

GUIDANCE BOOKLET

WMO Stewardship Maturity Matrix for Climate Data (SMM-CD)

The SMM-CD Working Group *

International Expert Group on Climate Data Modernisation (IEG-CDM) **
(formally the Ad hoc Expert Team on Climate Data Modernisation)

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Disclaimer This document is a guidance booklet to help facilitate the development and use case studies of the Stewardship Maturity Matrix for Climate Data (SMM-CD) by providing additional background information and resources. The views expressed herein do not necessarily reflect those of WMO or its Members. The document will be subjected to future evolution as knowledge improves and user requirements expand and/or change.

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Please direct your suggestions to: Ge Peng; Ge.Peng@noaa.gov. The latest unofficial version of this document will be maintained at and can be downloaded from figshare.com with the following persistent digital object identifier (doi): [doi:10.6084/m9.figshare.7002482](https://doi.org/10.6084/m9.figshare.7002482)

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1. EXECUTIVE SUMMARY

The World Meteorological Organization (WMO) is a United Nations specialized agency in the field of weather, water and climate. As part of its activities, WMO fosters international collaboration to develop technical guidance and standards for the collection, processing, management of data and forecast products. Under the technical advice of its Commission for Climatology, WMO decided recently to establish a High-Quality Global Data Management Framework for Climate (HQ-GDMFC) initiative as an international collaborative initiative for developing standards and recommended practices for sourcing, securing and managing climate data, and for sharing infrastructure and responsibilities for, e.g., data exchange, analysis and data service provision. The ultimate goal of the initiative is to ensure mature data management and governance in addition to the Global Climate Observing System (GCOS) climate data source reviewing process. The initiative includes, inter-alia the development and maintenance of a catalogue of easily discoverable and accessible high-quality climate datasets that are characterized by well documented methodologies and practices for their creation, management, stewardship and governance. Such a catalogue will provide an authoritative and trustworthy source of climate datasets useful for producing information on key climate indicators. Most prominent target users for the catalogue include, but are not limited to, the climate policy community in the context of the Paris Agreement Global Stock take which is expected to start in 2023.

The initial climate datasets such as temperature, precipitation, ice sheets, sea ice, sea level, glaciers, were chosen from a range of sources such as the research community, Climate Indices, Marine, and Hydrological data initiatives, and Crowdsourced data.

The WMO-wide Stewardship Maturity Matrix for Climate Data (SMM-CD) is a tool that will enable data providers to assess and rate their datasets quantifiably based on internationally validated data stewardship best practices. The process will help WMO in evaluating the stewardship maturity of the datasets which are to be submitted for inclusion in the WMO Catalogue for Climate Data. Ultimately, the SMM-CD and the catalogue aim at improving the maturity in the management and governance of, and therefore the reliability of, climate datasets worldwide.

The stewardship maturity assessment will start on a global scale and will eventually be extended to evaluate datasets at a regional and national level. This cascading approach (National, Regional, Global) should emerge in a horizon of few years after the operationalization of the process at the global level. This cascading approach will allow data references to easily cross these three levels in a consistent manner.

The catalogue will inform users on dataset maturity for which various aspects are assessed based on internationally validated approaches. The data included in the catalogue will be made discoverable and accessible in a prominent position through the WMO Information System (WIS) and internet search engines.

2. BACKGROUND

The World Meteorological Organization (WMO) is a specialized agency of the United Nations with members of 192 countries and territories. WMO provides the framework for international cooperation for the development of meteorology, climatology and operational hydrology, and for Member countries to reap the benefits of the mutual collaboration. WMO is the United Nations' authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources, snow and ice.

WMO is committed to, and continues to, facilitate free and unrestricted exchange of meteorological and related data and information, products, and services (e.g., WMO Resolution 40 (Cg-XII), 1995; WMO Resolution 25 (Cg-XIII), 1999; WMO Resolution 60 (Cg-17), 2016). WMO is dedicated to ensuring and providing the highest possible quality of meteorological, climatological, hydrological, and marine information and related environmental data, products and services (WMO, 2017).

There are several challenges regarding climate data that hamper full implementation of high-quality climate services. Among these, much of the existing guidance on climate data management is out of date due to rapid recent advances in technologies. The National Meteorological and Hydrological Services (NMHS) of many Member countries report lack of capacity in climate data management and there are significant gaps in stewardship, including a lack of standardization of terminology, processes and practices due to an inadequate regulatory framework. On the other hand, there is an opportunity to make better use of the proliferation of new data sources and advances in technology that can support climate services.

The Commission for Climatology (CCI) inter-programme initiative on the High-Quality Global Data Management Framework for Climate (HQ-GDMFC) aims at making use of an extended range of climate data types needed to support the Climate Services Information System (CSIS) of the Global Framework for Climate Services (GFCS) (CCI-16). It also aims to harmonize the definitions and processes that deal with climate data, and provide a more rigorous, standards-based regulatory framework around climate data practices. The WMO Executive Council (Abridged final report EC-65) requested that the CCI work closely with other commissions and programmes to move from a concept to a definition of the HQ-GDMFC. CCI issued Resolution 4 (CCI-17, 2018) agreeing on finalizing the manual on HQ-GDMFC in collaboration with other Technical Commissions and programmes. WMO EC-70 issued a Recommendation.2 (EC-70) to submit the Manual on the High-quality Global Data Management Framework for Climate for adoption by Congress (Cg-18) in June 2019.

