Protocol for verifying, monitoring, calibrating and validating FCDRs and TCDRs of the CDRs/ECVs

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1. Terminologies

Calibration[1]**:** The set of operations that establish, under specified conditions, the relationship between sets of values or quantities indicated by a measuring instrument or measuring system and the corresponding values realized by standards.

Validation[2]**:** The process of assessing by independent means the quality of the data products derived from the system outputs. Validation ensures that the quality of the products is properly assessed, via quantification of the uncertainties ~~in projects~~. Thus, a validated product is the output from the complete validated data generation chain. Geophysical validation is the process of assessing, by independent means, the quality of geophysical data products derived from the system.

FCDR[3]: Fundamental Climate Data Records are well-characterized, long-term data records of calibrated and quality-controlled sensor data designed to allow the generation of homogeneous products that are accurate and stable enough for climate monitoring. FCDRs usually involve a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate and stable in both space and time to support climate applications. FCDRs are typically calibrated radiances, backscatter of active instruments, or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them.

TCDR[3]:Thematic Climate Data Records are long-term data records of validated and quality controlled geophysical variables derived from FCDRs. TCDRs are specific to various disciplines, and often generated by blending satellite observations, in situ data, and model output.

CDR[4] [5]: Climate data record (CDR) is a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. These changes may be small and occur over long time periods (seasonal, inter-annual, and decadal to centennial) compared to the short-term changes that are monitored for weather forecasting. A CDR is a time series of a climate variable that tries to account for systematic errors and noise in the measurements.

ECV[5]: Essential climate variable (ECV) is a geophysical variable that is associated with climate variation and change as well as the impact of climate change onto Earth.

Level 0 Data[6]: are raw data after restoration of the chronological data sequence for each instrument, i.e. after demultiplexing of the data by instrument, removal of any data overlap due to the data dump procedure and relevant quality checks. Raw instrument data information (telemetry packets) is maintained during this process.

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[1] Jackson, T., A. Colliander, J. Kimball, R. Reichle, W. Crow, D. Entekhabi, P. O'Neill, E. Njoku, 2012: SMAP Science Data Calibration and Validation Plan, JPL D-52544, California Institute of Technology

[2] Guidelines for the generation of datasets and products meeting GCOS requirements, GCOS-128

[3] Description of Work for CORE-CLIMAX.

[4] NRC, 2004: Climate Data Records from Environmental Satellites: Interim Report (http://www.nap.edu/catalog/10944.html)

[5] Dowell, M. D. P. Lecomte, R. Husband, J. Schulz, T. Mohr, Y. Tahara, R. Eckman, E. Lindstrom, C. Wooldridge, S. Hilding, J.Bates, B. Ryan, J. LaFeuille, and W. Zhang, 2013: Strategy Towards an Architecture for Climate Monitoring from Space. Pp. 39.

[6] EUMETSAT, 2013 Feb., Product Navigator Glossary, Doc. No.: EUM/OPS/TEN/13/689034

Level 1 Data[7]: are data extracted by instrument, at full instrument pixel resolution, with Earth-location and calibration information.

Level 2 Data[7]: Geophysical value (temperature, humidity, radiative flux …) at instrument pixel resolution.

2. Introduction

2.1. Background

NRC (2004) outlines 14 key elements that are important for the successful generation of CDRs from space, which are categorized into three sets of functional elements: the CDR organizational elements, the CDR generation elements and the sustaining CDR Elements. The first sets of elements emphasize the importance of coordination mechanism among stakeholders, data providers and science communities. The second set of elements highlight that the successful generation of CDRs lies in creating reliable, consistent and stable FCDRs, based on which TCDRs will be created with rigorous validation and estimated uncertainty levels. The third set of elements focus on CDRs stewardship policies and procedures to ensure the data records and documentation are inexpensive and easily accessible for the current generation and permanently preserved for future generations (NRC, 2004).

International coordination of a structured process to generate CDRs from satellite data has been initiated at a GCOS and WMO-Space Program workshop titled Continuity and Architecture Requirements for Climate Monitoring – First Workshop on Space-based Architecture for Climate. This workshop proposed the establishment of a writing team comprised of representatives from CEOS, CGMS and WMO, that developed a strategy document for architecture for climate monitoring from space (Dowell et al., 2013). Figure 1 and Figure 2 show the sketches of an internationally coordinated structured process model to generate CDRs from satellite observations.

