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Part-I: GSICS Annual State of Observing System

Status of GSICS References

By Mitch Goldberg (NOAA) and Manik Bali (ESSIC/UMD)

The Coordination Group on Meteorological Satellites (CGMS) and the World Meteorological Organization (WMO) recently mandated GSICS (**A45.05**) to provide an overarching annual assessment of (Satellite) observing system performance with respect to GSICS reference instruments. This issue is Part-I of a two-part series of special issues of the GSICS Quarterly dedicated to providing the most up-to-date assessment of the State of the Observing System. In this part, the performance of only a select set of instruments that are also GSICS references is covered. The next issue will cover some of the instruments monitored by using the GSICS in-orbit references.

GSICS references are selected from the pool of satellites of the observing system, mainly by consensus among member agencies. Reference instruments satisfy a selection criterion (Bali et al. 2016) that is derived from principals of QA4EO (Quality Assurance for Earth Observation) and ensures that instruments that are many times more stable than most of the concurrently flying instruments and deliver high quality measurements over long periods of time are selected as reference instruments.
This gives all member agencies the ability to compare their satellites with single (or multiple agreed upon) references and make assessments that are intercomparable among agencies.

Using this selection criterion, GSICS member agencies identified VIIRS SNPP/J1 for assessing Visible and Near Infrared channels and IASI-A/B/C and CrIS SNPP/J1 for assessing Infrared channels. In addition, GSICS members are currently evaluating the use of Advanced Technology Microwave Sounder (ATMS) as an in-orbit reference for Microwave instruments.

In the second article Doelling et al. summarize the performance of the VIIRS on board the SNPP and J1.

Following this VIIRS article, the next three articles are on Infrared references and examine the in-orbit health and performance of the IASI -A/B/C (Carmine et al.), AIRS (Pagano et al.) and CrIS – SNPP/J1 (Iturbide et al.). GSICS has more than 30 instruments in the IR that are monitored by using these references.
The last article discusses the use of ATMS (Zou et. al.) as a reference for calibrating Microwave instruments that contribute to construction of Climate Data Records.

Conclusion
All the GSICS reference instruments covered here continue to satisfy reference criterion. They show a high stability over long periods of time and maintain performance within their design specifications.
The authors recommend that calibration community migrate to using IASI-B/C and SNPP/J1 CrIS as existing references, as IASI-A and AIRS are nearing end-of-life scenarios in the near future.

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GSICS recommends NOAA-20 VIIRS as reflective solar band (RSB) calibration reference

By David Doelling (NASA), Changyong Cao (NOAA) and Jack Xiong (NASA)

GSICS promotes best calibration practices amongst satellite agencies in order to improve and harmonize sensor retrievals. Consistent climate quality retrievals across sensors require actively monitoring onboard calibration systems for radiometric stability, as well as inter-calibration of analogous spectral bands. The radiometric scaling of concurrent visible imagers to an absolute or SI traceable calibration reference is not achievable with the current solar diffuser based onboard calibrators. It is expected that the CLARREO sensor will fulfill this requirement when it launches in 2023. The criteria for selecting a calibration reference sensor are: 1) An active calibration team that is monitoring the onboard sensor calibration systems in space, 2) Well documented prelaunch characterization and continued documentation of instrument performance, 3) The Level 1B (L1B) radiance data products are made publicly available in near real time, in an easily readable format, and archived, 4) The instrument L1B processing and archive center has adequate resources to readily reprocess the data after major sensor calibration anomalies are detected and mitigated along with proper data and software version control, 5) Preference is given to multiple sensor copy missions having overlapping records within in the same orbit and allowances made for inter-calibration opportunities, and 6) In the absence of SI traceability, it is advantageous to choose a sensor that is used for climate quality cloud, aerosol, land use and ocean color retrievals because these groups are also monitoring the sensor stability.

The Aqua-MODIS sensor was the first recommended GSICS visible calibration reference in the late 2000's. Typically, as sensors age the number of calibration system anomalies increases. As its follow-on sensor, the VIIRS also has the advantage of having very similar spectral response functions with the latest generation geostationary imagers. Now that the NOAA-20 VIIRS is the most optimally performing, well-characterized, and best understood VIIRS sensor, GSICS has recommended NOAA-20 VIIRS as the RSB calibration reference. The recommendation does not imply that GSICS deems that the NOAA-20 VIIRS absolute calibration reference is more accurate than SNPP VIIRS. For the M5 (0.675 µm) channel, the NOAA-20 and SNPP-VIIRS calibration difference is found to be 4.9%, see Table 1. It is expected that once CLARREO establishes the absolute RSB calibration reference on orbit, it can be transferred back in time to MODIS, VIIRS, and other historical instruments using the overlapping sensor records.

VIIRS bands	Band center (µm)	N20 VIIRS Bias relative to AQUA MODIS (N20 AQUA)*100%/AQUA	N20 VIIRS bias relative to SNPP (N20SNPP)*100%/SNPP
M1	0.415	-4.4%	-3.20%
M2	0.445	-4.0%	-1.66%
M3	0.490	-3.9%	-2.40%
M4	0.555	0.2%	-1.40%
M5	0.673	-3.7%	-4.90%
M6	0.746	-	-
M7	0.865	-2.2%	-3.80%
M8	1.240	0.5%	-3.20%
M9	1.378	-	-
M10	1.61	-1.6%	-2.27%
M11	2.25	-	-

Table 1. NOAA-20 VIIRS bias relative to AQUA MODIS (Collection 6.1) using extended SNOs over Saharan desert. M6, M9 and M11 are excluded because M6 is saturated over desert; M9 comparison is not reliable due to extremely small signal strength; and M11 RSR doesn't overlap with MODIS. NOAA-20 VIIRS bias relative to SNPP using double differencing with MODIS are also shown. Note: Spectral difference between the matching bands has been already accounted for. Also, note that SNPP M5 and M7 are biased high (1.5% and 2%), which have been corrected in the reprocessed NOAA SDR data. (Courtesy of the NOAA VIIRS SDR team.)

Details describing NOAA-20 VIIRS on orbit performance are found in Cao et al. 2018, Choi et al. 2020, Lei et al, 2020, and Xiong et al. 2020. NOAA-20 VIIRS, launched on November 18, 2017, is nearly an identical copy of the SNPP VIIRS sensor with slight differences in the band SRFs. Both VIIRS sensors are in the same 1:30 PM local equator crossing time orbit and are spaced a half an orbit apart with a ~50.5minute separation. Among the many instrument specifications, instrument noise or the Signal-to-Noise Ratio (SNR) for the reflective solar bands (RSB) is a major requirement for instrument performance. Table 2 indicates that the noise performance of NOAA-20 VIIRS is slightly better than SNPP VIIRS, and both sensors exceed their respective SNR specifications (Cao et al. 2018).

