

Shaping GSICS to meet future challenges

A vision for GSICS in the 2020's

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1. The aim of GSICS

The aim of the Global Space-based Inter-calibration System (GSICS) is to organize the production of satellite inter-calibration information to enable improved and consistent accuracy among space-based observations worldwide for climate monitoring, weather forecasting, and environmental applications.

2. The scope of GSICS

GSICS is an international collaborative effort initiated in 2005 by WMO and the Coordination Group for Meteorological Satellites (CGMS). Within GSICS, satellite operators and science teams collaborate to define, implement and share community-agreed best practices, standards, procedures and tools. These enable users to monitor, improve and harmonize the calibration of instruments aboard operational meteorological, climate and other environmental satellites of the Global Observing System (GOS).

The focus of this activity is the systematic generation of on-orbit inter-calibration information to correct the individual calibration of Level 1 satellite data.

This is however part of a comprehensive strategy, which involves a range of activities including:

- Prelaunch instrument characterization,
- Instrument bias monitoring,
- Level 1 data quality control and validation,
- On-orbit instrument intercomparison and calibration,
- Traceability to absolute calibration standards,
- Metadata provision (provenance, lineage),
- Enabling recalibration of archived data,
- Documenting state-of-the-art calibration techniques.

Through these activities, GSICS promotes greater understanding of instrument absolute calibration and root causes of biases, supports instrument global inter-operability and measurement quality, and enables better accuracy and global consistency of Level 2 environmental, climate and weather forecasting products.

To ensure the full benefit of its activities are realized and the above aims are met, GSICS seeks to work in partnership with other relevant inter-calibration initiatives and to cooperate with instrument experts and users with the view to leverage their expertise and promote greater use of the inter-calibration products.

3. Expected benefits for participating satellite agencies

GSICS methodology and reference instruments will be at the core of calibration activities of satellite operators. GSICS thus enables the satellite operators to perform assessments of uncertainties, error characterization and to deliver state-of-the-art, consistent calibration of observation data in near-real time or on historical datasets, e.g. through corrections to the “operational calibration”.

The GSICS best practices also provide a reference against which the calibration activities can be assessed (like for instance the maturity matrix for climate data records, or the Long-Term Data Preservation guidelines for historical data stewardship).

The research activity involved in GSICS helps satellite operators to understand sensor calibration differences and resolve them by mitigation strategies. GSICS should thus be a main element of the Plan-Do-Check-Act (PDCA) quality management cycle for instrument design and operation.

In addition to sharing knowledge on calibration issues, GSICS enables significant economic benefit since several agencies are sharing development effort, significant data management effort and infrastructure, test data sets, and the availability of calibration references.

4. Expected benefits for satellite users

The reliability of Earth Observation data for the monitoring of climate variability and change requires accurate and consistent calibration among instruments of different satellites and programmes worldwide, over long periods, with traceability to common – and if possible absolute – references.

Operational applications of satellite data relying on multisatellite products (e.g. composite imagery or quantitative products) require seamless merging of observation datasets acquired from distinct instruments and/or satellites. Performing such a seamless merging in a meaningful way requires understanding and coping with the calibration differences among sensors, which is precisely what GSICS is doing. Furthermore, instrument pre-processing is facilitated through accurate on-orbit calibration monitoring.

Satellite data assimilation in Numerical Weather Prediction models requires a reliable error and bias characterization.

In enabling the availability of high quality observations based on best practices, GSICS thus benefits to all these applications.

5. Expected benefits for WMO and other international programmes

GSICS is a pivotal element of the WMO Integrated Global Observing System (WIGOS), as it enables interoperability of different missions contributing to the space-based component of WIGOS.

In ensuring traceability to calibration references and comparability of measurements over long periods, GSICS should play an important role in the Architecture for Climate Monitoring from Space. The Architecture is a direct contribution to the Observation and monitoring pillar of the Global Framework for Climate Services (GFCS).

GSICS is a key contribution to the Global Climate Observing System (GCOS). The updated GCOS Implementation Plan (Implementation Plan for the Global Observing System for Climate in support of the UNFCCC, GCOS-138, August 2010) calls upon GSICS to ensure that Fundamental Climate Data Records (FCDRs) are well-calibrated and to deliver improved characterisations of contemporary instruments and pertinent documentation for users. The satellite supplement to the GCOS Implementation Plan (Systematic observation requirements for satellite-based products for climate, GCOS-107, September 2006) refers to GSICS as a good example of how to address its first cross-cutting need: comprehensive and routine calibration of satellite instruments.

Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) includes several projects for which GSICS provides inter-calibration methods to homogenize datasets from multiple satellite instruments, which is a key element required in the generation of FCDRs. These include the International Satellite Cloud Climatology Project (ISCCP) as part of the World Climate Research Programme (WCRP) GEWEX project. ISCCP heavily relies on establishing consistent records of satellite imagery from GEO and LEO satellites over now three decades. GSICS has the potential to help ISCCP improve the accuracy of its products.

