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Image Above shows uses of Satellite measurements (Curtesy: NASA/NOAA)

Sea surface temperature (SST) based cross-calibration for satellite infrared data

By Yukio Kurihara (JMA), Hiroshi Murakami (JAXA/EORC), and Misako Kachi (JAXA/EORC)

The Japan Aerospace Exploration Agency (JAXA) produces Himawari-8 sea surface temperature (SST) products generated by using the data from the Advanced Himawari Imager (AHI) aboard the Himawari-8 satellite [1]. In addition to this, JAXA plans to produce SST products by using the data from the Second-Generation Global Imager (SGLI) aboard the Global Change Observation Mission-Climate (GCOM-C) satellite [2].

Himawari-8 SSTs are retrieved by using a newly introduced SST method, and the same method will be used for GCOM-C SSTs. The SST method, we call it the quasi-physical method, determines SSTs by solving a modified infrared (IR) radiative transfer equation [3]. The use of the same method aims to generate consistent SST data set. However, the existence of inconsistency is highly possible in Himawari-8 and GCOM-C SSTs for several reasons such as an issue with the satellite data calibration. Inconsistency in physically retrieved SST's in our opinion, should be improved by the adjustment of the original radiance data rather than empirical bias corrections by comparisons of determined SSTs. Because of this, we developed a new cross-calibration method by utilizing the quasi-physical SST method. The cross-calibration method uses satellite SSTs as the intermediate data between two different sensors. Because of this, the new method is expected to be effective to the improvement of the consistency in retrieved SSTs.

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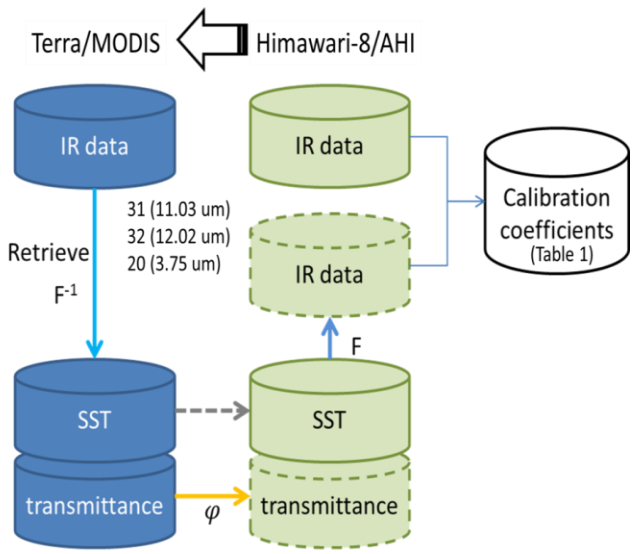

Fig. 1: Calibration coefficients are calculated by the comparison of simulated and observed satellite IR data. Simulation data is generated from the SST and transmittance data retrieved from Terra/MODIS data. F is the forward calculation derived by the simplification of the IR radiative transfer equation, and φ is an empirical function to translate the transmittance data to those for Himawari-8.

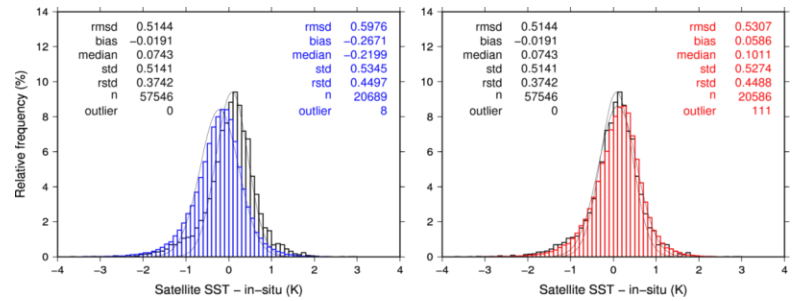

Fig. 2a: rmsd: the root mean square difference, std and rstd: the standard and robust standard deviation, n: the total number of the match-ups, and outlier: the total number of the satellite data >4 K out of buoy data.

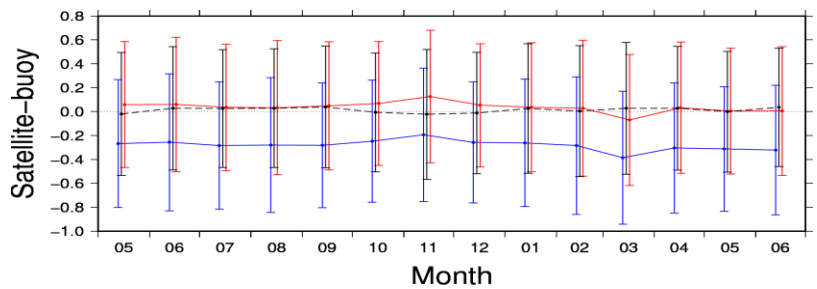

Fig. 2b: Monthly statistics variations

Fig. 2: Statistics against buoy data. Blue: original Himawari-8 SST, red: cross-calibrated Himawari-8 SST, and black: Terra/MODIS SST. Himawari-8 SSTs were determined by using the 10.4, 11.2 and 3.9 micron data (2a) and the 10.4, 11.2, and 8.6 micron data (2b).

The formula: $I'_\lambda = a_\lambda I_\lambda$ is used for the cross-calibration calculation. Here, λ is the central wavelength of each IR band. I'_λ and I_λ denote the calibrated and original IR radiance data, and a_λ is the calibration coefficient. The calibration coefficients are determined for each IR band by the comparison of observed and simulated satellite data. Fig. 1 shows a schematic diagram of the cross-calibration of Himawari-8 IR data. The Terra/MODIS L1 product Collection 6, which is provided by NASA, was used as the satellite data reference. To calculate reliable coefficients, we generated a huge amount of match-ups. The match-up window is 3 km and 10 min. Disagreements between observation angles are acceptable within 50 degrees because the transmittance is convertible to different observation angles by geometrical calculations. The threshold of 50 degrees is the maximum angle where the simulated data are unbiased. This threshold seems to be supported by stable quality of SSTs which is independent from the observation angles within the threshold; where, SSTs are determined by solving the same forward calculation. This flexible constraint on the agreement of observation angles is an advantage of the method. However, this threshold is so large that it needs to be verified carefully by using numerous samples. This verification is left for future. We used nighttime data because the 3.x micron data is available for SST determinations during nighttime and SSTs determined by using 3.x micron data are more accurate than those determined without using 3.x micron data. Table 1 shows the coefficients derived by using data for April 2016. We validated these coefficients indirectly by the comparison of the satellite SST and buoy data. We used buoy data provided by the in-situ SST quality monitor (iQuam) of NOAA [4]. Fig. 2a shows the relative frequency of differences between satellite SSTs and buoy data (satellite minus buoy) for May 2016. Blue and red show the statistics of the original and calibrated Himawari-8 SST, and black for Terra/MODIS SST. The result shows an improvement of the relative differences from ~0.25 K to <0.1 K by the cross-calibration. This is remarkable because this improvement is generated by the correction of only ~0.3 % of satellite data. We think this is a good example of sensitivity of satellite SSTs to the satellite data calibration. Furthermore, RMSE seems to be slightly improved by the calibration. This improvement may be a result of the improvement of the data calibration. However, the improvement is so small that we need further examinations to conclude this. Fig. 2b

