Improving the traceability to SI of Earth Observation (EO) measurements

Context

The CEOS Working Group on Calibration and Validation (WGCV) has prepared this document in response to the request made at the 13th CEOS Plenary to review the issue of traceability[1] to SI for Earth Observation (EO) measurements. Recommendations are made to CEOS Plenary to take this forward.

There are growing expectations on the use of Earth Observation data to support key decisions by governments concerning the sustainable development and good stewardship of our environment. This puts increasing pressure on the scientific process to deliver information that can be proven to be reliable. The measurements concerned may document small changes in key parameters and may be measurements extending over many years. In this context the WGCV working closely with representative National Standards laboratories (notably the USA's NIST and the UK's NPL) have prepared this report examining current practices concerning traceability in the Earth Observation community.

The recommendations made at the 20th General Conference of Comité International des Poids et Mesures (CIPM) (the international body responsible for SI) also add impetus to the study. This meeting concluded that "those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterised SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Metrè."

Current demand for traceability in the pre-launch and post launch phases

The product requirements emanating from Earth Observation data users are translated into the sensor domain by a team of instrument scientists and product developers. In a few instances the national standards laboratories already play an important role at this stage. Some of the traceability issues that should be addressed at the pre launch stage are:

- Radiometric characteristics of the sources of calibration (e.g., integrating sphere sources; thermal radiation sources; applicability and relevance of the concepts of "black body" and "gray body" in the calibration of thermal infrared sensors);
- Stability characteristics of detectors, components of the optical train; methods to minimize deterioration of scan mirrors; coating materials for scan mirrors;
- Characterization of the way in which instruments respond to radiant flux as a function of location, polarization, temporal domain, temperature of the detector , local environment and amount of flux (linearity)
- Establishment of rigorous procedures for pre-launch calibration to ensure the accuracy of calibration based on instrument characterization, and the traceability of the same to SI units;
- Concept and design of on board calibrators if they have been proposed; and
- A reasonable, reliable evaluation of the extent to which the results of the above could be used to evaluate the satellite sensor performance in orbit.

While pre-launch activities help in evaluating the extent to which the instrument meets specifications, it is in the post-launch environment that the issue of traceability to SI units becomes critical. Operational agencies– the data providers-- like to assure themselves that the data they provide the user community is of the highest accuracy and reliability. The scientific community– the data users– would like to have reliable information on the uncertainty associated with satellite-measured radiances so that they may propagate the same in their product algorithms to determine the accuracy with which they can generate their products, and whether such products are useful to study

[1] Traceability - refers to an auditable route describing and confirming the calibration chain and attributed accuracy back to an internationally agreed reference, usually SI as maintained by a national standards laboratory

the Earth system. The optimal fashion in which the users' objectives can be attained is through close co-operation between the instrument makers, the national standards laboratories, and the data users right from the stages of the conceptual design of the instrument. While this is highly desirable, so far, it has seldom happened. However, the operational agencies, and the national standards laboratories, with the help of the user community, and in consultation with international expert groups like the WGCV have begun in some instances steps to ensure this type of co-operation.

This is particularly so for the post-launch calibration of satellite sensors in the visible and near-infrared where effective vicarious techniques have been developed. Estimates of attainable accuracy in the derived radiances vary from about 5 to 10 per cent, with appropriate atmospheric corrections. Since the user community has expressed a keen need for satellite radiation measurements with higher accuracy, the issue of on board calibrators is raised often. This leads to the very often asked question– what is the attainable accuracy of radiation measurements in the visible and near-infrared with on board calibrators?

It is important for the operational agencies to see clear demonstration that traceability will lead to the improved assessment of the accuracy of radiance determinations. The use of retrievable, SI traceable spectroradiometers mounted on aircraft and space-borne platforms such as the International Space Station offer great potential in this context. Instruments can be calibrated before and after each field campaign in laboratories that maintain traceability to a national standards laboratory. The SI-traceable, retrievable instruments can be used to determine the radiance that should be measured by the satellite radiometers during under or over flights under congruent path conditions. This, together with an appropriate and well understood atmospheric model will serve to calibrate the satellite instrument absolutely in the absence of on board calibrators, or to monitor the performance of the on board calibrators when they are present. There are instances when this method has been used to characterise a satellite instrument, but they have been more of an exception than the rule.

