Data Set Quality Assessments:
Needs, Benefits, Best Practices and Governance

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1. Introduction

This document addresses the need for systematic assessments of the quality of data sets used in various applications such as climate services, climate science including the evaluation of climate model performance. The purpose of this document is to initiate a discussion inside of WCRP how the core projects and initiatives on the grand challenges can initiate data set quality assessments in a more coherent way ensuring that the outcomes of assessments are beneficial for their own activities but also for activities across WCRP.

The scope of this discussion paper is limited to a description of the general benefits, high level practises and potential governance structures of data set quality assessments. Detailed best practises are part of this document because they depend too much on the actual physical system and data sets that are being assessed. The document is entirely based on experience made within WCRP GEWEX that has conducted data set quality assessments since more than two decades.

The document provides a brief description of the background from which the need arises and a short history of data set assessments as they were performed in GEWEX. Then it lists the currently know types of assessments and the benefits that were drawn from them. The last set of sections proposes high-level best practises and addresses funding needs and governance issues.

2. Background

Climate variability and long term change poses significant challenges to societies. The availability and communication of climate information through climate services significantly supports prevention of economic setbacks and humanitarian disasters. In addition, climate services play a critical role in national development planning, for managing development opportunities and risks and for mitigation and adaptation. To provide authoritative information to all of this areas it is necessary to develop an as best as possible understanding of the quality of climate observations and derived products. Data set quality assessments are a suitable mean to analyse the fitness for purpose of climate data sets and can play a crucial role in the acceptance process of climate data products for climate services.

Comprehensive assessments of the physical science basis of climate change conducted by the Intergovernmental Panel on Climate Change (IPCC) contain detailed assessment of climate change observations throughout the climate system with dedicated considerations on specific areas such sea level change, biogeochemical cycles, clouds and aerosols and regional climate phenomena. Measurements are used to assess the status of the climate but also to evaluate climate model simulations for the past to build up confidence in model projections under specific emission scenarios. The use of measurements throughout the IPCC report is based on peer reviewed publications about the individual data records and sometimes on comparison of data records. The IPCC report Part I (IPCC, 2013), in particular chapter 2, provides comparison of a limited number of data records whereby the selection of data records rather depends on knowledge of the authors. Only in one case the IPCC refers to a publication related to a WCRP GEWEX assessment which is the

cloud data set assessment (Stubenrauch et al., 2013). IPCC assessments reveal important gaps in geographic and temporal observations, understanding of system processes, and confidence in observations and projections themselves. However, IPCC assessments could make much more extensive use of knowledge collected by individual or collective quality assessments of existing observations of climate which could be provided under the leadership of WCRP, in particular the WCRP Data Advisory Council (WDAC).

A specific activity to facilitate the comparison of satellite observations with climate model data is the Observations for Model Intercomparisons (Obs4MIPS) initiative that makes observational data products more accessible for comparisons (Teixera et al., 2014). Obs4MIPS organised a collection of well-established and documented data sets that have been organized according to the 5th Coupled Model Intercomparison Project (CMIP5) model output requirements and made available through the Earth System Grid Federation (ESGF). The technical alignment of data sets and model output fields is the key element that facilitates the comparison of model data and observations. In addition, Obs4MIPS has created a standardised documentation that is of particular relevance for model evaluation.

The Obs4MIPS activity was initiated by NASA but it is obvious that a great potential for contributions from a broader community exist. The broadening of the community is organised under the umbrella of WDAC by the establishment of a specific Obs4MIPS task team. Ferraro et al. (2015) have summarised the status of the evolution of Obs4MIPs in support of CMIP6. One particular challenge that arises from broadening the community is the management of many more data sets including multiple data sets for the same model output field and their quality assurance. This is already calling for a process that allows providing quality information about the data sets that enter the Obs4MIPS portfolio. Data set quality assessments, if performed efficiently, could be an attractive activity that provides the information in a systematic way covering the full Earth System. Thus, it is important to agree some standards and high-level practises throughout WCRP.

Independently of the WCRP activities, space agencies have started a collaborative activity to formulate a so called architecture for climate monitoring from space (Dowell et al., 2013) that shall facilitate the development of an end-to-end system – capable of delivering the necessary space-based observations for climate monitoring from space. One of the initial steps was to establish an inventory of data records for Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS). Such an inventory shall be used to analyse gaps in the whole value adding chain from satellite measurements to the information provided to decision/policy making processes as outlined in the architecture (Dowell et al., 2012). This includes the production and evaluation of climate data records where a careful assessment of the scientific quality is essential to not provide wrong or misleading information downstream. The joint CEOS-CGMS Working Group Climate has started a consideration of how such quality assessments may be conducted and who could contribute to it. It is obvious that a multitude of differently organised research structures can contribute to it but leadership of WCRP through WDAC may be envisaged for this undertaking.

