CGMS-XXXIII
WMO WP-21
Prepared by WMO
Agenda item: II.2

GLOBAL SPACE-BASED INTER-CALIBRATION SYSTEM (GSICS)

(Submitted by WMO)

Summary and purpose of document

WMO WP-21 describes the concept and strategy for a Global Space-based Inter-calibration System (GSICS) to be endorsed and implemented by CGMS space agencies with guidance from the WMO Space Programme. GSICS's concept and strategy contain a description of its objectives, enabler, users, current status, benefits, guiding principles, pre-requisites, and building blocks.

ACTION PROPOSED

CGMS satellite operators are requested to endorse the concept and strategy and to convene a task force to develop a GISCS Implementation Plan. NESDIS has informally agreed to continue its role to support the WMO Space Programme in leading the effort to develop the GISCS Implementation Plan.

1. Background

The following paragraphs propose the concept and strategy for a Global Space-based Inter-calibration System (GSICS) to be endorsed and implemented by CGMS space agencies with guidance from the WMO Space Programme. The goal is to present a concept and strategy for achieving operational inter-calibration of the space component of the World Weather Watch's Global Observing System (WWW's GOS) that addresses the climate, weather forecasting and other environmental needs of WMO Members.

A meeting was held at EUMETSAT's Headquarters Darmstadt, Germany on 21 and 22 July 2005 in order to have an open discussion for such a concept and strategy. Participants were asked to review a draft concept and strategy paper and provide feedback and ideas with the goal to develop the present draft concept and strategy at the meeting.

Requirements for more accurate satellite information products are steadily increasing. As numerical weather prediction models become more reliable, their appetite for more accurate data input steadily increases. As the requirements for monitoring global climate become clearer – temperature changes as tiny as a few tenths of a degree per decade, ozone trends as small as 1% per decade – the measurements become more demanding. To create the stable long-term data sets needed for monitoring climate change it becomes vital to inter-calibrate sensors on similar and different satellites. Also important is intercalibration of satellite observations with in situ observations. Additionally, the NWP community has demonstrated the potential contribution the assimilation community could make to an international effort and assist in the following continuous activities: relative calibration; channel validation and satellite radiances monitoring as reported on the Internet at various web sites. Also demonstrated by the assimilation community was the need for absolute calibration.

The Global Earth Observing System of Systems (GEOSS) is an international collaboration with the aim of integrating information from various Earth observing systems to provide better information and understanding, which then enables the public, private sector, and governments to benefit from informed decision-making. Improved information from GEOSS addresses nine societal benefits: improved weather forecasting, climate prediction, protect ocean resources, reduce loss of life and property from disasters, human health, sustained agriculture, ecological forecasts and protect, monitor and manage water, and energy resources.

Satellite observations are a major contributor to GEOSS. A single satellite in sun synchronous low earth orbit (LEO) provides global coverage with two observations per day (12 hour separation) for most locations on the earth. Geostationary satellites provide hourly or better coverage of the Earth over a fixed region. The WWW's GOS geostationary constellation of 6 satellites provides global coverage between +/- 60 degrees latitude, while the polar constellation of more than four LEO satellites provides hourly coverage near the poles. It is clear that multiple satellite systems are needed to provide observations with adequate temporal resolution covering the Earth in order to achieve an integrated information-based system that meets the nine societal objectives discussed above. The establishment of an operational global space-based inter-calibration system will also provide a means to retrospectively inter-calibrate satellite data.

To integrate observations and products from different satellite systems, the measurements must be inter-calibrated. Without inter-calibration of the space-based component of the WWW's GOS and of GEOSS, the full benefit of the observations will not be realized. For climate applications, the data cannot be used because jumps (systematic biases) can occur in a time series constructed from different sensor observations. For weather predictions, biases between different satellites are often resolved by computing differences between measured observations and those simulated from a model analysis or forecast. However, the radiance bias adjustments often do not identify the difference sources of the biases. A much better scientific approach to account for instrument-to-instrument biases is to directly compare observations from different instruments. The number of satellite-based Earth observing systems is going to increase

significantly - data volume by 5 orders of magnitude- during this decade and beyond. Additionally, an operational global space-based inter-calibration system will also serve to inter-calibrate in situ observing systems that would further improve assimilation systems. Thus, an operational global space-based inter-calibration system would be a critical step towards a total inter-calibration system.

