doi:10.7289/V59021P1

GSICS Global Space-based Inter-Calibration System Quarterly V6 No. 2 2012

CMA • CNES • EUMETSAT • IMD• ISRO• JAXA•JMA • KMA • NASA • NIST • NOAA • ROSHYDROMET• USGS• WMO

http://gsics.wmo.int Dr. Fangfang Yu, Editor

MSU/AMSU-A Inter-Satellite Calibration for Atmospheric Temperature Trend Monitoring

Long-term observations from the Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) onboard historical and currently-operating polar orbiting satellites play a key role in atmospheric temperature trend monitoring, providing key observational data for the rate of global warming. To generate high quality climate data records for reliable temperature trend detection, NOAA/NESDIS/STAR has inter-calibrated MSU/AMSU-A atmospheric temperature channels (MSU channels 2-4 and AMSU-A channels 4-14, Zou *et al.*, 2006, 2011) onboard NOAA TIROS-N through NOAA-18, MetOp-A, and NASA Aqua. Inter-calibration techniques were developed at STAR (Zou *et al.*, 2006) based on simultaneous nadir overpass (SNO, Cao *et al.*, 2004) matchups for these satellites. Essentially, new calibration offsets and nonlinearities that are different from those provided in the pre-launch operational calibration were obtained from the SNO inter-calibration process. The inter-calibrations minimize or remove different types of inter-satellite biases that affect the quality and reliability of the long-term MSU/AMSU time series, including relatively stable inter-satellite biases between most satellite pairs, bias drifts in certain satellite channels, sun-heating-induced instrument temperature variability of radiances, and scene temperature dependency of biases due to inaccurate calibration nonlinearity.

The inter-calibration resulted in new 28-year (1979-2006) MSU and 14 year (1998-present) AMSU-A level-1c radiance datasets for consistent climate and weather applications. The level-1c data is more consistent in the sense that inter-satellite differences are minimal over the entire satellite operational time period. Figure 1 shows an example of the global ocean mean inter-satellite difference time series before and after the SNO inter-calibration. Ocean mean differences between satellite pairs can be used to characterize satellite calibration errors since sampling errors such as those due to diurnal drift of the satellites are small for ocean means. It is seen that time-varying inter-satellite differences occur for operationally calibrated brightness temperatures. However, these biases are significantly reduced by the SNO inter-calibration.

In addition to refining calibration coefficients, the SNO recalibration process also identifies post-launch channel frequency shifts in AMSU-A channels. SNO methodologies were developed at STAR (Zou *et al.*, 2011) to determine the exact frequency shifts for such channels. The newly determined channel frequency removes frequency-shift related inter-satellite biases and their seasonal variations quite well (Figures 2 and 3).

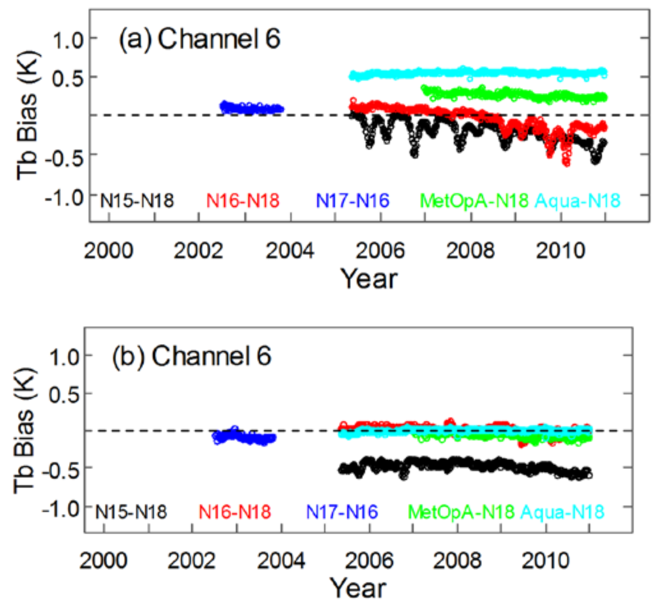

Figure 1. a) Global ocean mean inter-satellite Tb-difference time series for operationally calibrated AMSU-A channel 6 for satellites NOAA 15, 16, 17, and 18; MetOp-A; and Aqua. b) Same as a) except that the data are derived from SNO inter-calibration. The larger biases of NOAA 15 channel 6 relative to other satellites are due to its frequency shift from the prelaunch measurement.