6. Core principles for the generation of GSICS inter-calibration products

Regarding operational on-orbit instrument inter-calibration, GSICS coordinates systematic generation of inter-calibration products for Level 1 data from satellite sensors in accordance with the following principles:

- Calibration of satellite instruments is monitored and assessed by comparing their output with community references, using common methodologies, following international standards and community best practices, and, ultimately, tying these to SI-traceable standards.
- GSICS implements a continuous chain of comparisons, each with stated uncertainties, to ensure metrological traceability.
- Calibration corrections are generated for both Near-Real-Time use and retrospective analyses, with specified uncertainties, through well-documented, peer-reviewed procedures, based on various techniques to ensure consistent and robust results, which are applicable over a broad range of observing conditions.
- These inter-calibration assessments, comparisons and corrections are delivered to users through free and open access, adopting community data standards.

7. Trends in satellite instrument technology with impact on GSICS

The trends we observe in current satellite plans suggest new opportunities and new challenges.

Infrared hyperspectral as candidate references

Satellite instrument calibration will continue to improve and result in increasingly small measurement errors and uncertainties. This will and certainly should affect GSICS' choice of "reference" instruments; and GSICS needs to keep abreast of these instrument advances.

It is anticipated that the WMO Integrated Global Observing System (WIGOS) will further expand to include a constellation of hyperspectral infrared sensors with wide spectral coverage, which will have the potential to serve as calibration reference standards, or transfer standards. Some hyperspectral sensors will be on GEO platforms with imagers, facilitating their calibration.

Other benchmark measurements

A constellation of radio-occultation sensors will be used as anchors of upper-air temperature measurements for NWP, thus enabling NWP centres to provide more precise feedback on the quality of observations they assimilate.

Initiatives such as CLARREO and TRUTHS, proposed by NASA and NPL, respectively, aim to provide hyperspectral instruments, which are directly traceable to SI standards *in orbit*. These would provide critical benchmark observations for climate monitoring, but also absolute reference instruments for satellite inter-calibration.

Expanding range of instruments requiring calibration support

The spectral ranges and types of instrument used on a routine basis have considerably expanded over the past decade, with a significant development of microwave applications, both passive and active, and an emerging use of the UV range, in particular for atmospheric composition and radiative forcing monitoring for climate modeling.

For expanding its calibration activity to the Visible and Near-infrared (VIS/NIR) range, GSICS has to consider pseudo-invariant targets (including ground sites, deep convective cloud and the Moon), and on-board calibration.

Supporting the calibration of active sensors would open a new chapter in GSICS activity. Scatterometers have been used operationally for a number of years for ocean surface wind measurements and more recently for soil moisture. Space-borne precipitation radars have been demonstrated for a decade by TRMM to be followed by GPM. In the longer term, there are expectations for the operational use of cloud and aerosol radars or lidars. Synthetic Aperture Radars (SAR) are increasingly used for a number of Earth or ocean surface applications. There likely will be a requirement for operational calibration activity for such active measurements, for example with coordinated use of ground-based targets. The nature of the calibration problem is however fundamentally different from the passive problem, i.e. relating a measured radiance to an estimated “true radiance”. The advantages and limitations of a potential involvement of GSICS in this field should be evaluated before confirming this direction as an objective, taking into account in particular the activities and expertise of other bodies such as GPM/X-Cal, CEOS/WGCV.

8. Trends in user applications with impact on GSICS

Interoperability

The available constellations of Earth Observation satellites are expanding and becoming more diversified, with a growing number of contributing operators, implementing diverse instruments. Although the coordination efforts of WMO and CGMS are promoting a certain level of instrument harmonization, it is not anticipated that all instruments will be similar - at least because of the staged implementation of new generations and technology improvements. There is thus an increasing need to ensure interoperability of these datasets (as identified in WIGOS) for multiple

reasons: increasing interest in global products, need to make use of all possible and/or the latest observation available, need of product robustness in case of discontinuity of any of the satellite sources, and more and more stringent requirements of user applications. There is a compelling need to intercompare satellite data sources and articulate their differences in a more and more precise manner.

GSICS support to data assimilation

Satellite instruments provide over 90% of the data assimilated on a routine basis by NWP models. It is of utmost importance to understand the current and future needs of NWP as regards instrument calibration. NWP models are powerful means to monitor individual observation sources, as they can quickly detect any calibration difference with respect to other observation sources, or with respect to earlier observations of the same source. Support from GSICS is however needed to explain the anomalies revealed by data monitoring. Moreover, there is an increased need of traceability to absolute references to provide independent anchors, since models can reduce the relative bias and remove outliers but the possibility of a consistent, systematic model bias cannot be excluded. This is particularly important for medium or long-term forecasts for which the cumulative effect of a consistent bias can have a significant impact.