Comprehensive data set quality assessments are critical to move the science in a field forward in a systematic way. Trenberth et al. (2014) already stated: "*Originally the task was getting a single time series of an ECV. Now there is a proliferation of multiple datasets purporting to be "the correct one". Many are created for specific purposes but all differ, often substantially, and the strengths and weaknesses or assumptions may not be well understood or well stated. Consequently, assessments are required to evaluate these aspects and to help improve the datasets.*"

In a cycle of quality assessment and reprocessing of data sets the analysis of data products in direct comparison to reference data, with respect to their consistency with other data sets, e.g., in representing a part of the energy and water cycle, and/or in comparison to model output data always reveals differences that point to particular weaknesses in certain data sets but also and more important to limitations of our capability to perform measurements with the needed accuracy

and/or sampling. In addition, assessments reveal limitations on our understanding of the measurement process in general, the assignment of traceable uncertainties and our understanding of physical processes that is essential to convert measurements into derived data products, in particular for satellite data sets.

Assessment activities often bring together a critical mass of research groups that analyse deficits and work on improvements of methodology to analyse measurements but also to improve the measurements, e.g., by defining new satellite missions that address specific deficits in our knowledge.

The following outline for data quality assessments is partly based on experiences made within the WCRP core project GEWEX Data and Assessments Panel (GDAP) described in Kummerow et al. (2012).

3. History of Quality Assessments

GEWEX is promoting the assessment of existing data products to adequately characterise each product as to its use in various ways. The GEWEX Data and Assessments Panel (GDAP) (formerly the GEWEX Radiation Panel) conducted several data record assessments during the last decade that were related to the establishment of an observation-based estimate of the energy and water cycle.

Three quality assessments were finalised (precipitation (Gruber and Levizzani, 2008), radiation fluxes (Raschke et al., 2012) and cloud properties (Stubenrauch et al., 2012, Stubenrauch et al., 2013) and a couple of others are ongoing on aerosol properties, turbulent fluxes over ocean (SEAFLUX) and land surfaces (LANDFLUX) as well as water vapour. The motivation for these assessments has developed from studying the limits of applicability of a GEWEX data record (precipitation) to real multi data record comparison exercises (radiation, clouds, water vapour and heat fluxes). All quality assessments were done to answer the question what data product is the best to use or how a data product can be developed to become applicable in energy and water cycle studies at different space and time scales. Most of the GEWEX assessments are concentrating on satellite-derived data records with the exception of the precipitation assessments that also considered rain gauge data because they are used to calibrate satellite precipitation data records.

Prior to the GEWEX activities an assessment activity has also been performed by SPARC on the upper troposphere lower stratosphere (UTLS) water vapour (Kley et al., 2000) with the goal of an analysis and the assessment of the long-term changes of UTLS water vapour, with an emphasis on the observed increase of water in the stratosphere. SPARC currently plans to update the old assessment with improved knowledge from the past 10 years.

The described assessment activities from GEWEX and SPARC cover only a small fraction of the Earth System but may function as a nucleus for more extended systematic assessment activities in other domains. In addition to GEWEX and SPARC also in other areas in particular the oceanic research community assessment activities have started. For instance, the International Ocean Colour Coordination Group (IOCCG) sponsored by the Scientific Committee on Oceanic Research (SCOR) and the Global High Resolution Seas Surface Temperature (GHRSST) Climate Data Record Technical Advisory Group with their associated CEOS so called virtual constellations on Ocean Colour Radiometry and Sea Surface Temperature have started to develop coordination structures in which data record assessments can be performed.

Discussions among representatives of different communities facilitated by the CEOS-CGMS Working Group Climate revealed much communality in the current activities, e.g., emerging similar practises of providing estimates for uncertainty, but also important differences in particular in the specific aims of assessment activities.

4. Assessment Types and Potential Benefits

Data record diversity can be confusing for users, and without the proper background information and understanding of the limitations of available data, there is a danger that these data may be incorrectly applied or misinterpreted. On the other hand users need to realise that it is often difficult to define a single best climate data record. Data records are instead most often complementary in nature with varying strengths and weaknesses depending on the nature of the application the data record is used for and depending on the observing system used to construct the data record. For instance, the retrieval of basic cloud properties depends on the sensor channel wavelengths as demonstrated in the cloud assessment (Stubenrauch et al., 2013).