The VIIRS on orbit calibration is tied to the solar diffuser (SD) and solar diffuser stability monitor (SDSM), which were both carefully characterized during pre-launch. At the beginning of the mission, the H-factor, which is derived from the SDSM, revealed abnormal oscillation patterns. These patterns were caused by prelaunch measurement errors in the

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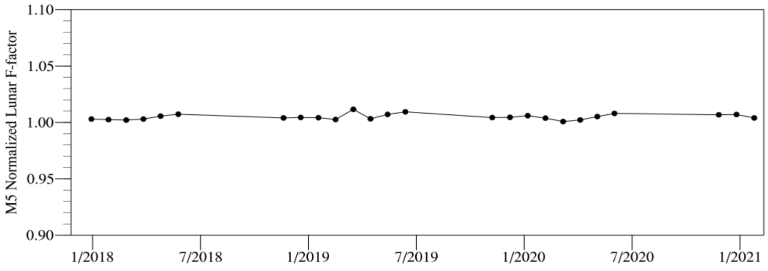
SDSM sun view transmittance screen function. A correction procedure, which relied on yaw maneuvers combined with on-orbit SDSM data, mitigated this effect. The F-factor, an overall scaling factor to track on-orbit changes in sensor response, can be derived from orbit-to-orbit SD observations, as well as near monthly lunar observations. Figure 1 shows the remarkable stability of the lunar F-factors normalized to the SD F-factors. Based on Fig. 2, the daily deep convective cloud (DCC) target trends indicate that NOAA-20 VIIRS is extremely stable and slightly more stable than SNPP-VIIRS. The GSICS community can be assured that the NOAA-20 VIIRS instrument is stable and suitable for sensor inter-calibration.

Band	Band Gain	N20 Spec SNR	N20 Measured SNR (on orbit) (01 13 2021)	SNPP Spec SNR	SNPP Measured SNR (on orbit) (01 13 2021)
M1	High	352	643	352	575
	Low	316	1106	316	1019
M2	High	380	570	380	581
	Low	409	1019	409	1069
M3	High	416	694	416	631
	Low	414	1071	414	1003
M4	High	362	546	362	537
	Low	315	848	315	862
I1	Single	119	225	119	197
M5	High	242	384	242	299
	Low	360	771	360	631
M6	Single	199	417	199	305
I2	Single	150	284	150	189
M7	High	215	529	215	322
	Low	340	712	340	412
M8	Single	74	322	74	156
M9	Single	83	298	83	175
I3	Single	6	174	6	129
M10	Single	342	675	342	509
M11	Single	90	199	10	20.3

Table 2. NOAA-20 and SNPP VIIRS band signal to noise ratio (SNR) based on post launch analysis during January 13, 2021. (courtesy of the NOAA VIIRS SDR team)

The remote sensing community is fortunate to have two independent calibration teams. The NOAA and NASA calibration methods mostly differ by their long-term stability reference targets, where NASA relies solely on the moon, NOAA also includes DCC and other invariant targets. For the VIIRS M5 band the bias between NOAA and NASA is <0.1 % and for other RSBs is <0.2% with almost no trend differences (STAR Cal/Val Systems). Both the NOAA JPSS VIIRS SDR (order from NOAA CLASS) and the NASA VIIRS Characterization Support Team (VCST) JPSS VIIRS L1B (order from NASA LandSIPS) datasets contain the well calibrated NOAA-20 VIIRS RSB reflectances. To further improve the calibration consistency and stability, NOAA is currently reprocessing the NOAA-20 VIIRS record from the beginning of the mission using the latest advanced algorithms (Cao et al., 2021), and the reprocessed data should be available in a few months. NASA has already reprocessed the NOAA-20 VIIRS record versioned as Collection 2. Users can choose either dataset as a matter of convenience.

Users should order the latest version of data. This especially relevant after a major onboard calibration event to avoid calibration discontinuities in the record (none so far for NOAA-20 VIIRS). No matter which dataset is ordered, it is very important to document in the journal article the NOAA-20 VIIRS L1B dataset source and version that is used in the inter-calibration study. This provides future traceability between the sensor intercomparisons in the midst of sensor recalibration efforts



lunar observatory (GIRO version 1.0.0) adjusted observed lunar irradiances. (courtesy of the NOAA VIIRS SDR team)

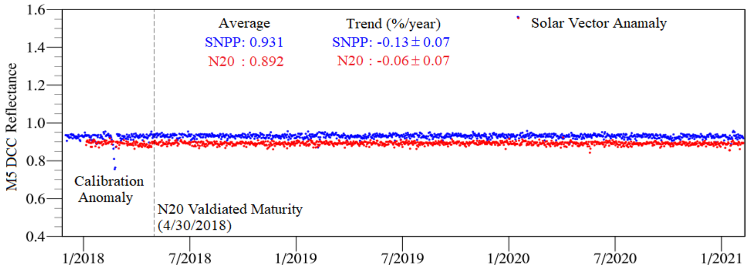


Figure 2. The daily DCC reflectance response for SNPP and NOAA-20 VIIRS M5 band. Note that after April 30, 2018, the NOAA-20 VIIRS SDSM sun transmittance screen function was recharacterized with onboard measurements. (courtesy of the NOAA VIIRS SDR team)

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Performance of the CrIS instruments as a GSICS IR reference

By Flavio Iturbide-Sanchez (NOAA), Zhipeng (Ben) Wang (UMD) and Kun Zhang (Global Science and Technology, Inc)

The Cross-Track Infrared Sounder (CrIS) on-board the NOAA’s Joint Polar Satellite System (JPSS) series of satellites is a Fourier transform spectrometer based on the Michelson interferometer configuration. Two CrIS instruments have successfully operated on the Suomi National Polar-Orbiting Partnership (S-NPP) satellite since October 28, 2011 and NOAA-20 satellite since November 18, 2017, respectively. Both satellites fly on nearly sun-synchronous polar orbits at an ascending node equator crossing time of 13:30 PM locally with a separation phase of 180 degrees. CrIS has three spectral bands: long-wave infrared (LWIR), middle-wave infrared (MWIR), and short-wave infrared (SWIR). The key design specifications of these bands can be found in Table 1 [1]. With a scan mirror rotating in cross-track direction, CrIS scans a 2,200 kilometer swath width, collecting Earth scene (ES) radiance spectra at a spatial resolution of 14 km at nadir and spectral resolution of 0.625 cm^{-1} when operating at its full spectral resolution (FSR) mode. The operational CrIS Sensor Data Record (SDR) radiance products have been generated from the instrument down-streamed Raw Data Record (RDR) since April 2, 2012 from the JPSS Interface Data Processing Segment (IDPS).