The SNO calibrated level-1c radiances are expected to improve climate reanalyses by removing artificial trends due to inter-satellite biases. To test the impact of the inter-satellite calibration in climate reanalyses, 20-years (1987-2006) of SNO calibrated MSU Level-1c radiances for channels 2, 3 and 4 onboard NOAA-10 through NOAA-14 were assimilated into the new generation NCEP Climate Forecast System Reanalysis (CFSR) and NASA Modern Era Retrospective-analysis for Research and Applications (MERRA) reanalysis (Saha *et al*., 2010; Rienecker *et al*., 2011). This was the first time that inter-calibrated satellite radiance data have ever been assimilated in reanalysis systems. Since the CFSR and MERRA reanalyses cover the entire period of MSU observations from 1978 to 2006, they actually assimilated two different MSU Level-1c data sets: the NOAA operationally calibrated data for TIROS-N through NOAA-9 and the SNO re-calibrated observations for NOAA-10 through NOAA-14. The fact that radiances from these different calibration procedures were assimilated into the same system serves as an ideal experiment for evaluating the impact and performance of the SNO inter-satellite calibration effort. Figure 4 shows the total bias correction patterns of MSU channel 2 in the CFSR for the eight satellites from NOAA-6 through NOAA-14. The total bias correction is a global mean difference between the satellite observations and a background short term forecast field. This quantity is an indicator of how well the observations agree with the model. These biases can also be used to determine the comparability of two different satellites, since differencing of the bias corrections of two satellites gives inter-satellite difference information.

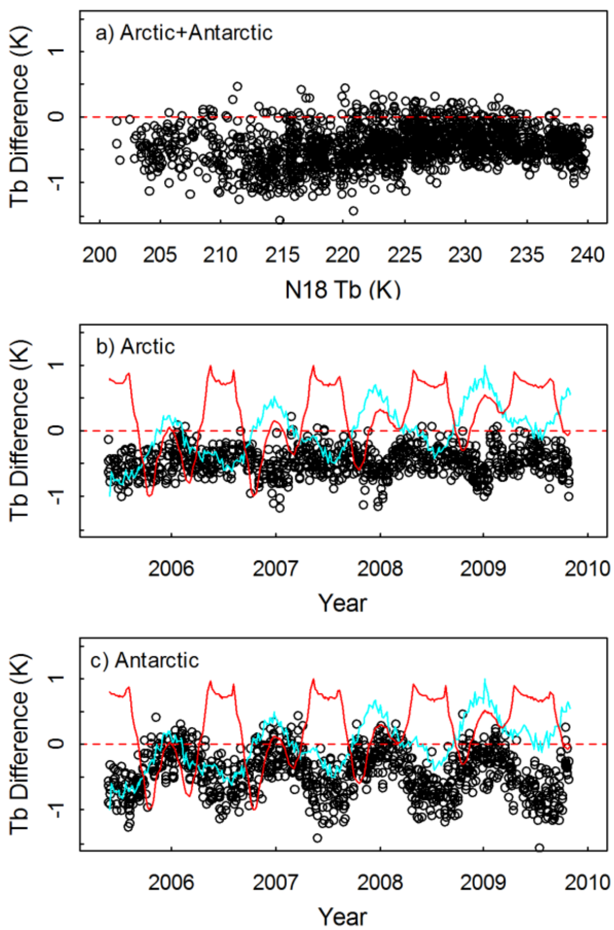

Figure 2 (a) SNO scatter plot for NOAA-18 brightness temperature (N18 Tb) versus brightness temperature differences between NOAA-18 and NOAA-15 [Tb (N15) - Tb (N18)]; (b) SNO time series over the Arctic for Tb (N15) minus Tb (N18); and (c) same as Figure 2b except over the Antarctic. The Tb data in these plots were already inter-calibrated so that calibration nonlinearity-related scene temperature dependent biases have already been removed. Thus, the SNO biases are caused only by frequency differences. The red and blue curves in Figure 2b and 2c represent the warm target temperatures of NOAA-15 and NOAA-18, respectively.

As seen in Figure 4, the bias corrections for NOAA-6 through NOAA-9 exhibit obvious seasonal and inter-annual variability, which is related to the solar heating induced instrument temperature variations. In contrast, no instrument temperature variability is observed in bias corrections of the SNO calibrated MSU observations for NOAA-10 through NOAA-14. In addition, the bias correction values for NOAA-10 through NOAA-14 are nearly the same, suggesting the inter-calibrated MSU data have reached their performance expectation in the reanalysis data assimilation.