Therefore, there is a compelling need for a concept and strategy for a global space-based inter-calibration system endorsed and implemented by space agencies with guidance from the WMO Space Programme. Here, the purpose of inter-calibration is to quantitatively relate the radiances from different sensors viewing the same target to allow consistent measurements to be taken over the globe by all elements of the space-based observing system. A Global Space-based Inter-calibration System would be part of an end-to-end capability consisting of: on-board calibration devices (e.g., black bodies, solar diffusers); in situ measurements of the state of the surface and atmosphere (e.g. the Cloud and Radiation Test-bed (CART) site, aircraft instruments with NIST calibrations); radiative transfer models that enable comparison of calculated and observed radiances; and assimilation systems that merge all measurements into a cohesive consistent depiction of the Earth-atmosphere system.

2. Objectives

The objectives for the operational Global Space-based Inter-calibration Systems (GSICS) are:

- ***Primary goal:*** To improve the use of space-based global observations for weather, climate and environmental applications through operational inter-calibration of the space component of the WWW's GOS and GEOSS;
- ***Secondary goal:*** To provide for the ability to retrospectively re-calibrate archive satellite data using the operational inter-calibration system in order to make satellite data archives worthy for climate studies

3. Enabler

- An operational global space-based inter-calibration system to better characterize space-based observations by measuring, documenting, understanding and accounting for differences between different sensors viewing the same target - analyses of the differences will provide for recommended actions to meet the benefits described below.

4. Users

- Climate, NWP, and related environmental application areas

5. Current status

- ***Current capability*:** Operational inter-calibration, as described above, presently does not exist for the WWW's GOS as an overall total system but rather only for components of the satellite system;
- ***Requirement stated by*:** CGMS-XXXII, Sochi, Russian Federation, May 2004, EUMETSAT/WMO/GCOS/CM-SAF, July 2004 and CBS-XIII Evolution of the GOS, February 2005;
- ***GAP:*** An overall system-wide operational inter-calibration system for WWW's GOS.

6. Benefits

The benefits resulting from the establishment of a Global Space-based Inter-calibration System are:

High-level

- Enhanced usefulness of satellite products to observe climate variability;
- Improved utility (ease of use) of satellite radiances in NWP;
- Improved cost-benefit ratio from an optimized global system of satellites.

Technical

- Consistent calibration of space-based radiometers;
- Significantly improved characterization of space-based radiometers;
- Move towards absolute calibration; this would also necessitate a reference measurement network;
- Improve understanding of physical processes in atmospheric models (requires absolute calibration).

7. Guiding principles

The guiding principles for a Global Space-based Inter-calibration System are:

- To utilize satellite radiances as a key element in GSICS;
- To have an agreed space-based calibration standard(s) (instruments and targets);
- To establish satellites as 'moving calibration references' for the surface-based component of the GOS.

8. Pre-requisites

The pre-requisites for a Global Space-based Inter-calibration System are:

- Pre-launch characterization of all instruments

  Pre-launch characterization requires extensive calibration tests that are necessary in order to properly characterize instruments and insure that calibrations are traceable to SI standards. Ideally, instruments should meet thresholds for spectral coverage and resolution, and radiometric performance (accuracy, precision and long-term stability). Instruments meeting these thresholds can then be used to anchor instruments that do not. All pre-launch instrument data must be archived with metadata and be freely and openly exchanged. In particular, pre-launch calibration includes fully and publicly documented pre-launch radiometric characterization, calibration, and uncertainty analysis traceable to international standards, preferably to the SI system of units, as maintained by the world's national metrology institutes. For the ultimate accuracy a system-level calibration should be performed with radiometric standards that mimic as closely as possible the spectral and spatial optical radiative properties of the expected Earth targets and with environmental conditions that mimic as closely as possible the temperature and vacuum conditions found in space. Onboard calibration utilizes radiometric standards (blackbodies, solar reflectance, etc.) to determine and correct the drift in the pre-launch calibration of the instrument while on orbit. The performance of the standards should be assessed during the pre-launch calibration.

- Some instruments in space with appropriate spectral coverage and resolution to act as a standard for inter-calibration

  Benchmark observations traceable to international standards are required as “gold” standards for validation and inter-calibration of other satellite sensors., e.g. benchmark observations, such as spectrally resolved radiances and GPS Radio-occultation measurements, are required. Instruments with appropriate spectral coverage and resolution should include continuous measurements in solar, thermal and microwave parts of the spectrum as well as narrowband and hyper-spectral radiance measurements.