Band	Spectral range (cm ^{1})	Spectral resolution (cm ^{1})	NEdN (mW/m^2/sr/cm ^{1})	Radiometric Accuracy @ 287 K (%)	Spectral Accuracy (ppm)
LWIR	650-1095	0.625	0.15-0.45	0.45	10
MWIR	1210-1750	0.625	0.045-0.055	0.58	10
SWIR	2155-2550	0.625	0.006-0.007	0.77	10

Table 1: CrIS spectral band specification

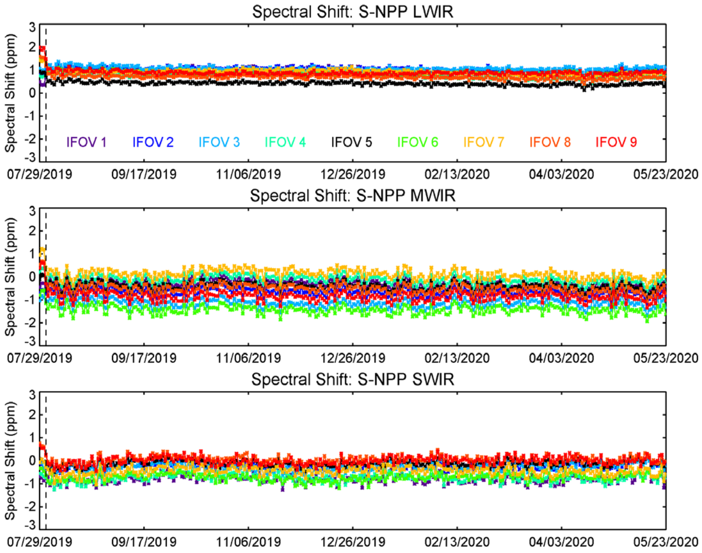

Figure 1. Year-long spectral shift trending demonstrating the accuracy and stability for the operational S-NPP CrIS SDRs.

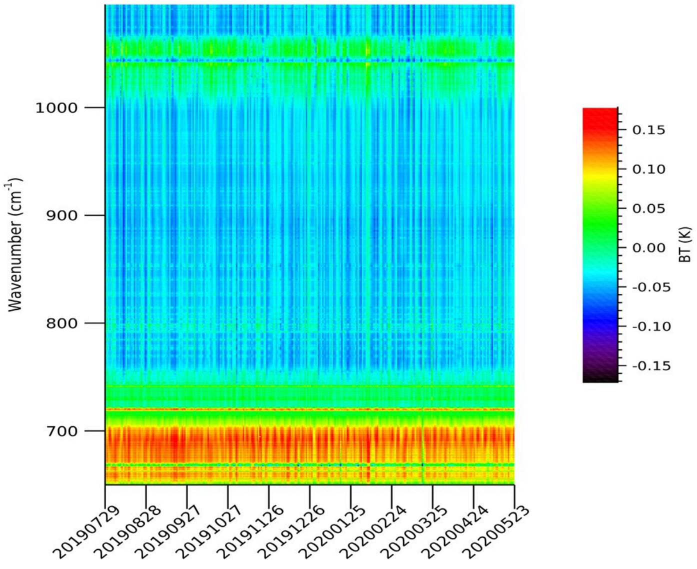

Figure 2. Long-term radiometric consistency of the operational CrIS SDR radiances between NOAA-20 and S-NPP for LWIR band.

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The CrIS SDR is calibrated on-board radiometrically, spectrally and spatially with stringent calibration requirements, part of which are provided in Table 1. The actual performance of both CrIS instruments has consistently exceeded the requirements. Therefore, they have been chosen by the Global Space-based Inter-Calibration System (GSICS) operational community as two of the IR calibration reference sensors in cross-sensor calibration and calibration inter- comparisons. The health of the CrIS instrument has been constantly monitored and the performance of the CrIS SDR has been regularly assessed by the CrIS SDR science team.

Date	Description
April 11, 2012	Update of the processing calibration coefficients
February 20, 2014	Updates of non-linearity coefficients and instrument line shape parameters
December 4, 2014	Transition to full spectral interferogram mode for RDR
March 8, 2017	
April 10, 2017	Update in calibration equation and CrIS SDR FOV remapping
October 2, 2018	Implementation of the spike detection and correction, which was turned off in December 2018 due to undesired false alarm)
December 17, 2018	Implementation of the lunar intrusion detection
June 24, 2019	Update of calibration coefficients in EP
January 29, 2020	Implementation of the polarization correction

Table 2: Major updates on calibration algorithms and coefficients.

As an example, the absolute spectral error is derived from comparisons. between the spectral radiance of the CrIS SDR against CRTM model simulations. Figure 1 shows the spectral accuracy and stability for the operational S-NPP CrIS SDR from July 29, 2019 to May 23, 2020. The third CrIS is scheduled to launch with the JPSS-2 satellite around September 2022. Results from the pre-launch characterization of the JPSS-2 CrIS have demonstrated that the instrument meets the design requirements and is ready for spacecraft integration. The fourth CrIS is currently under its pre-launch Thermal-Vacuum (TVAC) testing.

Recently, the CrIS SDRs have been reprocessed at NOAA/NESDIS/STAR for both S-NPP and NOAA-20 missions with consistent and optimized calibration algorithm and coefficients. This is in contrast to the operational SDR, which has seen multiple updates in processing algorithms and coefficients as knowledge about the instruments improves, as is summarized in Table 2. The comprehensive assessment of the quality of the baseline versions of the reprocessed CrIS S DR has been reported [2]. The assessment of the second version of the reprocessed CrIS SDR data is in progress. Preliminary results show improved accuracy and stability in the radiometric, spectral and spatial domains as expected, including a life-cycle spectral stability of approximately 1 ppm, much better than the 10 ppm requirement [3]. The version 2 represents an enhancement with respect to the baseline reprocessed version, which has been extended to CrIS observations at FSR to both the S-NPP and NOAA-20 CrIS observations. The assessment includes the period between March 26, 2019 and June 24, 2019 during which the S-NPP CrIS experienced a MWIR failure that stopped the production of operational CrIS SDRs. The reprocessed SDR is scheduled be publicly available to the user community in late 2021, through NOAA's Comprehensive Large Array-data Stewardship System (CLASS).In the radiometric domain, Figure 2 shows the long-term radiometric consistency between NOAA-20 and S-NPP CrIS operational SDR radiances for the LWIR band. The radiometric comparisons between the CrIS instruments rely on the daily averaged CRTM simulations over clear-sky scenes and ocean surface in the globe serving as a stable transfer target used in the double difference method. Using the operational CrIS SDR products over two years and half period, the long-term radiometric consistency of all IR channels was quantified with the radiometric differences within ±0.1 K on average. The CrIS calibration updates since 2018 were also verified to have positive radiometric impact and show stable performance as expected in the operational environments. In particular, the calibration updates related to the S-NPP side switch made the S-NPP CrIS radiometric performance consistent with NOAA-20 CrIS for all three bands before and after the side switch. The quantified radiometric differences can be used as the bridge to transfer the accuracy between the two instruments. A dedicated manuscript is being prepared to report the restoration and recalibration of the SNPP CrIS sensor after the anomaly found in the MWIR band. The overall assessment has shown that the SNPP CrIS SDR product meets the JPSS requirements and show quality continuity before and after the instrument was commissioned to operate under redundant electronics. Overall, the consistency of CrIS SDR products has been excellent and is expected to further extend into next

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decade, which is critical to its role as a reference for various inter-calibration and climate applications.

