New perspectives for the CEOS working group on calibration and validation

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Abstract

The Committee on Earth Observation Satellites (CEOS) was created in 1984. All major civil agencies responsible for Earth observation satellite programmes along with international user organisations are members. The CEOS has two working groups, the Working Group on Information Systems and Services (WGISS), and the Working Group on Calibration and Validation (WGCV). In conjunction with the International Group of Funding Agencies for global change research (IGFA) CEOS has also begun development of the Integrated Global Observing Strategy (IGOS). In the context of the day to day work of CEOS plenary and the developing IGOS, the WGCV provides a forum for calibration and validation information exchange, co-ordination and co-operative activities. This paper describes the WGCV's perspectives and plans for calibration and validation.

1. Introduction

The Committee on Earth Observation Satellites (CEOS) was formed in 1984 under the aegis of the Economic Summit of Industrialised Nations' Working Group on Growth Technology and Employment. The overall goals of CEOS are to promote co-operation so as to maximise the benefits of space-borne Earth observations, to aid members and users by acting as a focal point for international co-ordination of space related EO activities and to exchange policy and technical information. CEOS membership includes all the world's major civil agencies responsible for Earth observation satellite programmes along with international user organisations. CEOS established working groups to address issues needed to meet these overall objectives. There are two working groups, the Working Group on Information Systems and Services (WGISS), and the Working Group on Calibration and Validation (WGCV).

WGCV has two objectives. These are firstly sensor-specific calibration and validation, and secondly geophysical parameter and derived product validation. Calibration is defined by WGCV as the process of quantitatively defining the system response to known, controlled signal inputs, and validation is the process of assessing by independent means the quality of the data products derived from the system outputs (CEOS 1995).

This paper describes the context in which the Working Group on Calibration and Validation operates, and presents new perspectives in the light of a new CEOS initiative (in collaboration with the International Group of Funding Agencies for global change research, IGFA) the Integrated Global Observing Strategy (IGOS). The IGOS has the overall objectives of deriving greater benefit from both operating and planned observing systems, identifying gaps in current system planning, increasing the range of Earth observation applications and improving the integration of global observation activities.

2. The Need for Calibration and Validation

The raw digital counts collected at satellite can only be converted into physical quantities of radiance or reflectance if sensor calibration coefficients are available. Radiance or reflectance values can then be used for the derivation of geophysical parameters, such as sea surface temperature or albedo. Because sensors' sensitivities can change with time absolute calibration and temporal radiometric stability must be determined before judgements can be made concerning geophysical quantities derived from space earth observations (Slater 1997).

Though always pre-requisite, the accuracy/ precision with which calibration and validation (cal/val) are required are to some extent user dependent. For example, certain short-term meteorological applications may be satisfied by "relatively" coarse calibration. Major changes from one day to another in sensor response / sensor stability are unlikely, and the users may be satisfied with measurements with a precision of a few percent. Long-term climatology observations require observing systems capable of detecting small changes over a long period of time, calling for far more stringent cal/val requirements (Allen et al. 1994). The increasing use of data from series of satellites carrying nominally identical sensors and/or different sensors measuring similar parameters also emphasises the need for cal/val. Even when users are presented with well-calibrated data sets, they must still check that different algorithms generating the same high level product produce consistent results, and that where appropriate, accuracy statements accompany these results.

Accuracy is defined by N. Fox of the UK's National Physical Laboratory as "how well a measurement is known compared to an internationally agreed standard or scale, e.g. SI units" and precision as "how well a measurement can be repeated" (Fox 1997 personal communication). Specification of cal/val in terms of accuracy leads to compatibility of data set from different instruments and satellites, and enables long term validity of data sets, recovery of a break in data set and compatibility with other terrestrial data. The goal is to bring accuracy closer to precision. WGCV through its open exchange of information allows satellite operators to compare their methods of calibration. Following presentations from National Standards laboratories the WGCV is more and more aware of traceability issues and is actively seeking greater use of SI standards.

Whilst the need for cal/val is clear and unequivocal, these activities are expensive. As such they have often been accorded second place in mission planning and implementation programmes. Fortunately this situation is changing. Growing sophistication among the user community is demanding better documentation and implementation of cal/val steps by data providers.