The WMO Workshop on Information Management (WWIM), which was convened by CCI and WMO Commission for Basic Systems (CBS), 4–6 October 2017, included a

recommendation for a project plan for identifying high quality climate datasets and providing access to them. A key conclusion was that a process needs to be defined on how datasets can be endorsed by WMO. Essentially, in addition to being high-quality climate data products, how datasets are managed must also meet standards as defined by a maturity index that indicates strong stewardship and governance of the data. The WWIM and following CBS Task Team on Information Management (TT-IM) developed a framework for a generic maturity model for information management, intended to be applied to all WMO domains.

The meeting of the International Expert Group on Climate Data Modernisation (IEG-CDM), 16–18 April 2018, used this framework and WWIM’s key conclusion to develop a climate data-specific version of a WMO-wide stewardship maturity assessment model, to be used to consistently assess and score how the individual climate datasets are managed and stewarded.

The key points addressed during the meeting were (IEG-CDM, 2018):

- a. Identification of an initial and provisional limited number of climate related datasets which, after proper evaluation, could eventually become part of the WMO Catalogue of Climate Data;
- b. Development of a WMO-wide Stewardship Maturity Matrix for Climate Data (SMM-CD) based on existing maturity assessment models. The SMM-CD assesses and scores various aspects of the management and stewardship of datasets. This model has been subjected to a broad review process, and was road-tested by using it to assess the initial and provisional list of climate datasets identified in the previous bullet point;
- c. Development of a data discovery and access process for the catalogue through the WIS and major internet search engines, by recommending key metadata requirements and methods of optimising internet searches. The aim is that non-technical users can easily discover these high-quality datasets.

Resources:

- About WMO (<https://public.wmo.int/en/about-us/who-we-are>)
- WMO Resolution 25 (Cg-XIII), 1999: http://www.wmo.int/pages/prog/hwrrp/documents/Resolution_25.pdf
- WMO Resolutions (40, 60), 2016: http://www.wmo.int/pages/prog/sat/meetings/documents/CM-13_Doc_03-01_WMO-Data-Policies.pdf
- WMO, 2017: Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers, WMO-No.1100

- Final report for the 2–4 October 2017 WMO Workshop on Information Management (available at: <http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/meetings/ET-CDM-2018.php>)
- IEG-CDM 2018 Project Plan (<http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/meetings/documents/ET-CDM2018-Flyer.pdf>)
- WMO Workshop on Information Management (Project plan for climate data access) (WMO Workshop on Information Management, 2-4 October 2017)
- High Quality Global Data Management Framework for Climate, 2016 (available at: <http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/documents/HQ-GDMFC-CONOPS-VER2.5-31Mars2016-1.pdf>)
- WWIM-Data wiki (<https://wiswiki.wmo.int/tiki-index.php?page=WWIM-Data&structure=WIS+up>)
- Meeting Report for 16-18 April 2018 International Expert Group on Climate Data Modernization (<http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/meetings/documents/DraftMeetingReport.pdf>)
- CCI-16 Session Information (<http://www.wmo.int/pages/prog/wcp/ccl/mg/ccl-16-mg3.php>)
- CCI-17 Session Information (<http://meetings.wmo.int/CCI-17/SitePages/Session%20Information.aspx>)

3. SCOPE, RATIONAL AND INTENDED AUDIENCE

WMO endorsed datasets need to be of high scientific quality, commencing with well-established and utilized global datasets identified by various scientific domain Subject Matter Experts (SMEs). The process for a dataset to be included into the WMO Catalogue of Climate Data starts with an assessment of the degree of stewardship of the dataset by the data provider. The assessment is then submitted to WMO and undergoes review by the respective domain SMEs. For example, the Global Climate Observing System (GCOS) has established data sources for key Essential Climate Variables (ECV) based on the expert knowledge and judgement of atmospheric, oceanic, and terrestrial communities. They are curated by the ECV Stewards, who are members of the three GCOS scientific panels (i.e., AOPC, OOPC, and TOPC) and focal points for the respective communities. The selection of the datasets is based on five criteria, which have been derived and summarized from the GCOS Monitoring Principles (GCOS-143, 2010, adopted by WMO Resolution 9 (Cg-XIV) and revised according to the United Nations Framework Convention on Climate Change (UNFCCC, 2007)) and in line with the GCOS Observation Requirements (GCOS-200, 2016). The five criteria are:

- i. Worldwide in coverage
- ii. Free and open access
- iii. Quality controlled with documentation
- iv. Include metadata
- v. Considered and recommended by the appropriate GCOS Science Panel Experts

The GCOS ECV data source review process primarily addresses these five criteria in a non-quantitative way. It considers the maturity levels of observation networks by relying on community expertise. This review process aims to identify the best available data sources for climate variables and to help ensure the science quality of derived climate data products.