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IASI radiometric noise assessment based on Earth views

By Carmine Serio, Guido Masiello, and Pietro Mastro (SI-Unibas, Italy)

The IASI (Infrared Atmospheric Sounder Interferometer) radiometric noise has been recently assessed based on a new methodology that directly uses the Earth emitted spectral radiance observed from the orbiting instrument in space. The radiometric noise is an essential ingredient of the calibration of a given spectral device. It is usually assessed through the calibration unit with the sensor looking at blackbody targets of known temperature. However, once in orbit, a given instrument is looking at Earth-scenes, which do not have temperature such as that of the blackbody source. Besides, radiation is absorbed by the atmosphere in a way that depends on the wavenumber. The integrated radiation at the top-of-atmosphere can be thought of as emission from a continuum range of temperature. Therefore, it is desirable to check if there are noise-dependencies on the Earth views. Also, in the short-wave range, reflected solar radiation adds other signals within the Field of View, increasing the shot or photon noise.

IASI has been developed in France by CNES and is flying onboard the MetOp (Meteorological Operational) platforms. These are satellites of the EUMETSAT European Polar System (EPS). The instrument has a spectral coverage extending from 645 to 2760 cm^{-1}, with a sampling interval $\Delta\sigma$=0.25 cm^{-1} providing 8461 data points or channels for every single spectrum. IASI is a cross-track scanner with 30 adjacent Field of Regard (FOR) per scan, spanning an angular range of $\pm$ 48.33° on either side of nadir. Each FOR consists of a 2 × 2 matrix of so-called instantaneous fields of view (IFOV).

The technique we have developed computes the spectral residual *Observations- Calculation* $(O - C)$ from a set of observed spectra, and related calculations, and the covariance matrix, $\boldsymbol{S}_\varepsilon$ is computed considering ensemble variances and covariances of the spectral residuals. In principle, C can be obtained in many ways. One obvious way is to use a forward model with the atmospheric state vector obtained through a fitting procedure, e.g., Optimal Estimation. This approach has been used in [1], but it has the potential disadvantage of relying on a forward model, introducing an unknown source of errors, e.g., extra bias. The latest approach [2,3] we have developed consists of first projecting the data into an orthogonal basis (PCA). Second, back projecting the data to the physical space through a suitable truncated expansion, which can be thought of as a reconstruction or representation of the *signal* or *S*.

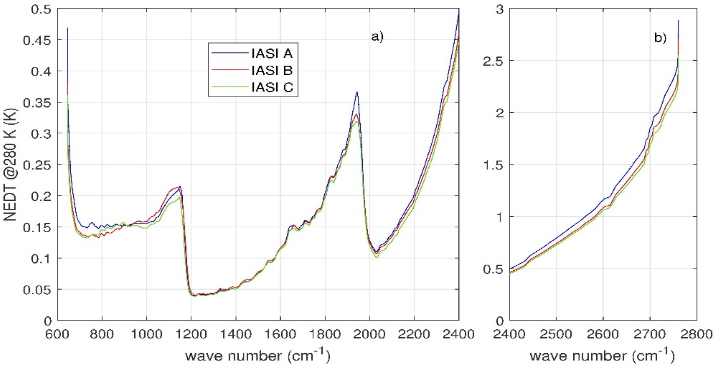

Figure 1. IASI radiometric noise (NEDT) for three instruments flying onboard the Metop Satellites. The IASI spectral coverage has been divided into two intervals a) 645 to 2400 cm^{-1} and b) 2400 to 2760 cm^{-1} for better reading.

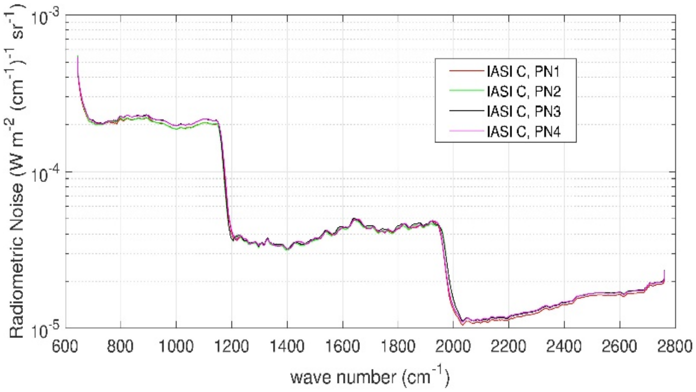

Figure 2. IASI radiometric noise (NEDR) for the four IASI C pixels, as assessed directly from Earth view observations

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Finally, it obtains the spectral residual according to $O - S$, where now S plays the role of C. A crucial point in this approach is to choose the optimal number, say τ, of PC scores to represent the s*igna*l, whereas the remaining $N - \tau$ are left for the noise. For the optimal selection of τ we use the Bayesian Information Approach or BIC, which has been developed in [4] to estimate the dimension of a model. The methodology has been used to assess the radiometric noise of the three IASI interferometers today in space, namely IASI A-B-C. Representative, averaged, results are shown in Fig. 1 in terms of NEDT at T=280 K and have been obtained by averaging over the four IASI pixels or detectors and different scene conditions. In fact, the analysis (e.g., [2,3]) has considered a time span of one year (2016 for IASI A,B and 2020 for IASI C) and a variety of scenes, including clear sky alone, overcast conditions alone, and IFOVs with fractional cloud coverage ≤ 1. It is possible to see that the radiometric noise figures do not heavily depend on the instrument. We have also found that the radiometric noise has no strong dependence on the scene, apart from cases, such as sun-glint, desert regions, which have a high reflectivity to sun radiation in the IASI band 3.

In general, the analysis shown in Fig. 1 compares well to the radiometric noise assessed through in-flight blackbody calibration [2,3]. We have found that IASI is stable in its spectral and radiometric characteristics. No considerable drift has been evidenced during the years in the radiometric noise (e.g., see Fig. 15 in ref. [2]), making it an excellent candidate to be used as a standard or in-orbit reference, as in fact, GSICS does. Our analysis has shown that IASI meets the specifications and requirements issued by the IASI Sounder Science Working Group (ISSWG), especially in band 2 where its performance is by far better than expected.

However, it is worth mentioning that the radiometric noise can degrade in the interval 600 to 900 cm^{-1} because of ice contamination of the entrance window, which seals the detectors' cold box (e.g., see Fig. 16 and Fig. 17 in ref. [2]). However, de-icing operations are regularly established by CNES, which reset the nominal conditions. Another significant result from our analysis is the excellent independence of NEDT on the pixel or detector. For IASI C, this is exemplified in Fig. 2.

