Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Conformity testing of satellite-derived quantitative surface variables

Jean-Luc Widlowski *

European Commission, DG Joint Research Centre (JRC), Institute for Environment and Sustainability, Land Resources Management Unit, Via E. Fermi 2749, 21027 Ispra (VA), Italy

ARTICLE INFO

Article history:
Available online 4 May 2015

Keywords:
Conformity testing
ECV
Quality assurance
GCOS compliance
Environmental regulations
Earth observation
Climate change
COPERNICUS

ABSTRACT

Reliable compliance information of quantitative earth observation (EO) products is a prerequisite for future usages of satellite-derived evidence in (1) regulatory initiatives addressing air quality, development aid, climate risk, agricultural subsidies and the state of the environment among others, (2) liability debates between customers and providers of value-added (quantitative) EO products and services, and (3) auditing efforts and/or contractual negotiations for the operational exploitation of EO data. Irrespective of context, the conformity of an item can only be established with respect to permissible deviations from an agreed reference. The uncertainty of the reference should ideally be smaller than that of the candidate item, and their combined uncertainty should be smaller than the width of the interval defining permissible deviations. While these considerations are an integral part of conformity testing in legal metrology they are not yet included in validation efforts of satellite-derived quantitative surface information. Outside of scientific application contexts, however, the certified compliance of quantitative earth observation products is likely to induce new usages of such information in commercial, judiciary and regulatory contexts. This contribution introduces conformity testing and compares it to validation efforts assessing the value of biophysical EO products with respect to the quality objectives provided by the global climate observing system (GCOS). The findings suggest that, (1) current GCOS quality objectives must be complemented before they may serve as unambiguous requirements for conformity testing of EO products, (2) a consensus on the choice of decision rules must be sought (between data providers and users) since this has a direct impact on what is deemed compliant, and (3) the uncertainty associated with current field validation methods for quantitative biophysical variables is presumably too large to meet the ISO-13528 criteria. The latter thus challenges the eligibility of current field validation methods to provide the reference needed in efforts assessing GCOS compliance of third party EO datasets.

1. Introduction

Satellite remote sensing enables a regular monitoring of our planet's surface from continental to global scales. So-called *retrieval algorithms* convert calibrated satellite measurements into variables describing the chemical and physical properties of the Earth's surface and its constituents. Such earth observation (EO) products are ideally suited to identify, monitor and analyze key environmental variables and

* Tel.: +39 0332 789663.
E-mail addresses: Jean-Luc.Widlowski@jrc.ec.europa.eu, widloje@yahoo.com.
http://dx.doi.org/10.1016/j.envsci.2015.03.018
1462-9011/

processes, as well as potentially hazardous transnational events, be they related to volcanic ash-clouds, atmospheric pollutants, droughts, floods, or other abnormal patterns in seasonal signatures. The quality of quantitative EO information is currently not assessed with possible regulatory applications in mind. In fact, current space law appears rather vague when it comes to the responsibility that service providers must assume to ensure the quality of satellite-derived information products [Ito, 2011]. So far, the use of remote sensing data in legal contexts focuses primarily on its ability to delineate the spatial extent of certain land cover classes (e.g., roads, forests, wetlands, etc.) or to detect temporal changes [De Leeuw et al., 2010; Mayer and Lopez, 2011], rather than it being a source of trustworthy reference data, for example, to challenge infringement procedures or to enforce environmental directives that hinge on the level(s) of specific physical and/or chemical quantities.

Quantitative EO products have the advantage that they can be potentially validated against calibrated in situ measurements rather than through a process of subjective human interpretations. Satellite-derived concentrations of particulate matter (e.g., PM_{10}), ozone, and nitrogen oxides, for example, can be compared against measurements from traditional reference networks in view of supporting European legislation on air quality [WWW-1]. Similarly, satellite-derived quantitative biophysical information can be validated through intensive field campaigns such as to ensure their reliability prior to informing farmers and decision makers about the health and anticipated yields of crops, and – on a larger scale also – the emergence of droughts and food security situations. In addition, quantitative EO products can also be used in the verification, initialization and improvement of numerical prediction models. This is especially relevant for short term climate forecasts where poorly known initial conditions are the main source of uncertainty [Cox and Stephenson, 2007]. Last but not least, the use of quantitative EO products is also likely to increase in commercial applications, among others, for targeted estimates of risks and policy costs by the insurance sector.