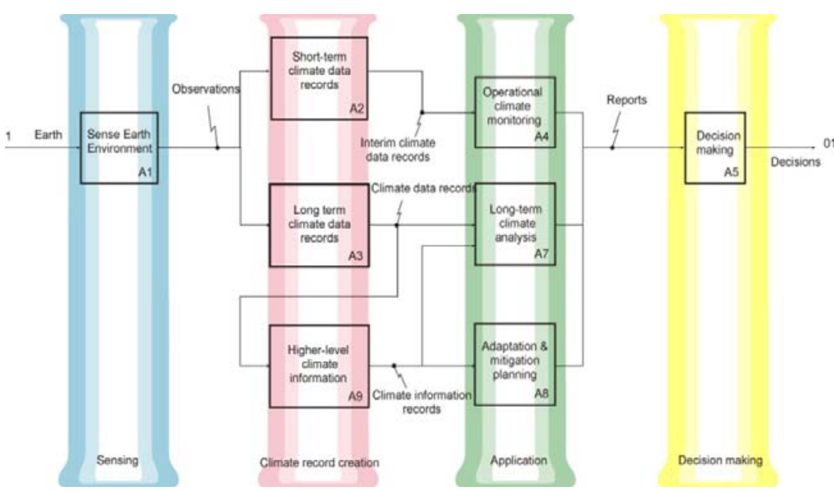

Figure 1. The logical view of architecture for climate monitoring from space and it is decomposition focus on "Climate Record Creation" and "Application".

[7] WMO, From data to products, Data processing levels, http://www.wmo.int/pages/prog/sat/dataandproducts_en.php

Figure 1 presents an information flow starts with the sensing of the Earth Environment. The resultant observations are then assembled processed and converted to climate records. These records are then used by the relevant applications to generate reports that are, in turn, used by decision-making entities to decide on a course of action. Figure 2 illustrates the effect of “drilling down” climate record creation pillar, with a focus on the main constituent elements of function A3: “Long term climate data records”.

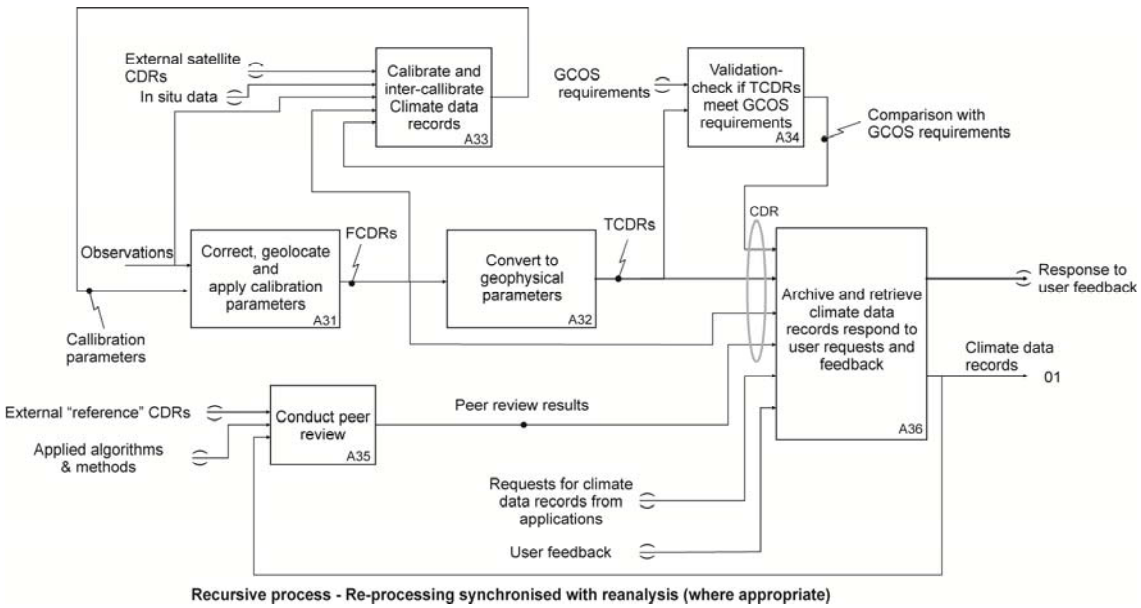

Figure 2. Map to "Long-term Climate Data Records" (function A3 in Fig. 1). The TCDR may only be considered as a CDR upon the validation process given by component A34, which may form just one component of an ECV.