It also has to be stressed that IASI is Gaussian apodized, which means that nearby channels are correlated. This correlation is shift-invariant, i.e., it does not depend on the wavenumber and, for a given channel, it drops symmetrically to zero after three wavenumbers. However, our analysis is capable of estimating the full covariance matrix, $\boldsymbol{S}_{\varepsilon}$ and we have also evidenced extra-correlation, which is likely due to micro-vibrations. The problem can become higher at merging of the IASI bands, as shown in [3].

In conclusion, the methodology we have developed can be used for any high spectral resolution infrared sensors, and does not need any forward model and can be used on a routine basis to check the stability of the radiometric noise.

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Status of the Atmospheric Infrared Sounder on the EOS Aqua Spacecraft

By Thomas Pagano, Hartmut Aumann, Steven Broberg, Evan Manning and William Mathews (JPL)

The Atmospheric Infrared Sounder (AIRS) is a "facility" instrument developed by NASA as an experimental demonstration of advanced technology for remote sensing and the benefits of high-resolution infrared spectra to science investigations [1]. It was launched into polar orbit on May 4, 2002 on the EOS Aqua Spacecraft, and is expected to provide data until 2025. AIRS has 2378 infrared channels ranging from 3.7 mm to 15.4 mm and a 13.5 km footprint. The AIRS data are used for weather forecasting, climate process studies and validating climate models [2]. For more information see http://airs.jpl.nasa.gov. AIRS is a vital IR reference sensor for GSICS and is used by JMA for comparison to Himawari 8/9 AHI [3], KMA for comparison to COMS [4], NOAA for comparison to CRIS [5] and GOES [6], and EUMETSAT for comparison to IASI [7].

AIRS and Aqua Operations Status

AIRS instrument health remains excellent. It collects science data continuously except for short interruptions for spacecraft maneuvers, MODIS calibration rolls, and AIRS detector calibration tests, all of which occur about once a month. AIRS has never had to switch to redundant electronics. Since 2003 there have been seven instrument and spacecraft anomalies that have interrupted AIRS operations, most recently an event that caused data corruption in Aqua's science data collection module. All anomaly responses to date have successfully restored nominal science data flow. Details on anomalies and data outages can be found here: https://airs.jpl.nasa.gov/data/outages/. The Aqua spacecraft remains in good condition but is running low on fuel. Aqua is expected to exit the A-train in early 2022 where it will continue the high inclination polar orbit and normal operations of all the instrument, but with a mean local time that will drift to later in the afternoon through 2025 when the drift leads to insufficient solar illumination to provide power to operate the entire spacecraft and instruments.

AIRS Channel Health

Long-term exposure to radiation and/or high-energy particle impacts can cause detectors suddenly to change their noise characteristics. Some affected detectors recover in a few days, weeks, or months; but for others the change persists. In most cases the detector remains useful, especially for climate studies involving averages of large amounts of data. The 274 photoconductive channels on AIRS (λ > 13.7μm) are essentially immune to this problem. The remaining 2104 photovoltaic channels each have two detectors whose outputs are combined on board and transmitted as a weighted sum. The weights are specified in an uploadable table, and an affected channel can often be recovered or improved by changing the weight table to cause the offending detector to be ignored. Figure 1 shows the count of AIRS low-noise (i.e., healthy) channels (those with a Noise Equivalent delta Temperature [NEdT] < 1 K) throughout the mission. The improvements in early 2012, early 2015, and late 2019 are due to weight table uploads to the spacecraft. After the most recent upload, AIRS has approximately as many healthy channels as it had near the start of the mission.

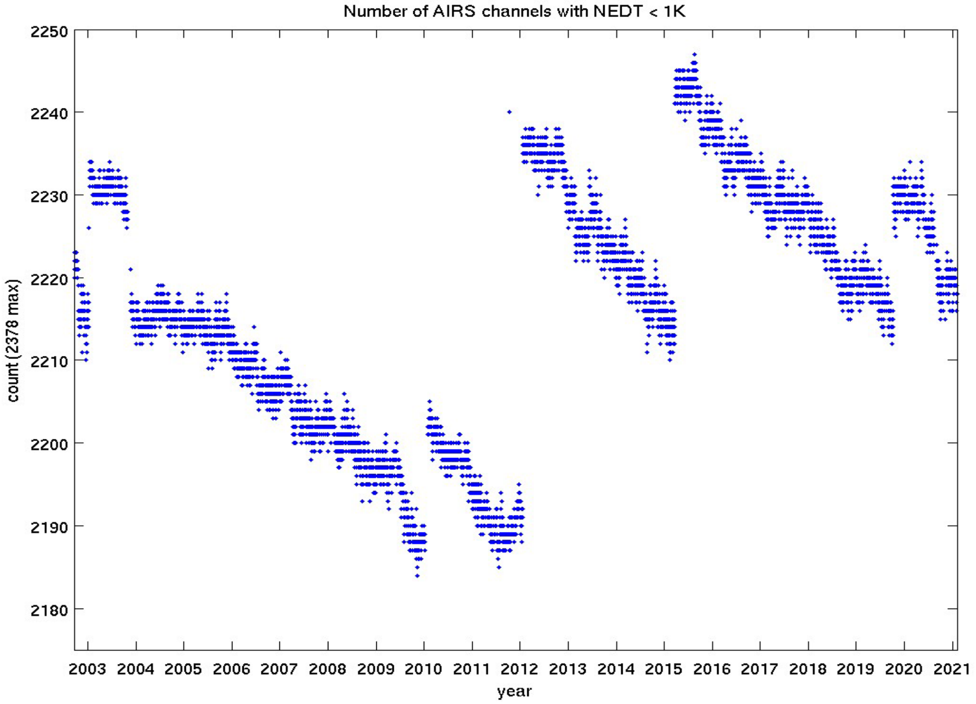

Figure 1. Count of AIRS low-noise (healthy) channels vs time.

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AIRS Radiometric Uncertainty (RU)

Comprehensive testing of the radiometric response of the AIRS instrument was performed preflight and with onboard calibrators during the mission. An assessment of the RU of the AIRS Level 1B Version 5 data products was made using the preflight test data, viewing highly accurate blackbodies, and the in-flight data acquired using the onboard calibrator blackbody and space views during the mission. Figure 2 shows the resulting median RU for all channels (RSS Total) in each of the 17 modules of AIRS (plotted at the center wavelength for the module). The total is computed as the RSS of uncertainties in the radiances due to the uncertainty in the individual contributors to the calibration equation. The results include trends observed using SST comparisons (included in the emissivity uncertainty) and uncertainties derived from L/R asymmetries viewing Deep Convective Clouds (included in the mirror polarization uncertainty). Results are shown at 260K but have a significant wavelength dependence, and are larger at colder scene temperatures, [8].