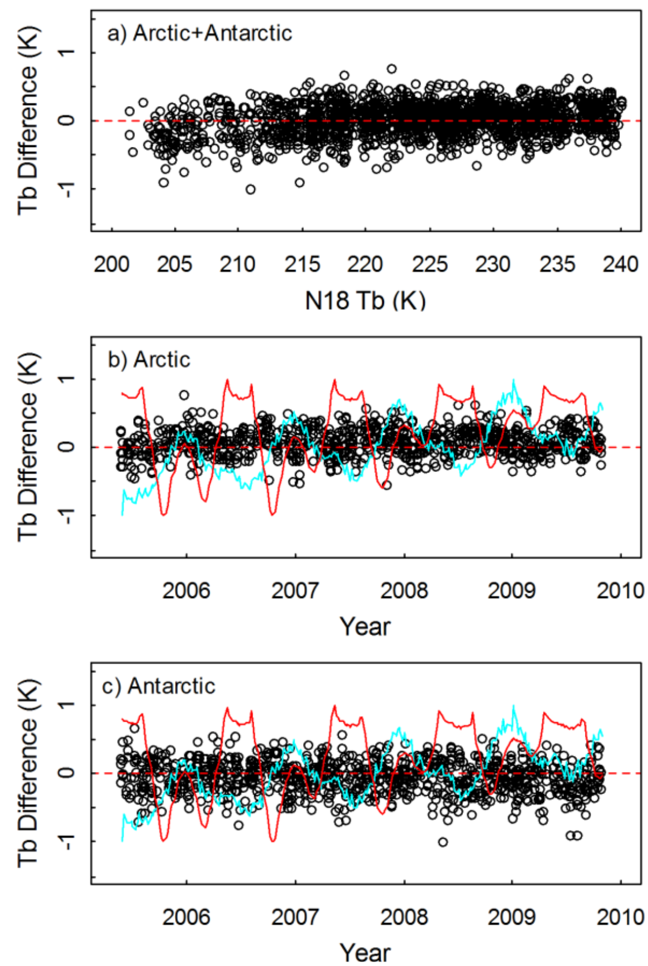

Figure 3 Same as Figure 2 except for the adjusted SNO time series between NOAA-15 and NOAA-18 in which the CRTM simulated differences due to the NOAA-15 frequency shift were subtracted from the observed NOAA-15 Tb.

The recalibrated MSU/AMSU-A radiance data have been used to generate the NOAA/STAR version of the deep-layer atmospheric temperature climate data record. Figure 5 shows the well-inter-calibrated and well-merged MSU/AMSU anomaly layer temperatures for the mid-troposphere (TMT, peaks near 500 mb), upper-troposphere (TUT, peaks near 250 mb), and lower-stratosphere (TLS, peaks near 75 mb). The climate community has been extensively using these time series for upper-air temperature trend monitoring and investigations.

The MSU/AMSU level-1c radiance datasets and the merged layer temperature time series can be freely accessed at the NOAA/STAR website: http://www.star.nesdis.noaa.gov/smcd/emb/mscat/index.php.

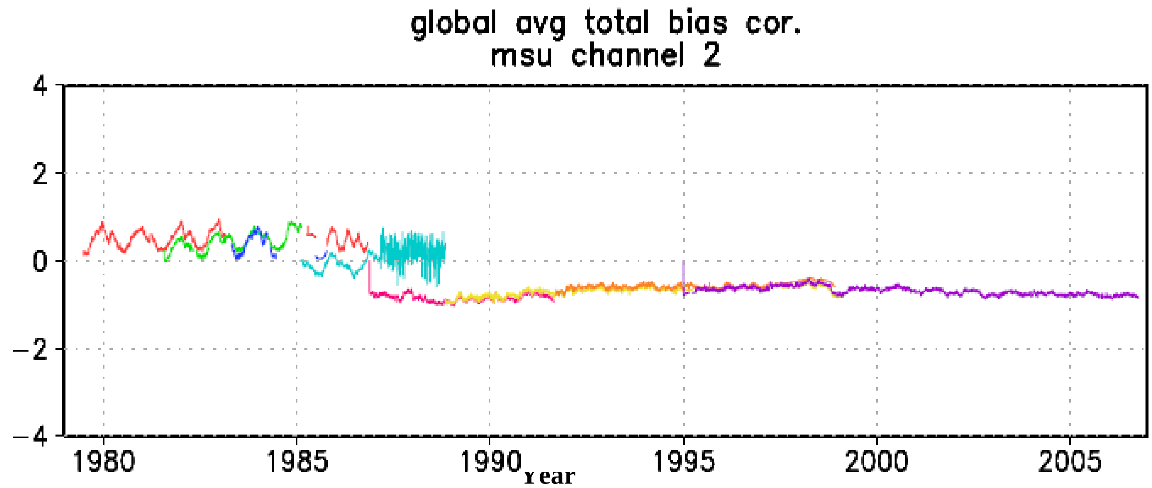

Figure 4 Daily average global-mean total bias correction (Kelvin) for MSU channel 2 onboard satellites NOAA-6 to NOAA-14. The time series from 1979 to 1988 in 4 different colors (with larger seasonal variability) are for NOAA-6 through NOAA-9, and the smoother time series from 1987 to 2007 in another 4 different colors are for NOAA-10 through NOAA-14 (Plot from Saha *et al.*, 2010).

