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GSICS Global Space-based Inter-Calibration System **Quarterly**

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http://gsics.wmo.int Dr. Robert A. Iacovazzi, Jr., Editor

Kalpana Thermal IR Channel Inter-calibration Using AIRS Measurements: Sensors

The inter-satellite calibration of new and existing satellite sensors with state-of-the-art satellite instruments is useful for monitoring sensor performance. It also helps in the radiance bias correction before using data for various applications, such as radiance assimilation in numerical weather prediction models.

Currently, India has two geostationary operational meteorological satellites, Kalpana and INSAT-3A, that make routine observations in thermal infrared (TIR) (10.5-12.5μm) and water vapor absorption (5.7-7.1μm) channels. India is scheduled to launch the INSAT-3D geostationary satellite in 2011 that will carry an 18-channel IR Sounder, and a six-channel Imager. Hyperspectral sounder measurements from polar orbiting satellites would be utilized for the inter-satellite calibration of the INSAT-3D Sounder and Imager.

Recently, ISRO has taken initiative in the Global Space-based Inter-Calibration System (GSICS) for inter-calibrating Indian geostationary satellite measurements. An effort has been made to inter-calibrate the Kalpana TIR channel using AIRS measurements. The next two articles in this newsletter summarize the procedure and main outcome of the Kalpana TIR-channel inter-calibration with AIRS for clear-sky conditions. In this article, the Kalpana Very High Resolution Radiometer on-board Kalpana, and the Atmospheric Infrared Sounder (AIRS) onboard EOS-Aqua are briefly described.

The Very High Resolution Radiometer (VHRR) onboard Kalpana has three channels:

- Visible channel (VIS, 0.55-0.75 μm) with a 2 km spatial resolution;
- Water vapor absorption channel (WV, 5.7-7.1 μm) with an 8 km spatial resolution; and
- Thermal infrared window channel (TIR, 10.5-12.5 μm) with an 8 km spatial resolution.

Figure 1 shows the Kalpana channel spectral response functions (SRFs) overlaid on the AIRS brightness temperature spectrum. Kalpana data received at Bhopal Earth Station (BES), Space Applications Centre (ISRO), is used for the present study.

Meanwhile, the AIRS onboard the EOS-Aqua satellite provides a wealth of highly-accurate atmospheric and surface information using 2378 high-spectral-resolution ($\nu/\Delta\nu \approx 1200$) infrared channels ranging from 650 to 2675 cm^{-1} (corresponding to 3.74-15.4 μm). However, there are two major gaps between 1135-1215 cm^{-1} and 1615-2170 cm^{-1}. AIRS scan in the cross-track direction with ±49.5° swath centered at nadir. Each scan line contains 90 footprints, with a resolution of 13.5 km at nadir and 41 km x 21.4 km at the scan extremes from 705.3 km satellite orbit.

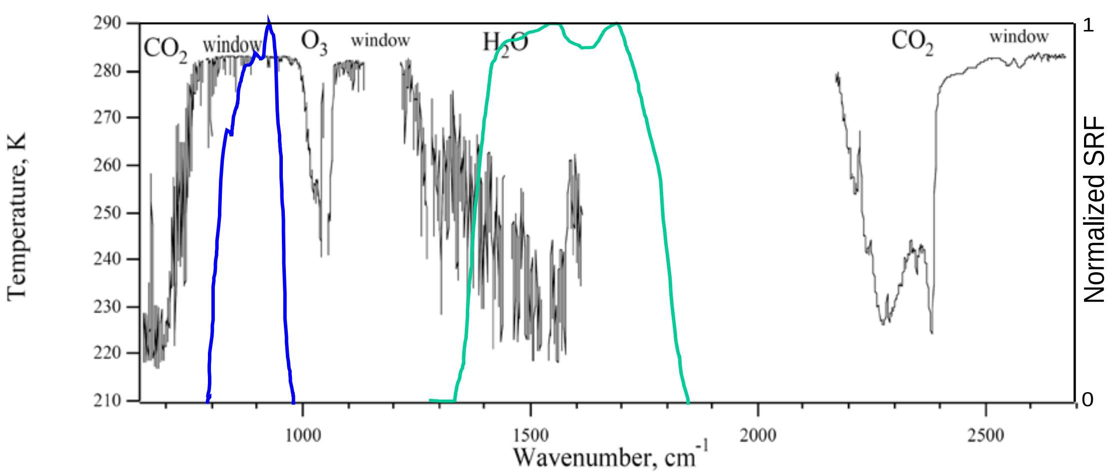

Figure 1. Simulated AIRS brightness temperature spectrum along with the SRFs for Kalpana TIR (blue) and WV (green) channels.