Current best practice

Whereas there are a number of historical examples of space-borne EO missions with less than satisfactory accuracy, calibration, consistency and stability of the higher level data products (representing geophysical variables), in recent years several space agencies have responded to the more stringent requirements in this respect. Pathfinder projects were launched to improve the long-term historical time series and satellites with exceptional calibration were launched. A striking example of this was the seamless transition from ESA 's ERS-1 to ERS-2 operation in terms of radar image calibration (level-1) and wind/wave products (level-2). This practise will be continued for the upcoming Envisat mission. NASA also has put great emphasis on calibration during the development of its SeaWiFS and EOS programs. In the latter case, the emphasis stems in part from the need of users to know the accuracy of data that will be used in combination derived from some dozens of instruments located on several different platforms. With the establishment of thematic global programmes like "Ocean colour" and "Mission to planet Earth" NASA has developed a new strategy for ensuring the quality of EO data. This strategy was designed to improve the rigour of calibration and accuracy claims for the instrument and calibration teams and facilities involved in the support of missions like SeaWiFS and Terra. NASA engaged the support of NIST, the US national standards laboratory to work with it and the instrument teams to select a consistent and appropriate method of assessing and presenting uncertainties to be adopted for these missions. They also developed dedicated transfer standards in order to carry out "round-robin" comparisons between the various instrument calibration teams, both within the US and elsewhere, so as to ensure equivalence. As a result of these activities NASA now has a higher level of confidence in the likely performance of the instruments.

The accuracy, calibration, consistency and stability requirements were and will be achieved partly in collaboration with national standards laboratories and did involve "round-robin" campaigns with secondary standards to achieve inter-agency consistency.

During the development phase of the project the agencies are usually the consumers buying components, subsystems or complete satellites with payloads. The agencies then involve the national standards laboratories to ensure the quality of these elements as appropriate. The decision to involve national standards laboratories is made by the space agencies and follows the technical requirements for the satellite and its payload subject to the usual financial and schedule constraints of typical space-borne EO missions.

During the operational phase of the mission the space agencies appear as the data providers and the "user community" represents the consumers. It is the consumer interest that is served by knowledge about the quality of EO data and products. This knowledge is generated by co-operation between several groups, including the agencies themselves, qualified users who understand instrument characterisation and calibration, existing standards organisations, commercial calibration laboratories, accreditation laboratories, instrument test facilities and university groups. The decision to involve the national standards laboratories should in this phase be made by the user community and should be derived from the data quality requirements of the relevant data products.

Traceability to SI and the Mutual Recognition Arrangement (MRA)

In October 1999 Directors of the national metrology institutes (NMIs) of 38 states which are signatories of the convention of the metre agreed to a new arrangement under which calibration certificates and measurements made in one country would be automatically accepted in another, without the need for individual bilateral agreements. This arrangement is the Mutual Recognition Arrangement (MRA). It operates through comparisons organised by the working committees of the Comite International des Poids et Mesures (CIPM).

The most important of these are the so called “Key Comparisons” of the most basic quantities associated with each SI base unit (generally <10 for each SI unit) and involve a sub-set of NMIs which have a proven historical record of research activity in the technical area, and which also geographically cover the globe. The results of these Key Comparisons establish Reference Values for the quantities, which is an approximation of the true SI quantity. This is followed by a series of geographically regional comparisons of the same quantity to bring all the other NMIs into the system. The results of all the comparisons, together with the differences of each laboratory from the reference value are then entered on to a database and available to all via the WWW.

Conclusions

The WGCV in examining this issue recognises that traceability is of growing importance, and should be the ultimate goal of all EO data providers. This is especially so if EO data are to be employed in legally binding situations, such as compliance with internationally negotiated environmental treaties. The WGCV recognises that this is a process that will require change. The following recommendations to CEOS Plenary are proposed to improve traceability and encourage the use and take up of best practise and nurture innovation.

All EO measurement systems should be verified traceable to SI units for all appropriate measurands.

Pre-launch calibration should be performed using equipment and techniques that can be demonstrably traceable to and consistent with the SI system of units, and traceability should be maintained throughout the lifetime of the mission.

The decision to implement these recommendations must be taken by the individual Space Agencies. This decision in turn must rest on a clear demand from users that the levels of accuracy and accountability that could be achieved from implementing the recommendations are not just desirable but absolutely essential.