The process of creating “Climate Data Records” starts with the availability of “Observations” (assumed to be raw sensor data). These observations are then calibrated, geo-located, inter-calibrated and atmospherically corrected (see A31), to generate calibrated Level 1 data (e.g., radar backscatter or brightness temperature), which is termed a FCDR, with the calibration parameters applied being derived from ancillary data information consisting of internal data, in-situ data and external satellite data (see A33). The FCDRs is then converted, by means of inversion, to a geophysical/bio-geophysical parameters which is termed a TCDR (see A32). This TCDR may correspond directly to an ECV, or may from just one component of an ECV. Both FCDRs and TCDRs are then archived together (see A36) with relevant information, such as the results of the “Peer Review” (see A35), “Validation” (see A34), and user feedback etc. This information is collectively termed “Climate Data Records”. It is noted that the functions depicted in Figure 2 are recursive, because when improved information/algorithm becomes available the observations are reprocessed to generate improved CDRs.

This document will focus on the calibration (A33, for FCDRs) and validation (A34, for TCDRs) part of the CDR generation elements.

2.2. Calibration of FCDRs

FCDRs usually involve a series of instruments, and are the times series of calibrated signals (e.g. radiances, brightness temperatures and radar backscatter) from a family of sensors (e.g., passive microwave sensors: Nimbus-SMMR, DMSP-SSM/I, AQUA-AMSR-E etc.), together with the ancillary data used to calibrate them. Per its definition, calibration is a process quantitatively defining the system response to known, controlled signal inputs, and stops at level 1 data products, as in higher level processing external-system information (e.g. different retrieval algorithm) is used. The international Satellite Cloud Climatology Project recognized that calibration is an iterative process, including three types of calibration: (1) nominal calibration (e.g. for internal data); (2) vicarious calibration (e.g. for in-situ data); and (3) satellite inter-calibration (e.g. for external satellite data) (NRC, 2004).

Nominal calibration is a standard prelaunch practice, which involves determining the calibration of a single sensor on a single platform. The calibration of the instrument must be monitored in orbit, which may involve onboard calibration and maneuvers to view a celestial body (e.g. sun, moon, deep space etc.). The vicarious calibration is defined as the process of quantitatively defining the system responses to signal inputs coming from a stable and/or known natural target, or to simultaneous in-situ balloon, radiosonde, or aircraft measurements. Vicarious calibration can serve as an additional means for monitoring instrument stability. The satellite inter-calibration involves adjusting multiple instruments to a common baseline, to enable the delivery of fully operational services. It has become increasingly important and demanding, as the slightly different changes in satellite characteristics (e.g. orbital drift, sensor degradation and instrumental biases etc.) will affect the consistency and accuracy of the long-term FCDRs (Goldberg et al., 2011; Chander et al., 2013; Sapiano et al., 2013).

GCOS has developed Climate Monitoring Principles for satellites, highlighting the importance of calibration during the life cycle of the instrument as a requirement (GCOS 128). Although FCDRs will need to be reprocessed as new information is acquired or better calibration, these records will eventually become stable as our ability to improve calibrations of past satellite sensors will diminish over time (NRC, 2004). Unlike nominal calibration (e.g. prelaunch) and vicarious calibration (e.g. post-launch for those instruments without on-board calibrators) as standard practices in space agencies and related institutions, inter-calibration of satellite instruments allow us to achieve relative consistency among satellites and remove biases between them. However, without traceability to stable reference standards, inter-calibration is exposed to the risk of drifting over time and such drifts may obscure the climate trend over several decades. The Global Space-based Inter-Calibration System (GSICS) has been initiated in 2005 by the WMO and the GMES with a goal to ensure the comparability of satellite measurements taken at different times and locations by different instruments operated by different satellite agencies, and then tie the measurements to SI units. It highlights the desirability of establishing calibration traceability to the SI units.