The over-all quality of the data received by end users can also be influenced by the quality of data management, stewardship, and services. (See Peng et al. (2018) for a list of quality attributes associated with the science, product, stewardship, and services dimension of data and information quality). Quality associated with how datasets are managed and stewarded are critical in ensuring and improving overall quality and ongoing reliability of individual climate datasets, and should be also included in the process for identifying high-quality climate datasets (Wright, 2018b). For example, if data files are corrupted during the data ingest process or during staging for data access without this being noticed because suitable proper data integrity practices or procedures are lacking, then the quality of the data product obtained by users is compromised.

In contrast to the GCOS ECV data source review process, a maturity matrix approach allows for comparable ratings across all climate variables. While a maturity matrix approach has been used by several organizations, the focus may vary. For example, the NCEI/CICS-NC Data Stewardship Maturity Matrix (DSMM) focuses more on data management aspects (metadata, preservation, accessibility, etc.) (Peng et al., 2015), namely assessing stewardship maturity. The European Core-Climax gives more weight to the product itself (uncertainty, peer-review, availability, etc.) (CORE-CLIMAX, 2015), namely assessing science and product maturity. See Peng (2018) for an overview of multi-dimensions of information quality, and examples of maturity models that can be utilized for Earth Science data and products.

The WMO decided to develop a WMO-wide maturity model that targets key aspects of stewardship maturity of high scientific quality climate indicator datasets. This SMM-CD aims to ensure and improve the stewardship quality of these climate datasets. Utilizing the SMM-CD will enable WMO, its Member NMHS, Regional Climate Centers and global data and analysis centres, to use a common approach for assessing the stewardship maturity of their datasets independent of the maturity of observation networks.

The following are some of the benefits of utilizing the SMM-CD:

- Divides data management activities into a manageable set of categories and aspects that will help data providers identify the most relevant aspects for applications such as climate indicators;
- Allows members to assess their data management practices to identify those aspects that would benefit most from process improvement;
- Provides a roadmap and a way of measuring progress towards improving information management capability in support of WMO Programmes;
- Allows Members to identify an appropriate level of process maturity that should be used for the data they are managing;
- Provides a reference model for helping prioritize cost planning, resource allocation and funding for data management;
- Allows for a quantitatively measured and consistent way to convey how the WMO endorsed high-quality climate datasets are managed.

Resources:

- WWIM-Data wiki (<https://wiswiki.wmo.int/tiki-index.php?page=WWIM-Data&structure=WIS+up>)
- IEG-CDM (used to be known as the ET-CDM) 2018 Project Plan (<http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/meetings/documents/ET-CDM2018-Flyer.pdf>)
- Wright, W., 2018: Current status of the WMO maturity matrix convergence model. (Available for download at: <https://wiswiki.wmo.int/tiki-index.php?page=WWIM-Data-2018-1>)
- Siegmund, P., 2018: Setting the state for a maturity-based approach. (Available for download at: <https://wiswiki.wmo.int/tiki-index.php?page=WWIM-Data-2018-1>)

4. CATEGORIES, ASPECTS AND MATURITY SCALE STRUCTURE

Eight categories for measuring the stewardship maturity of environmental datasets were initially identified by the WMO TT-IM (Wright, 2018a). The SMM-CD Working Group decided to minimize the number of categories and identified that, for climate data management purposes, four major elements should be highlighted on the SMM-CD, these being designated as the Categories. For each category, the Working Group identified two to four sub-categories, these being referred to as “Aspects”. There are 12 rating categories/aspects in total. The IEG-CDM members reviewed and endorsed this approach and the scope of the SMM-CD.

In terms of assessing maturity against each Aspect, it was decided to adopt the maturity scale levels from the NCEI/CICS-NC scientific data stewardship maturity matrix (DSMM, Peng et

al. 2015; see also Figure 1).

Figure 1. The maturity scale structure for the WMO-wide Stewardship Maturity Matrix for Climate Data (SMM-CD)

Maturity Scale Levels for Each Aspect				
Level 1	Level 2	Level 3	Level 4	Level 5
AD HOC	MINIMAL	INTERMEDIATE	ADVANCED	OPTIMAL
Not Managed	Limit-Managed	Managed	Well-Managed	Level 4 +
	Not Defined	Defined	Well-Defined	
		Partially Implemented	Fully Implemented	
				Measured, Controlled, Audited

- At Level 1, there are few or no procedures or processes defined or in place, or at least they are not reported or poorly documented. Behaviours are *ad hoc*. Often, information about what has been done to the dataset is not publicly available. For example, an individual researcher created a data file and stored it on their own hard disk.
- At Level 2, some efforts have been made to move the dataset to a managed state. However, the procedure or process is typically defined by an individual entity (person, team, or project). The procedure or process is not documented and is not compliant with an established national or international standard. For example, a project may define a preservation process to address its own archival requirements but is not compliant with any international standard such as the ISO Open Archival Information System (OAIS) Reference Model (ISO 14721, 2012; CCSDS, 2012a).
- At Level 3 and higher, requirements or standards, procedures, and processes associated with that particular aspect are defined and compliant with national or international standards. For example, a data center may adopt the OAIS RM in defining its preservation process. Levels 3 and 4 measure the degree of compliance to the defined requirements or standards and the degree of implementations: Level 3 indicates lack of complete compliance with a partial implementation of standards, while at Level 4, well-defined procedures or processes are fully compliant with national or international standards and fully implemented. For example, the OAIS RM standard is fully applied to a preservation process, while only a part of the OAIS RM is implemented at Level 3.