The basic goal of a quality assessment is to point out differences and limitations of data records and, if possible, to provide reasons for them. The information found shall become part of the peer reviewed literature (open access journals preferred) and be distributed as wide as possible, e.g., into ECV inventories, commentary meta data tools, web portals, etc.

Panels as the GDAP currently consider two types of assessments that have value for user communities:

1. Development of review articles on data records considering specific science aspects spanning from process understanding to trend analysis, specific geophysical variables, e.g., GCOS ECVs or topics of importance for IPCC climate assessments. Such review articles can be written by a group of experts selected by a panel such as GDAP and reviewed by the panel members not involved in writing the article and of course the journal reviewers. The result can be of immediate use for instance to IPCC report authors also avoiding too restrictive approaches on data selections for IPCC reports. It provides balanced and peer reviewed judgement of the existing knowledge;
2. Dedicated data record quality assessment projects that perform a scientific analysis of existing data records and publish results in peer reviewed literature.

Type one assessments may follow cycles of IPCC assessments and can also be pointing to the need for a type two assessment, e.g., if the available information for a review article is insufficient and/or incomplete.

Type two assessments should not be viewed as static but rather as dynamic activities that are continuously ongoing and provide outputs at regular intervals, e.g., every 2 years. The reporting should contain updates due to updated and/or new data records and considerations of specific topics, e.g., precipitation in mountainous regions that is very hard to observe.

Data record quality assessments have benefits for the science, applications as well as data record providers. For the science and user communities, assessments:

- provide independent and transparent quality assurance for data records;
- endorse the use and the credibility of data records to a broader community;
- identify key limitations in data records to stimulate improvements;
- allow objective selections of appropriate data records,

and for the data record providers the assessments:

- provide background information on available data records;
- provide easy access to data in a common user friendly format;
- establish reference data test-beds and tools for external evaluations that can be reused for further developments.

In addition as many climate data records are using multi-satellite program data the data quality assessments are also contributing to the assessment of the strengths and deficiencies of the current

observing system that is very useful to support the development of the future observing system which is for instance part of the CEOS-CGMS WG Climate tasks.

5. High Level Best Practises

Because generalisation of assessment practises is sometimes impractical and may even not be useful, converging in some areas can be very useful to ensure a similar evaluation of the quality of climate data records describing the Earth climate system including all types (in situ, satellite and combined) of measurements and perhaps numerical weather prediction model based reanalyses. To make assessments comparable it is important to agree on some high level principles:

1. A general procedure, e.g., to ensure at least a certain degree of independency to avoid that data products be evaluated too favourably by the developers themselves in order to encourage data usage;
2. A general structure of an individual assessment including the definition of a certain set of mandatory sections in the assessment report but not preventing the publication of additional results. For instance, essential elements that define the usefulness of a data record are certainly its accuracy and uncertainty characterisation;
3. A lexicon of best practises to create climate data records also including practises on data comparisons and nomenclature used for characterising uncertainties;
4. Metrics to assess how far best practises have been followed.

The four principles should be followed by any group that performs an assessment and should help to keep comparability of the assessment results without applying a too strict standardisation.

1. Under general procedures it is understood that each assessment should be hosted by a scientific body such as the GDAP where the group that performs the assessment is reporting to and that signs responsible for the assessment report. As mentioned above the assessment is tasked to conduct objective and independent evaluations and inter-comparisons. It helps to involve the scientists that created the data records so that sufficient background information on involved instruments, applied methods, and underlying assumptions and limitations can be more fully understood and conveyed to the user. But to keep independency findings and reports shall be reviewed by independent experts to prevent too favorable results for specific data records, e.g., by selecting of comparison metric, reference data or physical range of parameter. Although this is not easy to achieve GDAP is practicing this with the Panel acting as reviewer whereas the assessment group appears as a GDAP project that reports annually to the Panel and receives feedback and help for the continuation of the assessment.

   Another aspect of involving product developers in an assessment is the tendency to broaden the goal of the assessment from its original intent of informing the user community to one of using the assessment itself as a diagnostic to help investigators improve their respective data products. Although this is a clear benefit for the data producers and may ascertain their participation, GDAP has found that these two objectives are, in fact, compatible with one another but should always be kept distinct in the assessment to keep the assessment manageable. Thus, in general a data quality assessment should concentrate on providing information to the science and user community first and then move to updates outside of the assessment.