It is important to note that inter-calibration does not imply that the derived correction will completely homogenize observations from the sensor. Instead, the inter-calibration procedure must ensure that measurements between the sensors are physically consistent. In CORE-CILMAX, the calibration of instrument data to generate FCDRs will be advised to follow GSICS-defined implemented procedures to remove biases among satellite measurements for a consistent FCDR generation. In addition, a maturity matrix will be proposed to assess if the operationalization of the process of data record production is following best practices.

2.3. Validation of TCDRs

The strategy for validation of CDRs/ECVs is illustrated in Fig. 3, which shows two most typical validation concepts, the scaling method and the direct comparison method, in peer-reviewed scientific literature. This is an elaboration of the validation process given by component A34 in Fig. 2.

The Scaling method uses an intermediate Very High Resolution satellite data layer (or airborne campaign data) to compare the ground measurements (at less than 1 m of resolution) with products at coarser spatial resolution. This permits to reduce the uncertainties and the difficulties during the integration of several punctual ground measurements over a common area (or an Elementary Surface Area, ESU) to be used for the validation of the product at pixel levels. This is valid especially for products around 100m of resolution or more, for which it is very difficult to integrate several measurements to reach an ESU of that dimension taking also in consideration the landscape heterogeneity. This is the case for most of the terrestrial CDRs/ECVs (e.g. land use, LAI).

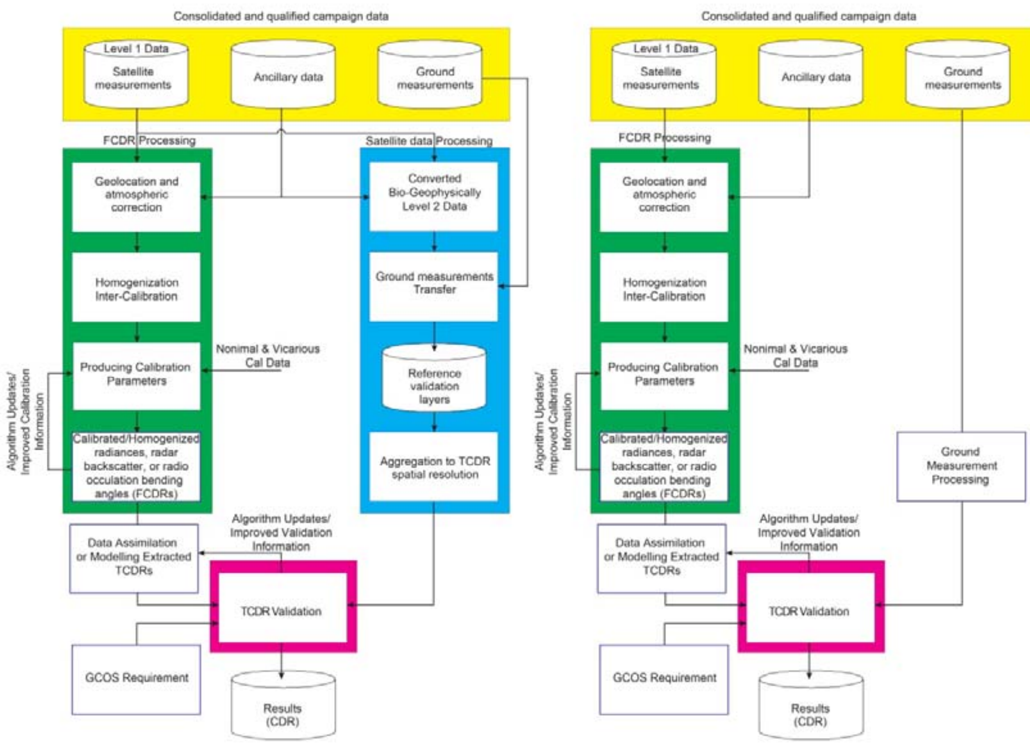

Figure 3: Validation strategy for CDRs/ECVs as an expansion of the validation function A34 in Fig. 4 showing two most typical validation concepts, the scaling method (left) and the direct comparison method (right).