- At Level 5, a procedure needs to be in place and documented to quantitatively monitor the defined process. In some cases, Level 5 may measure whether an internal or external audit has been performed.

Sometimes, an organization may have a defined process in place but not yet applied to all its data holdings. The same is true of its data management capability. In this case, datasets from the same organization may have different maturity ratings. For example, one data center may have a Thematic Real-time Environmental Distributed Data Services (THREDDS) Data Server in place but not all datasets are being served through this particular THREDDS Data Server (TDS). Therefore, the accessibility ratings could be different.

The requirements or standard against which the maturity of a dataset has been evaluated should be described in an assessment report prepared by the dataset owner. WMO defined requirements and standards are recommended where they are applicable. It should be noted that dataset maturity ratings are not fixed, and ideally should be utilized to identify priorities for improving stewardship quality.

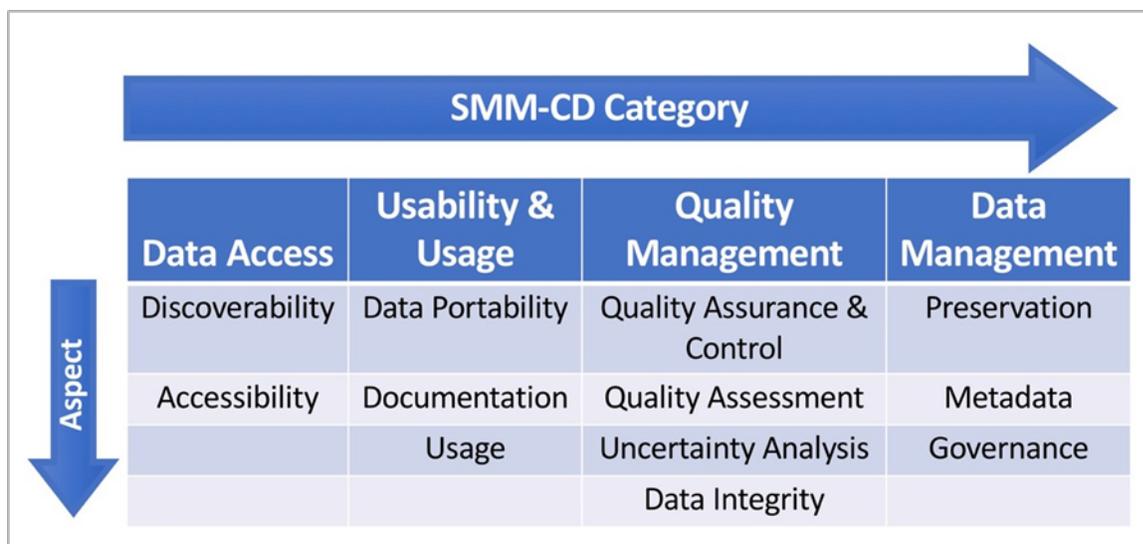
Resources:

- CCSDS (The Consultative Committee for Space Data Systems), 2012: Reference Model for an Open Archival Information System (OAIS), Recommended Practices, Issue 2. Version: CCSDS 650.0-M-2. 135 pp. <http://public.ccsds.org/publications/archive/650x0m2.pdf>
- Peng, G., J.L. Privette, E.J. Kearns, N.A. Ritchey, and S. Ansari, 2015: A unified framework for measuring stewardship practices applied to digital environmental datasets. *Data Science Journal*, 13, 231 - 253. [doi:10.2481/dsj.14-049](https://doi.org/10.2481/dsj.14-049).

5. DEFINING CATEGORIES, ASSOCIATED ASPECTS AND MATURITY LEVELS

The four categories defined for SMM-CD are: Data Access, Usability & Usage, Quality Management, and Data Management. These, along with their selected Aspects, are shown in Figure 2 below. The current version of the matrix produced by the SMM-CD Working Group, along with illustrative examples and other “in progress” notes, is shown in Tables 1–4.

Figure 2. The diagram of SMM-CD categories and aspects.



5.1 DATA ACCESS CATEGORY

Data Access refers to the ability to locate (Discoverability) and get (Accessibility) the dataset in question, with higher levels of maturity corresponding to the ease for a potential user of being able to find and gain access to the dataset. The highest levels will contain broadly-available online information in enough detail that the user will be able to assess with confidence the details and suitability of the dataset for their purposes.