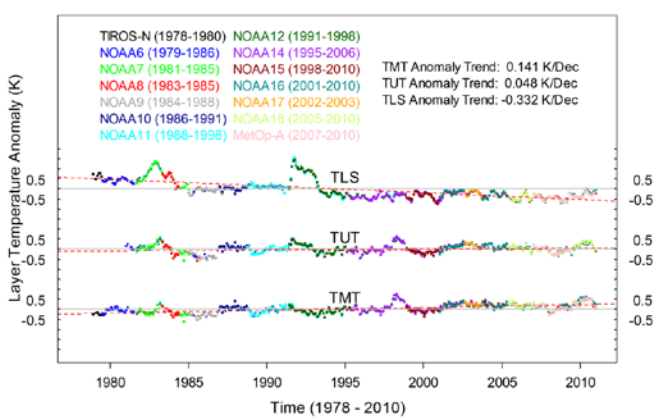

Figure 5. STAR MSU/AMSU Version 2.0, monthly global mean anomaly time series and trends for the layer temperatures of mid-troposphere (TMT), upper-troposphere (TUT), and lower-stratosphere (TLS). The TMT, TUT, and TLS time series are updated every month. Each update adds the monthly-mean, inter-calibrated and well-merged AMSU-A observations from the latest month to the dataset.

(by Dr. Cheng-Zhi Zou, NOAA/NESDIS/STAR)

REDERENCES

Zou, C.-Z., M. Goldberg, Z. Cheng, N. Grody, J. Sullivan, C. Cao, and D. Tarpley, 2006: Recalibration of microwave sounding unit for climate studies using simultaneous nadir overpasses. *J. Geophys. Res.*, **111**, D19114, doi:10.1029/2005JD006798

Zou, Cheng-Zhi and Wenhui Wang, 2011: Inter-satellite calibration of AMSU-A observations for weather and climate applications. *J. Geophys. Res.*, **116**, D23113, doi:10.1029 /2011JD016205.

Cao, C., M. Weinreb, and H. Xu, 2004: Predicting simultaneous nadir overpasses among polar-orbiting meteorological satellites for the intersatellite calibration of radiometers. *J. Atmos. Oceanic Technol.*, **21**, 537–542, doi:10.1175/1520-0426.

Saha, S., et al., 2010: The NCEP climate forecast system reanalysis. *Bull. Am. Meteorol. Soc.*, **91**, 1015–1057, doi:10.1175/2010BAMS3001.1.

Rienecker, M. M., et al., 2011: MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Clim.*, **24**, 3624–3648, doi:10.1175/JCLI-D-11-00015.1.

Improvement of FY-2E Operational Calibration Based on the GSICS Correction

In September 2009, the Chinese Meteorological Administration (CMA) GSICS Processing Center (GPRC) implemented the GEO-LEO inter-calibrations with the Atmospheric Infrared Sounder (AIRS) and Infrared Atmospheric Sounding Interferometer (IASI) for the geostationary satellites FY-2C/2D Infrared (IR) channels. This operation was achieved by modifying the Japanese Meteorological Administration (JMA)'s GSICS GEO-LEO inter-calibration source codes (Owada, 2009). Since then, all in-flight operational data of FY-2C/2D/2E since 2005 have been collected for the GSCIS calibration reprocessing or near real-time monitoring. GSICS recalibration processing for FY-2C for its entire lifetime from 2005 to 2009 has been completed, while FY-2D/2E GSICS monitoring is still ongoing. The GSICS evaluation of the FY-2X operational calibration accuracy shows that the FY-2 imager has apparent biases with respect to AIRS and IASI and significant radiometric calibration variations, especially during the eclipse phase. The detailed radiometric calibration evaluation results using the GSICS GEO-LEO inter-calibration method for the FY-2 IR data are available in Hu *et al.*, (2012)