The consolidated and qualified campaign data (yellow) boxes in Fig. 3 indicate the elements needed for validation. The satellite data, the ancillary data and ground (reference) measurements. The left (green) boxes represent the FCDR processing and TCDR generation (the retrieved quantity or the retrieval) while the right (blue) ones in the scaling method are the processing of campaign (reference) data to produce reference validation layers (true quantity). In the FCDR processing, raw satellite measurements are geolocated and atmospherically corrected first when relevant and then homogenized and inter-calibrated, to generate calibrated radiances, backscatter of active instruments, or radio occultation bending angles. Afterwards by means of data assimilation or modeling (e.g. radiative transfer model or specific retrieval algorithms), TCDR products are retrieved. In the right (blue) boxes, level 1 data are used to derive level 2 data products at very high resolution. Afterwards the ground measurements are processed and "transferred" directly to the level 2 data product obtained from level 1 data to represent the validation layers. Finally in the bottom (red) box, the TCDR products are validated by the use of the previously generated Very High Resolution reference validation layers.

It is noted that the generations of both FCDRs and TCDRs are recursive because when improved information becomes available (e.g. better algorithms or improved calibration/validation information) the observations are re-processed to generate improved Climate Data Records. As understanding of sensor calibration issues and radiative transfer from the Earth and Atmosphere improves, algorithms can be improved, and products can be generated via reprocessing.

The main advantage of the scaling scheme is the fact that these intermediate layers are very close in terms of quality and resolution to the ground measurements (since obtained by VHR data), thus the uncertainties due to the ESU integration can be reduced because now the integration is applied to surfaces at the same spatial scale as the satellite pixels. On the other hand, the level 2 data retrieval, the transfer processing and the aggregation introduce uncertainties that have to be monitored.

In the Direct Comparison method, the ground measurements are directly compared with the TCDR product retrieved by standard processing. The only elaboration needed is the processing/integration of ground measurements to generate ESU comparable with the TCDR product. This method is more "direct" with respect to the other, but the ground measurement processing for the ESU generation can introduce additional uncertainties that again have to be estimated and monitored. Moreover, this processing is applicable if the campaigns ground measurements have followed a specific protocol and the area to be covered by the ESU is comparable in size with the product pixel.

3. Maturity Matrices

In establishing confidence in climate monitoring (e.g. satellite & in-situ) datasets, so that various end-users realize the strengths and weaknesses of the dataset, it is now well accepted by the climate service community to have an agreed vocabulary in assessing the maturity of the datasets. A maturity index was first proposed by Bates and Barkstrom[8] (2006), to facilitate the dialogue between data producers and users by classifying datasets on a transitioning scale from research to operational. The proposed CDR maturity matrix combines best practices from the scientific community, preservation description information from the archive community, and software best practices from the engineering community into six levels of completeness.

Each level is defined by six thematic areas: software readiness, metadata, documentation, product validation, public access, and utility. In a swirling-evolving evolution fashion, each level is classified as initial, experimental, provisional, demonstrated, sustained and benchmark. The first two levels

[8] Bates, J.J. and Barkstrom, B.R. (2006) A maturity model for satellite-derived climate data records. 14Th Conference on Satellite Meteorology and Oceanography, Poster P2.11, January 2006

are indicating that although products at this stage of development may be used in research, there is no confidence for its use in decision making and so. The level 3 and 4 are achieved when the product may tentatively be used in decision making, which is also called as initial operation capacity (IOC). Finally, full operation capability (FOC) can be marked when the product has demonstrated that all aspects of maturity are complete, which demonstrates that the product can be reliably used for decision making.

The Bates and Barkstrom maturity index has been adopted to perform self-assessment by several academic institutions and governmental agencies. The most comprehensive test of the maturity index was implemented in April 2011 by the World Climate Research Programme Observation and Assimilation Panel. One of the most important finding was having interdisciplinary discussions of CDR maturity against a common standard (e.g. Bates and Barkstrom maturity index as a starting point), which was referred to the interpretation of the terms used (e.g. needs for a lexicon).

The maturity matrix is still new as Bates discussed[9], and the terminology needs to be refined. It is pointed out and fed back that the application of the index will always be somewhat subjective, and the index may need slight modifications when goals of different programs varies. It is emphasized that the refinements and improvements of more precise language and standards and templates for the elements of the matrix should be achieved by getting feedbacks from community practices.