Since future fine-mesh models will have shorter assimilation windows, and make greater use for instance of satellite rapid scan, this may entail more stringent timeliness requirement for the data and metadata to be provide by GSICS, together with a requirement on precise geolocation.

GSICS and climate applications

Constructing multi-satellite decadal Climate Data Records will require expertise in calibration, for example, to characterize long-term calibration drift in archive datasets. GSICS can provide support in this area based on its developed best practices. The responsibilities of GSICS, other initiatives such as SCOPE-CM, the individual satellite operators, and the processing centres, should be clearly delineated in order to ensure a seamless flow of activities regarding the re-calibration of data records for reanalysis.

9. Trends in the calibration community

Space-based instrument calibration is addressed by several organizations, including the CEOS Working Group on Calibration and Validation (WGCV), the Bureau International des Poids et Mesures (BIPM), the WMO Commission for Instruments and Methods of Observation (CI MO), or programme teams such as the GPM Inter-satellite Calibration Working Group (GPM X-Cal). Relationships should be encouraged and strengthened with these and other relevant initiatives:

- The joint WMO-BIPM Workshop on Measurement Challenges for Global Observation Systems for Climate Change Monitoring: Traceability, Stability and Uncertainty (Geneva, 30 March – 1 April 2010) issued a number of recommendations.
- The Conference on Calibration and Radiometric Characterization for Remote Sensing (CALCON Technical Conference), which is hosted every year by the Space Dynamics Laboratory (SDL) of the Utah State University Research Foundation is a well established forum on calibration and evaluation of infrared radiometric sensors, expanding now to the microwave, visible, and UV domains.

- The Quality Assurance Framework for Earth Observation (QA4EO) initiative, which emerged from WGCV and the Group on Earth Observation (GEO), is also promoting the need to systematically evaluate and document the quality of Earth Observation data and products.
- Within the Global Climate Observing System (GCOS) programme, the GCOS Reference Upper-Air network (GRUAN) was established with the goal to provide long-term, highly accurate measurements of the atmospheric profile, complemented by ground-based state of the art instrumentation, to constrain and calibrate data from more spatially-comprehensive global observing systems including satellites and current radiosonde networks.

10. Strategic guidelines

Based on the considerations above, the following guidelines are derived to frame the future mission of GSICS in terms of scope, priorities, technical approach, fields of competence, resources, membership, partnership and user interaction.

- *Activity scope and priorities*

GSICS shall continue to build expertise and develop best practices. GSICS shall promote better physical understanding of instrument performance and calibration issues, along with a comprehensive physically-based uncertainty analysis, and before any changes or adjustments to sensor data record calibration is made. Interoperability among satellite programmes will result in mutual confidence in the data provided by other agencies through scientific collaboration and the implementation of the community-agreed best practices developed within GSICS. GSICS will thus increasingly generate benefits to the users and to the satellite operators, namely through improving practices, capacity building, and sharing of efforts and assets.

GSICS is requested to support the provision, on an operational basis, of the “best calibration information”. “Operational” refers here to the maturity, e.g.: product validation along the GSICS procedures, continuous, near-real time availability of products and metadata, product maintenance, comprehensive documentation and user support on the operational use of GSICS products. Advances in user applications will shape requirements for delivering calibration products with a better accuracy, and possibly high timeliness.

In parallel, GSICS shall support the generation of climate data sets through the periodic re-calibration of historical data. In this respect, the respective roles of the various entities should be clarified. The role of GSICS is to provide the understanding and the community-agreed approach and algorithms that are needed to enable satellite operators to perform the best possible re-calibration of historical data sets, in support of reanalysis by processing centres. The recalibration itself, i.e. the generation of historical FCDRs is often conducted by satellite operators as part of SCOPE-CM or other coordinated initiative.

- *Passive radiometric sensor calibration*

The success of GSICS in the future depends on its ability to incorporate additional instrument types (e.g. microwave, UV) in its portfolio, which raises new challenges, but also to take advantage of the opportunities arising from the improved performances of upcoming instruments.

Based on its area of strong expertise, GSICS should continue focusing on and improving the operational monitoring of passive radiometric sensors and on the inter-comparison of Level 1

data, gradually widening its services to include VIS/NIR and microwave sensors, in relationship with GPM X-Cal for the latter.

In doing so, GSICS shall keep under review its strategy for maintaining a calibration reference and transfer standards. As part of this strategy, GSICS should advocate and seek to secure the availability of suitable on-orbit calibration references, traceable to SI standards.

GSICS should also coordinate information on other applicable references, e.g. ground-based, and centralize expertise and information on instrument models and characteristics.

