Global Space-based Inter-Calibration System

INTRODUCTION TO GSICS

“Space-based” is in fact too restrictive because the GSICS calibration system is not only based in space but includes elements on ground (ground calibration sites, and data management infrastructure). Instead “Satellite” Inter-Calibration System would correctly mean that we are calibrating the “satellites” (instruments).

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INTRODUCTION TO GSICS

1. Background

The Global Space-based Inter-calibration System (GSICS) was established in 2005 by WMO and the Coordination Group for Meteorological Satellites (CGMS). Its initial concept and strategy were submitted by WMO and endorsed by the 33rd CGMS meeting (Tokyo, Japan, 1-4 November 2005). On this basis, the Implementation Plan for a Global Space-Based Inter-Calibration System was developed in April 2006 and subsequently endorsed by WMO and CGMS.

GSICS was recognized in 2009-2011 as a Pilot Project in the Demonstration Phase of the WMO Integrated Global Observing System (WIGOS). During its first ten years, GSICS has built up an active expert community, developed a range of methodologies and tools, implemented a data management infrastructure, and brought satellite inter-calibration products to the operational stage. Meanwhile, GSICS has become a reference for WIGOS. In its section on space-based observing system calibration and traceability, the Manual on WIGOS, Annex VIII to the Technical Regulations (WMO-No.1160, 2015 edition) requests WMO Members to follow the recommendations of GSICS.

The present document provides a high-level description of the purpose, targeted users, organizational structure, services and deliverables of GSICS. It replaces the initial GSICS Implementation Plan, which guided the early years of GSICS. This document is supplemented by other reference documents addressing more specific subjects:

- GSICS Terms of Reference
- Vision of GSICS
- GSICS User Guide (Draft)
- GSICS User Requirements (Draft)
- Technical documentation available on-line via the GSICS Coordination Center

2. Purpose and scope of GSICS

Space-based observations of meteorological variables, atmospheric composition, ocean and land surfaces, represent a large majority of observation data assimilated in NWP models or climate models, and are increasingly used in a wide range of environmental applications. The accuracy of these observations, and their suitability to be used in an interoperable manner with other observations, directly depend on the reliability of instrument calibration. Furthermore, the

1 http://www.star.nesdis.noaa.gov/smcd/GCC/index.php

2 http://gsics.wmo.int
challenges of monitoring climate variability and climate change require the careful exploitation of multiple satellite data records over several decades and establishing their traceability to common references.

The aim of GSICS is to coordinate the production of satellite inter-calibration information enabling the use of space-based observations with improved and globally consistent accuracy for climate monitoring, weather forecasting, and environmental applications. GSICS is therefore an essential element for interoperability and traceability of observations within WIGOS.

Within GSICS, satellite operators and science teams are collaborating to develop community-agreed best practices, standard procedures and tools. This enables to monitor, improve and harmonize the calibration of instruments aboard operational meteorological, climate and other environmental satellites of WIGOS. The focus of this activity is the systematic generation of in-orbit inter-calibration information to correct the individual calibration of Level 1 satellite data.

This routine production of in-orbit inter-calibration information is part of a comprehensive strategy, which involves a broader range of activities including:

• In-orbit instrument Level 1 data monitoring,
• In-orbit instrument comparison with references,
• Routine generation of intercalibration corrections for near real-time applications,
• Provision of algorithms enabling recalibration of archived data,
• Traceability to absolute measurement standards,
• Prelaunch instrument characterization
• Documentation of state-of-the-art calibration techniques.

3. GSICS deliverables

While the systematic generation of calibration corrections to Level 1 data is the initial focus and the main end product of GSICS, a wide range of other products and services associated to this activity are also delivered to respond to the needs of satellite data users or providers. The GSICS deliverables can be grouped in 5 broad categories:

- **GSICS inter-calibration products related to specific instruments.**
  - *Assessment of instrument behavior* (results of instrument monitoring, statistical analysis of these results, records of anomalies, measured reflectivities of known targets, etc.)
  - *Correction algorithms based on these assessments* (correction algorithm for bias, gain, non-linearity, wavelength shift, change of SRF, etc.)
  - Corrections based on these algorithms (generated in near-real time, or time centered, or bias adjustment sequences of archived data). These corrections are either adjusted calibration coefficients, or adjustments to be applied by the user to the operational calibration coefficients.

These inter-calibration products are generated by GSICS members in accordance with GSICS practices, standards, procedures and principles. Their
compliance is assessed by a strict peer-review process. They are registered in the GSICS Catalogue.

