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Dr. Robert A. Iacovazzi, Jr., Editor

SCOPE-CM: The sustained generation of climate data records from satellite data

Generating satellite-based climate data records (CDRs) that are robust enough to allow analysis of climate variability, and to detect climate trends, is a significant challenge. Creating reliable retrieval algorithms that convert instrument measurements into geophysical parameters are an important prerequisite for CDRs. However, to observe variability and trends over a long time (decades), special attention has to be given to individual technical aspects of each sensor and satellite used to create a given CDR from different sensors on different satellites. Even if the instrument design is identical, individual sensors can be different in behaviour and change with time differently. In addition, satellite orbits of older polar orbiting satellites were not always stable, i.e., equatorial overpass times drifted and observations were taken at different times of day during the course of their operational life. This makes it difficult to distinguish the trends in climate from "trends" of the sensors and potential diurnal cycle aliasing. The processing of satellite data that allow quantitative assessment of Essential Climate Variables (ECVs), therefore has to include careful re-calibration and/or inter-calibration, as well as other correction methods. The resulting Fundamental Climate Data Records (FCDRs), e.g. homogeneous records of radiances or brightness temperatures, are the basis for further analysis and retrievals that lead to the processing of Thematic Climate Data Records (TCDRs).

The WMO Network for Sustained and Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) is an international mechanism for the provision of high-quality long-term data sets of Global Climate Observing System (GCOS)-defined ECVs using observations from space. Within SCOPE-CM, the contributing organisations coordinate their related activities and cooperate on the basis of shared and distributed responsibilities in the generation of global products. The particular capability and responsibility of the operators of long-term satellite missions is obvious in this effort.

The SCOPE-CM Network (originally named the Regional/Specialized Satellite Centres for Climate Monitoring (R/SSC-CM)) was established in November 2008 through the approval of its Implementation Plan, which occurred after several preparation and discussion events. The initial participating organisations include the operational satellite agencies: China Meteorological Administration (CMA), European Organisation for Meteorological Satellites (EUMETSAT), Japan Meteorological Agency (JMA), and the United States National Oceanic and Atmospheric Administration (NOAA). To ensure proper liaison with other relevant initiatives and organisations, SCOPE-CM maintains formal links to several other organizations: Committee on Earth Observation Satellites (CEOS), Coordinated Group of Meteorological Services (CGMS), GCOS, Group on Earth Observation (GEO), GSICS, World Climate Research Programme (WCRP)/Global Energy and Water Cycle Experiment (GEWEX), and naturally WMO.

SCOPE-CM is currently in its initial phase, establishing five pilot projects focusing on common areas of interest and expertise. These common areas include clouds and aerosols from Advance Very High Resolution Radiometer (AVHRR); water vapour, clouds and precipitation from Special Sensor Microwave/Imager (SSM/I); and surface albedo, winds and humidity from geostationary satellite Imagers. The second phase, which is currently in preparation, will aim to establish the sustained CDR generation infrastructures and activities.

A simplified view of the satellite derived climate products processing, and the related organisational structures within WMO is shown in Figure 1. The inter-calibration of satellite sensors (of different as well as of similar types) is highly beneficial for the generation of FCDRs, and therefore services developed and provided within the GSICS framework are crucial for the objectives of the SCOPE-CM. SCOPE-CM will benefit largely from the GSICS satellite data corrections, and/or correction methodologies. In very general terms, the SCOPE-CM needs following corrections:

- Corrections applicable to recent/current data;
- Corrections applicable to historic data; and
- The most appropriate corrections to be applied for a sustained extension of FCDRs into the future.

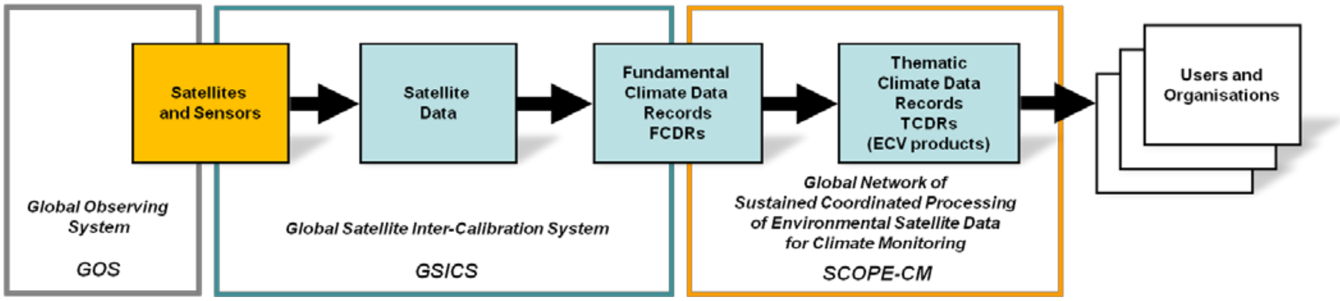

Figure 1. Processing chain from satellite measurements to the climate products and organisational WMO parts responsible for each step.