This maturity matrix model may serve in the future as a requirement for use of data sets in international assessments or in other societal and public policy applications, similar to certification programs that engineering professions conduct[10]. On the other hand, Global Climate Observing System has published 12 guidelines[11] for generation of datasets and products meting GCOS requirements[12], which include 20 principles for climate monitoring, and ESA CCI initiatives documented “responses by ESA to GCOS requirement” [13] as well to guide the ESA CCI projects deliverables[14]. Table 1 demonstrates how these guidelines, principles and deliverables being captured by the thematic areas in the maturity index. For ESA CCI, all deliverables are allocated into different thematic areas and sub-thematic areas, which indicates that the Bates & Barkstrom maturity matrix can be used to assess the maturity of ESA CCI projects, with slight modification.

When check the maturity matrix with GCOS guidelines, it was found that the thematic areas in the matrix can capture the guidelines very well. Most of guidelines have multiple matches (e.g. same number with different font colors) of the thematic areas or sub-thematic areas. However, it is not the case when GCOS monitoring principles were checked[15]. Except for the principle 3, 4, 5, 10, 17

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[9] Bates, J.J. (2013) Published NOAA defined Index – A Maturity Matrix, Presentation 3.1, CEOS Working Group on Climate, 3rd Session, Feb. 2013.

[10] Bates, J.J. and J. Privette, (2012) A Maturity Model for Assessing the Completeness of Climate Data Records, Eos, Vol. 93, No. 44, pp.441.

[11] Guidelines for the generation of datasets and products meeting GCOS requirements, GCOS-128.

[12] GCOS Climate Monitoring Principles, GCOS 143.

[13] ESA Climate Office, 2011, Response by ESA to GCOS, Results of the Climate Change Initiative, Requirements Analysis, Issue 2, Rev. 1, DG-H/2011/3007/ECO/dms/kw.

[14] ESA CCI Project Teams and ESA CCI Programme Team, 2010, ESA Climate Change Initiative, CCI Project Guidelines, Issue 1, EOP-DTEX-EOPS-SW-10-0002.

[15] One note here is appropriate. It is not the intention to cover all GCOS requirements in the maturity matrix, by doing the comparison here. It is a trial to understand how the maturity matrix stands in the context of existing requirements.

and 20, most of principle (e.g. 14 principles) are not included in the maturity matrix. Table 1 also lists the NRC CDR generation elements. There are in total 7 elements, among which 5 were captured by various maturity thematic areas. Two elements out of the range of the matrix are "Pre-launch characterization of sensors and lifetime monitoring" and "Thorough calibration of sensors". These two items are related to calibration of sensor (e.g. Level 0 or Level 1 data) for generating FCDRs, the assessment of which is not well captured by the maturity matrix. Actually, another element that is barely put in the matrix is "high accuracy and stability of FCDRs", which corresponds to the sub-thematic area of "operational monitoring".

Table 1 Matches of GCOS Guidelines, Requirements, ESA CCI Responses and NRC CDR generation elements to the Maturity Index thematic areas. The different font color (excl. black) indicates that one single guideline or requirement can be reflected in different thematic areas.

Bates & Privette Maturity Index		CCI	NRC CDR Generation Elements	GCOS Monitoring Principles	GCOS Guidelines for CDR Generation
Software Readiness	*Documentation*	Product Specificication Doc. System Requirements Doc. System Specification Doc.		10 17	1 1 8
	Portability	System Prototype Description System Verification Report			
	Numerical Reproducibility	Detailed Processing Model			
	Meets coding standards				
	Security				
Metadata	*File level*				
	Collection level				
	Standards	Product Specificication Doc.			8
Documentation	*CDR-ATBD*	Algorithm Theoretical Baseline V0&1			6
	CDR-OAD(Operational Algorithm. Doc.)	Algorithm Theoretical Baseline V2			6
	Process Flow Chart	Data Access Requirements Doc. Input/Output Data Dscription Product User Guide		3	8 1, 8
	Peer Reviewed Docs.				5
Product Validation	*Independent validation*	Prod. Val. and Algo. Selection Rep. Round-Robin Exercise Prod. Val and Inter-Comparrison Rep.	Use of In-situ data for validation	4	1, 3 5, 10 1, 11
	Uncertainty (for TCDRs)	Product Validation Plan Product Validation Report Comprehensive Error Char. Rep.	Well-defined criteria for TCDR Validation	20	2 4 3
	Quality flag	Product Validation Plan			
	Operational monitoring		High Accuracy and Stability of FCDRs		8
Public Access	*Archive*	Ancillary Database Multi-Source Level 1 Database Climate Research Databaase (Level 2)		3	 9 8
	Updates to Record			4	6
	Version				7
Utility	*Data usage if TCDR*	Climate Assessment Report			4, 12
	Societal Sector Decision Support Systems		Stakeholder Involvement and Feedback for TCDRs	5	
	Citations in peer-reviewed literature				
	Feedback to CDRP	User requirements Doc.	Stakeholder Involvement and Feedback for TCDRs		10