AIRS Radiometric Stability

The radiometric stability of the AIRS Level 1B Version 5 data product has been evaluated by comparing the observed brightness temperatures between 2002 and 2018 under clear ocean conditions relative to calculated brightness temperatures based on the NOAA SST products and the ECMWF Interim reanalysis [9, 10]. Although this cannot be done for all channels, the evaluation indicates that many AIRS channels are stable to better than 0.02K to 0.03K per decade, well below climate trend levels. The effects of scattering due to scan mirror contamination are evident at extremely cold temperatures.

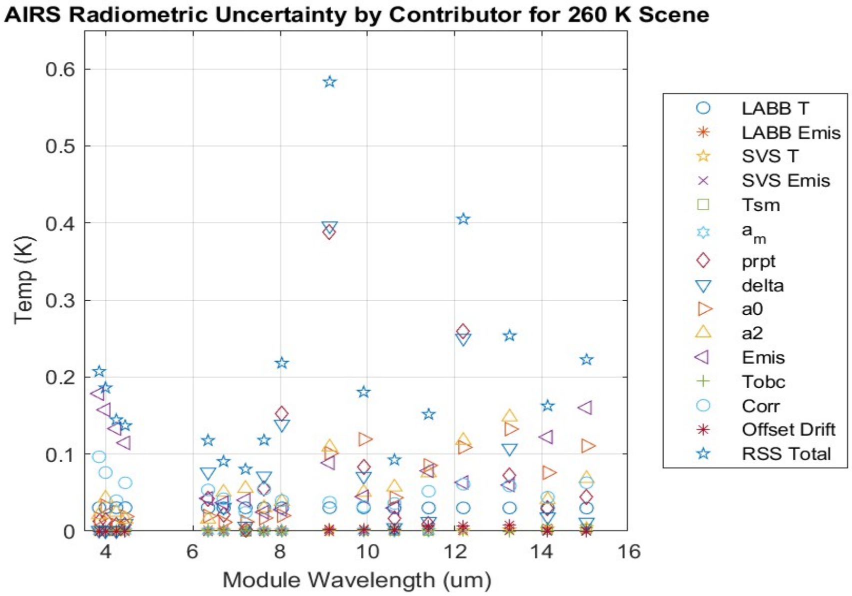

Figure 2. AIRS RU for the Version 5 Level 1B product

AIRS Spectral Response and Level 1C

The AIRS project released Version 6.7 of the AIRS L1C data product in March of 2020. The Level 1C product is recommended for comparisons of radiance with other instruments and for use in most science applications. The AIRS Level 1C product consists of calibrated and corrected radiances which have been processed beyond Level 1B to correct for select AIRS instrument characteristics, including the elimination of spectral gaps, spectral overlaps, co-registration errors in the presence of high spatial contrast, and small shifts in instrument channel center frequencies. Details are provided in the AIRS L1C ATBD. The AIRS Level 1C V6.7 product is generated using V5.0 of the AIRS L1B product and is available with documentation at NASA's Goddard Earth Sciences Data and Information Services Center (https://disc.gsfc.nasa.gov).

AIRS Version 7

A new version of the AIRS Level 2 data product (which includes temperature and water vapor profiles, composition products and cloud products) was released to the public in July of 2020. Major improvements include: 1) an improved Stochastic Cloud Clearing Neural Network (SCCNN) used as a first guess; 2) removal of ambiguity in surface classification in the infrared-only (IR-only) retrieval algorithm; 3) algorithm improvements that lead to better ozone, water vapor, and temperature products. Release of Version 7 of the AIRS Level 1B. The new version of L1C will make adjustments to compensate for temporal changes in the channel center frequencies and will include minor changes in the calibration, QC, and will be in NetCDF format.

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Reference Microwave Sounder Instruments for FCDR Development

By Cheng-Zhi Zou (NOAA), Hui Xu (UMD), and Xianjun Hao (GMU)

Defining reference satellite measurements would involve different criteria for weather and climate studies. Measurement requirements for weather studies address absolute accuracy where measurements with an absolute accuracy better than 0.1 K are high enough for data assimilations in numerical weather predictions (NWPs) without a bias correction. In contrast, measurement requirements for climate change detection and development of fundamental climate data records (FCDRs) address long-term consistency and measurement stability. Unless biases are absolutely zero, small but unstable biases may result in long-term non-climate trends that are comparable in magnitudes to the real climate trend signals. For instance, small biases changing within the range of ±0.1K in a decade can lead to a bias trend of 0.2K/decade. This is comparable to or even larger than magnitudes of the observed global surface temperature trends and is thus unacceptable. As such, high radiometric stability would be the primary requirement for climate change detection and for selecting reference satellites for inter-calibrating other satellites in FCDR development. The required measurement stabilities for reliably detecting climate trends are 0.04K/decade for the tropospheric temperatures and 0.08K/decade for the stratospheric temperatures, respectively (Ohring et al. 2005, 2014).

Zou et al. (2018) compared long-term time series of brightness temperatures between the Advanced Technology Microwave Sounder (ATMS) observations onboard Suomi National Polar-orbiting Partnership (S-NPP) satellite and the Advanced Microwave Sounding Unit-A (AMSU-A) observations onboard Aqua and MetOp-A satellites and suggested that most ATMS and AMSU-A channels on these satellites had achieved a high radiometric stability within 0.04 K/Decade. Such a quantitative assessment could be made possible because the three satellites were in stable sun-synchronic orbits. Diurnal drifting errors do not exist in satellite observations on stable orbits and thus inter-satellite differences only represent calibration drifting errors. Figure 1 gives an example on the comparisons between the MetOp-A AMSU-A channel 9 and S-NPP ATMS channel 10 observations. These two channels measure the same layer of the lower-stratospheric temperatures with exactly the same channel frequencies. As seen, the long-term trend difference in global mean brightness temperatures between the two channels is only -0.02K/decade, much better than the required measurement stability for the stratospheric temperatures. Due to the high radiometric stability performance, both ATMS and MetOp-A can be used as references for inter-calibrating other satellites for FCDR development.

As an example, here we demonstrate how MetOp-A is used as a reference to recalibrate AMSU-A observations onboard NOAA-15, which has been operational for more than 20 years and overlaps with MetOp-A for more than 13 years. Figure 2 shows inter-satellite difference time series between NOAA-15 and MetOp-A for AMSU-A channel 5, a channel being broadly used to detect mid-tropospheric temperature trends. Before recalibration, data quality problems in NOAA-15 manifested as a large seasonal variability in brightness temperatures relative to MetOp-A since 2013. The root cause for this seasonal variability is inaccurate calibration nonlinearity in NOAA-15 (Zou and Wang 2011).