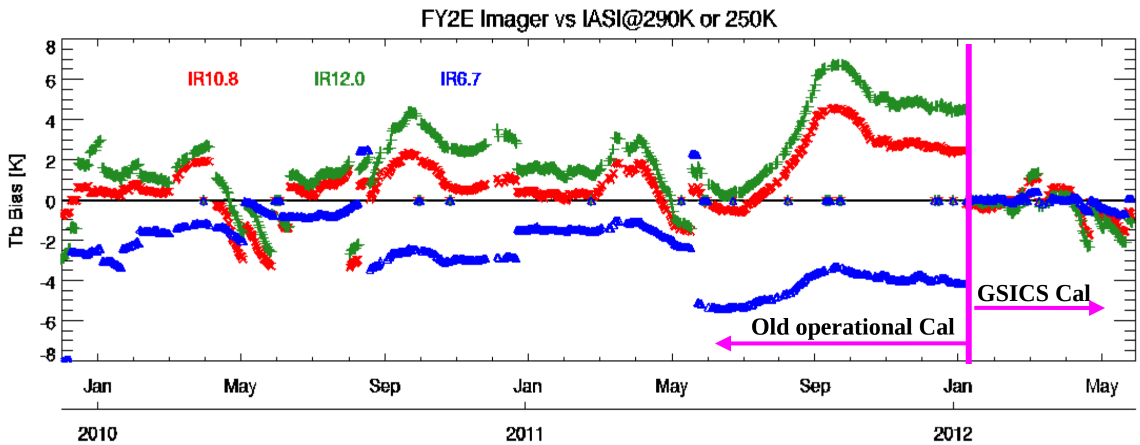

Figure 1. Time series of FY-2E/VISSR IR biases with respect to Metop-A/IASI, expressed as brightness temperature difference at reference scenes (290K for IR10.8um and IR12.0um, 250K for IR6.7μm).

Figure 1 shows the time series of the brightness temperature (Tb) biases at the reference scene radiances with respect to Metop-A/IASI for the three FY-2E long-wave IR bands since its operation in November, 2009. The average Tb biases (@290K or 250K) before January 12, 2012 are +0.31 K, +1.27K, and -1.67K for IR10.8μm, IR12.0μm, and IR6.7μm, respectively. The reference scene Tb biases of the three FY-2E IR channels are larger than that of FY-2D. But the seasonal fluctuation of the reference scene Tb biases is slightly smaller than that of FY- 2D (the standard deviation values of Tb biases are about 1.5K for FY-2D and about 1.1K for FY-2E).

The GSICS GEO-LEO IR correction coefficients are generated based on the regression relationship of the collocated GEO and LEO radiances. These GSICS products are normally provided to the users for application to the Level-1 radiances. However, due to the large radiometric calibration uncertainty (large Tb bias relative to the reference instrument) and the large seasonal variation, CMA decided to provide users with a new calibration Look-Up-Table (LUT) in Level-1 format based on the GSICS correction coefficients. This way, the users do not need to update their Level-1 decode package, which makes it very convenient to apply the GSICS products.

The traditional operational FY-2 calibration algorithm based on the AVHRR and HIRS measurements was replaced with the GSICS inter-calibration method for FY-2E on January 12, 2012. The significant improvement of the calibration accuracy after the GSICS correction is shown in Figure 1. The new bias is less than 0.2K with standard deviation below 0.1K. We use this GSICS correction to re-calibrate the historical FY-2 data for climate studies and provide updated LUT files. But note that current FY-2 vs. IASI inter-calibrations do not resolve all the calibration issues of FY-2 data, such as the diurnal cycle, because its collocated radiances are limited to times of each day that cannot cover all the images of FY-2X – especially during the eclipse phase when the instrument temperature changes dramatically. It is expected that large calibration residuals will be difficult to eliminate during this period.

In addition to the GSICS correction of current FY-2 operational calibrations, the GSICS GEO-LEO IR inter-calibration can also be used to tune the FY-2 on-board blackbody (BB) calibration to ensure the absolute calibration of FY-2 data. The FY-2 BB observations supply frequent relative radiometric responsivities of all infrared channels each day since there is one blackbody observation every two hours. But the blackbody is inserted into the FY-2 optic in the middle path whose optics are different from the earth viewing full optical path. The front optics model correcting (the BB observation doesn't cover the front optic) for these issues is derived with the help of the GSICS reference radiance for full optics. Hence, the GSICS calibration of both infrared channels helps to tune the partial BB calibration into the full optic to guarantee the absolute accuracy of the BB calibration.

(by Dr. Xiuqing Hu, CMA/NMSC)

REFERNCES

Owada, H., 2010: Theoretical Basis for MTSAT-AIRS/IASI Inter-Calibration Algorithm for GSICS, dated on July 14, 2010, available at: https://gsics.nesdis.noaa.gov/wiki/Development/AtbdCentral.