2. As a general structure an assessment of geophysical products should always cover the following elements:
   - A survey of available data records and background information about these;
   - A quantitative examination of strengths and limitations against reference data (especially if data of higher accuracy and higher maturity are available);

- Comparisons of different data records at different time and space scales. GDAP has found that including model and reanalyses data sets in the comparisons is often useful in that it immediately incorporates needs of an eventual user community;
- Recommendation for intended data record uses and identification of areas for which data should "not" be applied;
- Open, full and easy access to the assessment report and all examined data records[1] and methods.

On the last item GDAP has observed that even if the validation data, procedures and previously assessed data are archived for interim use for new product developments, comprehensive assessments are critical to move the field forward in a systematic way.

Furthermore assessments should include:

- A dedicated, motivated, and respected person to lead the effort;
- Complementary assessment team members with specialized knowledge;
- Regular team meetings – open and closed workshops;
- A centralized data depot for data sets created specifically for the assessment (e.g., validation data or common gridded products) that can be used to facilitate assessments by new products or new versions of existing products.

3. A lexicon of best practises to ensure coherent use of nomenclature could be developed and hosted by a subgroup of WDAC. It would be needed to coordinate such a lexicon with other bodies such as GCOS and the CEOS-CGMS Working Group Climate. Such a development could take benefit of ongoing initiatives such as QA4EO and related projects such as the European QA4ECV project.
4. A metric to assess how far best practises have been followed in generating the climate data records is useful in the survey of available data records and also helps to keep the assessment activity manageable by concentrating on data records having a certain maturity that measures the sustainability of data record production. Progress on such metrics based on that published by Bates and Privette (2012) has been made in projects such as the European Union project CORE-CLIMAX (CORE-CLIMAX, 2015).

In addition to the described best practises, each assessment needs to have a strategy how to disseminate its results and reach impact in the scientific community. The classical way of peer reviewed publications and a WCRP report remains important because it secures a proper review. However, the WCRP core project web appearance should put stronger emphasis on assessment activities and results. Data catalogues of the providers could be enhanced with tools providing commentary meta data for a data set, e.g., those developed in the EU CHARMe project. These can point to assessment results and also data bases used in the assessment. In addition the platform of Obs4MIPS can also serve as a very good mean to disseminate the results at least for those data stes used in climate model evaluation. Also other suitable internet platforms such as the NCAR Climate Data Guide can be used for better dissemination into the community.

6. Needs for Funding

Past and current assessment activities usually relied on pure voluntary efforts, thus, they can take considerable time to finish and can collapse unless there is strong leadership. Within GDAP several assessments took a very long time (>10 years) which is far too long to address the needs for assessments. Assuming that a full funding of assessment activities is out of scope for most funding agencies, it is however mandatory that at least some seed funding for centralized activities, e.g., on a centralised data depot and initial workshops is provided to establish the assessment. A good recent

[1] Some data will not be hosted in one place because of too high data volumes. Thus, easy access is fulfilled if the data are readily accessible via the internet without needing special permission.

example was the setup of the GEWEX water vapour assessment where ESA was sponsoring an initial workshop and EUMETSAT is funding central activities through its Climate Monitoring Satellite Application Facility (CM SAF) for about 2 years. This is allowing the assessment to advance and keeps the participants together and active.

It is recognised that funding practises strongly differ across the world but the membership of WDAC including the CEOS-CGMS WG Climate representing space agencies can certainly help to improve the situation if convincing cases for assessments are brought forward. Such cases could be taken up by existing national and international programs such as the NOAA Climate Data Record Programme, NASA Measures, ESA Climate Change Initiative, the EUMETSAT SAFs or other initiatives.

7. Governance Aspects

A couple of relevant questions related to the governance of assessments are:

- Who should initiate an assessment?
- Who should organise it?
- Who should undertake the assessment?
- Who should overlook quality assessments?

Currently, there is no overall coordination of data record quality assessments related to GCOS ECVs, energy, water and matter cycles or topics of importance to the IPCC. Assessments are often initiated and performed by specific scientific or other organisational bodies that represent both users and developers. The aims of these assessments are ranging from providing objective information to the scientific community about the status of data records to more ambitious goals such as making trend estimates and using the data record comparison as a mean to find or create the best data record for that specific purpose. It is also observed that data record assessments are much more common in communities and bodies that work with satellite data compared to those more related to in situ data records.