Kalpana Thermal IR Channel Inter-calibration using AIRS Measurements: Method

The standard procedure documented in the "GSICS Algorithm Theoretical Basis Document (ATBD) for GOES-AIRS Inter-Calibration" by Xiangqian Wu (2009), has been used for the inter-calibration. Currently, the simplified procedure described in this article has been adopted, while a detailed procedure following the ATBD document is under way. Once finalized, the detailed procedure will be used for a routine inter-calibration of Indian geostationary satellites with hyperspectral observations from AIRS and IASI.

AIRS granules are collocated in time, space and zenith angle with the Kalpana observations. Since AIRS does not cover the entire spectral bandwidth of the Kalpana water vapor (WV) channel, we have restricted the present inter-calibration study to the Thermal Infrared (TIR) channel only. We restrict comparison only over clear scenes by selecting a threshold of brightness temperature of 285K and imposing a spatial coherence test to identify relatively homogenous scenes. More detailed steps of this method are described below.

AIRS radiances are first convolved over Kalpana TIR SRFs. Convolved radiance for Kalpana TIR channel using '*n*' number of AIRS hyperspectral sounders channels is computed using:

$$R_{conv} = \sum_{i=1}^{n} R^{i}_{AIRS} S^{i}_{Kalp} \Delta\nu \Big/ \sum_{i=1}^{n} S^{i}_{Kalp} \Delta\nu \qquad (1)$$

Where, R_{conv} is convolved broadband radiance, R_{AIRS} is radiance of AIRS channels, superscript '*i*' is AIRS channel index, S_{Kalp} is the sensor response function of broadband sensor at the central wavenumber of hyper-spectral channel '*i*', $\Delta\nu$ is the hyperspectral channel width and '*n*' is the total number of hyper-spectral channels in broadband sensor's SRF range. Brightness temperature (T_b) from the Kalpana broadband convolved radiances is computed using the equivalent inverse Planck function for the broadband sensor:

$$R_{conv} = \frac{2hc^2\nu^3}{\exp\{hc\nu / k(a_1 + a_2 T_b)\} - 1}, \qquad (2)$$

where, a_1 and a_2 are the band correction coefficients for Kalpana TIR channel, h is the Planck constant, k is the Boltzmann constant and c is the speed of light. For Kalpana TIR channel, $a_1 \approx 1.0515$K, $a_2 \approx 0.9962$, and $\nu \approx 885.602$ cm^{-1}.

The collocation criterion for AIRS and Kalpana pairs is adopted from the GSICS ATBD (2009) as follows:

i. **Observation time difference check**
Since Kalpana observations are available at half-hour intervals, we have chosen the time difference less than 15 minute for temporal collocation, i.e.,

$$| t_{AIRS} - t_{Kalpana} | < 15 \text{ minutes}$$

ii. **Environment uniformity test**
Measurements over uniform scene conditions have been used to avoid the problems arising due to the differences in the time of observation, observation path length, navigation error, etc. of AIRS and Kalpana. The standard deviation of the T_b in 5 x 5 pixels for the Kalpana TIR image and 3 x 3 pixels for AIRS surrounding the central pixel is computed, which corresponds to the scene of approximately 50 km x 50 km. If the standard deviation is less than 2 K, then the scene is considered as uniform and the collocated pair at the central pixel is considered for inter-calibration.

iii. **Spatial collocation test**
After the application of environment uniformity test we re-sampled the Kalpana and AIRS observations to the coarser resolution of 0.2° which corresponds to approximately 20 km. This is accomplished by averaging of 2 x 2 pixels of Kalpana over AIRS FOV. This averaging will not introduce much error as the observations have satisfied the uniform scene condition over 50 km x 50 km.

iv. **Satellite zenith angle difference test**
Since AIRS and Kalpana observations are at different zenith angles (β) it is required to compare similar zenith angle observations. In order to keep the difference in path length small we use the following test:

$$| \sec(\beta_{AIRS}) - \sec(\beta_{Kalpana}) | < 0.01.$$

References

Wu, X., 2009: GSICS Algorithm Theoretical Basis Document (ATBD) for GOES-AIRS Inter-Calibration, NOAA. Found at https://gsics.nesdis.noaa.gov/wiki/Development/AtbdCentral.