Table 1. Expected behaviours for the Data Access category, along with illustrative examples and preliminary notes

<i>Aspect</i>	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>	<i>Level 5</i>
Discoverability	By personal contact only; Dataset information not discoverable	Limited dataset information, such as scientific description of the methodology in the literature	Minimal catalogue-level metadata; Dataset searchable online	Complete set of collection-level discovery metadata and minimal granular metadata	Level 4 + available on an international catalogue, prominently displayed online and routinely updated

Examples and Notes	<i>Data users must know who the right person is to find the data</i>	<i>Journal articles; technical reports; user guides available</i>	<i>Compliant with the WMO CORE Metadata Profile - collection-level</i>	<i>Attribute Convention for Data Discovery http://wiki.esipfed.org/index.php/Attribute_Convention_for_Data_Discovery_1-3 ;_Compliant with the WMO CORE Metadata Profile - granular-level</i>	<i>WIGOS Metadata Standard (WMO, 2017) compliant</i>
Accessibility	Data not available publicly; Person-to-person contact needed	Basic online services available for data access (e.g. FTP/HTTP direct download)	Non-standard data services	Standard-based interoperability data services	Level 4 + full capability of sub-setting, aggregation and visualization
Examples and Notes	<i>Restricted data; Data producer-owned</i>	<i>FTP/HTTP</i>	<i>Check GE-OSS Standards and Interoperability Registry http://geoss.omstech.com/</i>	<i>THREDDS, Web Map Services, etc.</i>	

5.2 USABILITY AND USAGE CATEGORY

This Category describes how easily the data product may be understood and used by users and incorporated into the user’s own working environment. It incorporates aspects of compatibility of the publication medium with community standards and supporting documentation. Low levels of maturity correspond to formats that are difficult to work with and require pre-processing to incorporate the data, with minimal supporting documentation, while high levels of maturity reflect good interoperability, accessible and complete documentation. Data Usage is also included in this category. It measures how much and at what impact level the dataset has been utilized based on relevant scientific literature. Note that citations refer not just to citations in peer-reviewed journals, but also in widely accepted, authoritative institutional reports. A general guidance on weak, intermediate, and strong citations is provided. It should be recognized, however that what is considered as an intermediate number of citations may vary largely with different disciplines, for example, hydrology versus cryosphere. In that case, one could document the domain citation baseline adopted in the assessment report.

Table 2: Expected behaviours for the Usability & Usage category, along with illustrative examples and preliminary notes

<i>Aspect</i>	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>	<i>Level 5</i>
Data Portability	Non-machine readable	Basic machine readable	Standards-based machine readable	Machine independent, self-describing, interoperable format	Level 4 + capability of providing user required format
Examples and Notes	<i>Untapped data; Paper forms; Obsolete media</i>	<i>formatted binary data</i>	<i>ASCII, CVS; ASCII format may be considered as standard-based but not interoperable. GRIB can be machine independent but not as self-describing and interoperable as netCDF and may be assessed at 3.5</i>	<i>netCDF; OGC WaterML</i>	

Documentation	Product information not publicly available online	Limited online documentation (e.g., User Guide)	Document on how the data product was created and how to use it, is available online	Full documentation based on a standard template and available online	Level 4 + online tutorial on using and analyzing the dataset; Complete production system information
Examples/Notes	<i>Documents, such as Readme or user guide could be available, but one has to know the right person to obtain them.</i>	<i>Just basic information for users to know what the variables in the file are and how to read data</i>	<i>Including additional product information such as input data sources and processing steps</i>	<i>Compliant to WMO documentation requirements on transparency and traceability; At this level, documents should be under document management (e.g., assigned a unique ID and version controlled)</i>	<i>Enough information including provenance for users to reproduce the data product</i>
Usage	No or weak citations in scientific publication in peer-review journal or as institutional reports	Intermediate citations + referenced in institutional climate assessment reports (e.g., by NOAA)	Strong citations + referenced in national climate assessment reports (e.g., by USGCRP)	Level 3 + referenced in international climate assessment reports (e.g., by IPCC)	Level 4 + referenced in international decision & policy making published reports (e.g., by UNFCCC, UN-ISDR, World Bank, etc.)

Examples/Notes	<i>Less than 5 without any for national/international climate assessment reports or decision/policy making reports, or as data utilized in studies published in peer-reviewed journals</i>	<i>Greater than 6 but less than 10. For example, NOAA: Blunden, J and Arndt, DS (eds) 2017: State of the Climate in 2016. Bull. Meteor. Soc., 98 (8), S1-S277, doi: 10.1175/2017BAMSStateoftheClimate.2</i>	<i>Greater than 10. USGCRP (U.S. Global Change Research Program) 2014: Third National Climate Assessment. (Available online at: https://nca2014.globalchange.gov/)</i>	<i>Greater than 10. IPCC (Intergovernmental Panel on Climate Change) 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). IPCC, Geneva, Switzerland, 151 pp.</i>	<i>UNFCCC (United Nations Framework Convention on Climate Change)</i>
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5.3 QUALITY MANAGEMENT CATEGORY

Quality management encompasses quality assurance (QA) procedures including quality monitoring, quality control (QC) and quality assessment and communication of reliability. At the lower levels, quality monitoring and correction procedures are poorly defined and policed, whereas the higher levels move towards a well-managed full end-to-end quality assurance process traceability. High level QC might also include a retrospective QC, whereby the full historical climate record, not just incoming data, is assessed using best practice methodologies. This Category also includes to what extent uncertainty in the data are quantified, and an assessment of Data Integrity, which measures the checks put in place to ensure that data received and archived conforms to the initial data files (it may be viewed as the opposite to data corruption).