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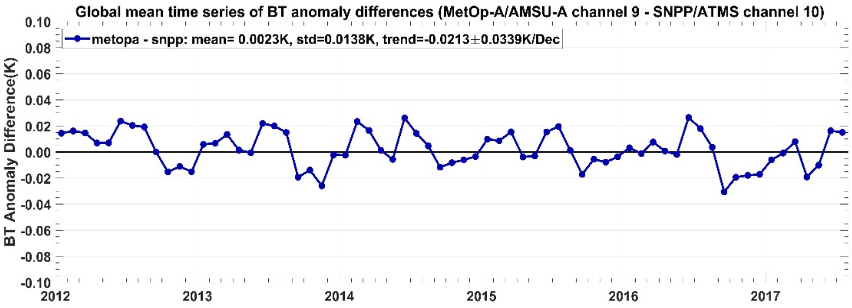

Figure 1: Monthly global mean anomaly difference time series of brightness temperatures between MetOp-A AMSU-A channel 9 and S-NPP ATMS channel 10. The MetOp-A orbit started to drift since August 2017, so only data before July 2017 were used in the comparison.

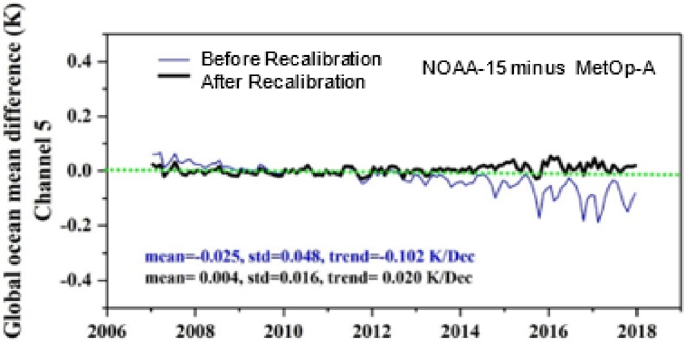

Figure 2: Monthly difference time series of global ocean mean brightness temperatures between NOAA-15 and MetOp-A during their overlapping period from January 2007 to December 2017 for before and after the recalibration of NOAA-15.

The Integrated Microwave Inter-Calibration Approach (IMICA, Zou and Wang 2011) was used to recalibrate NOAA-15 with MetOp-A as a reference. In this method, calibration coefficients in the instrument transfer equations for generating level-1c NOAA-15 radiances were obtained from regressions of simultaneous nadir overpass (SNO) matchups and satellite overlap observations over the global oceans between NOAA-15 and MetOp-A. Calibration offsets and nonlinear coefficients in NOAA-15 were allowed to change linearly with time to address its long-term trends and seasonal variability relative to MetOp-A. In contrast to pre-launch determined calibration coefficients which were instrument temperature dependent, the calibration coefficients obtained from SNOs do not depend on instrument temperatures and they are optimal in removing residual errors caused by inaccurate pre-launch calibrations (Zou and Wang 2011). The difference time series between NOAA-15 and MetOp-A after the recalibration is also shown in Figure 2 for a comparison with that before recalibration. As seen, the recalibration significantly reduced the large seasonal variability and the long-term cold drift in NOAA-15 found before recalibration. The standard deviation and relative trend between NOAA-15 and MetOp-A for their 10-year global ocean mean differences were respectively 0.016 K and 0.02K/decade after recalibration, in contrast to 0.048 K and -0.10K/decade before the recalibration. These large improvements occurred because more accurate time-varying calibration coefficients were obtained using the overlap observations between MetOp-A and NOAA-15.

We have also recalibrated other channels of interest onboard NOAA-15, NOAA-18, and NOAA-19 using MetOp-A as a reference. These recalibrations generated a consistent radiance FCDR across AMSU-A and ATMS onboard multiple satellites spanning from 1998 to present. This FCDR is an update to the previous FCDR generated nearly ten years ago (Zou and Wang 2011). With this updated FCDR, more accurate atmospheric temperature data records are expected to be developed. Calibration coefficients for generating the updated FCDR will be published elsewhere. Once becoming more mature, the updated FCDR will be transitioned to NOAA data center for long-term archiving and distribution to the user community.

Disclaimer: The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official NOAA or U.S. Government position, policy, or decision.

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NEWS IN THIS QUARTER

Outcome of the Third Joint GSICS/IVOS Lunar Calibration Workshop

By S. Wagner (EUMETSAT), V. Mattioli (EUMETSAT), T. Stone (USGS), X. Hu (CMA) and X. Wu (NOAA).

The Third Joint GSICS/IVOS Lunar Calibration Workshop was originally planned to be hosted by EUMETSAT in Darmstadt, Germany, in November 2020. Because of the Covid-19 pandemic, the physical meeting was replaced by a series of web meetings. Despite the constraints, between 70 and 80 participants from Asia, Europe and the United States participated to the discussions. A total of 22 presentations over four days addressed most of the topics initially targeted by the workshop:

- Measurements and Moon observations: towards SI traceability
- Lunar calibration reference and model development
- Instrument monitoring using lunar calibration
- Thermal Infrared and microwave remote sensing and lunar observations
- Alternative applications of lunar observations, including geometric and MTF post-launch characterisation

Lunar measurements and SI-traceability

The inherent stability of the lunar reflectance properties and the predictability of the lunar brightness makes the Moon a calibration reference with a potential total uncertainty of less than 1% (k=2) [1], which fulfills the accuracy requirements for climate monitoring [2]. In order to tie the models to an absolute scale and to reduce their uncertainties, several projects are on-going to acquire SI-traceable lunar measurements. The status of Air-LUSI, ARCSTONE and Mauna Loa LUSI projects was presented and discussed during the workshop. Air-LUSI provides hyperspectral measurements of the Moon over a spectral interval of about [415,1000] nm from the NASA ER-2 high altitude aircraft. Those measurements eliminate a large part of the uncertainties related to the atmosphere. Instrument calibration is conducted before and after each flight, and a rigorous uncertainty budget has been developed. The demonstration flight campaign was a success and data will benefit the adjustment of lunar models on an absolute scale. This project is complemented by the Mauna-Loa LUSI project, led by NIST. It uses a similar measurement principle to the Air-LUSI project but from a ground site. Installation is foreseen in March 2021 for a period of 6 months (this date subsequently revised). Finally, NASA presented an update of the ARCSTONE project to measure lunar disk spectral reflectance from a 6U CubeSat. ARCSTONE would cover the full spectral range of interest for reflective solar bands ([350,2300] nm).