It is suggested that data record quality assessments can be initiated by any scientific or organisational body that identifies a need for an assessment. But then an assessment needs a 'harbour' to anchor and to get support and independent review.

Within WCRP the Core Projects may task their panels to act as initiator, organiser and reviewer of data record quality assessments following the model of GDAP. For assessments requested from outside, e.g., the CEOS-CGMS Working Group Climate recognises that WCRP should play a critical role in performing scientific assessments, WDAC could become the known receiver of such requests and can help to channel it within WCRP. WDAC could also play an important role for developing a prioritisation of assessment needs to guide funding agencies in their support of assessments.

The organisation of an assessment is best placed at the level of panels such as GDAP because this is the place where the scientific knowledge is concentrated and lead scientists for assessments can most easily be identified.

Scientific groups undertaking the assessments should be formed in an open way to assure broad participation but should pay attention to the selection of data records to not end up with only one off activities that have limited value for the users. The assessment lead scientists need to report to the responsible panel in regular intervals, e.g., annually. The panels themselves are reporting to their specific Steering Groups, e.g., GDAP is reporting to the GEWEX Science Steering Group (SSG), and the SSG present these activities to the WCRP Joint Scientific Committee (JSC).

Organisation of assessments will not be restricted to WCRP as other domain/topic specific competence bodies (e.g., CGMS working groups as ITWG, IPWG, CEOS Virtual Constellations) exist that may organise their own assessments.

The role of WDAC should be to overlook assessments performed within and outside of WCRP from a higher level in particular pointing to missing assessments in critical areas for science, IPCC and climate services. The membership of WDAC is favourably to do this in coordination with GCOS and the space sector. WDAC should have a kind of assessment inventory to become capable to provide such information to the WCRP JSC.

By identifying missing assessments WDAC can also act as initiator of data quality assessments, e.g., later performed by WCRP core projects. WDAC also should be active in supporting the funding of data quality assessments as this is important. In addition WDAC may organise collection and publication of best practises for climate data record generation.

8. Conclusion

This paper provides an outline for data quality assessments explaining the needs, benefits, high level best practises and a potential light governance structure for it. It is mostly based on experience made by the GEWEX Data and Assessments Panel but is also referring to more recent discussions among space agencies on the architecture for climate monitoring from space where quality assurance is a very important topic.

WDAC is invited to take note, discuss, provide feedback and lay out a way forward.

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10. Glossary

CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group of Meteorological Satellites
CHARMe	European Union Framework 7 Project on commentary metadata and tools (charme.org.uk)
CMIP	Coupled Model Intercomparison Project
CM SAF	EUMETSAT Satellite Application Facility on Climate Monitoring
CORE-CLIMAX	European Union Framework 7 Project in the context of Climate Services (www.coreclimax.eu)
ECV	Essential Climate Variable (defined by GCOS)
ESA	European Space Agency
ESGF	Earth System Grid Federation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GCOS	Global Climate Observing System
GDAP	GEWEX Data and Assessment Panel (former GEWEX Radiation Panel)
GEWEX	Global Energy and Water Cycle Exchanges (core project of WCRP)
GHRSST	Global High Resolution Seas Surface Temperature (international open group for SST data producers, users, and scientists)
IOCCG	International Ocean Colour Coordination Group (affiliated programme of SCOR)
IPWG	CGMS International Precipitation Working Group
IPCC	Intergovernmental Panel on Climate Change
ITWG	CGMS International TOVS (TIROS Operational Vertical Sounder) Working Group
JSC	Joint Scientific Committee (highest scientific body of WCRP)
LANDFLUX	GDAP project on turbulent heat fluxes over land surfaces
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
Obs4MIPS	Observations for Model Intercomparisons
QA4EO	Quality assurance framework for earth observation (QA4EO has been endorsed by **CEOS** as a contribution to facilitate the **GEO** vision for a Global Earth Observation System of Systems (**GEOSS**).
QA4ECV	European Union Framework 7 Research project on establishing a Quality Assurance Framework for Climate Data Records (www.qa4ecv.eu)

SCOR	Scientific Committee on Oceanic Research
SEAFLUX	GDAP project for turbulent heat fluxes over ocean
SPARC	Stratospheric Processes and their Role in Climate (core project of WCRP)
SSG	Scientific Steering Group (sub body of WCRP core projects that reports to the WCRP JSC)
UTLS	Upper Troposphere Lower Stratosphere
WCRP	World Climate Research Programme
WDAC	WCRP Data Advisory Council