Table 3: Expected behaviours for the Quality Management category, along with illustrative examples and preliminary notes

<i>Aspect</i>	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>	<i>Level 5</i>
Quality Assurance & Control	Ad hoc or no data quality assurance (QA) & quality control (QC) procedure or information unknown	QA/QC procedure are defined, documented, and partially implemented	QA/QC procedure are well-defined according to community best practices, documented and fully applied	Level 3 + provision of error statistics published or tracked with results made available online and communicated to data providers; Procedure for user feedback, improvement prioritization in place	Level.4 + detailed analysis of errors and gaps at space-time unit level: (Station, grid- points, daily, monthly and or annual time-scale, etc.) QA/QC procedure monitored; Retrospective QC
Examples and Notes			<i>Compliant with WMO QA/QC guidelines</i>		<i>QA/QC is applied to the full historical record, which is what we would expect of a fully reliable dataset</i>
Quality Assessment	Product quality assessment not done or done internally and information not available	Assessed by Principal Investigator (PI) or data producer; Assessment results available online	Level 2 + product validation and evaluation done by PI published in peer-reviewed journal	Level 3 + independent product validation and evaluation published in peer-reviewed journal	Level 4 + complete product provenance is captured and publicly available

Uncertainty Analysis	Uncertainty estimates not available	Uncertainty estimates presented without explanation	Uncertainty estimates presented with partial explanation	Full uncertainty budget available with all assumptions; Estimates of accuracy of trend available	Full uncertainty assessment published in peer reviewed journal
Examples and Notes	<i>Either uncertainty analysis has not yet been done or results are not available publicly</i>	<i>e.g. +/- x% without further explanation</i>	<i>Some of the underlying assumptions and the method used e.g. "error propagation"</i>		
Data Integrity	Unknown or no data integrity check	Random data integrity check	Data integrity verified systematically but methodology not commonly known	Data integrity systematically verified and following well known practices but not necessarily consistent across platforms	All steps in data integrity check systematically verified and adhering to well-known practice and reported
Example and Notes		<i>Data integrity check only being performed occasionally, and/or on some of the granules of the dataset, including manual checks</i>	<i>Processes in place for instance to ensure data expected are actually received.</i>	<i>Data integrity verifiable with well-known technologies such as checksums or others. Archive might have different schemes in different databases</i>	<i>Ensures that: data sent is same as received; data ingested is same as archived; data put online has not changed during posting process. Well known integrity practices such as checksum</i>

5.4 DATA MANAGEMENT CATEGORY

Data Management is the set of operations, procedures, protocols and policies required to organize, archive, quality control, secure and enable access to an organization’s data holdings. This characteristic refers to the processes undertaken to ensure the data and contextual metadata are securely archived. It covers not just the preservation of the data and metadata with appropriate safeguards, but well defined and enforced governance processes to ensure that the right procedures are followed at the right times by the right people. Lower levels refer to unsystematic approaches with risk of the dataset being lost, corrupted, or even inadvertently deleted. At higher levels, there are well-regulated and regularly audited processes to ensure that the security and integrity of the data set are guaranteed. The Metadata category also includes the aspect of provenance metadata, with high levels corresponding to an ability to trace back to the original version of the data, and to link products to the version of the data from which they were derived.

Table 4: Expected behaviours for Data Management category, along with illustrative examples and preliminary notes

<i>Aspect</i>	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	<i>Level 4</i>	<i>Level 5</i>
Preservation	Any storage location; Data only; Data not backed up	Non-designated repository; A backup copy of electronic data is made	Designated archive; Basic retention policy defined. Routine backups made, including offsite copy	Level 3 + conforming to community archiving standards. Comprehensive retention policy defined and implemented	Level 4 + archiving process performance controlled, measure and audited. Future archiving standard changes planned

Examples and Notes	<i>High risk of data loss</i>			<i>Example: WMO CDMS specifications (WMO-No. 1131) – required and recommended components</i>	<i>State the type of audit, such as NARA record management, ISO 16363 (2012) (also CCSDS, 2012b), or WDS-DISA-RDA core trustworthy data repositories (Edmunds et al. 2016)</i>
Metadata	Metadata not publicly available and/or not usable	Limited Metadata publicly available; Conforming to community-standard; Basic characteristics of dataset	Level 2 + conforming to international standards in most aspects; limited quality and provenance metadata	Fully compliant with international standards; Rich metadata content; Basic granular-level metadata	Level 4 + complete granular-level metadata; Metadata QCed and regularly updated