Future SCOPE-CM plans are to efficiently utilize services already provided by GSICS and GSICS is expected to take into account the specific needs of SCOPE-CM. Just like a suspension bridge, GSICS will provide and maintain reliable pillars and cables, which will support SCOPE-CM to construct and maintain robust roads (with no bumps and/or gaps) that span from shore to shore. In this spirit, the common goal between GSICS and SCOPE-CM is the generation of reliable, homogeneous, long-term climate data records, which span decades.

(by Dr. L. Schüller, [EUMETSAT])

The Moderate Resolution Imaging Spectroradiometer (MODIS)

The Moderate Resolution Imaging Spectroradiometer (MODIS) is one of the key instruments on-board NASA's polar-orbiting Earth Observing System (EOS) Terra and Aqua spacecraft, launched on December 18, 1999 and May 4, 2002, respectively (http://modis.gsfc.nasa.gov/). The MODIS design is improved with respect to its heritage sensors, providing better spectral, spatial, and temporal characteristics, as well as more stringent calibration accuracy requirements (Barnes *et al.*, 2003). For these reasons, GSICS plans to inter-calibrate the solar reflective bands of the international constellation of operational geostationary (GEO) imager instruments using MODIS as a community accepted intrinsic standard.

The MODIS instrument has 36 spectral bands: 20 reflective solar bands (RSB) with center wavelengths ranging from 0.41 to 2.1 µm and 16 thermal emissive bands (TEB) with center wavelengths from 3.7 to 14.4 µm. It collects data in three spatial resolutions (nadir): 250 m for bands 1-2, 500 m for bands 3-7, and 1 km for bands 8-36. MODIS is a cross-track scanning radiometer with a wide field-of-view (FOV), enabling a complete global coverage of the Earth in less than 2 days. Table 1 is a summary of MODIS key design requirements, including primary applications of MODIS spectral bands and their bandwidths, typical radiances, and signal-to-noise ratios (SNR) or noise-equivalent temperature differences (NEΔT).

Table 1. MODIS design specifications.

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dims:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size/Wgt/Pow:	1.0 x 1.6 x 1.0 m / 228.7 kg / 162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Res:	250 m (bands 1-2); 500 m (bands 3-7); 1000 m (bands 8-36)
Design Life:	6 years

Primary Use	Band	Band Width [1]	Spectral Radiance [2]	Required SNR [3]
Lnd/Cld Boundary	1	620-670	21.8	128
	2	841-876	24.7	201
Lnd/Cld Property	3	459-479	35.3	243
	4	545-565	29.0	228
	5	1230-1250	5.4	74
	6	1628-1652	7.3	275
	7	2105-2155	1.0	110
Ocn Color/ Phyto-plankton/ Biogeo-chemistry	8	405-420	44.9	880
	9	438-448	41.9	838
	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516
Atmos Water Vapor	17	890-920	10.0	167
	18	931-941	3.6	57
	19	915-965	15.0	250
Primary Use	**Band**	**Band Width [1]**	**Spectral Radiance [2]**	**Required NEDT(K) [4]**
Sfc/Cld Temp	20	3.660-3.840	0.45(300K)	0.05
	21	3.929-3.989	2.38(335K)	2.00
	22	3.929-3.989	0.67(300K)	0.07
	23	4.020-4.080	0.79(300K)	0.07
Atmos Temp	24	4.433-4.498	0.17(250K)	0.25
	25	4.482-4.549	0.59(275K)	0.25
Cirrus	26	1.360-1.390	6.00	150SNR
Water Vapor	27	6.535-6.895	1.16(240K)	0.25
	28	7.175-7.475	2.18(250K)	0.25
	29	8.400-8.700	9.58(300K)	0.05
Ozone	30	9.580-9.880	3.69(250K)	0.25
Sfc/Cld Temp	31	10.780-11.280	9.55(300K)	0.05
	32	11.770-12.270	8.94(300K)	0.05
Cld Top Altitude	33	13.185-13.485	4.52(260K)	0.25
	34	13.485-13.785	3.76(250K)	0.25
	35	13.785-14.085	3.11(240K)	0.25
	36	14.085-14.385	2.08(220K)	0.35