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shows monthly variations of the statistics. The same calibration coefficients were used through the period. Mean differences are smaller than ~0.1 K between calibrated Himawari-8 and Terra/MODIS SSTs, and no characteristic seasonal variation is found. Differences of ~0.1 K are likely to be caused by issues with the SST method such as cloud contaminations and/or insufficient atmospheric corrections. These issues are more serious in Himawari-8 SSTs because of its wider observation coverage, and those influences on the derived cross-calibration coefficients need to be examined; however the examination is left for future.

As introduced above, we developed a new cross-calibration method which shows good capability for the improvement of consistency in satellite SSTs. However, the consistency in retrieved SSTs can differ from it in measured radiances because the range of the data used for the calibration is limited by the SST range. To examine this, comparisons of calibration results might be interesting. We are planning to introduce the current version of the cross-calibration method for the consistency in Himawari-8 and upcoming GCOM-C SSTs. However, there are still some issues such as the examination of influences of cloud contaminations. These issues will be examined for the next step. Lastly, it should be noted that the method never tells us the best-calibrated satellite data. To find well-calibrated reference data is another issue.

λ (μm)	a	R	N
10.4	0.10034E+0l	0.20963E-02	17785
11.2	0.10030E+0l	0.20764E-02	17785
12.4	0.99788E+00	0.38349E-02	17785
8.6	0.10054E+0l	0.61276E-02	17785
3.9	0.10117E+0l	0.77898E-04	17770

Table 1: Calibration coefficients for each Himawai-8/AHI band derived from the data for April 2016. λ: wavelength, a: coefficient, R: fitting residual, and N: the total number of match-ups. The calibration formula: $I'_\lambda = a_\lambda I_\lambda$ is used to calibrate data.

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[3] Y. Kurihara, H. Murakami, and M. Kachi, 2016: Sea surface temperature from the new Japanese geostationary meteorological Himawari-8 satellite. Geophys. Res. Letters. DOI: 10.1002/2015GL067159.

[4] NOAA: iQuam. https://www.star.nesdis.noaa.gov/sod/sst/iquam/index.html

Inter-calibration without simultaneous nadir observations

by Terhikki Manninen, and A. Riihelä, Finnish Meteorological Institute, A. Heidinger, NOAA, C. Schaaf, UMB, A. Lattanzio, EUMETSAT, J. Key, NOAA

A method for intercalibration of two satellite instruments is proposed that uses statistical fitting of reflectance data covering the same area during the same period, but not simultaneously.

A necessary condition for high quality long-term Climate Data Records (CDRs) derived from satellite remote sensing is an accurate intercalibration over long time scales (Chander et al., 2013). The data to be intercalibrated may be produced by one instrument type on several satellites or two different kinds of instruments with reasonably similar spectral channels. An established intercalibration method for two satellite instruments is the use of simultaneous nadir observations (SNO), which has been proven to be very effective over a wide spectral range (Chander et al., 2013). It requires reliable atmospheric correction and either SNOs or reliable bidirectional reflectance distribution factor (BRDF) estimates. Recently a new intercalibration method (Manninen et al., 2017) has been proposed that requires neither simultaneous retrievals, nor information about the surface or atmospheric properties in the images used. It is applicable to the whole range of viewing angles to be used.

The new method is based on comparing top of atmosphere (TOA) reflectance distributions of a large area covering the entire dynamic range of global TOA reflectance data. The assumption is that for a large enough statistical sample the reflectance distributions (with equal viewing-illumination geometry) should be equal, as the instruments are observing the same target. The data sets to be intercalibrated should be in the same resolution to provide similar dynamic range of the reflectance values. Hence, before carrying out the intercalibration one should average the higher spatial resolution data set to match the coarser spatial resolution. The TOA reflectance constant ranges of the angle triplets consisting of: sun zenith angle, satellite

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view angle and azimuth angle between the sun and satellite. The number of available individual bins (i.e. reflectance distributions) per instrument equals the number of different angle triplets existing in the whole data mass of images. In the intercalibration of two data sets, only those distributions are used for which the matching angle triplets exist for both data sets.

Each reflectance distribution is then described by its mean value <*R*> and the 8% and 98% quantiles, R_8 and R_{98} respectively, which are mostly related to the reflectances of ocean and snow (Figure 1). Including the clouds in the intercalibration provides a continuum of reflectance values starting from cloud-free ocean to cloud-free snow. These reflectance quantitates <*R*>, R_8 and R_{98} per angle triplet, based on all existing distributions, are then gathered as one total set of reflectance values per instrument. Linear regression is then sought for the two reflectance data sets to be intercalibrated (Figure). To pay due attention to the heteroskedastic character of the individual pixels, iteratively reweighted general Deming regression (IRGDR) is used (Manninen et al., 2017; Martin, 2000).

In order to check the validity of the method, it was first applied to several cases of two non-overlapping data sets from the same instruments, as then a 1:1 relationship should apply (Figure 2) Indeed, it turned out that the slopes of values of the images are binned in MODIS vs. MODIS and AVHRR vs. AVHRR cases were achievable with better than 0.5% accuracy.

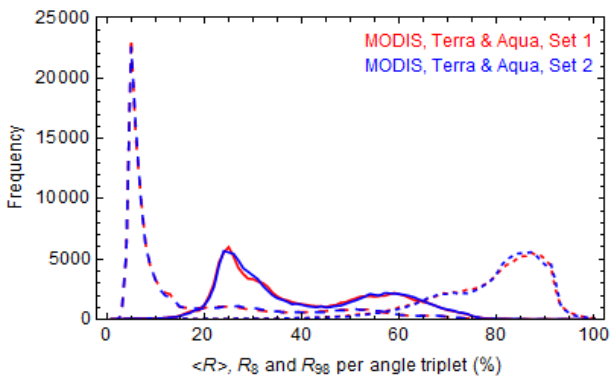

Figure 1. Variation range of the mean (solid curves) and 8 % (dashed curves) and 98 % quantile (dotted curves) values of the red channel TOA reflectance values of two non-overlapping data sets of MODIS Terra & Aqua covering the same area covering latitudes 0° N … 75° N and longitudes -130° E … 45° E and period June-July 2010. Chronologically every second MODIS image (granule) was taken in Set 1 and the rest in Set 2 (Manninen et al., 2017).