Hu X., N. Xu, Y. Zhang, L. Chen, P. Zhang, 2012: Calibration Evaluation and Correction of the Infrared bands of FY-2 satellites using reference instrument AIRS and IASI, *IEEE Geo. Remote Sensing*, in review (currently under revision).

Evaluation of the Performance of GOES Imager Infrared Midnight Blackbody Calibration Correction (MBCC) using GSICS GEO-LEO Inter-Calibration

The Geostationary Operational Environmental Satellites (GOES) is a series of three-axis body-stabilized geostationary (GEO) satellites operated by the National Oceanic and Atmospheric Administration (NOAA) to provide continuous streams of satellite data for weather monitoring and forecasting for the U.S. and its neighboring environment. The infrared (IR) radiances of the weather instruments are calibrated on-board via a two-point calibration method using the blackbody and space as the hot and cold calibration sources and it is assumed that the instrument background flux remains constant between the space view and blackbody scan events (Weinreb *et al.*, 1997). However, the requirement of constant instrument environmental flux may be violated for hours around satellite midnight, during which the GOES instrument temperatures vary by tens of degrees Kelvin. When the temperature of the structural components in the vicinity of the blackbody is different from the blackbody, the extraneous flux is then reflected by the non-perfect blackbody to the detectors during the blackbody scan event, resulting in erratic calibration responsivity. This midnight slope error was found to cause up to an approximate 1K brightness temperature (Tb) depression in the Imager short-wave channels (3.8μm) from scenes over the Gulf of Mexico (Johnson and Weinreb, 1996). To compensate for the satellite midnight calibration anomaly, an empirical algorithm called the Midnight Blackbody Calibration Correction (MBCC) was developed based on the relationship between the calibration slopes and the instrument component temperature outside the midnight effect period [Johnson and Weinreb, 1996] and has been implemented for the GOES Imager channels since 2003. Note that the MBCC slopes can be switched on or off by an operator directly and can also be used at any time to enhance calibration accuracy (GOES OGE DRL, 2005).

The Global Space-based Inter-Calibration System (GSICS) GEO-LEO (Low Earth Orbit) inter-calibration provides an opportunity to evaluate the MBCC performance. In the NOAA GSICS GEO-LEO inter-calibration project, two well-calibrated hyperspectral radiometers, the Atmospheric Infrared Sounder (AIRS) on the Aqua satellite and the Infrared Atmospheric Sounding Interferometer (IASI) on the Metop-A satellite, are selected to evaluate and enhance the GOES Imager IR calibration accuracy (Wu *et al*., 2009). As Aqua crosses the Equator twice a day, around 1:30am and 1:30pm, close to the peaks of the instrument temperature diurnal variations, the GOES bias with respect to AIRS can be used to examine the day/night calibration variation of the GOES IR data and thus the performance of the MBCC algorithm. Also, since the differences between AIRS and IASI are small and consistent within the GOES IR spectral ranges (Yu *et al*., 2012), the biases with respect to AIRS and IASI at different ascending/descending node times can be used to examine the trending patterns of GOES Imager IR diurnal calibration accuracy. This paper is the summary of the recent study of diurnal variations in the calibration of GOES Imager IR channels [Yu *et al.*, 2012].

Figure 1 and 2 are examples of statistics (mean and standard deviation) of the brightness temperature (Tb) bias with respective to AIRS and IASI and at half-hour bins for the GOES-11 (January 1, 2008 - March 1, 2008) and GOES-12 (June 1, 2008 - August 1, 2008, as well as the MBCC application frequency during the study periods. To avoid of the day-time directional reflectance/emissivity at the short-wave channel (Ch2, 3.8μm), only the night-time data Tb bias statistics are calculated in Figure 1a and Figure 2a. The following conclusions can be drawn from the figures.

1). The frequency of MBCC application varies greatly for the different channels. While it is intensively applied for Ch2 (3.8μm) (frequency > 80%) with up to 6-8 hours' duration centered around the satellite midnight time, it is used much less frequently for the other IR channels. In fact it is not used at all for GOES-12 Imager Ch3 (6.5μm) during the study period. Also, MBCC is often used outside the midnight effect window for all the IR channels. However, the mechanism for the application of the MBCC slopes outside the midnight effect period is not yet fully known.

2). Ch2 (3.8μm) in general is well calibrated over the night-time with high frequency and long time duration of MBCC applications. The consistent Tb biases before and after the intensive MBCC application (~20:00-21:00 satellite local time (SLT) and ~3:00-4:00SLT) may indicate that data outside the midnight effect period at the channel are also well-calibrated.