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
[2] Spectral Radiance values are (W/m^2 -µm-sr)
[3] SNR = Signal-to-noise ratio
[4] NED(delta)T = Noise-equivalent temperature difference
Note: Performance goal is 30-40% better than required

The 36 spectral bands and 490 individual detectors on MODIS are arranged according to their wavelengths on four focal plane assemblies (FPAs): visible (VIS), near-infrared (NIR), short- and mid-wave infrared (SMIR), and long-wave infrared (LWIR). The spectral bands are aligned in the cross-track direction and the detectors of each band are aligned in the along-track direction. The VIS and NIR detectors are of photovoltaic (PV) silicon hybrids and the SMIR detectors are PV HgCdTe hybrids. The LWIR FPA consists of PV HgCdTe detector arrays for bands 27-30 and photoconductive (PC) HgCdTe detectors for bands 31-36. The VIS and NIR FPA are referred to as the warm FPA, operated on-orbit without temperature control. On the other hand, the SMIR and LWIR FPA are referred to as the cold FPA, nominally controlled at 83K via a passive radiative cooler.

There are approximately 40 science products generated from MODIS observations and used for studies of the Earth's system of land, oceans, and atmosphere (Salomonson *et al.*, 2002). To assure data product quality, both Terra and Aqua MODIS went through extensive pre-launch calibration and characterization. The radiometric calibration included measurements of each detector's gain, nonlinearity, dynamic range, and Signal-to-Noise Ratio (SNR) or Noise Equivalent Delta Temperature (NEΔT). The spectral characterization included measurements of each detector's relative spectral response (RSR) and, therefore, its center wavelength and bandwidth. The pre-launch derived spatial characterization parameters included detector instantaneous field of view (IFOV), band-to-band registration (BBR), modulation transfer function (MTF), and line spread function (LSF). Other system level measurements were also made to characterize sensor response versus scan-angle (RVS) and the scan angle dependent polarization sensitivity for the VIS and NIR spectral bands.

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Salomonson, V. V., W. L. Barnes, X. Xiong, S. Kempler, and E. Masuoka, 2002: An Overview of the Earth Observing System MODIS Instrument and Associated Data Systems Performance. *Proceedings of IGARSS.*

(by Dr. X. Xiong, [NASA])

MODIS On-Board Calibration

MODIS level 1B (L1B) primary data products are the top of atmosphere (TOA) reflectance factors for the RSB and TOA radiances for both the RSB and TEB. For the RSB, the calibration accuracy requirements (1σ) at the typical scene radiances are ±2% for the reflectance factors and ±5% for the radiances. For the TEB radiance product, the requirements are ±1% except ±0.75% for band 20, ±10% for band 21, a low gain band for fire detection, and ±0.5% for bands 31 and 32 at 11 and 12 μm. In order to maintain its on-orbit calibration quality, MODIS was designed and built with a set of on-board calibrators (OBC), including a solar diffuser (SD), a solar diffuser stability monitor (SDSM), a blackbody (BB), and a spectro-radiometric calibration assembly (SRCA). MODIS OBC and its scan cavity are illustrated in Figure 1.

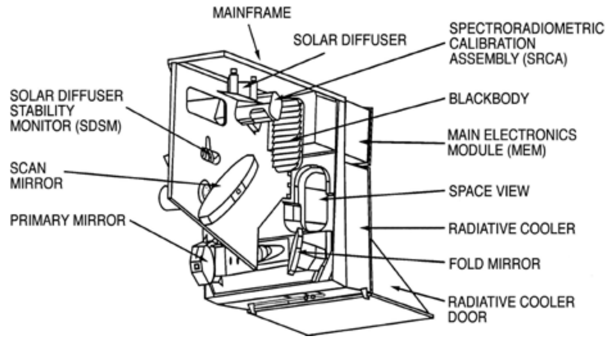

Figure 1. MODIS scan cavity and on-board calibrators.