- **GSICS best practices, standards and procedures.**
  These practices, standards and procedures are supporting the generation of intercalibration products, but may also be more widely applicable. They include for instance:
  - Metadata and data formats
  - Standard vocabulary
  - Procedures (for product acceptance, for versioning, for archiving, for selection of a reference sensor, etc.)
  - Best practices (for instance for pre-launch instrument characterization, or instrument performance monitoring)

- **Contribution to maintaining resources shared by the calibration community**
  - Selected space-based reference instruments and calibration datasets
  - Ground-based calibration targets with their characteristics
  - Solar spectra, lunar spectra
  - Models and calibration datasets,

  The calibration references are either ground-based or space-based, to provide the best possible support to radiometric measurement in the various spectral domains used by the WIGOS space-based component.

- **GSICS tools**
  - Infrastructure elements giving access to the data (THREDDS servers, etc)
  - Software tools used for the generation of intercalibration products (for Simultaneous Nadir Observation matchup, Bias monitoring, Ray matching)
  - Software tools used by satellite data users (For example, Plotting)
  - Software tools to facilitate product development (Format readers, product generator, etc.)

- **GSICS user services**
  - Registration and messaging
  - Product catalogue
  - Wiki and websites
  - Documentation and information on different media to assist satellite data users and GSICS member agencies in understanding GSICS activities and using GSICS services.

The GSICS deliverables are illustrated in Figure 1.
4. GSICS users

Two main categories of users are expected to benefit from the deliverables above: (i) the satellite data user community, including the climate community, and (ii) the satellite operators themselves. The User Requirements addressed by GSICS are summarized in the GSICS User Requirements Document [RDURD].

4.1. The satellite data user community

Satellite data users are benefitting from the GSICS products and related resources, tools, documentation and services.

GSICS Products are intended to support any application relying on accurate and globally consistent satellite data. This is the case of the generation of seamless composite satellite imagery products, or of stable quantitative Level 2 products such as cloud analysis, aerosol detection, or sea or land surface observations. It is also important for integrating surface and space observations. For Numerical Weather Prediction users it is useful to provide an understanding of the initial bias of the data and to remove most of the bias in the ingested data, thus enabling the linear bias correction to be more meaningful, and the data to have a better impact; absolute calibration also helps to anchor the model.
A particular use of GSICS products is climate change detection and monitoring. While climate applications normally do not require near real-time products they have stringent uncertainty and long-term stability requirements, as the monitoring of global climate change requires the detection of temperature changes as tiny as a few tenths of a degree per decade and e.g. ozone trends as small as 1% per decade. To support climate analysis and the creation of stable long-term climate data records it is necessary to monitor and inter-calibrate sensors on similar and different satellites, and inter-calibrate satellite observations with in-situ observations. In this respect, GSICS aims to serve as a building block of the Architecture for Climate Monitoring from Space, as described in more detail below.

Satisfying the needs of the NWP, climate and environmental monitoring communities for historical and current satellite data with reduced calibration uncertainties requires an integration of a diversity of approaches.

4.2. GSICS in the Architecture for Climate Monitoring from Space

The Strategy towards an Architecture for Climate Monitoring from Space\(^3\) has defined a logical view identifying four pillars: sensing, climate record creation, application, decision making. Figure 2 illustrates GSICS activities, which are aiming at delivering intercalibration information and corrected calibration as part of the “Sensing” pillar. The use of this information for the reprocessing of historical data series is part of the “Climate Record Creation” pillar.

![Diagram of calibration functions within the “Sensing” process.](image)

GSICS contributes to the Architecture for Climate Monitoring from Space in multiple ways:

a) GSICS provides a calibration infrastructure
   - In orbit references providing traceability
   - Ground-based calibration sites
   - Databases and software tools

b) GSICS develops processes to be implemented by satellite operators
   - Best practice for pre-launch characterization
   - Procedures for in-orbit calibration with uncertainty estimation
   - Procedures for in-orbit comparison and inter-calibration
   - Procedures for vicarious calibration with ground targets
   - Algorithms for re-calibration of archive data
   - Communication and capacity building.

4.3. The GSICS member agencies

GSICS members operating satellites are both contributors and users, as they benefit from the best practices, standards and tools developed and promoted in the GSICS framework. In fostering sharing expertise and tools among satellite operators, GSICS contributes to capacity building, resource optimization, and improvement of calibration techniques.

5. GSICS structure

WMO Members participate in GSICS through their satellite operating agencies and associated scientific and technical institutes. Participation in GSICS implies acceptance of the GSICS principles, practices and procedures. Details on accession to GSICS are provided in Annex 1.