In Table 2, those elements, principles that cannot be captured by the maturity matrix are listed and grouped. The most unaddressed topic is calibration or inter-calibration of sensors (e.g. for FCDRs) and the strategy or activities related to it. It highlights the necessity of including a thematic area of calibration of FCDRs in Bates and Barkstrom's maturity matrix, to facilitate its application in a broader range. Although it is not the intention to include all GCOS requirement in the maturity index, apart from the Table 2, the monitoring of the calibration process of FCDRs is still crucial in providing climate data record to detect climate trends and variations, because FCDR is the upstream information in the CDR generation chain (Figure 2). The topics of prioritization of CDR generation and the sustainable observing requirements are well beyond the scope of this document, and will not be discussed in this document.

Table 2 The NRC CDR generation elements and GCOS monitoring principles beyond the maturity matrix

Beyond Maturity Matrix	NRC CDR Generation Elements	GCOS Monitoring Principles
Calibration or Inter-calibration Strategies/ Activities	1. Pre-launch Char. of Sensors and Lifetime Monitoring 2. Thorough calibration of sensors	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. 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 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 institue, should be ensured. 15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored
Prioritization of CDR generation		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 16. Operational production of priority cliamte products should be sustained and peer-reviewed new produtcs should be introduced as appropriate.
Sustainable observing requirements		6. Operation of historically-uninterrupted stations and observing systems should be maintained 8. Long term requirements, including appropriate sampling requencies, should be specified to network designers, operators and instrument engineer at the outse of system design and implementation 9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted 18. Use of functioning baseline instrumetns 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

The application of the Bates and Barkstrom's maturity matrix in CORE-CLIMAX needs modification, which is implemented in WP2. Based on different aspects of capability (e.g. scientific and engineering practices, utilization of products, and quality of products), the maturity matrix is expected to assess if data record generation follows best practices. It is expected to provide an internal view on strengths and weakness of the processes to generate data record for agencies and data record providers. On the other hand, the assessment of the quality of products is facilitating an external view on the data record (e.g. is the quality good enough for a specific application?).

A System Maturity Matrix (SMM) and an Application Performance Matrix (APM) were proposed to be the matrices to fulfill the internal and external evaluation functions. The SMM evaluates if the production of the ECV CDR follows best practices for science, engineering and utilization. The APM evaluates the performance of an ECV CDR with respect to a specific application. For the use of APM, the user requirements for each application are needed to measure the performance.

The major differences between the SMM and Bates and Barkstrom's maturity matrix are on "Software Readiness", "Uncertainty Characterization" and "public access, feedback, update" thematic areas. In terms of the "Product Validation" sub-matrix in the Bates and Barkstrom's maturity matrix, it has been revised as "Uncertainty Characterization". The SMM is independent of individual applications and it is assumed that following best practices can result in better data records. The APM depends on well formulated user requirements and results change with changing user requirements. Cautions were given with respect to the application of the matrices, which is the need to document the reasoning of each evaluation. The details of SMM and APM are referred to WP2 deliverables.

4. Calibration in Maturity Matrix

To establish a thematic area in the maturity matrix, it is necessary to identify its sub-thematic areas for a more precise index scoring (e.g. with a range of 1 to 6). As discussed in session 2.2, calibrations of sensors include nominal calibration, vicarious calibration and satellite inter-calibration. The nominal calibration corresponds usually to pre-launch period while vicarious calibration and satellite inter-calibration are usually implemented during post-launch period. In terms of generating FCDRs, inter-calibration of instrument sensors is the key procedure to obtain long-term consistent observation data, because the same series of sensors on different satellites do not produce consistent measurements despite the best effort in pre-launch and post-launch calibration[16]. Therefore, pre-launch, post-launch and inter-calibration are three sub-thematic areas that need to be considered in maturity matrix. The Uncertainty Characterization sub-matrix in the System Maturity Matrix developed in WP2 can be utilized to address these three sub-thematic areas relevant to calibration.