At present, the accuracy of quantitative satellite-derived surface information has not yet become part of liability debates. However, given the increasingly prominent role that long term records of quantitative EO products assume in the generation of reference datasets for climate models [Dowell et al., 2013] as well as in efforts to attribute the causes of extreme events, it is likely that the quality of these datasets will come under increasing scrutiny in the future. Similarly, the anticipated uptake of quantitative EO information by the private sector, whether in the context of crop yield forecasts, air quality warnings, or other value-added services [COM-312, 2013], is also likely to bring about a discussion on the responsibility (and liability) of EO service providers (and contributing scientists) as to the quality of these information. Finally, the public (as well as any relevant funding and auditing authorities) should have a means to verify/know that the results of costly EO programmes are trustworthy and comply with predefined quality requirements.

Methods to ensure compliance with quality criteria exist for quite some time already in legal metrology and the manufacturing sector. Logically, any such endeavour must start with an unambiguous definition of the target item/quantity itself. For satellite-derived quantitative surface information, this is often far from trivial due to sensor-specific retrieval algorithms using inherent assumptions and shortcuts. Next, it must be possible to have access to unbiased candidate and reference estimates of that target quantity, as well as, reliable descriptors of the uncertainty associated with these. Again, this may be far from trivial in the EO context, especially if the spatial heterogeneity of the target quantity is large within the nominal field of view of the observing satellite sensor or else changes rapidly in time. In a final step, the compliance of the candidate method/dataset must be evaluated against clearly defined quality requirements. In a regulatory context, the exact specification and wording of the compliance criteria (as well as the procedures to assess these) is typically the result of a negotiation process between (governmental, industrial, private and scientific/expert) stakeholders and may become rather involved. In operational EO contexts, it is the mission requirements issued by the relevant space agencies or, more generally, the quality objectives formulated by international scientific bodies that are used.

The development of reliable reference methods for satellite-derived information products is actively pursued by the working group on calibration and validation (WGCV) within the Committee for Earth Observation Satellites (CEOS). In doing so, CEOS WGCV focuses on a series of so called "essential climate variables" (ECVs) given that many of these quantities are also relevant in contexts other than climate change. The concept of ECV was developed in the 1990s by the Global Climate Observing System (GCOS) in collaboration with user communities and other stakeholders [Bojinski et al., 2014]. Since then, GCOS publishes at regular intervals implementation plans (and satellite supplements) that provide detailed descriptions of the growing number of ECVs as well as the quality objectives that these (satellite-derived) ECV products should ideally satisfy if they are "to be of relevance" to the work of both UNFCCC and IPCC [e.g., GCOS-138, 2010; GCOS-154, 2011]. Over the past few years, the GCOS quality objectives – while intended as high-level programmatic guidance – have become the *de facto* reference criteria for validation efforts of biophysical surface ECVs. While this choice may appear surprising at first, it is a consequence of the general absence of detailed compliance criteria, on the one hand, and the advantages that a GCOS parentage offers with respect to ad hoc quality assurance efforts on the other hand. Perhaps most pertinent from the perspective of the validation community are the facts that the GCOS quality objectives (1) are regularly updated, (2) undergo public consultation, and (3) provide increasingly detailed definitions of the target quantities.

Despite much progress in recent years, trustable and ideally also SI-traceable evidence as to the quality of the retrieved information is still lacking for most satellite-derived quantitative EO products over land. In part, this is due to the complex, multi-stage retrieval process of biophysical ECV estimates from optical remote sensing data (whether acquired by satellites, from observation towers or with hand-held devices in the field). At the same time, it is also clear that EO product compliance cannot be demonstrated conclusively if the quality requirements and decision rules needed to assess