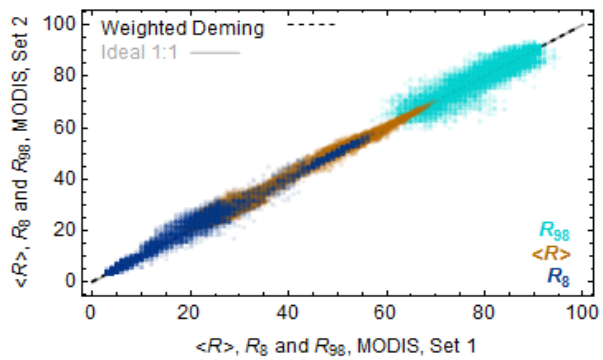

Figure 2. Regression of the mean and 8% and 98% quantile values of the red channel TOA reflectance values of the two non-overlapping data sets of MODIS Terra and Aqua of Figure 1. The ideal 1:1 relationship is shown for comparison to the iteratively reweighted general Deming regression. Only TOA reflectance distributions per angle triplets having at least 5000 points were included (Manninen et al., 2017).

The advantage of the presented method is the possibility of using the entire range of TOA reflectance values and sun/ satellite angles as the basis for the intercalibration without cloud masking. In addition, no assumption that the calibration derived for nadir viewing will apply also for other satellite angles is necessary. Hence, this method can be used as an additional test for the angular reliability of the SNO based calibration. If one is specifically interested in some special target type (such as vegetation or the ocean), one could make a dedicated calibration for that purpose using only related areas as the basis for the calibration.

Radiances instead of TOA reflectance values can be used, if all images are first normalized to a reference earth-sun distance (Manninen et al., 2017). In order to extend this method to completely non-overlapping temporal/spatial data sets of the past, some ancillary data to prove that the calibration sites have not been changed markedly during the time in question would be necessary. For the ocean and the central parts of some large ice sheets it might be useful to exploit such possibility.

Since the new intercalibration method does not need cloud masking or specific calibration sites and can be applied to all satellite view angles, it complements existing intercalibration methods and thus serves the GSICS objective to ensure quality and comparability of satellite measurements taken at different times and locations, by different instruments, operated by various satellite agencies.

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Inter-satellite radiometric calibration of cross-track scanning microwave radiometers in GPM constellation

by Hamideh Ebrahimi, University of Florida/ University of Central Florida Gainesville, FL

The Global Precipitation Measuring (GPM) mission is an international scientific collaboration to measure precipitation worldwide every three hours. The GPM Microwave Imager (GMI) is a conical scanning microwave radiometer with 13 channels ranging from 10 to 183 GHz. A major requirement of the GPM observatory is to provide a space-borne standard for collective precipitation measurements from the cooperative satellites in the constellation. Because of its 65° inclination low earth orbit, the GPM observatory provides frequent near-simultaneous collocations of brightness temperatures (Tb) between GMI and other satellite radiometers. The use of GMI as the calibration transfer standard enables a unified inter-satellite radiometric calibration (X-CAL) between all other GPM constellation passive microwave instruments.

Previous X-CAL work during the Tropical Rainfall Measuring Mission (TRMM) era involved of conical scanning radiometers below 100 GHz. Now in the GPM constellation, there is a combination of cross-track and conical scanning millimeter-wave sounders that must be cross-calibrated to provide consistent Tb's for precipitation measurements. For example, GMI and SSMIS on the Defense Meteorological Satellite Program (DMSP) are conical scanners; whereas cross-track scanners operate on most polar orbiting weather satellites, such as the Advanced Technology Microwave Sounder (ATMS) on board of NPP, AMSU and MHS on NOAA 18 & 19, METOP A & B and SAPHIR on Megha-Tropiques. These different scanning geometries involve new and different techniques to perform the X-CAL that account for the different slant path geometries through the atmosphere when comparing the different sensors.

There are several methods for inter satellite calibration which have been discussed in previous publications [1, 3]. Because the radiances for millimeter sounders come primarily from the atmosphere, there are different considerations than those used for the X-CAL of the lower frequency imaging channels. Often, GMI and cross-track scanners have near-identical viewing geometries (incidence angles) whereby direct Tb comparisons are possible. However for the majority of coincident observations, where the viewing geometries have different incidence angles, a transformation of Tb's to a common basis is required before inter-comparisons can be interpreted. Here the double difference (DD) technique [1], which was successfully applied for imager channel calibration, has been modified and applied to sounders. The purpose of this technique is to find a radiometric calibration bias from one radiometer to another. Having two independent radiometers (e.g., GMI and Sounder), we obtain the differences between the observed brightness temperatures, which are named observed single differences (OSD). Next, using a theoretical radiative transfer model, the modeled Tb values for the two instruments are subtracted to produce the modeled single differences (MSD). The difference of the single differences (double difference, DD) is calculated by subtracting the MSD from OSD as:

DD = (Tb_GMI_obs – Tb_Target_obs) – (Tb_GMI_mod – Tb_Target_mod)

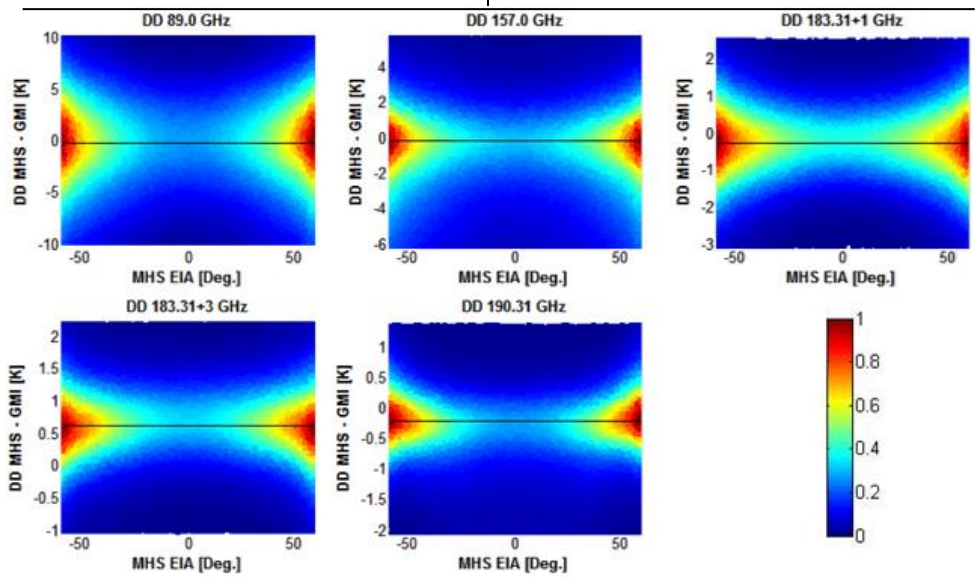

Figure 1: Double difference dependence on earth incidence angle for MHS on board of MetOp-B minus GMI for the corresponding five channels. The colours represent the normalized number of matchups.