5. Traceability

The need for minimal uncertainty in climate monitoring, together with the need to combine data from a variety of sources (space and in-situ), and emerging products with data assimilation, have placed "traceability" and its quantification at the top of the agenda for climate monitoring (Dowell et al 2013). Traceability is defined as the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations/validations each contributing to the measurement uncertainty. It implies that a reference standard needs to be established. In CORE-CLIMAX, the System Maturity Matrix proposed in WP2 has included this in the uncertainty characterization sub-matrix. In addition, quality indicator has to be determined. The quality indicator (QI) is a means of providing a user of data or derived product with sufficient information to assess its suitability for a particular application (i.e. fitness for purpose). In CORE-CLIMAX, the Application Performance Matrix proposed in WP2 can be utilized as such indicator. This

[16] Report of a workshop organized by NOAA, NIST, NASA, NPOESS and Space Dynamics Laboratory of Utah State Univ. 2007: Achieving satellite instrument calibration for climate change (ASIC3), Edited by George Ohring.

information should be based on a quantitative assessment of its traceability to an agreed reference or measurement standard, but can be presented as numeric or a text descriptor, providing the quantitative linkage is defined.

6. Protocols-Adhere to Community Reference Standards

As mentioned in session 2, the focus of this document will focus on calibration of FCDRs and validation of TCDRs. As it is important in generating a quantitative score for each FCDR/TCDR in time history to check if a FCDR/TCDR meet GCOS requirement, a quality indicator should be designed and used to facilitate this purpose. Maturity matrix developed in WP2 can serve as a quality indicator for calibration and validation. With the quality indicators (e.g. calibration & validation thematic areas in maturity matrix), gap analysis of the generation of FCDR/TCDR can be implemented. One note is appropriate here. The maturity matrix developed in CORE-CLIMAX is to assess if the operationalization of the process of data record production is following best practices, instead of assessing the quality of the data set itself. The quality indicator here refers to how much extent the process of data record production can follow the best practice.

So far, the quantitative measures for the function A33 & A34 in Figure 2 have been proposed to be implemented with both SMM and APM. As the purpose of calibration and validation is to provide confidence in the quality of FCDRs/TCDRs and their uncertainties, it is important to provide sufficient information on how the CalVal activities are carried out, at each stage of the data process chain (e.g. Figure 2). It allows all end-users to evaluate a data product's suitability for their particular application (e.g. 'fitness for purpose'). To achieve this purpose, it is suggested in session 5 that the documentation, at each stage of the data process chain (e.g. Cal/Val in the case discussed here), should follow guidelines or best practices, which aims to achieve transparency of approach (e.g. traceability) and improve efficiency. This has been covered by the SMM with the "Metadata", "User Documentation" and "Uncertainty Characterization" sub-matrices.

As the existing GCOS principles, requirements, NRC generation elements, QA4EO (http://qa4eo.org/), CEOS-WGCV and similar efforts are aiming to provide common reference standards for CDR monitoring and generation in a community-desired-endorsed manner. It is important for CORE-CLIMAX to adhere to these common reference standards. Therefore, the Cal/Val protocols for FCDRs/TCDRs can be proposed as follow:

1. Generation of FCDRs should adhere to community-desired-endorsed principles, requirements and standards (e.g. Table 2), and be assessed with SMM and APM developed in session 4;
2. Validation of TCDRs should adhere to community-desired-endorsed principles, requirements and standards (e.g. CEOS working group on Cal/Val-WGCV protocols), and be assessed with SMM and APM;
3. The Cal/Val activity under planning should be documented, adhering to community-desired-endorsed principles, requirements and standards (e.g. QA4EO, GCOS-153). The documented Cal/Val plan should be evaluated with the SMM sub-matrices to understand how the Cal/Val plan is traceable;

4. When the Cal/Val activities related to FCDRs/TCDRs are beyond the assessment of the calibration and validation thematic areas proposed in this protocol, feedbacks should be given.