3). As shown in Figure 1b, the night-time data at Ch3 (6.5µm) can also be well calibrated with consistent Tb bias over 24 hours if the MBCC is applied with high frequency. The trending of the Tb biases with respect to AIRS and IASI in Figure 2b indicates that the midnight effect at this channel becomes apparent ~3 hours before midnight and peaks around 1:00-2:00 SLT.

4). Although there is a slight reduction in the Tb bias with respect to AIRS around satellite midnight when the MBCC frequency jumps to >80%, a large Tb bias residual is generally observed at Ch4 (10.7µm) (Figure 2c). This may indicate that MBCC does not work as effectively for Ch4 as for other channels.

5). For GOES-11 Ch5 (12.0µm) or GOES-12 Ch6 (13.3µm), the MBCC can greatly reduce the Tb bias to the day-time magnitude once the MBCC is intensively applied.

As the GOES instrument temperature peaks after midnight, close to the AIRS descending node time at 01:30 satellite local time (SLT). The GOES calibration around the AIRS ascending time (13:30 SLT) is used as reference to evaluate the MBCC performance.

MBCC Performance=

$$\text{mean}(\Delta Tb_{GEO\text{-}AIRS,i}) - \text{mean}(\Delta Tb_{GEO\text{-}AIRS,j}) \qquad (1)$$

where $\Delta Tb_{GEO\text{-}AIRS,i}$ is the Tb bias with respect to AIRS at 01:00-02:00 LST and $\Delta Tb_{GEO\text{-}AIRS,j}$ is the Tb bias with respect to AIRS at 13:00-14:00 SLT. These one-hour time periods cover the two time bins across the AIRS ascending/descending time. The frequency of MBCC application must be larger than 80% at 01:00 – 02:00 SLT to evaluate the MBCC performance. The result is reported in Table 1 for the *winter* and *summer* of 2008 data.

Table 1. Impact of the MBCC on the diurnal calibration variations, calculated using Equation 1. Results with a high frequency of MBCC applications (>80% of the time) are in bold-italic font.

Channel name	GOES-11 – AIRS (K)		GOES-12 – AIRS (K)	
	Winter	Summer	Winter	Summer
Ch3 (3.9µm)	***-0.12***	***-0.13***	-0.38	0.50
Ch4 (6.5µm)	-0.54	***-0.49***	-0.58	***-0.48***
Ch5 (12.0µm)	***-0.13***	-0.31		
Ch6 (13.3µm)			***-0.04***	***+0.11***

In conclusion, MBCC should be applied hours before the satellite midnight time. When intensively applied, it can greatly reduce the impact of midnight calibration anomaly to within 0.15K at all the IR channels except for Ch4 (10.7µm). Even with a high frequency of MBCC application, there is still about a 0.5K difference from the daytime reference data for GOES-11 and GOES-12 Ch4. A new MBCC method to fundamentally correct the extra radiation viewed by the detector may be needed to improve the midnight calibration accuracy.

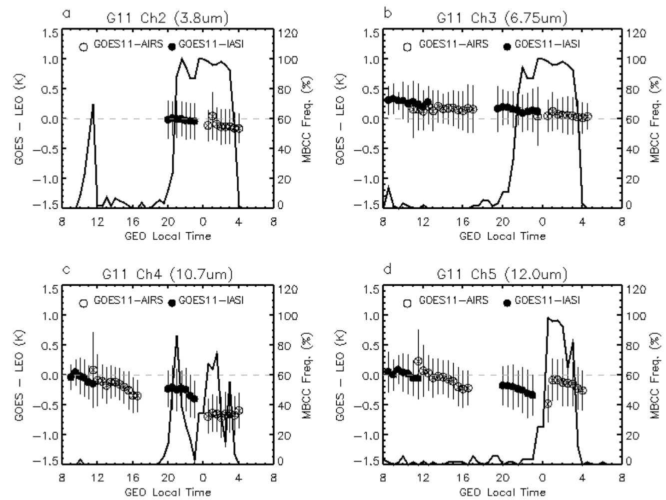

Figure 1. Mean GOES-11 Tb biases to AIRS (open circles) and IASI (solid circles) for each time bin during the period of Jan. 1 2008 – Mar. 1, 2008. The vertical lines through each circle represent the standard deviations of the Tb biases in each time bin. The frequency of MBCC onset (quasi-continuous curve) in each time bin are also plotted using the second y-axis.