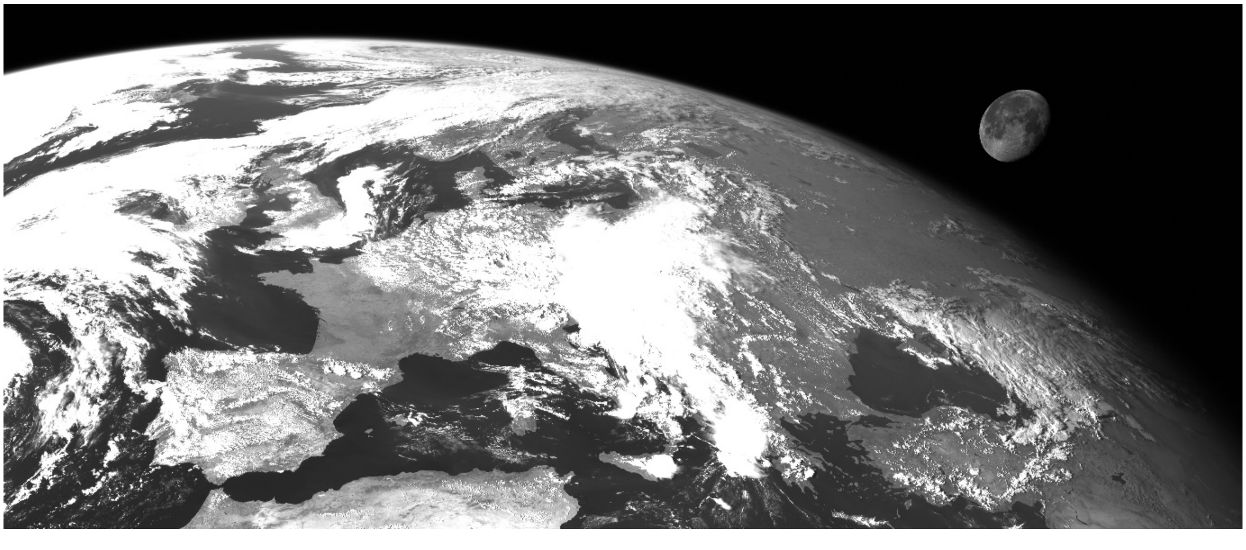

Figure 1 - An example of Moon acquisition in SEVIRI High Resolution Visible channel

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Lunar model development

Lunar models are inferred from repeated observations of the Moon over many years. This is for instance the case of the USGS ROLO model [3]. Most of those models estimate the total lunar irradiance. However, radiance models are also being developed, such as the model developed by AIST and JAXA from Kuguya Spectral Profiler (SP) data. During the workshop, more recent developments were discussed on the SP model and another three new irradiance models: SLIMED, LIME and LESSSR (for references see [4]). SLIMED is empirically tuned to blend observations from a variety of ground and satellite instruments. It is based on an iterative process to derive relative gains for each instrument band. LIME is based on measurements acquired with a Cimel aerosol photometer instrument at the Pico Teide in Tenerife. The model uses a similar parametrisation to the ROLO model, with some additional spectral dependencies. A large effort was done to ensure the SI-traceability of the sensors' calibration and to characterise the uncertainties. Finally, LESSR is a model inferred from both SCIAMACHY lunar measurements and RELAB reflectance spectra retrieved from the analysis of lunar soil samples. It allows a broader coverage of the solar spectrum, going from about 250nm to 2600nm. All those models, together with ROLO and GIRO, are taking part to an on-going inter-comparison exercise.

Instrument monitoring using lunar observations

This session addressed geostationary imagers and Low Earth Orbit Missions, including microsatellites. Detailed analysis such as that by RESTEC for GCOM-C showed the need for lunar models to address accurately phase and libration effects when the instruments observe the Moon under different geometrical and illumination conditions. On the other hand, an accurate determination of parameters needed to infer the observed lunar irradiance (such as oversampling factors, solid angles, deep space offsets, stray light artefacts) remains a key element when monitoring the absolute biases with respect to the models. The discussions echoed the recommendations made in the two previous GSICS/IVOS Lunar Calibration Workshops for inferring the observed lunar irradiance from the sensors' data.

Usage of the Moon for microwave and thermal infrared instruments

The workshop was also an opportunity to exchange information on microwave and thermal infrared lunar observations, and to discuss in particular i) lunar contamination correction methods for microwave imager and sounding instruments, ii) channel co-registration, pointing error identification, and antenna beamwidth characterization, iii) lunar disk-averaged microwave brightness temperature spectrum from satellite observations and model simulations, and iv) use of hyperspectral infrared measurements for mission monitoring and inter-calibration of infrared sensors. A proposal for future activities in the context of the GSICS and the microwave community has been prepared and shared with the Microwave subgroup of the GSICS Research Working Group. In the thermal infrared, CNES is investigating the use of lunar acquisitions by IASI to perform inter-calibration with other sensors and to have an additional means to monitor over time the instrument radiometric stability. CNES is also looking at possibly using such observations for absolute calibration.

Alternative usage of lunar imagery – Post launch assessment of co-registration and MTF

NOAA presented the status of their activities to monitor the on-orbit band-to-band registration and the modulation transfer functions for NOAA-20 VIIRS using regular lunar observations.

Finally, the initiative started in 2017 and led by NOAA to compare the methods to assess in orbit the instrument MTF using the Moon was recalled and is supported by the Lunar Calibration Community. NOAA has been encouraged to pursue this effort in collaboration with the participating agencies.

Conclusions

The presentations and discussions that took place during the four virtual sessions of this Lunar Calibration Workshop led to a series of actions and recommendations that are available in the meeting summary [4]. Despite the circumstances, the 3rd Joint GSICS/IVOS Lunar Calibration Workshop successfully brought together the members of the Lunar Calibration Community. It offered the possibility to share the latest progresses that the various agencies, organizations and institutes made in the field of lunar observations and measurements, lunar modelling, and instrument radiometric monitoring. Due to the Covid-19 pandemic, the organization of the next event was not discussed. However, there is a strong interest and motivation to continue with those community exchanges and collaborations. The Community is expanding, with a clear interest in pursuing coordinated efforts also in areas such as usage of lunar imagery in the thermal infrared and microwave domains.

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Announcements

2021 EUMETSAT Meteorological Satellite conference to be held virtually

By Tim Hewison, EUMETSAT

The 2021 EUMETSAT Meteorological Satellite Conference will take place virtually from 20 to 24 September.

EUMETSAT will be joined in the organisation and hosting of the event by the National Meteorological Administration, the national provider for weather and climate services in Romania.

The conference will cover the following topics

1. Status of meteorological satellite systems and future evolutions
2. First results from sentinel-6 Michael Freilich
3. How the new generations of satellites revolutionise weather forecasting: mtg & eps-sg user preparation
4. Impact of satellite data in global NWP (joint with ECMWF)
5. From agriculture to hydrology: the future of land applications
6. Marine meteorology from the tropics to the polar regions
7. Climate and greenhouse gases monitoring from space
8. Air quality from space: the contribution of satellite data
9. Evolving data services: are we ready for artificial intelligence and machine learning applications

For most updated information visit conference website https://www.eumetsat.int/eumetsat-meteorological-satellite-conference-2021

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Submitting Articles to the GSICS Quarterly Newsletter:

The GSICS Quarterly Press Crew is looking for short articles (800 to 900 words with one or two key, simple illustrations), especially related to calibration / validation capabilities and how they have been used to positively impact weather and climate products. Unsolicited articles may be submitted for consideration anytime, and if accepted, will be published in the next available newsletter issue after approval / editing. Please send articles to manik.bali@noaa.gov.

With Help from our friends:

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