Kalpana Thermal IR Channel Inter-calibration using AIRS Measurements: Results

The present inter-calibration study has been conducted during January, April and October 2009. The month of July is not presented due to heavy cloudy conditions in the monsoon season. The AIRS granules (recording of 6 minutes) in both ascending (daytime) and descending (nighttime) mode have been used. The observations for daytime and nighttime have been compared separately to examine the bias in the Kalpana observation. Since the sub-satellite point of Kalpana is at (0°N, 74°E), we have restricted the study over the region bounded by 30°N-30°S and 50°E-100°E. The statistics for the collocated pairs in each day have been generated separately for day and night time observations.

Figure 1 shows a sample comparison of brightness temperature (T_b) over an AIRS granule using convolved AIRS radiances and Kalpana observation. In general there is a good match in the brightness temperature observed from Kalpana and that convolved using AIRS observations. However, there are large differences in T_b over those regions where, differences in the zenith angle between AIRS and Kalpana observations are large (not shown). The statistics are computed for the dataset that is collocated using the procedure explained in the previous article. Statistics are computed separately for day and night time, corresponding to the AIRS overpass in ascending and descending orbits, respectively. We have further classified the collocated data in two sets, (i) having all collocated pairs and (ii) collocated pairs with zenith angle, β < 20°.

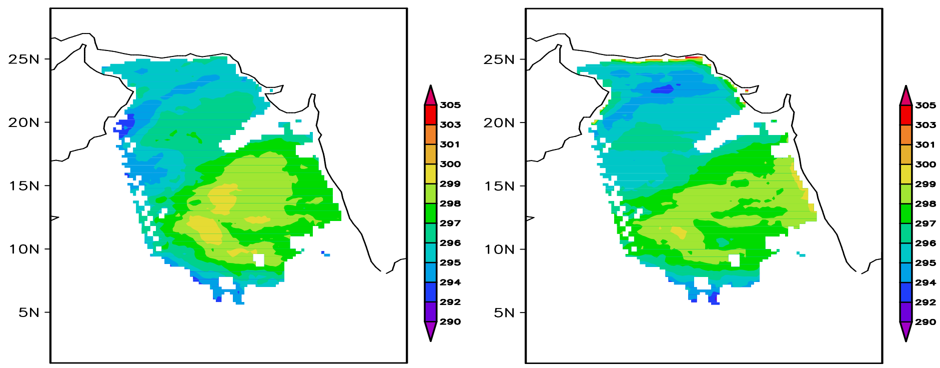

Figure 1. Comparison of Kalpana TIR T_bs over AIRS granule using (left) convolved AIRS radiances (right) Kalpana Radiances.

Figure 2 show the time-series and histogram of the daytime statistics of RMSE and BIAS from Kalpana T_b simulated from AIRS radiances minus observed Kalpana T_b values.

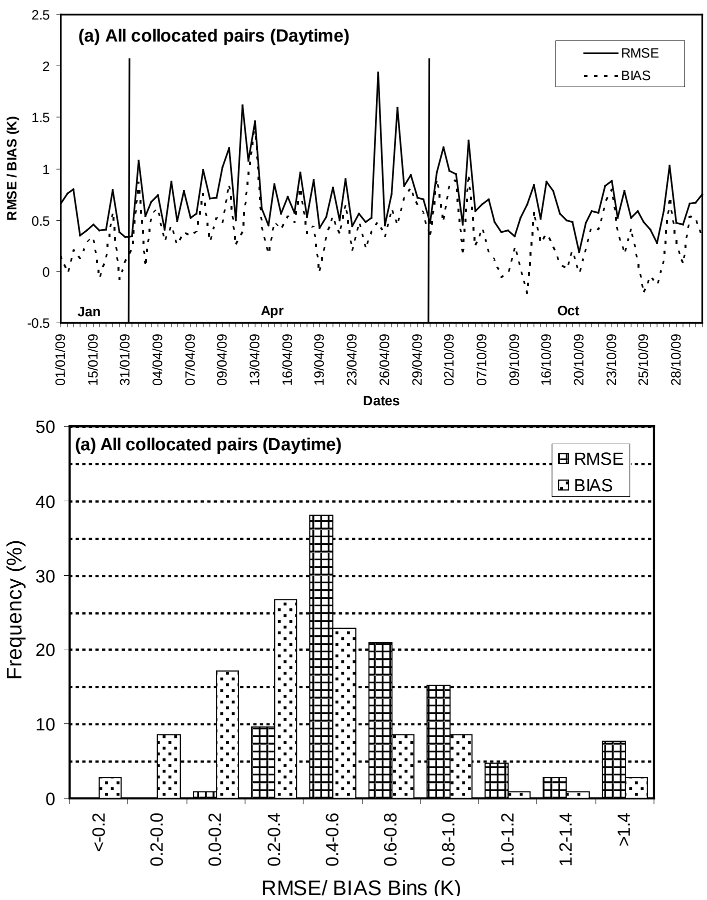

Figure 2. (top) Time-series and **(bottom)** histogram of daytime estimates of RMSE and BIAS of Kalpana TIR T_b with respect to convolved AIRS T_b for entire dataset.