3. The Advanced Very High Resolution Radiometer; a case study

Data from the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration's (NOAA) Polar-orbiting satellites were destined for meteorological applications. The first afternoon-pass NOAA satellite carrying a five channel AVHRR became operational in August 1981 (NOAA 7). That same year the use of these data for terrestrial applications was proposed (Schneider et al. 1981, Townshend and Tucker 1981). However, the instrument was not designed to look at seasonal variations in vegetation, and no on-board calibration was present. Pre-launch calibration information was available, but changes in sensor performance post launch were unknown. Thus AVHRR based observations of vegetation behaviour over entire growing seasons could be made. But with no information concerning radiometric stability trends in the data could only be loosely associated with biophysical variations. This did not deter early users, and many qualitative, though valuable, studies were made (Tucker 1996).

With experience came a growing awareness of the calibration limitations. Empirical approaches such as creation of temporal composites improved data quality but did not address the fundamental cal/val limitations (Holben 1986). Once vegetation monitoring communities began to use data from AVHRRs on more than one NOAA satellite and over the full life span of individual AVHRRs problems became even more acute. In-orbit degradation of the visible (0.58-0.68um,) and near-infrared (0.72 - 1.1 um) channels for individual satellites, and the requirement for calibration linkage across multiple satellites became pressing (Rao and Chen 1995).

However, vicarious calibration of the sensors (Che and Price 1992, Teillet and Holben, 1994) with underpinning from airborne calibration flights (Abel et al. 1993), have established calibration trends which give users a great deal of confidence in the AVHRR time series. The launch of NOAA K (to be designated NOAA 15 following launch) presently planned for 16th February 1998 highlights the need for continued, regular calibration exercises.

Whilst calibration undoubtedly provides this basic confidence in the data, users are aware of the need for validation and "quality assurance" at all steps towards generation of information. Errors at any point in the processing chain are cumulative, and will result in a poorer final product. Thus stringent quality control is needed at all processing steps (Zhu and Yang 1996).

Validation in particular is a major issue. Validation of thematic products, such as land cover classifications is typically based on contingency tables, or confusion matrices, where class accuracy is expressed in terms of errors of omission and commission, or in terms of agreement analysis using the Kappa test statistic

(Congalton 1991). The contingency table is created by comparing on a class by class basis the land cover classification with an independent data source - field observations, existing maps, higher resolution imagery - collected using a statistically valid sampling strategy. However, there are few precedents to work to for validation of high level products. This is one area that WGCV is now beginning to address. By the turn of the century there will be more than 60 operational Earth observation satellites, providing hundreds of different measurements, leading to many different projects (CEOS 1997b). Calibration and validation information exchange, co-ordination and co-operative activities will thus grow ever more important. It is in this context that the WGCV is working.

4. The WGCV's work-plan

The WGCV promotes the exchange of technical information and documentation, joint experiments, and the sharing of facilities, expertise and resources among its members as appropriate. The WGCV also seeks to be a major point-of-contact for the international user community for calibration and validation information. Technical work is mainly performed by the four sub-groups: Infra-red and Visible Optical Sensors (IVOS), Microwave Sensors (MS), Synthetic Aperture Radar (SAR) and Terrain Mapping (TM).

With the advent of the IGOS, WGCV has embarked on a new three-year work plan. The main elements are improving co-ordination and communication and implementation of validation activities.

4.1 Co-ordination

To meet each agency's standards, space agencies plan cal/val activities for each sensor. Whilst selected scientists/ organisations may be part of the programmes, WGCV participation ensures that plans are known internationally, and offers the possibility for co-ordination with the activities of other agencies. This avoids duplication of effort, inconsistencies in approach, and helps to promote global observation networks for validation of observations destined for global scale applications.

To maximise information exchange on test sites and on instruments, WGCV is maintaining an on-line database. This database provides information on calibration laboratories, on test sites and on instruments in a uniform way. The data base development, led by NASA, will continue over the next three years, and can be found at http://spso. gsfc.nasa. gov/calval/homepage.html.

4.2 Communication

The WGCV secretariat hosts and maintains a new World Wide Web (WWW) site at http://www.eos.co.uk/ceos-calval. This contains background material, contact details for members and links to both CEOS and non-CEOS sites dealing with calibration and validation issues. If the global land cover project were starting out today, for example, the project would be able to access the full AVHRR calibration trends information maintained on-line by NOAA, via WGCV home page links. The site also lists cal/val related conferences, bibliographic material (and links to relevant bibliographies), copies of WGCV's newsletters, and meeting reports. New introductory material is also being prepared, and a slide set providing generic cal/val examples is being prepared; slide sets related to specific cal/val topics will follow.