Examples and Notes		<i>Limited number of metadata like lat/long only</i>	<i>WMO Core Profile compliant; “Most aspects” may include archiving and usability metadata</i>	<i>Sufficient information captured in the metadata for data to be used for homogeneity analysis; support product-level provenance; Changes to the dataset are fully documented, so that the original version of the data can be reconstructed if necessary</i>	<i>Complete information available so that data product can be linked to the version of the data from which it was derived</i>
Governance	Responsibility is not defined; No person is assigned.	Responsible entity is identified; Accountability and competency are not well-defined	Responsibility, accountability and compliance mechanisms are defined; Good competency; Processes established conforming to community standards	Level 3 + competency defined; Confirming to international standards; auditable	Level 4 + accountability and responsibility well-defined and fully compliant with international standards; Transparent; Monitored and audited

<i>Examples and Note (organizational and process capability and competency)</i>		<i>Reasonable competency: WMO definition of competencies for data management</i>	<i>Clear Point-of-Contact (POC), security protocols; Compliant with competency and standards in data management</i>	<i>Auditable: information that could be used for audit as evidences has been collected or documented but not yet initiated the audit process</i>	<i>Met Service data practices are audited: achieved high performance against relevant metrics</i>
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Resources:

- NCEI/CICS-NC Scientific Data Stewardship Maturity Matrix (<https://datascience.codata.org/articles/abstract/10.2481/dsj.14-049/>)
- CORE-CLIMAX Production System Maturity Matrix (Instruction manual can be down- loaded at: https://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=PDF_CORE_CLIMAX_MANUAL&RevisionSelectionMethod=LatestReleased&Rendition=Web)
- CEOS WGISS Data Management and Stewardship Maturity Matrix (http://ceos.org/document_management/Working_Groups/WGISS/Interest_Groups/Data_Stewardship/White_Papers/WGISS%20Data%20Management%20and%20Stewardship%20Maturity%20Matrix.pdf)
- NCEI/ESIP DSC Data Use/Service Maturity Matrix (v00r05 20180412; please contact Peng)
- WMO Competency Requirements (<http://www.wmo.int/pages/prog/dra/etrp/competencies.php>)
- BOG B Report (available at <https://wiswiki.wmo.int/tiki-index.php?page=WWIM-Data-2018-1>)
- WDS-DSA-RDA core trustworthy data repositories requirements (https://www.coretrustseal.org/wp-content/uploads/2017/01/Core_Trustworthy_Data_Repositories_Requirements_01_00.pdf)
- CCSDS Audit and certification of trustworthy digital repositories - Recommended Practices (<https://public.ccsds.org/pubs/652x0m1.pdf>)

6. SMM-CD TEMPLATE

A SMM-CD self-evaluation template (MS Word format) has been developed to facilitate the assessment process (Lief and Peng, 2018). We encourage the use of this template to capture evidence when evaluating the stewardship maturity of a dataset.

The latest version of the template will be maintained at, and can be downloaded from figshare.com: [doi:10.6084/m9.figshare.7003709](https://doi.org/10.6084/m9.figshare.7003709).

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9. DEFINITIONS

- **Data Access** refers to the ability to locate (Discoverability) and get (Accessibility) the dataset in question.
- **Data Documentation** will ensure that your data will be understood and interpreted by any user. It will explain how your data was created, what the context is for the data, structure of the data and its contents.
- **Data Governance** includes standard procedure, policies, approval process, along with accountabilities and compliance mechanism for ensuring the data is secure, accessible and useable.
- **Data Integrity** refers to the extent to which data are recorded, preserved and used exactly as intended, and that data are free from corruption or loss when transferred between systems or in storage throughout the data life-cycle. It is a critical aspect to the design, implementation and usage of any system which stores, processes, or retrieves data. Data integrity is the opposite of data corruption.
- **Data Management** is the set of operations, procedures, protocols and policies required to organize, archive, quality control, secure and enable access to an organization’s data holdings.
- **Data Portability** is a concept to protect users from having their data stored in closed platforms that are incompatible with one another. Data portability requires common technical standards to facilitate the transfer from one data controller to another, thus promoting interoperability.
- **Data Preservation** means ensuring data remains accessible and usable for as long as it is required for operational, research, business evidentiary or historical purposes. It

includes securing the data and making provision for obsolescence of storage media used to store the data; the hardware used to access the data; and the software and hardware required to access the data.

