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Analysis of current validation practices in Europe for space-based climate data records of essential climate variables

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ABSTRACT

The Climate Data Records (CDRs) of Essential Climate Variables (ECVs) that are based on satellite observations need to be precisely described. In particular, when these products are delivered to end-users, the error characteristics information and how this information is obtained (e.g., through a validation process) need to be documented. Such validation information is intended to help end-users understanding to what extent the product is suitable for their specific applications. Based on how different European initiatives approached the validation of CDR and ECV products, we reviewed several aspects of the current validation practices. Based on the analysis of current practices, essentials of validation are discussed. A generic validation process is subsequently proposed, together with a quality indicator.

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1. Introduction

Both Global Climate Observation System (GCOS) climate monitoring principles (GCOS, 2003) and the USGCRP (U.S. Global Change Research Program) principles (USGCRP, 2003) highlight the important role of calibration and validation (hereafter, Cal/Val) in producing climate quality data from space. As most Cal/Val results concern short-term data records, it is important to define a realistic generic validation strategy for (long-term) climate data records (CDRs), derived from the existing validation practices. This is illustrated by the architecture for climate monitoring from space proposed by (Dowell et al., 2013): "Climate record processing requires a sustained expert understanding of both new and legacy climate sensors as well as a sustained web of support activities, including a significant effort on Cal/Val; research to reduce uncertainties, establish 'community reference standards'; and collaborative product assessment and inter-comparison."

Cal/Val activities are integral components of the Fundamental Climate Data Records (FCDRs) and Thematic Climate Data Records (TCDRs) processing chain, as illustrated in Fig. 1. The FCDR refers to a long-term data record of calibrated and quality-controlled sensor data designed to allow the generation of consistent products that are accurate and stable enough for climate monitoring (NRC, 2004). FCDRs are typically calibrated radiances, backscatter of active instruments or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them. The TCDR denotes a long-term data record of validated and quality-controlled geophysical variables derived from FCDRs (NRC, 2004).

Fig. 1 shows that processing starts with the availability of observations (e.g., raw sensor data). These observations are then calibrated, geolocated, and corrected for perturbing factors (e.g., atmospheric effects) to generate FCDR (or Level-1) products (e.g., radar backscatter or radiometer brightness temperature), which are then used to produce TCDRs (i.e., geophysical and biogeophysical variables) that are subsequently validated to check if GCOS requirements are met. Both TCDRs and FCDRs are then archived, together with relevant metadata. It is to note that the processes depicted in Fig. 1 are recursive. The observations are

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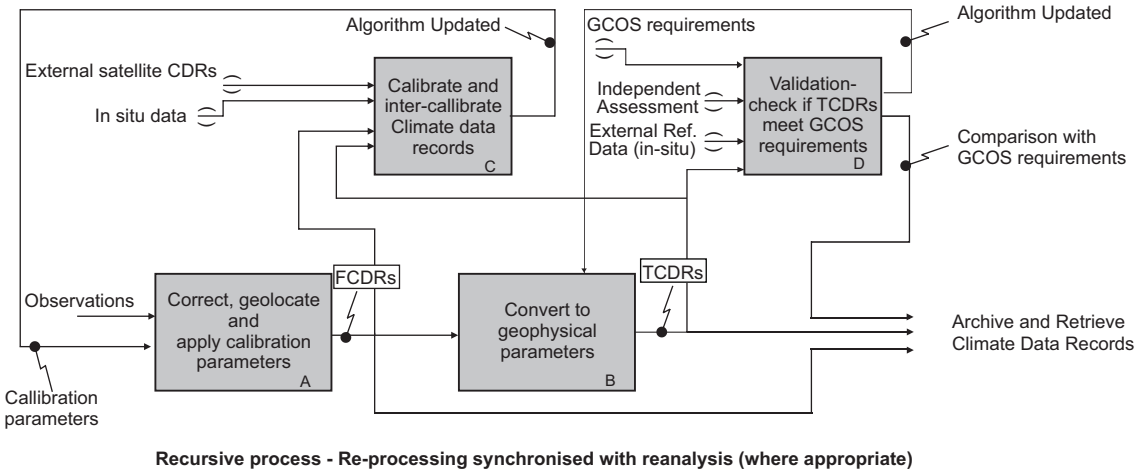

Fig. 1. Processing Chain of FCDRs and TCDRs. (Adapted from Fig 6.3 in Dowell et al., 2013).

reprocessed to generate improved FCDRs/TCDRs when improved information or algorithms become available. In fact, the complete chain of generating climate data records also includes the processes related to the peer-review of a new data record, assessments of data records, and the responses to user feedbacks (Dowell et al., 2013). The calibration ("C" in Fig. 1) is a process quantitatively defining the system response to known, controlled signal inputs (NRC, 2004; Xiong et al., 2010; Chander et al., 2013) have conducted a comprehensive overview of the current practice on the (inter) calibration of satellite sensors.

In this study, we focus on the validation ("D" in Fig. 1) of CDRs of ECVs (Essential Climate Variables). In practice, the validation approaches may vary from one application to another. For example, for weather forecast, the validation of certain variables does not need to consider time series of sufficient length, consistency, and continuity (e.g., the data collection and quality control approaches at different observation networks are not necessary coordinated and harmonized) (Estévez et al., 2011). On the other hand, such conditions are required to assess the climate variability and change. From discussions with TCDR users and data providers (Su et al., 2013a,b), a number of recommendations were derived for the implementation of validation: (1) a traceable validation documentation, (2) an independent review mechanism, (3) regular updates of validations, and (4) analysis of the factors generating uncertainties in CDRs.

The objective of this paper is to assess how different European initiatives/services approach the validation of ECV CDRs. The validation process will differ from ECV to ECV, and individual ECV production teams have already developed specific validation processes for their particular ECVs (ESA, 2010). It, therefore, comes to a point that a transparent, traceable validation process should be documented. In the following Section 2, the aspects of the validation process are discussed. In Section 3, the essentials of validation are discussed, after analyzing the current validation practice with some examples. In Section 4, a generic validation process is proposed. A set of quality indicators (a system maturity matrix) is introduced in Section 5, to facilitate the benchmarking of validation processes. A demonstration on how to assess a validation process using the quality indicator is presented. Conclusions and recommendations are drawn in Section 6.

2. Product validation

The Committee on Earth Observing Satellites (CEOS) working group for Cal/Val (WGCV) defines validation as the process of assessing, by independent means, the quality of the data products derived from satellite observations. This can be called product validation. The product validation ensures that the quality of the products is properly assessed, through quantification of the uncertainties in both the data itself and the measurement system deployed for generating the data. It includes a quantitative understanding and characterization of the measurement system and its bias in time and space. In this context, validation can be considered a process that encompasses the entire system, from sensor to product.

2.1. Validation concept

Fig. 2 shows two typical validation concepts: the scaling method and the direct comparison method. Fig. 2 can be regarded as an elaboration of the validation process given by component "D" in Fig. 1.

The scaling method is shown in the left panel of Fig. 2. The scaling method uses an intermediate Very High Resolution (VHR) satellite data layer (or airborne campaign data) to compare the ground measurements with products at coarser spatial resolution. This permits reducing 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 a pixel level. 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 also taking into consideration the landscape heterogeneity. This is the case for most of the terrestrial ECV CDRs (e.g., land use, LAI).

The consolidated and qualified campaign data (yellow) boxes in Fig. 2 indicate the elements needed for validation, including the satellite data, the ancillary/auxiliary 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 are the processing of campaign data to produce VHR 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 to represent the validation layers. Finally in the bottom (red) box, the TCDR products

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