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Concerning the geometry, there are major differences between crosstrack scanners and conical scanners. In conical scanning, the antenna is pointed off-nadir a fixed cone angle of incidence and the plane of incidence (containing the line-of-sight) is rotated about the nadir pointing axis, which results in a fixed constant: Earth incidence angle (EIA), fixed vertical and horizontal beam polarization, and a constant instantaneous field of view (IFOV) along a circular path on the surface. So, when comparing the Tbs with mixed polarization with the Tbs from the conical scanners, we need to calculate the Tbs with the mixed polarization from the Tbs with the vertical and horizontal polarizations. The quasi-vertical brightness temperature is calculated as:

$$T_{Qv} = T_v \cos^2(\alpha) + T_h \sin^2(\alpha)$$
$$T_{Qh} = T_h \cos^2(\alpha) + T_v \sin^2(\alpha) \quad ...(1)$$

where the scan angle, α, is related to the EIA as:

$$\alpha = \sin^{-1}\left(\frac{R_e}{R_e + H} * \sin(\pi - EIA)\right) \quad ..(2)$$

$R_e =$ 6,371 km is the Earth radius, and H is the satellite altitude in km. GMI which is a conical scanner, is the transfer standard in the GPM constellation, whereas most of satellites with sounder channels are cross-track scanners. The sensors that we have used here are SAPHIR on board of Mega-Tropiques, ATM on board of NPP, and four nearly identical MHS on the board of MetOp-A, MetOp-B, NOAA-18 and NOAA-19. These sensors with their frequencies bands have been displayed in Table 1. In the GPM constellation, the required consistency in the input brightness temperatures is accomplished by inter-calibrating the constellation radiometers using the GPM Microwave Imager (GMI) as the calibration reference. MHS radiometers, as part of GPM constellation, have been calibrated with GMI as well. It should be considered in the cross track scanners the polarization of the Tbs changes with the scan position that it's a mixture of vertical and horizontal polarizations. In Fig. 1, the double differences as a function of MHS EIAs are presented. From this figure, it is noticeable that the 89 GHz channel has the largest variations, and these decrease in the channels with higher frequencies. The average values of the biases are shown with solid black line; the averages are very small for all the channels, which show that MHS and GMI are in a good agreement. Also, the results of biases for the all the MHS sensors is presented in Table 2. Similar analysis have been conducted for the other cross track scanners in the constellation as well.

Table 1: Sounder channels pairing

Sensor	Sounder channel frequencies in GHz, ±n refers to 183.31 ± n									
SAPHIR (Cross Track, Inclined Orbit)				± 0.2	± 1.1		± 2.7	± 4.2	±6.8	± 11
MHS on METOPA, B NOAA18 and 19 (Cross Track, Polar)		89 V	157 V		± 1		± 3		190 V	
ATMS (Cross Track, Polar)	23.8 V	88.2 V	165.5 H		± 1	± 1.8	± 3.0	± 4.5	±7.0	
SSMIS on F17, F18, F19 (Conical, Polar)			150 H		± 1		± 3		±7.0	
GMI Freq. (Conical, Inclined)	23.8 V	89 V	166 H/ 166 V	± 3.0					±7.0	

Table 2: Brightness temperature biases in K between GMI and MHS sensors for 2015.

CHANNELS	89QV	157QV	183.31± 1.0QH	183.31± 3.0QH	183.31± 7.0QH
MetOp_A - GMI	0.43±2.20	-0.41±1.2	0.16±1.4	-0.31±0.57	-0.25±0.44
MetOp_B - GMI	0.38±1.17	-0.47±1.0	0.06±1.6	-0.35±0.56	0.22±0.43
NOAA18 - GMI	-0.04±1.25	-0.23±1.2	0.52±1.4	0.10±0.56	0.21±0.41
NOAA19 - GMI	-0.08±1.2	-0.48±1.1	0.26±1.5	-0.02±0.54	0.23±0.45

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Improved SNO analysis demonstrates the robust calibration of NOAA OC SDRs for SNPP VIIRS solar bands

by Mike Chu and Junqiang Sun (NOAA)

The inter-sensor comparison methodology has been a main staple of the calibration community to evaluate the performance of one satellite sensor against another. For SNPP VIIRS, which has been on orbit for more than six years since its launch on 21 October 2011, the evaluation of its radiometric performance has often been carried out against Aqua MODIS. The two sensors share many common elements, including numerous spectrally well-matched channels, nearly identical orbits, and a common calibration methodology. Early comparison studies have used the operational VIIRS sensor data records (SDRs) generated by the Interface Data Processing Segment (IDPS) or other version variants to evaluate against the Aqua MODIS Collection 6 (C6) release. However, the early efforts have largely not indicated the successful calibration of the SNPP VIIRS reflective solar bands (RSBs).

The recent independent effort of the NOAA Ocean Color (OC) Team has achieved a robust calibration of the RSBs for SNPP VIIRS. Beyond the milestone and the achievement of the subsequent ocean color product maturity, the improved and robust SDRs also help to clarify inter-sensor comparison studies. The rigorous calibration efforts have cleansed many anomalous features in the VIIRS RSB calibration results, and most importantly, mitigated the long-term radiometric drift emerging from a flaw in the standard calibration methodology (See, e.g., Sun and Wang 2015; Sun *et al.* 2016).

A follow-up study of inter-sensor comparison between SNPP VIIRS and Aqua MODIS has been carried out (Chu *et al.* 2018) to make a direct evaluation of the radiometric performance of OC SDRs as well as the IDPS SDRs. A strict one-pixel matching condition is imposed in a simultaneous nadir overpass (SNO) analysis over a small 36x36 km-square region centered at each nadir crossing. The comparison of the radiometric performance, the ratio of the radiance of Aqua MODIS over that for SNPP VIIRS, is computed at the pixel-level by using homogeneous sub-scenes within each comparison region. A bias over larger spatial scales and a nominal 2% scene-based variability are among the key issues identified. Constraints and selection filters, constructed based on data examination, are applied to generate robust time series that achieve a precision of 1% or better in the trend. Selected results are shown in Figure 1. The blue square symbols are the time series of the ratio of Aqua MODIS sensor radiance against the SDRs using the reprocessed look-up-tables (LUTs) generated by the OC Team, and the red star symbols are the time series of the ratio of the Aqua MODIS sensor radiance against the SDRs of the operational IDPS LUTs. The overall result clearly demonstrates the more stable performance of the OC SDRs. It can be seen that the OC-based time series achieve overall better agreement with Aqua MODIS, including the significant improvement in the early mission where IPDS SDRs show large discrepancy. Arguably the most important outcome is the long-term flatness of the time series, demonstrating that the mitigation has corrected the worsening long-term RSB calibration bias.