- Independent observations (calibration/validation sites – ground based, aircraft)

  Independent observations can be vicariously calibrated at sites with temporally and spatially stable surface characteristics and generally clear skies are useful for characterizing calibration drifts of VIS and NIR instruments. Where possible, vicarious calibrations incorporate observations of extra-terrestrial sources proven for their stability (sun, moon, stars) in monitoring in-flight sensor degradation and sensor inter-comparisons. Special CAL/VAL campaigns using aircraft and ground-based measurements are encouraged and resulting data must be archived with metadata and be readily accessible. Sustained ground-based observations (including oceans) are required and need to be part of the satellite inter-calibration program. A reference network that includes high-quality radiosondes and other measurements such as those found at the Department of Energy (DOE) CART sites should also be a contributing external component to a satellite inter-calibration program. A Community Radiative Transfer Model (CRTM) for all sensors must be maintained including free and open access.

9. Building Blocks

A Global Space-based Inter-calibration System can be described in terms of four building blocks (collocation, data collection, coordinated operational data analyses, and assessments, communication including recommendations) as follows. The four building blocks also serve as a system design to which system participants must commit to implement and operate:

Collocation

- Determination and distribution of locations for simultaneous observations by different sensors (space-based and in situ)

  Ideally the data needed for satellite inter-calibration are collected from simultaneous collocation of observations. For LEO to LEO, this has been demonstrated at NOAA/NESDIS using a new technique called Simultaneous Nadir Observations (SNO) and Simultaneous Conical Observations (SCO) that collocates sensor data from different NOAA, DMSP and NASA instruments. For LEO to GEO, simultaneous observations from collocations between a LEO and all GEO sensors have also been demonstrated and can be used as a means to inter-calibrate GEO satellites. Conversely, for GEO to LEO, an instrument with high accuracy, precision and stability in geostationary orbit can be used as a means to inter-calibrate all LEO sensors. Additionally, collocated high spectral resolutions observations (e.g. AIRS, IASI, CrIS) are important for validating and vicariously calibrating broader-band radiometers (HIRS, MODIS). All collocated observations for satellite inter-calibration must be archived with metadata and be freely and openly exchanged as well as have easy access to inter-satellite calibration coefficients. Space Agencies should share responsibility in providing required sub-samples of satellite observations needed for

inter-calibration. A designated agency or agencies (TBD) should provide collocation (location and time) events for various satellite intersections.

Data collection

- Archive, metadata - easily accessible

  All data archives should contain relevant metadata and allow for free and unrestricted access to the collocated data.

- Coordinated operational data analyses

  There is a need to identify processing centres that will be responsible for the generation of the sub-sampled data.

- Collaboration for algorithm development – workshops

  In order to achieve agreed-upon inter-satellite calibration algorithms, periodic workshops should be sponsored and held to review inter-satellite calibration techniques. Publication of papers in the open literature on results of satellite inter-calibrations is essential.

- Standard approach to document

- Assessments, communication including recommendations

- Use of websites and GTS

  It is essential to assess and optimize observing system performance through two-way communication between the user communities and relevant space agency. Thus, the provision of recommendations resulting from coordinated operational analyses should be communicated amongst the impacted user community and relevant space agency as effectively as possible. One example of an effective communication method is an inter-calibration web-site with pertinent information about the program, instrument calibration coefficients, useful ground and aircraft CAL/VAL data set (or links to), links to CRTMs, etc.

Relevant previous activities

Previous activities towards the establishment of a Global Space-based Inter-calibration System include:

- ISCCP normalization of VIS and IR radiances to polar orbiter (AVHRR) (a long-term activity that offers lessons to be learned);
- CGMS-led satellite inter-calibration for IR and WV channels (typically geostationary satellites referenced to HIRS or, more recently, to AIRS);
- Pilot work on re-calibrating archived satellite radiance observations (e.g. the re-calibration of the Meteosat First Generation VIS channels at EUMETSAT, as pre-requisite for the derivation of surface albedo);
- Pilot work on re-navigation and re-calibration of archived AVHRR data at NESDIS;
- SNO and SCO activities at NESDIS.

CGMS actions and future activities

WMO WP-21 describes the concept and strategy for a Global Space-based Inter-calibration System (GSICS) to be endorsed and implemented by CGMS space agencies with guidance from the WMO Space Programme. GSICS's concept and strategy contain a description of its objectives, enabler, users, current status, benefits, guiding principles, pre-requisites, and building blocks. CGMS satellite operators are requested to endorse the concept and strategy and to convene a task force to develop a GISCS Implementation Plan. NESDIS has informally agreed to continue its role to support the WMO Space Programme in leading the effort to develop the GISCS Implementation Plan.