GSICS Production and Research Centres (GPRC) are performing operational calibration, comparison and calibration adjustment of the instruments they are operating. They also contribute to GSICS research and development activities. The GSICS Calibration Support Segments (CSS) provide tools, calibration references, and contributions to GSICS research and development activities.

The GSICS Coordination Centre (GCC) coordinates the definition of GSICS products and services, it maintains a repository of GSICS practices, procedures and tools, it coordinates the acceptance procedure of new products and the information exchange with the user community.

GSICS operates under the guidance of the GSICS Executive Panel composed of representatives designated by each participating organization. The WMO Secretariat serves as Secretary of the Panel. Representatives of partner organizations or potential future GSICS members can be invited to participate in the GSICS Executive Panel as Observers. The Executive Panel is advised by a Data Management Working Group (GDWG) and a Research Working Group (GRWG).
GSICS works in partnership with organizations pursuing complementary activities and organizations involved in the applications of calibrated data. An active collaboration is maintained with the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration Validation (WGCV), in particular between its subgroup on Infrared and Visible Optical Sensors (IVOS) and the relevant GRWG subgroups.

GSICS reports to WMO through the Open Programme Area Group on Integrated Observing Systems (OPAG-IOS) of the Commission for Basic Systems (CBS) and to the Coordination Group for Meteorological Satellites (CGMS) through its annual report to the CGMS plenary.

6. GSICS production approach

6.1. High-level principles

The generation of calibration adjustments for Level 1 satellite sensor data is performed 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 with specified uncertainties, through well-documented, peer-reviewed procedures, based on various techniques aiming 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.

### 6.2. Product acceptance

The recognition of a product as a GSICS product is subject to the GSICS Procedure for Product Acceptance (GPPA) which aims to assess the relevance, maturity, and availability of the products through a comprehensive review process coordinated by the GCC and under the responsibility of the Executive Panel. The GPPA foresees different stages: demonstration, pre-operational, operational.

The GPPA requires that each GSICS Product be delivered with an Algorithm Theoretical Baseline Document (ATBD) and an uncertainty analysis.

### 6.3. Intercalibration

Intercalibration of satellite instruments involves relating the measurements of one instrument to those of another. Instruments can be inter-calibrated when they are viewing the same scenes at the same times from the same viewing angles. Or, for satellite time series data in an archive, when the overlapping records of two satellite instruments can be compared; generally, the time series of large-scale spatial and temporal means are inter-calibrated. The result of an inter-calibration is the consistency, and the absence of any bias, of one instrument’s measurements with respect to the other’s.

Furthermore, an inter-calibrated system which would not be tied to measurement reference standards based on the SI system of units would be prone to drift over time. The magnitude of such drift is hard to predict, but for climate measurements where small changes are of prime interest, it may become an issue for future generations trying to track changes over several decades. Therefore, development of procedures for linking the observations to the international SI system of units is highly desirable.

Whenever possible, the main approach for comparison of contemporaneous sensors is to use Simultaneous Nadir Observations (SNO), for nadir scanning instruments. A variant of SNO is the Simultaneous Conical Observations (SCO) for conical scanning instruments.

The ATBD describes the agreed practices for each step of the processing leading to a GSICS product, including for instance:

- **Subsetting**: selecting portions of data collected by the two instruments that are likely to produce collocations.
- **Collocating**: identify the pixels that are spatially collocated, temporally concurrent, geometrically aligned and spectrally compatible and calculate the mean and variance of these radiances.
- **Transforming**: modifying the spectral, temporal and spatial characteristics of the observations, to account for differences in instrument characteristics. The outputs of this step are the best estimates of the channel radiances, together with estimates of their uncertainty.
- Filtering: if relevant, to remove certain data that should not be analyzed (quality control), and to add auxiliary data that will add further analysis.
- Monitoring: comparison of the collocated radiances produced in Steps 1-4, the production of statistics summarizing the results to be used in the Correcting step, and reporting any differences in ways meaningful to a range of users.
- Correcting: to calculate the GSICS Correction, allowing the calibration of one instrument's observed data to be modified to become consistent with that of the reference instrument.

6.4. Calibration references

For the thermal infrared domain, an “anchor” reference is chosen among the most accurate and stable of the available infrared spectrometers, in accordance with an agreed set of criteria. To the extent possible, the reference instrument should be SI traceable, for instance through the use of thermo-regulated black-bodies with phase-change cells.