The lone exception is the time series of SNPP VIIRS M1 versus Aqua MODIS Band 8 (410 nm), in Figure 1a, that shows a downward drift of about 1% in the OC-based comparison time series. This means that the IDPS version of SNPP VIIRS M1 radiance is about 1% lower than that of the OC version. However, the source of the downward drift in the OC-based time series is eventually identified to come from Aqua MODIS Band 8, and the argument is presented as follows. Wu *et al.* (2014), using the Land PEATE version of the SNPP VIIRS SDRs, quantified a 1% downward drift in SNPP VIIRS M1 via the monitoring of Earth sites, yet in the same study their inter-sensor comparison with Aqua MODIS Band 8 resulted instead in a flat comparison time series. Central to resolving these inconsistencies is to note that the Land PEATE version, similar to the IDPS version, was not corrected for the long-term growing bias in RSB calibration mentioned earlier. Therefore, both the Land PEATE and the IDPS SDR versions for SNPP VIIRS M1 radiometry necessarily contain the same downward drift. The Wu *et al.* result can only be made consistent by concluding that while the Land PEATE version of SNPP VIIRS M1 demonstrates a 1% downward drift in Earth-target monitoring, Aqua MODIS Band 8 contains also a similar downward drift, thus resulting in a flat comparison time series with SNPP VIIRS M1. Because the IDPS SDR for SNPP VIIRS M1 has the same downward drift, its inter-sensor comparison with Aqua MODIS Band 8 will also demonstrate a near flat

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comparison time series. This is indeed seen in Figure 1a. On the other hand, since the OC SDRs have been mitigated for the worsening bias in RSB calibration, the OC version of SNPP VIIRS M1 radiometry correctly captures the ~1% downward drift in Aqua MODIS Band 8, as seen in Figure 1a. The Aqua MODIS Band 8 drift is estimated to be about 1.15% over the four-year period from 2012 to 2016.

This latest inter-sensor comparison using OC SDRs for SNPP VIIRS further strengthens the case that the OC SDRs for SNPP VIIRS RSBs are robust and appropriate for serious science studies and applications. The calibration result for the OC SDRs has been adopted into the SDR reprocessing (Choi *et al.* 2017, Sun and Wang 2017) that is to be released. And in an interesting twist, the inter-sensor comparison originally intending to demonstrate the radiometric performance of SNPP VIIRS has instead revealed a 1.15% downward drift in Aqua MODIS Band 8. Any future studies, including inter-sensor comparisons, referencing to Aqua MODIS Band 8 should be aware of this downward drift that seemingly started in 2013.

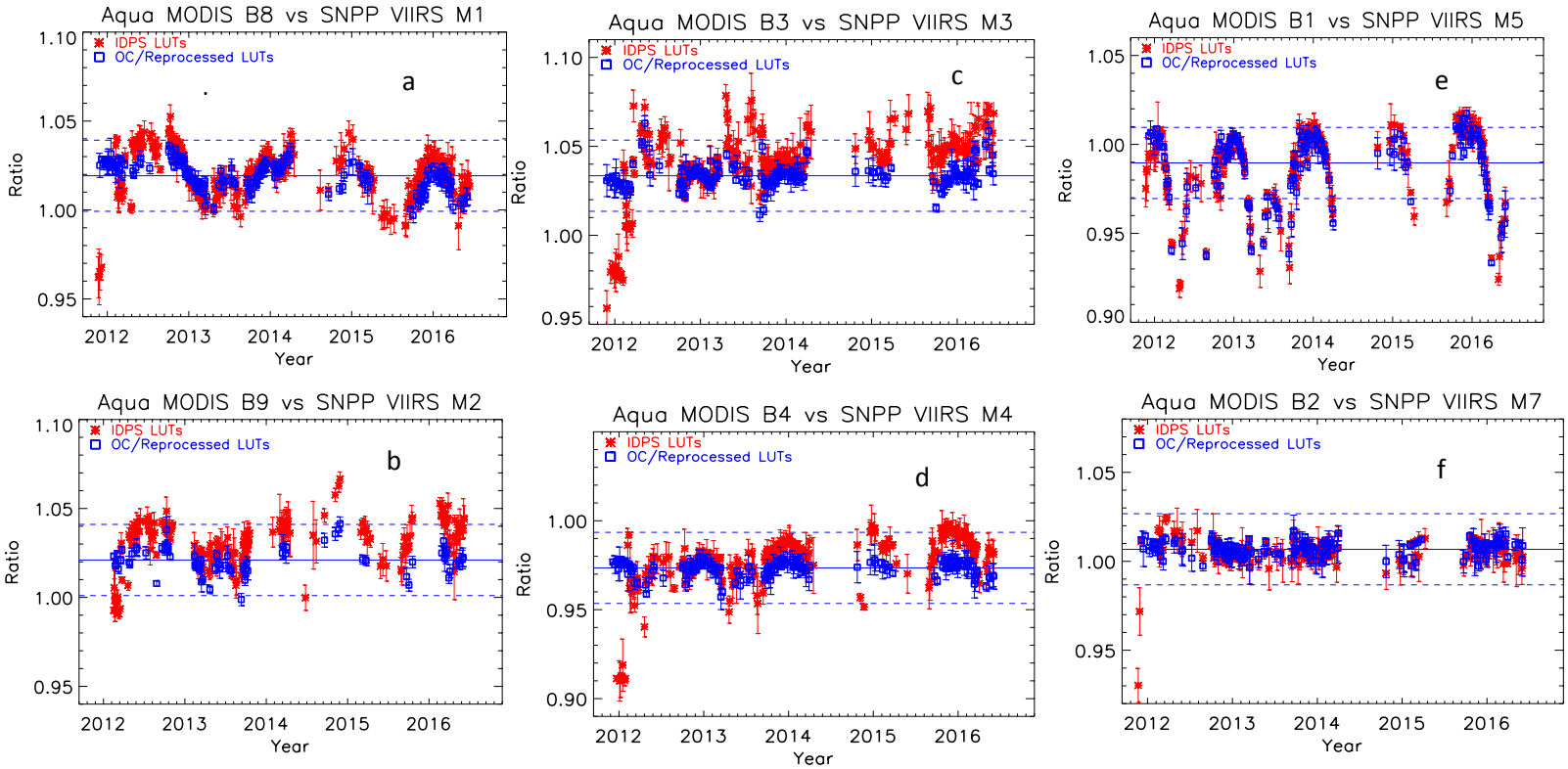

Figure 1: Selected inter-sensor comparison time series of Aqua MODIS versus SNPP VIIRS.