- *Active sensors*

GSICS should evaluate the relevance of extending its scope to include active sensing and observations. Should this extension be confirmed as desirable, a strategy to gradually initiate and implement this new activity should be devised, e.g. by adding sub-groups focusing first on the monitoring of such new instruments, formulating best practices for individual calibration, organizing the sharing of calibration resources and promoting intercomparisons. A challenge would be to implement such new activities whilst ensuring that the primary tasks of GSICS continue to be fulfilled.

- *Partnership*

GSICS should keep abreast of developments in the international calibration community, and contribute to this community, through maintaining liaison with the BIPM and the relevant CIMO activities, involvement in relevant international conferences, and active partnership with WGCV.

The WGCV has subgroups for Microwave, for QA4EO, and for Infrared and Visible Optical Sensors (IVOS). Since IVOS is dealing with calibration methodologies, metrology and standards, which are of direct relevance to GSICS, the effective interaction among GSICS/GRWG and IVOS shall be strengthened. The operational inter-calibration is an area of strength of GSICS and should remain its core activity; WGCV has a strong experience in other areas such as pre-flight calibration, cal/val sites and field campaigns. Cross-participation of some experts and leaders contributes to the synergy among both groups, helping to ensure that both groups mutually benefit of each other's areas of strengths, maintain a complementary focus of activity and avoid overlap. Both groups should share information on their respective practices (e.g. ATBD templates) with a view to adopt them if relevant, or improve them as appropriate.

GSICS should also support collaboration with GRUAN with a view to draw mutual benefits. On one hand, GRUAN could benefit from GSICS in using accurately calibrated satellite measurements as "travelling reference standards" for GRUAN stations; on the other hand, GRUAN in combination with forward radiative transfer models could provide useful references for the calibration of e.g. space-based microwave measurements. Furthermore, GRUAN could support the validation of the use of GSICS corrections in Level 2 products through three-way collaboration among GSICS, GRUAN, and downstream communities like SCOPE-CM

GSICS will need to strike a balance between expanding its scope of activity and fostering partnerships and interaction with communities with adjacent or downstream fields of activity.

Particular attention should be paid to the cooperation with the community involved in Radiative Transfer Model (RTM) developments, and other thematic application communities:

- Use of ground-based calibration targets is dependent on the quality of a forward RTM. GSICS needs thus to establish partnership with organizations providing radiative transfer algorithms in order to promote RTM intercomparisons and improvements. This includes the International TOVS Working Group (ITWG) and other groups working under the auspices of the International Radiation Commission (IRC) of IAMAS: (<http://www.irc-iamas.org/groups/>)
- Foster interaction with users involved in product development in order to assist in validation activities and progress in the understanding of product quality issues. This interaction should take advantage of International Science Groups dedicated to thematic areas, such as: the International Winds Working group (IWWG), the International Precipitation Working group (IPWG), the Group for High-Resolution Sea Surface Temperature (GHRSSST), the International TOVS Working Group (ITWG), the WCRP Global Energy and Water Cycle Exchanges project (GEWEX), the International Satellite Cloud Climatology project (ISCCP), the Polar Space Task Group (PSTG), the International Ocean Colour Coordination Group (IOCCG). Interaction with these groups would allow seeking feedback from validation or monitoring activities in order to help defining priorities on the highest impact topics.
- Greater cooperation with the NWP community to explore the potential application of NWP bias monitoring statistics for satellite-satellite inter-calibration, synergy of calibration monitoring systems, as well as comparison and validation of RTMs. NWP data assimilation systems also allow instruments calibration to be tied to absolute methods, such as GPS radio-occultation in geophysical space.
- The Climate Re-Analysis community extends this opportunity to evaluate GSICS products' ability to inter-calibrate data from a series of satellite instruments, and allows further investigation of the root causes of biases – for example by variationally adjusting instruments' spectral responses. We should promote the use of GSICS products in this community and encourage dialogue on these issues.
 - *Membership and organization*

All CGMS Members should ultimately experience the benefit of participating in GSICS. GSICS members should feel engaged and continue to be actively involved in GSICS activities. The Terms of Reference of the Executive Panel and its advisory groups should facilitate a rotation of responsibilities, thus reflecting the global and collaborative nature of GSICS.

A key to the future success of GSICS is also to document its current and future processes. As the GSICS best practices will reach a sufficient maturity level, they should be recognized and recorded as official best practices of the CGMS and, accordingly incorporated in the appropriate WMO regulatory material (e.g. CIMO guide, WIGOS guide).

In parallel, actions should be taken to raise user awareness, e.g. in promoting showcase applications, and to provide guidance or training on the use of GSICS products e.g. through the WMO/CGMS Virtual Laboratory (VLab) and the COMET programme, in multiple languages.