MODIS RSB calibration is reflectance based (Xiong *et al*. 2009). The scene reflectance factor is derived using a simple linear algorithm with reference to the on-board solar diffuser (SD) bi-directional reflectance factor (BRF). The SD panel was made of space-grade Spectralon materials. Its BRF was characterized pre-launch using reference samples traceable to the NIST reflectance standard. Each complete set of RSB calibration consists of SD observations in two consecutive orbits, one with and one without an attenuation solar diffuser screen (SDS). The SDS is used for the high gain bands (bands 8-16), whose responses saturate to the sunlight directly reflected from the SD. On-orbit changes in SD BRF are tracked by the on-board SDSM. The SDSM is essentially a ratioing radiometer. It is operated during each scheduled SD calibration event, making alternate observations of the Sun and the sunlight reflected from the SD. In addition to using its on-board SD/SDSM observations, MODIS makes lunar observations on a near-monthly basis to support its RSB calibration. For radiometric calibration stability monitoring purposes, these observations are planned at the same lunar phase angle for each instrument. MODIS lunar observations have also been used for sensor calibration inter-comparison (Xiong *et al*. 2008).

The TEB calibration is performed on a scan-by-scan basis using detector responses to the on-board blackbody (BB) and space view (SV) via a quadratic algorithm (Xiong *et al*. 2009). For nominal operation, the BB is set at a constant temperature, 290 K for Terra MODIS and 285K for Aqua MODIS. Each scan, the BB temperatures are measured by a set of 12 thermistors uniformly embedded in the BB panel. The BB thermistors were characterized pre-launch with reference to the NIST temperature standards. The TEB on-orbit calibration source includes contributions from the BB (dominant term), scan mirror, and instrument scan cavity. Periodically, a BB warm-up and cool-down (WUCD) operation is performed, during which the BB temperatures vary from approximately 272K, the instrument ambient temperature, to 315K. This operation allows the quadratic calibration coefficients, the offset and nonlinear terms, to be computed and updated on an as-needed basis.

The SRCA is a unique device and can be operated in three different modes: radiometric, spectral, and spatial. It was designed with internal calibration sources and wavelength calibration capability. The radiometric and spectral modes can be used for the spectral bands with wavelengths below 1μm. The spatial mode can be applied for all MODIS spectral bands. On-orbit changes in center wavelengths and bandwidths (RSB only) and band-to-band registrations (BBR) are tracked by the SRCA over the entire missions of both Terra and Aqua MODIS. It is expected that experiences and lessons from MODIS on-orbit calibration will continue to provide useful input for developing future missions and sensors.

Since the solar reflective bands of the current international constellation of operational geostationary (GEO) imagers do not have on-board solar diffusers, nor any other SI-traceable calibration devices, inter-calibration of these instruments with well-characterized community intrinsic standards is required. At this time, because of their quality, and relatively long time record, GSICS has chosen to use the MODIS instrument to carry out this task.

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Xiong, X., B. Wenny, and W. L. Barnes, 2009: Overview of NASA Earth Observing Systems Terra and Aqua Moderate Resolution Imaging Spectroradiometer Instrument Calibration Algorithms and On-orbit Performance. *J. Appl. Remote Sens*., **3**, 032501

Xiong, X., J. Sun, and W. L. Barnes, 2008: Inter-comparison of On-orbit Calibration Consistency Between Terra and Aqua MODIS Reflective Solar Bands Using the Moon. *IEEE Geosci. Remote Sens. Let.,* **5**(4), 778-782.

(by Dr. X. Xiong, [NASA])

News in this Quarter

Recent GSICS Web Meetings

Web meetings have become regular fixtures in the diaries of GSICS developers. They allow us to conveniently keep in touch without incurring the extra time, cost and pollution overheads that attending meetings in person would require. However, given the global distribution of participants, there is a rather narrow time window each day when it is reasonable to expect attendees in East Asia, Europe and the East Coast of the USA to participate. On the other hand, this narrow time window has proved to be sufficient, as participants are willing to exercise the convenience of accessing web meetings from home. We are particularly grateful that some guest attendees from the Central USA have made the effort to get up especially early to participate in web meetings.