To improve communication with organisations lacking CEOS representation WGCV also invites individuals to meetings as technical experts when appropriate. Invited representatives from National Standards Laboratories are an excellent example where non-CEOS organisations have made positive contributions to the thinking and strategy of the WGCV.

4.3 Geophysical parameter validation

Complete cal/val solutions embracing accurate sensor calibration, continuous post-launch calibration (on-board and/or vicarious), validation of algorithms used to derive higher level products and validation of the products themselves are far from the norm, yet are clearly needed. The global land cover exercise for example had no recognised precedents to work to concerning validation of the final product, and the solution adopted is far from perfect. Instrument calibration has occupied the WGCV since its creation, and WGCV will endeavour to ensure that the best possible information on instrument calibration is made available to the widest possible audience. However, as suggested by the nascent IGOS appropriate CEOS co-ordination is needed at all stages in EO product generation.

Validation will thus form a focus for WGCV over the coming years. A series of pilot projects to analyse issues such as accuracy requirements, measurement and sampling protocols, test site(s), data management requirements and implications for all CEOS participating organisations has begun. The four sub-groups have identified priority parameters on the basis of existing activities, as the cost of international validation exercises is high. The priority list recognises that not all parameters are at the same level of maturity.

The IVOS sub group is examining validation issues for visible/near-infrared top-of-atmosphere reflectance measurements through the inter-comparison of data from all sensors with visible and near-infrared bands operating during May and June 1997 over Northern Africa. Derivation of validated visible and near-infrared measurements is a critical first step to creation of derived parameters such as Leaf Area Index. IVOS is also co-ordinating a similar programme examining validation of Sea Surface Temperature measurements, again through the inter-comparison of data from a range of platforms.

The Terrain Mapping sub-group is examining the issues surrounding the validation of Digital Terrain Models generated from both optical and microwave data. And the SAR and Microwave Sensors sub groups are examining the validation of wind speed, significant wave height, wave frequency and wave direction.

The parameters currently examined by the WGCV sub-groups are important not only in their own right, but also bear directly on the IGOS. To test the IGOS concept, six IGOS pilot projects have been started: long term continuity of ozone measurements, long-term ocean biology measurements, global observations of forest cover, upper air measurements, global ocean data assimilation and disaster management support (CEOS 1997a).

Each IGOS project aims to identify if there are suitable satellite missions available, and over which time periods. They will establish to what extent the missions meet stated requirements, identify gaps in current service and identify which variables are observed best, and which least well. The projects also consider implementation issues, data access, and data exchange raising key questions such as the need for systematic sensor calibration and the lack of measurement protocols for validation of particular products. Calibration and validation are implicit requirements for all of these projects, and the WGCV with its mandate for cal/val activities will fully participate in this new CEOS work.

5. Conclusions

Scientific users and applications oriented users have ever increasing expectations concerning the integrity of Earth observation data. Cal/val activities are to some extent meeting these expectations and newer sensors with better on-board calibration are also emerging. Data sets steadily improving in quality are the result. This commendable state of affairs must not be allowed to falter. Equally, our improvements must be phased to build on the past. It will not lead to user confidence if improved data-sets completely negate previous efforts. Just as pertinently, waiting for perfection will mean that important lessons go unlearned; the pioneer users of AVHRR for terrestrial studies still made valuable contributions to our knowledge of the Earth's systems, even though calibration was not perfect.

Responsibilities for calibration and/or validation are not always clearly identified. These can devolve to the satellite operator, data archive holder / distributor, data analyst and even the end user. WGCV will continue to act as a focal point for cal/val and will endeavour, through the CEOS plenary (which embraces all those in the EO chain), to resolve areas of confusion.

Cal/val activities vary across discipline / parameter / sensor. WGCV will endeavour to identify gaps and act accordingly. In situ data access is vital to cal/val activities. This requires mechanisms for interfacing relevant bodies (national and international), identifying data holdings, establishing data access and exchange policies, determining and documenting in situ data and measurement method quality, and identifying the time-span and update frequency of in situ measurements. Responsibilities for these tasks go beyond the remits of WGCV, but fall firmly into the scope of the proposed IGOS.

International co-operation brings with it commitment. The agencies supporting their members' activities in the Working Group on Calibration and Validation continue to honour this commitment. They thus contribute towards meeting our obligations to maximise the exploitation of space for the benefit of the world's environments and peoples.

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