOS Climate Monitoring Principles), supported by comprehensive metadata, and sufficiently complete to describe global atmospheric states with respect to spatial and temporal distribution.

WMO (2007b)¹⁶ provides guidance to climate data management using standardized software tools which include the provision of minimum metadata. WMO (2003)¹⁷ makes recommendations on best practices in climate data management and homogenization, including required metadata, site documentation and data analysis tools, and WMO (2004)¹⁸ gives practical procedures for data rescue. Finally, the *Guide to Climatological Practices* (WMO, 2009)¹⁹ encompasses the full range of best practices in acquiring, handling and analyzing climate datasets.

The Quality Assurance framework for Earth Observation (QA4EO)²⁰ has been developed as a contribution by space agencies, through CEOS, to the quality assurance strategy of the Global Earth Observation System of Systems (GEOSS). Based on the fundamental principle that "all Earth observation data and derived products should be associated with a documented and fully traceable quality indicator", a set of guidance documents has been published with the aim to enable harmonization and interoperability of observing systems within GEOSS. While initially focusing on satellite-based data, contributions by national metrology institutes to QA4EO also reflect best practices of the non-space communities. Finally, the Open Archival Information System²¹ has provided guidance to space agencies on the set-up of data archive systems conforming to ISO standards.

The checklist given in section 2 of this guideline represents a condensed synthesis of the existing body of guidance literature. It is recognized that, given the complexity of some ECV-related datasets and products, additional expertise and guidance may be needed for the generation of FCDRs and ECV satellite products, depending on the specifics of each case and application.

¹³ GCOS (2009) : *Guideline for the Generation of Satellite-Based Datasets and Products Meeting GCOS Requirements*, GCOS-128 (WMO/TD-No. 1488), <http://www.wmo.int/pages/prog/gcos/Publications/gcos-128.pdf>

¹⁴ WMO (2007a): *Guide to Meteorological Instruments and Methods of Observation (Seventh Edition)*, WMO-No. 8,

¹⁵ WMO (2007): *WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008-2015*, WMO-GAW Report 172 (WMO/TD-No. 1384). <ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw172-26sept07.pdf>

¹⁶ WMO (2007b): *Guidelines on Climate Data Management*, WCDMP-60 (WMO/TD-No. 1376)

¹⁷ WMO (2003): *Guideline on Climate Metadata and Homogenization*, WCDMP-53 (WMO/TD-No. 1186)

¹⁸ WMO (2004): *Guidelines on Climate Data Rescue*, WCDMP-55 (WMO/TD-No. 1210)

¹⁹ WMO (2009): *Guide to Climatological Practices*. WMO-No. 100

http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.html

²⁰ <http://ga4eo.org>

²¹ http://en.wikipedia.org/wiki/Open_Archival_Information_System

4. Terminology

Fundamental Climate Data Record (FCDR):

In this document, the term "Fundamental Climate Data Record" (FCDR) is used to denote a long-term data record, generally involving a series of instruments (all platforms), with potentially changing measurement approaches, but with overlaps, calibration and quality control 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-type measurements, the principles of continuity obviously do not apply, but as many of the other principles as possible (e.g., those for rigorous instrument characterization prior and during operations, complementarity of surface and satellite-based observations, etc.) should be followed.

Product:

The term "Product" denotes, in the context of this document, values or fields of Essential Climate Variables derived from FCDRs. Products may be generated by blending satellite observations and *in situ* data, or by blending multiple *in situ* or multiple satellite data sources. Some products are generated within model assimilation schemes. Some satellite-based products are created by using the laws of radiative transfer to retrieve ECVs from the FCDRs. Other documents use the term "Thematic Climate Data Record" (TCDR)²² for such products; in the GCOS Implementation Plan, the term "integrated climate product" was used. The development of products may require strong collaboration between organizations responsible for the generation of datasets (e.g., meteorological services, oceanographic centres, environmental agencies, space agencies) and the separate research or operational groups that generate products, to ensure continuous refinement and extension. Adequate details of the product generation approach need to be documented and made available, along with the products, to ensure repeatability and incremental improvement of the products.

Accuracy:

Measured by the bias or systematic error of the data, i.e. the difference between the short-term average measured value of a variable and the true value. The short-term average is the average of a sufficient number of successive measurements of the variable under identical conditions, such that the random error is negligible relative to the systematic error. The latter can be introduced by instrument biases or through the choice of remote sensing retrieval schemes.

Stability:

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

Horizontal resolution:

Usually means sampling distance on the ground. In the case of satellite images, horizontal resolution means the image resolution.

Vertical resolution:

Vertical sampling distance or average spacing of independent pieces of information.

Observing cycle:

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

Calibration:

The process of quantitatively defining system responses to known, controlled signal inputs. Thus, a calibrated product is the output from the complete calibrated data generation chain. In the case of

²² 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.

satellite-based measurements, vicarious calibration is indirect calibration achieved by simulating the signal at the satellite sensor input based on independently measured geophysical parameters, and comparing it to the actual signal measured by the sensor. The outcome of the comparison can be used to calibrate the sensor output.

Validation:

The process of assessing, by independent means, the quality of the data products derived from system outputs. Validation ensures that the quality of the products is properly assessed. In the case of satellite-based measurements, this is done via quantification of the uncertainties in Level 1b and Level 2 products. Thus, a validated product is the output from the complete validated data generation chain.

Traceability:

Refers to an unbroken chain of comparisons relating an instrument's measurement to a known standard. Calibration to a traceable standard can be used to determine an instrument's precision, accuracy and stability.

Essential Climate Variables (ECVs)²³

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	<p>Surface²⁴: Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.</p> <p>Upper-air: Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).</p> <p>Composition: Carbon dioxide, Methane, and other long-lived greenhouse gases; Ozone and Aerosol, supported by their precursors</p>
Oceanic	<p>Surface²⁵: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour (for biological activity), Carbon dioxide partial pressure, Ocean acidity,</p> <p>Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers, Phytoplankton; Marine biodiversity and habitat properties²⁶</p>
Terrestrial	River discharge, Water use, Ground water, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture

²³ Based on the 2010 update of the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (Draft 13 November 2009; Final version to be published on <http://gcos.wmo.int> by August 2010). The 2009 review copy of the Plan contained an additional ECV 'Terrestrial biodiversity and habitat properties' which was questioned in the review on the grounds of maturity, and is therefore not included here. A final decision will have been made by August 2010.

²⁴ Including measurements at standardized, but globally varying heights in close proximity to the surface

²⁵ Including measurements within the surface mixed layer, usually within the upper 15m

²⁶ At selected sites and areas (e.g., coral reefs)

GCOS Climate Monitoring Principles (GCMPs)

*Effective monitoring systems for climate should adhere to the following principles*²⁷:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

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

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.

²⁷ The 10 basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.
19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

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