For the near infrared and visible domains (solar channels) an “anchor” reference is chosen among the most accurate and stable of the available short-wave spectrometers, in accordance with an agreed set of criteria. Natural targets such as the moon’s surface (together with a lunar model), deep convective clouds, ocean surface or desert targets are used as transfer standards. The radiometric and spectral character of Earth-reference targets, such as stable desert areas are determined using in-situ measurements from ground-, aircraft-, and balloon-based instruments. These in-situ measurements, made during long-term measurement projects and short-term special field campaigns, are used to monitor satellite instrument performance.

For the micro-wave domain, an “anchor” reference is chosen among the most accurate and stable of the available microwave radiometers, in accordance with an agreed set of criteria, using an atmospheric Radiative Transfer Model as a transfer standard. Radiances computed from NWP analyses of atmospheric conditions can be compared with those observed from satellite.

Additional references are defined in order to serve as transfer standards when the primary references are no longer available. In order to ensure robust and stable space-based references in spite of the transition from one instrument to its successor, a weighted combination of several reference instruments can be considered. Furthermore, performing comparisons with several references enables combining the advantages of several instruments (e.g. different local solar times, different spectral bands) as long as consistency is ensured between these different references.

6.5. Product catalogue

GSICS intercalibration products are referenced in an on-line Product Catalogue which is maintained by the GCC. The Guide to GSICS Products and Services provides details on the product categories, including their definition, detailed characteristics, access and usage.
The products are classified according to the spectral domain (UV, Visible, Infrared, Microwave), the orbit type (GEO, LEO), the reference instrument, and the temporal approach: Near real-time products are calculated over a time window including the latest measurements; Retrospective corrections are calculated for measurements performed several days in the past, over a time window centered at the measurement; Recalibration algorithms are validated on a given data sample and made available to re-process historical data, often from recurrent instruments, for climate data records.

7. GSICS Services and Tools

Collaborative tools and services have been developed and implemented in order to support data exchange, development and usage of GSICS deliverables:

- Collaboration Servers for the exchange of calibration dataset and product download;
- Bias plotting tool for the visualization of GSICS products hosted on the GSICS collaboration servers;
- GSICS product subscription service for the automated downloading of new products as they become available (to be available in 2016);
- GSICS product generation framework and products format checker to simplify GSICS products development and their validation (to be available in 2015/2016);
- GSICS Implementation of the ROLO Model (GIRO) lunar calibration software and associated GSICS Lunar Observation Dataset (to be available in 2015).

GSICS User Services include:

- GSICS portal maintained by WMO (http://gsics.wmo.int) with high-level information on GSICS and links to the GCC website maintained by the GCC, and related websites maintained by each GPRC;
- GSICS User Messaging Service managed by the GCC;
- GSICS Quarterly newsletter distributed electronically to all registered users;
- GSICS User Workshop organized in conjunction with major satellite user conferences;
- GSICS wiki providing access to technical documentation such as the Algorithm Theoretical Baseline Documents (ATBD) of each product.

8. GSICS Reference Documents

The strategic and governance framework of GSICS is provided in the following documents, which are approved by the GSICS Executive Panel and made available on line:

- Introduction to GSICS (the present document)
- Vision for GSICS in the 2020s "Shaping GSICS to meet future challenges"
- GSICS User Requirements Document (Not yet available)
- GSICS Science Plan (TBC)
- Guide to GSICS Products and Service (Being drafted)
- GSICS Product Catalogue,
- GSICS Procedures, Standards and Technical Guidelines.
ANNEX

Annex 1: Accession to GSICS Membership

Membership in GSICS is open to all satellite operators participating in the Coordination Group for Meteorological Satellites (CGMS). The GSICS members operating a satellite on an operational basis are invited to establish GSICS Production and Research Centres (GPRC). Other satellite operators can contribute to GSICS as Calibration Support Segment (CSS).

In order to apply to become a GSICS member, a satellite operator shall write a letter to WMO (Director of the Space Programme) indicating its intention to participate in GSICS and designating its representatives to the GSICS Executive Panel and the Research and Data Management Working Groups.

Applying as a Member implies agreement and support to the scope and high-level principles of GSICS as stipulated in the present GSICS Functions and Organization document [GSICS-BDFOR] and to the GSICS technical standards and procedures.

A CGMS satellite operator can also propose the participation of a partner public institute involved in satellite instrument calibration matters as a Calibration Support Segment.

A CGMS Satellite Operator or a partner organization which is not ready to participate in GSICS as a member can be invited to participate in GSICS activities as an Observer. Observers participate in all GSICS activities on a consultative and non-binding basis.

The chair, vice-chairs or co-chairs, of the Executive Panel and GSICS Working Groups are designated among the representatives and experts of GSICS members.