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Discuss the Article

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News in this Quarter

A New GOES-East

by Robert Iacovazzi, NOAA

GOES-16, the first of a new generation of Geostationary Operational Environmental Satellite R-series (GOES-R), became operational as GOES-EAST on December 18, 2017 at 75.2°W, providing the public and forecasters with sharper images in more bands and at faster pace to monitor severe storms, hurricanes, wildfires and other weather hazards twenty-four hours a day and seven-days a week in near real-time. An example of a GOES-16 image taken from the GOES-East location (represented in Figure 1) is provide in Figure 2 – A GOES-16 image taken on 21 February 2018 at 1730 UTC. GOES-16 imagery can be found in near-real time at https://www.star.nesdis.noaa.gov/GOES/index.php.

Since its launch in November 2016, NOAA's GOES-16, even in its testing stage, showed its potential to improve weather forecasts and brought new levels of situational awareness to forecasters, emergency managers, and the public. For example, "The GOES-16 satellite provided invaluable data on deadly hurricanes long before they touched the shore this season," said Secretary of Commerce Wilbur Ross. "GOES-16 has proven to be one of the most important tools we've ever developed for our weather and hazard forecasts," said retired Navy Rear Adm. Timothy Gallaudet, Ph.D., acting NOAA administrator. "From its impressive first image of Earth last January to monitoring tropical storms and wildfires, GOES-16 has and will continue to greatly improve our ability to visualize potential threats, and enhance forecasts and warnings to save lives and protect property." These game-changing attributes of the GOES-16 satellite are a result of the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM). The ABI has 3 times as many channels, 4 times better resolution, and 5 times faster scans than the legacy GOES-NOP instruments. In addition, besides a more advanced infrared channel calibration target, GOES-R ABI

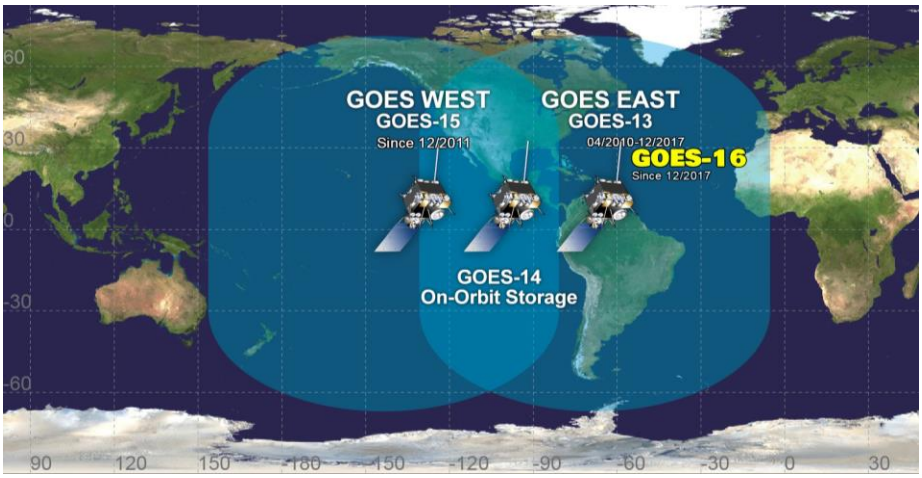

Figure 1: Illustration of GOES-WEST and GOES-EAST locations and coverage areas for GOES operational satellites

Figure 2 – A GOES-16 image taken on 21 February 2018 at 1730 UTC. GOES-16 imagery can be found in near-real time at https://www.star.nesdis.noaa.gov/GOES/index.php.

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instruments are equipped with a solar diffuser for the purpose of performing VNIR channel calibration. Meanwhile, the GLM makes its debut on a geostationary satellite on GOES-16, so it now occupies a new and unique position in the NOAA satellite observing network.

Data from GOES-16 has been available to NOAA forecasters and the national and international weather modeling and forecasting community during the satellite's testing phase and will continue to do so as it goes into operations. The next new NOAA satellite, GOES-S is scheduled to launch March 1, 2018 followed by GOES-T in 2020 and GOES-U in 2024. These satellites will enable NOAA to more closely monitor weather systems over North America, South America, and the Atlantic and Pacific Oceans, to help protect lives and property.

*Some article content condensed from a NOAA article published at http://www.noaa.gov/media-release/noaa-s-goes-16-now-at-goes-east-ready-to-improve-forecasts-even-more

Discuss the Article

GSICS and GRUAN Coordination

by Tony Reale (NOAA), Xavier Calbet (AEMET), Cheng-Zhi Zou (NOAA), Isaac Moradi (ESSICS, Univ. Maryland), Viju John (EUMETSAT), Dave Tobin (SSEC, Univ. Wisconsin, Madison) and Bomin Sun (NOAA, IMSG)

Introduction

The Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) (https://www.gruan.org/) is a reference observing network designed to provide long-term, climate quality data records from the surface, troposphere and stratosphere. GRUAN observations are calibrated through an unbroken traceability chain to SI or community standards and the uncertainty in each step in the chain is fully characterized, meaning the resulting estimates can be used with high confidence that the true measurement exists within the interval (Immler et al., 2010). Among the primary objectives of GRUAN is the constraining and calibration of data from other more spatially extensive observing systems such as space-based environmental satellites. In this context, two areas for coordination exist, one is for satellite derived geophysical product (*i.e.*, atmospheric sounding) cal/val (Reale *et.al.* 2015) the other is for satellite sensor monitoring (Tradowsky *et.al.* 2016). This second objective is strictly aligned with the GSICS program and beckons the question "is this feasible" and what would be the respective prognosis and strategy for assessing infra-red (IR) and microwave (MW) sensors. This was addressed at the 2017 (March) GSICS Annual Meeting resulting in two actions to provide a draft of uncertainty analysis and examples to monitor satellite microwave and infra-red instruments, respectively, using GRUAN observations. These actions were later concurred at the 9th GRUAN Implementation and Coordination Meeting (ICM-9) held in Helsinki, Finland in June (2017). The following article summarizes the ongoing coordination, prognosis and strategy for these actions.