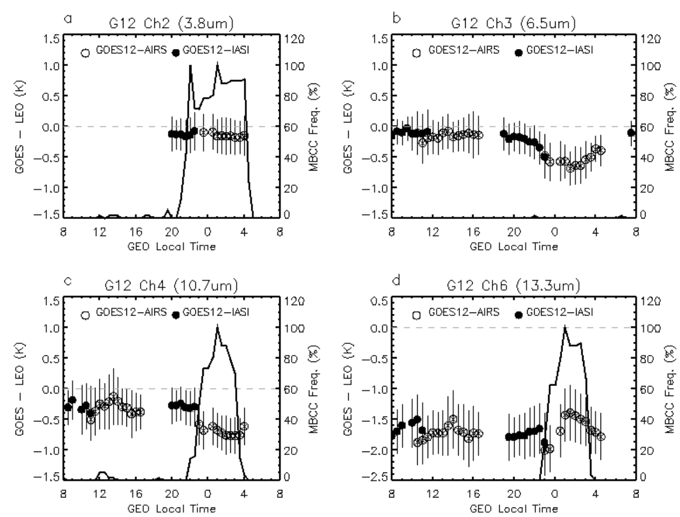

Figure 2. Same as Figure 1 but for GOES-12 from Jun. 1 2008 – Aug. 1 2008

(by Drs. Fangfang Yu and Xiangqian "Fred" Wu, NOAA/NESDIS/STAR)

REFERENCES

Weinreb, M., M. Jamieson, N. Fulton, Y. Chen, J. Johnson, J. Bremer, C. Smith, and J. Baucom, 1997: Operational calibration of Geostationary Operational Environmental Satellite-8 and -9 imagers and sounders. *Applied Optics*, **36(27)**, 6895-6904.

R.X. Johnson, R.X. and M. Weinreb, 1996: GOES-8 Imager midnight effects and slope correction. *Proc. SPIE*, **2812**, 596-607.

GOES Operations Ground Equipment (OGE) Interface Specification, Section 3.0, GVAR Transmission Format, DRL 504-02 Part 1, Revision 2, 2005. available at http://www.osd.noaa.gov/gvar/documents/G023_504.02_DCN3_Sect_3.pdf.

Wu, X., T. Hewison, and Y. Tahara, 2009: GSICS GEO-LEO inter-calibration: Baseline algorithm and early results. *Proc. SPIE*, **7456**, 745604-1-745604-12.

Wang,L., M. Goldberg, X. Wu, C. Cao, R. Iacovazzi, F. Yu and Y. Li, 2011: Consistency assessment of Atmospheric Infrared Sounder and Infrared Atmospheric Sounding Interferometer radiance: Double differences versus simultaneous nadir overpass. *J. Geophys. Res.*, **116**, D11111, doi:10.1029 /2010JD14988.

Yu, F., X. Wu, M.K. Rama Varma Raja, Y. Li, L. Wang and M. Goldberg, 2012, Diurnal and scan angle variations in the calibration of GOES Imager Infrared channels. *IEEE Trans. Geosci. Remote Sensing*, in press.

News in this Quarter

Success of 12th GSICS Executive Panel Meeting

The 12th GSICS Executive Panel meeting (EP) meeting was successfully held in College Park, Maryland, USA from 30 May 2012 to 1 June 2012.

Just Around the Bend …

GSICS-Related Meetings

- The IEEE International Geoscience and Remote Sensing Symposium (IGARSS) meeting will be held in Munich, Germany from 22 to 27 July 2012.
- The SPIE meeting will be held in the San Diego Convention Center, San Diego, California, USA from 12 to 16 August 2012.
- The Conference on Characterization and Radiometric Calibration for Remote Sensing will be held in Logan, Utah, USA from 27 to 30 August 2012.
- The 2012 EUMETSAT Meteorological Satellite conference will be held in Sopot, Poland from 3 to 7 September 2012. The 4th GSICS Users' Workshop will be held in one of the EUMETSAT conference's post sessions on 4 September, 2012 (Tuesday).

GSICS Publications

Helder, D. et al., 2012: Radiometric calibration of the Landsat MSS sensor series. *IEEE Trans. Geosci. Remote Sensing*, 50(6), 2380-2399.

Helder, D. et al., 2012: Landsat 4 Thematic Mapper calibration update. *IEEE Trans. Geosci. Remote Sensing*, **6**, 2400-2408.

Ramos-Peres, I. 2012: Optimum intercalibration time in synthetic aperture interferometric radiometers: Application to SMOS. *Geosci. Remote Sensing Letters*, **9(4)**, 774-777.

With Help from our Friends:

The *GSICS Quarterly* Editor would like to thank those individuals who contributed articles and information to this newsletter. The Editor would also like to thank Dr. George Ohring for careful proofreading and editing assistance, our European Correspondent, Dr. Tim Hewison of EUMETSAT, and Asian Correspondent, Dr. Yuan Li of CMA, in helping to secure and edit articles for publication.

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