GSICS web meetings are held approximately once a month, typically for 2 hours, focusing on a single topic. The topics are chosen in advance to address issues with currently developing products. Recent themes have included reviewing the work flow required for products to progress to operational status, conducting error analysis and qualitative assessments of different inter-calibration methods, selection of reference instruments and their traceability, and methods of ensuring consistency between different inter-calibration products. Summaries and presentations from these meetings are uploaded to the GSICS Wiki at the following URL: https://cs.star.nesdis.noaa.gov/GSICS/MeetingsAndConferences.

(by T. J. Hewison [EUMETSAT])

GPM X-Cal Meeting

GSICS was again represented at a recent meeting of the GPM X-cal Working Group by Tim Hewison, who provided an update on the GSICS Procedure for Product Acceptance and access to products through the GSICS Data and Products Servers. This group has made excellent progress in establishing inter-calibration methods for the TRMM Microwave Imager, TMI, and WindSat and plan to extend these methodologies to include other conically scanning microwave imagers, as well as the window channels of cross-track sounders. They are also investigating other methods, such as NWP double-differencing, for the sounding channels. More details of the meeting can be found at http://www.gpm-x-cal.info/. Future interaction between GPM X-cal and GSICS were discussed, identifying a need for addition support to adapt this group's valuable work into GSICS-compliant products. It is intended that this will be performed as part of a GSICS subgroup of microwave experts.

(by T.J. Hewison [EUMETSAT])

Just Around the Bend …

GSICS-Related Meetings

- **Second GSICS User's Workshop,** To be held as a breakout session on 21 September 2010 during the 2010 EUMETSAT Meteorological Satellite Conference 20-24 September 2010, Córdoba, Spain.
- **GPM X-Cal Meeting**, 21-22 October 2010, NOAA/National Climate Data Center, Ashville, NC, USA

GSICS-Related Publications

Hu, X., J. Liu, L. Sun, Z. Rong, Y. Li, Y. Zhang, R. Wu, L. Zhang, Z. Zheng, X. Gu, 2010: Characterization of CRCS Dunhuang test site and vicarious calibration utilization for Fengyun(FY) series sensors. *Canadian Journal of Remote Sensing*, Special issue "Terrestrial reference standard test sites for post-launch calibration", **in press**.

Hu X., L. Zhang, Z. Zheng, Y. Zhang, L. Sun, L. Ding, X. Huang, 2010: Multi-detectors radiometric calibration for infrared band of Medium Resolution Spectral Imager onboard FY-3A. *Optics and Precision Engineering*, **in press**.

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Wang L., X. Wu, Y. Li, S.-H. Sohn, M. Goldberg, and C. Cao, 2010: Comparison of AIRS and IASI radiance measurements using GOES Imagers as transfer radiometers. *J. Appl. Met. and Clim.*, **49**, 478-492.

Zhang Y., Y. Li, Z. Rong, 2010: Comparisons and analysis on the spectral response functions' difference between FY-2E's and FY2C's split window channels, *Spectroscopy and Spectral Analysis*, **30(6)**, 1634-1637.

Zou, C.-Z. and W. Wang (2010), Stability of the MSU-derived atmospheric temperature trend, *J. Atmos. Oceanic Technology*, **in press**.

Please send bibliographic references of your recent GSICS-related publications to Bob.Iacovazzi@noaa.gov.

GSICS Classifieds

Submitting Classified Advertisements: Are you looking to establish a GSICS-related collaboration, or do you have GSICS-related internships, exchange programs, and/or available data and services to offer? *GSICS Quarterly* includes a classified advertisements section on an as-needed basis to enhance communication amongst GSICS members and partners. If you wish to place a classified advertisement in the newsletter, **please send a two to four sentence advertisement that includes your contact information to Bob.Iacovazzi@noaa.gov.**

With Help from our Friends:

The *GSICS Quarterly* Editor would like to thank those individuals who contributed articles and information to this newsletter. The Editor would also like to thank *GSICS Quarterly* Associate Editor, Dr. Gordana Rancic-Sindic of GCC, European Correspondent, Dr. Tim Hewison of EUMETSAT, and Asian Correspondent, Dr. Yuan Li of CMA, in helping to secure and edit articles for publication.

Submitting Articles to GSICS Quarterly: The *GSICS Quarterly* Press Crew is looking for short articles (<1 page), especially related to cal/val capabilities and how they have been used to positively impact weather and climate products. Unsolicited articles are accepted anytime, and will be published in the next available newsletter issue after approval/editing. **Please send articles to Bob.Iacovazzi@noaa.gov, *GSICS Quarterly* Editor.**