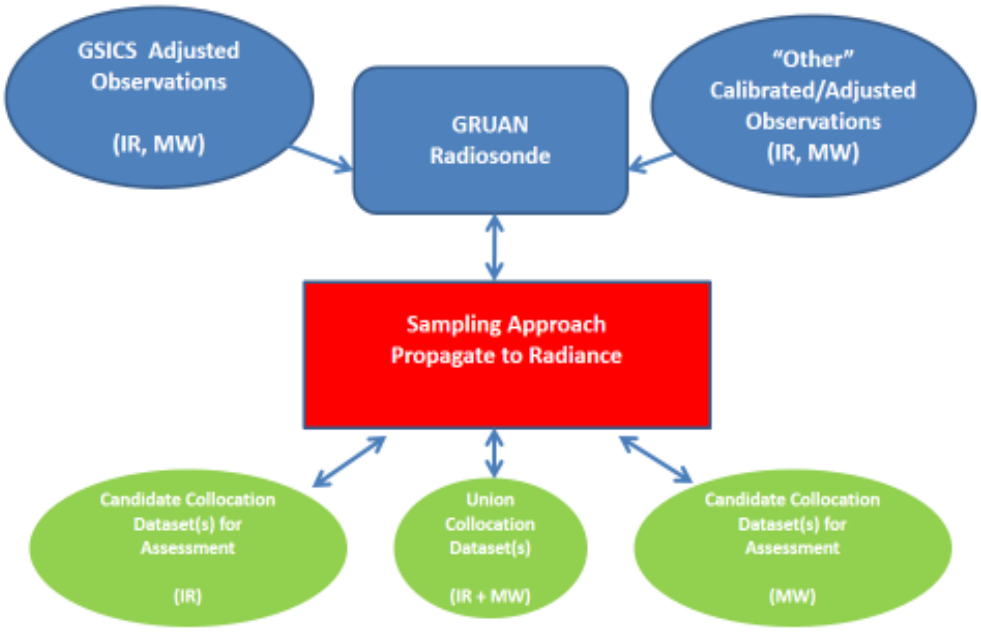

Figure 1: Proposed strategy to assess the suitability of GRUAN observations to monitor satellite sensors

Studies to use GRUAN radiosondes to assess IR and MW satellite sensor data are few. Calbet (2017), for example, used sets of Infrared Atmospheric Sounding Interferometer (IASI onboard MetOp-B) and radiosonde collocations from U.S. Department of Energy

(DOE) Atmospheric Radiation Measurement (ARM) sites at Manus and Nauru located in the Tropical Western Pacific where the synoptic launches are in proximity to MetOp satellite overpass. Using mismatch windows within 30 minutes and 25 km and selected "cloud free" scenes, approximately 20 candidates among the over 300 originally available collocations were identified. Globally, these numbers broaden to over 20,000 collocations with GRUAN observations since 2013, about 3000 within the tightened mismatch constraints and perhaps 500 that are suitably clear. Higher numbers could be expected for S-NPP for which the NOAA Joint Polar Satellite System (JPSS) Program has supported satellite synchronized radiosonde launches at U.S. Department of Energy (DOE) Atmospheric radiation measurement (ARM) sites since 2012. The targeting of radiosonde at satellite overpass is an emerging GRUAN priority.

The general consensus is that satellite spectra for IR and MW are more accurate than for GRUAN geophysical profiles with known uncertainty propagated to the radiance space. For example, typical hyperspectral IR sensors have relatively low uncertainty (0.1K or less) with a straightforward uncertainty methodology and traceability. Inter-calibration via SNO has already brought observations of microwave sensors from different satellites to be within a relative accuracy, for oxygen channels, of 0.1K-0.2K with a standard deviation of 0.5-0.8K (Zou et al, 2006). On the other hand, comparisons between calculated radiance and calibrated spectra can result in bias exceeding 1K (Zou and Wang, 2011). Sources of these differences are either Radiative Transfer (RT) model or sensor calibration errors. Using collocations with GRUAN to better understand these differences introduces a third factor namely the mismatch or representativeness error. Furthermore, the uncertainty and traceability of RT calculations based on GRUAN profiles are inherently more difficult to trace. However, of equal importance is whether these observations are consistent. Ultimately, GRUAN consistency with the sensor data is needed to constrain and inter-calibrate the satellites data, a primary objective of GRUAN. A question also beckons as to whether we can broaden the sample of collocations to provide meaningful analysis in a global context. In this respect, the prognosis for microwave would appear better given the reduced sampling constraints due to clouds. Performing calculations focused on quantifying the consistency among the different sets of calibrated and calculated sensor data will likely yield some surprises and insight, for example, are the reported uncertainties (i.e., from GSICS, GRUAN) supported by the observations.

Figure 1 outlines the overall plan of action. Part 1 (blue) is to identify and compile datasets of collocated GRUAN radiosonde and satellite sensor observations for a given period (two years). These shall be leveraged from existing NPROVS + (Reale 2015) and EU GAIA-CLIM (http://www.gaia-clim.eu/) collocation datasets. Part 2 (red) combines sampling approach and RT modeling to compile candidate subsamples of collocations suitable for IR and MW assessment, respectively. It is proposed for Step 2 to use a line-by-line (LBL) RT model and two sampling approaches, a) akin to Calbet (2016) solely based on spatial/temporal mismatch and b) based on coverage or consistency factor "k" from the Guidelines for Uncertainty Measurements (GUM) (Immler, 2010):

$$|m_1 - m_2| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

where "m" are radiances, "u" the associated uncertainties, "σ" the uncertainty due to mismatch and "k" the coverage factor. Part 3 performs selected sensor and/or RT model assessments using the candidate samples. Steps 2b and 3 require uncertainty estimates for all sets of observed and calculated radiance including guidance on integrating the GRUAN uncertainty, defined in geophysical space, to calculate radiance.

Assessments will focus on the consistency of observations (and uncertainties) in the context of "k". A key preliminary result is the range and distribution of "k" values among selected sets of observed, adjusted, calculated and calculated-minus-observed radiances. These address the consistency of different sets of observations, RT models and potentially the sensor and RT model accuracy. A preliminary demonstration of strategy, results and path forward is planned for presentation at the 2018 Annual GSICS meeting.