- **Dataset Quality Assessment** is the process of scientifically and statistically evaluating datasets and their level of stewardship, to determine whether they are of sufficient quality to reliably support their intended use.
- **Data Quality Assurance** refers to the processes for maintaining a desired level of quality in a dataset or collection. Data verification, quality control and validation are important steps in supporting defensible products and decisions.
- **Data Quality Control** is the process of ensuring that errors in the data are detected, flagged and corrected. It involves checking the data to assess representativeness in time, space and internal consistency, and flagging any potential inconsistencies. The purpose of Quality Control (and broader Quality Management) is to ensure that meteorological and climate data available to potential users is sufficiently reliable to be used with confidence.
- **Data Quality Management** is the process of overseeing the activities, tasks and policies required to ensure that data maintain a required standard of excellence. Quality Management involves quality planning, the establishment and continued operation of a quality assurance system, including adequate quality control, and quality assessment and improvement processes.
- **Data Uncertainty** is a measure of noise that deviates from the correct, intended or original values. All measurements of an observed phenomenon have a degree of uncertainty regardless of precision and accuracy. This is caused by two factors, the limitation of the measuring instrument (systematic error) and the skill of the observer making the measurements (random error). Further uncertainty can arise when, for instance, values are rounded, interpolated or extrapolated.
- **Data Usability and Usage** is how easily the data product may be understood and used by users and incorporated into the user's own working environment.
- **Metadata** is information about data and sometimes referred to as "data about data". It is important to distinguish between a number of different types of metadata, as described below. To ensure that data are fit for purpose for climate services and research, Entities which produce data for climate purposes are required to create and maintain all of the following types of metadata.
- **Metadata, Contextual** is information about how the data were collected or generated, featuring the who, how, when and where a measurement was made. This information is required to establish fitness for purpose, as well as providing indispensable information for operations such as homogenisation. In the case of meteorological data, it includes such details as where and when the measurement was made, with what instrumentation, by whom, under what siting conditions, what changes to the above have occurred, quality control status, intellectual property information. If the data/information were created by processing or analysis methods, details of the algorithms and methodology used are also required.

- **Metadata, Discovery** is metadata which enables a user to query or search a catalogue to determine what information is held, where it's held and by whom, along with some details about the data/information set. There is a considerable body of knowledge about the requirements for such metadata, with the internationally-accepted standard for what metadata should be maintained referred to as ISO 19115.
- **Metadata, Network.** Changes to the way climate variables are measured apply not only at the individual station level, but to whole networks of stations. An example might be when manual observations are replaced by Automatic Weather Stations (AWS), or when a network of AWSs are progressively replaced by a model with a different central processing unit, or when new sensors are introduced. It is important again to document the time, location and details of any such changes. Moreover, to support the effective homogenisation simultaneous changes across an entire network should be avoided.
- **Metadata, Provenance** Apart from the need to know what changes to observation siting, practices, etc. have been made over time (an essential step in homogenisation procedures), it is important to know about changes to the versions of a dataset. This is because of the need for traceability – being able to identify the version of a dataset from which a particular analysis or product was derived. Provenance should therefore include details of any quality control or homogenisation processes, details of disaggregation or infilling, or any other changes made to the dataset. Climate products and services need to contain a link to the particular version of the data on which they are based.
- **Granular data** is detailed data. For example, at pixel level the granular satellite data record could be a brightness of that pixel as recorded by the satellite on-board radiometer. It is also used to describe the breaking down of a dataset into finer-detailed components or individual elements; for instance, the rainfall record of a particular station within an overall rainfall dataset.

10. ACRONYMS

AOPC	Atmospheric Observation Panel for Climate
BOM	The Bureau of Meteorology
CCL	Commission for Climatology
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CF	Climate and Forecast
CICS-NC	NOAA's Cooperative Institute for Climate and Satellites - North Carolina
CORE-CLIMAX	European Union Framework 7 Project in the context of Climate Services (www.coreclimax.eu)
CSIS	Climate Services Information System
DSMM	Data Stewardship Maturity Matrix
DWD	The Deutscher Wetterdienst
ECMWF	European Centre for Medium-range Weather Forecasts

ECV	Essential Climate Variable
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GFCS	Global Framework for Climate Services
GCOS	Global Climate Observing System
GPCC	Global Precipitation Climatology Centre
HQ-GDMFC	High-Quality Global Data Management Framework for Climate
IEG-CDM	International Expert Group for Climate Data Modernization
ICOADS	International Comprehensive Ocean-Atmosphere Data Set
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JAXA	Japan Aerospace Exploration Agency
JMA	Japanese Meteorological Agency
KNMI	Royal Netherlands Meteorological Institute
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
Met Office	United Kingdom's national weather service
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NCSU	North Carolina State University
NHMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
OAIS	Open Archival Information System
OAIS RM	Open Archival Information System Reference Model
OOPC	Ocean Observing Panel for Climate
RCC	Regional Climate Center
SMM-CD	Stewardship Maturity Matrix for Climate Data
TDS	THREDDS Data Server
THREDDS	Thematic Real-time Environmental Distributed Data Services
TOPC	Terrestrial Observation Panel for Climate
UNFCCC	United Nations Framework Convention on Climate Change
USGCRP	U.S. Global Change Research Program
WCRP	World Climate Research Programme
WGISS	CEOS Working Group on Information Systems and Services
WIGOS	World Meteorological Organization (WMO) Integrated Global Observing System
WMO	World Meteorological Organization