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Discuss the Article

Announcements

Call for papers for 2nd Workshop of the CGMS International Cloud Working Group (ICWG)

by Andy Heidinger (NOAA) and Rob Robelling (EUMETSAT)

The organizing committee cordially invites scientists and researchers from around the world, who work in cloud physics and/or the retrieval of cloud parameters from satellite observations, to participate in the 2nd Workshop of the ICWG. The 2nd Workshop of the CGMS International Cloud Working Group (ICWG-2) will take place from 29 October 2018 through 2 November 2018 in Madison, Wisconsin, USA. This workshop will be organized by the University of Madison, Wisconsin, and is co-sponsored by EUMETSAT and NOAA. The main topics of ICWG-2 are:

- Algorithms
- Assessments
- Climate Applications
- Weather Applications

The ICWG-2 participants are encouraged to contribute to one (or more) of these Topical Groups. The topics and the leads of these Topical Groups are listed in the announcement. Please contact the leads of the Topical Groups and discuss with them how you would like to contribute. For further information on the workshop, please visit the announcement page from a link at

http://www.icare.univ-lille1.fr/crew/index.php/Meetings

GSICS Executive Panel Meeting 2018 to be held at ISRO in Bangalore, India

by Toshiyuki Kurino, WMO

The GSICS Executive Panel meeting 2018 will be held in Bangalore, India, 1-2 June 2018. It will be held in the same venue as the 46th session of the Coordination Group for Meteorological Satellite (CGMS) which will meet the following week. A travel logistics package that includes information on accommodations and local area information for Bangalore will be available in due course.
WMO is setting up the meeting web site. All information and meeting document will be available from the following link; http://www.wmo.int/pages/prog/sat/meetings/GSICS-EP-19/GSICS-EP-19.html. A provisional agenda of the meeting and document template are also available from there. The website will be updated regularly. Online registration is also available from the following link; https://eventregistration.eumetsat.int/events/gsics-ep-19/ .

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The Ninth Asia Oceania Meteorological Satellite Users' Conference (AOMSUC-9) to be held in Jakarta, Indonesia from 6-11 October 2018

by Riris Adriyanto, BMKG, Indonesia

Following on from eight successful conferences in China, Japan, Korea, Australia, and Russia, the 9th Asia-Oceania Meteorological Satellite Users' Conference (AOMSUC-9) will be hosted by the Indonesia Agency for Meteorology Climatology and Geophysics (BMKG). The conference will be held in Jakarta on 8, 9, and 10 October 2018 and will be preceded by a 2-day regional training event on 6 - 7 October 2018, and will be followed with Coordination Meeting of WMO RA V Task Team on Satellite Utilization (TT-SU) on 11 October 2018.

This conference is the major Satellite Meteorology Conference in the Asia/Oceania region, where the densest constellation of advanced geostationary satellites resides, and is an eminent scientific event in the Asia-Pacific for those scientists working in satellite remote sensing with applications in meteorology, climatology, oceanography and related fields. The attendees will include world leaders in the field of satellite meteorology, satellite operators and leading scientists from around the world.

Conference Topics

Topics or areas to be covered at the conference include:

- Current and future meteorological satellite programs and user plans within Asia/Oceania
- Facilitation of data access and utilization
- Atmospheric parameters derived from satellite observations
- Application of satellite data to weather analysis and disaster monitoring, nowcasting and forecasting
- Application of satellite data to numerical weather prediction
- Application of satellite data for climate and environmental monitoring
- Satellite precipitation measurements
- Land surface and ocean parameters derived from satellite observations
- Global Spaced-based Inter-Calibration System (GSICS)
- Capacity building and training activities

Conference Schedule

- Saturday, 6 October 2018:
  - Satellite training for trainer on RGB techniques for meteorological applications (Day-1)
- Sunday, 7 October 2018:
  - Satellite training for trainer on RGB techniques for meteorological applications (Day-2)
- Monday, 8 October 2018:
  - The Ninth Asia/Oceania Meteorological Satellite Users' Conference (Day-1)
- Tuesday, 9 October 2018:
  - The Ninth Asia/Oceania Meteorological Satellite Users' Conference (Day-2)
- Wednesday, 10 October 2018:
  - The Ninth Asia/Oceania Meteorological Satellite Users' Conference (Day-3)
- Thursday, 11 October 2018:
  - Coordination meeting of WMO RA V Task Team on Satellite Utilization (TT-SU)

Call for Papers

Those whose professional fields relate to the above themes and who wish to present at the conference are invited to register. To submit an abstract please contact the Local Organizing Committee via the following e-mail: **aomsuc9@bmkg.go.id**

The deadline for abstract submission is **1 July 2018.** There will be ***no*** *registration fee required* for attendance at the conference.

The language of the conference is English. The abstracts should be no longer than one page (A4). Please note that the person who submits the abstract will automatically be identified as the presenter and the point of contact for future correspondence.

Abstracts will be reviewed for inclusion in the conference program. Authors may be asked to switch verbal presentations to poster presentations, or vice versa, if considered more appropriate. Selected authors will be notified via e-mail around July 2018, and their abstract will be posted on the conference website.

2nd Announcement

Further advice will be provided with the 2nd announcement regarding submission of abstracts, accommodation details and travel information. The exact venue is yet to be confirmed but the conference will be held in Jakarta. The second announcement will be posted on the AOMSUC-9 website (click http://aomsuc9.bmkg.go.id/) around **July 2018**.

GSICS-Related Publications

Chen, R., F. Alquaied, and W.L. Jones. 2017. 'Assessing Radiometric Stability of the 17-Plus-Year TRMM Microwave Imager 1B11 Version-8 (GPM05) Brightness Temperature Product'. *Climate* 5 (4). https://doi.org/10.3390/cli5040092.

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Gierens, K., Eleftheratos, K., and Sausen, R.: Intercalibration between HIRS/2 and HIRS/3 channel 12 based on physical considerations, Atmos. Meas. Tech., 11, 939-948, doi: 10.5194/amt-11-939-2018, 2018.

Ke, Zhou, Liu Li, Yu Tao, Gu Xing-fa, Zheng Feng-bin, and Zang Wen-qian. 2017. 'Sensitivity Analysis of Spectral Band Adjustment Factors For GF-1/WFV Sensor Cross-Calibration'. *Spectroscopy and Spectral Analysis* 37 (12):3809–13 : **doi:** 10.3964/j.issn.1000-0593(2017)12-3653-05

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Xie, Y., J. Han, X. Gu, and Q. Liu. 2017. 'On-Orbit Radiometric Calibration for a Space-Borne Multi-Camera Mosaic Imaging Sensor'. *Remote Sensing* 9 (12). https://doi.org/10.3390/rs9121248

Zhong, B., A. Yang, S. Wu, J. Li, S. Liu, and Q. Liu. 2018. 'Cross-Calibration of Reflective Bands of Major Moderate Resolution Remotely Sensed Data'. *Remote Sensing of Environment* 204 (January):412–23. https://doi.org/10.1016/j.rse.2017.10.014.

Submitting Articles to 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.

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With Help from our friends:

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