It may be noted that the RMSE and BIAS for the entire data set, and for the collocated pairs with zenith angle of observations smaller than 20° (not shown), are within 1K for most of the time. On the other hand, the RMSE for the data set with zenith angle of observations less than 20° has smaller errors. However, there is a large cold bias in the Kalpana observations throughout most of the time-series. The bottom panel of Figure 2 shows the histogram of RMSE and BIAS for daytime Kalpana observations. This shows that about 40 % of observation RMSE values lie between 0.4-0.6K with the BIAS peaking at 0.2-0.4K for the entire dataset. For the dataset with β < 20°, the frequency of both RMSE and BIAS values peak between 0.4-0.6K (not shown).

Similar statistics have been generated for the nighttime observations, and these are shown in Figures 3 and 4. Figure 3 shows that there is an RMSE of more than 1.5K throughout the time-series with almost equal amount of cold bias during nighttime observations. Meanwhile, the histogram in Figure 4

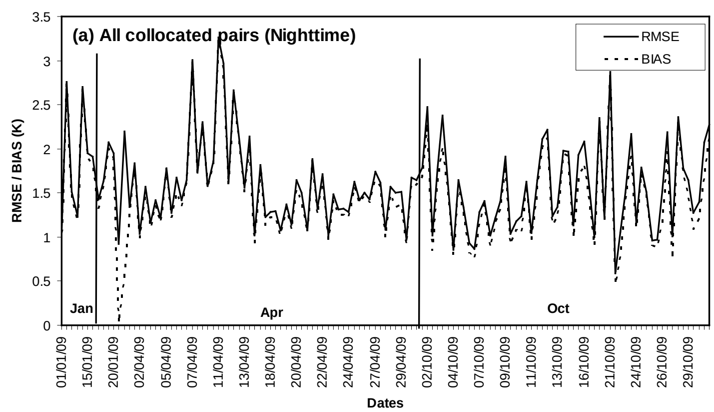

Figure 3. Time-series of nighttime estimates of RMSE and BIAS of Kalpana TIR T_b from convolved AIRS T_b for entire dataset.

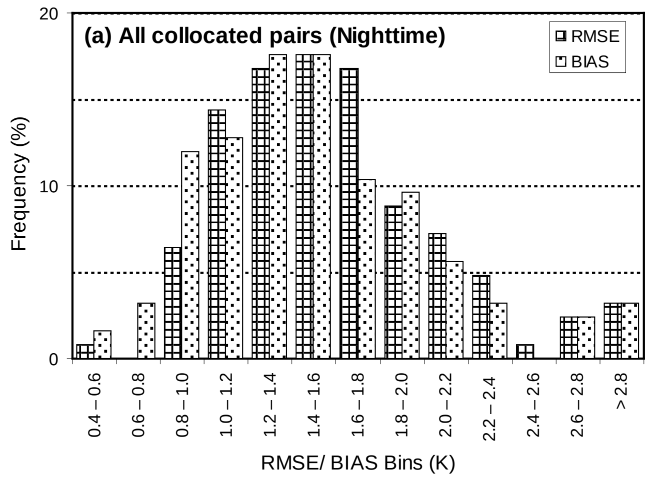

Figure 4. Histogram of the nighttime RMSE and BIAS in the Kaplana TIR T_b from AIRS observations.

shows high frequency of occurrence in RMSE and BIAS in the range of 1.0K - 1.8K.

The combined statistics has been presented in the Table 1. Though the RMSE values are higher during nighttime (1.43K and 1.45K) as compared to the daytime (0.71K and 0.58K), it is mainly due to the large cold bias in the Kalpana observations during nighttime (1.29K and 1.32K) as compared to the daytime (0.33K). The standard deviation of the differences between the Kalpana brightness temperature and the AIRS observations are consistently in the range of 0.5-0.6K. These results are comparable with previous studies for inter-calibration (Wang *et al*. 2007; Gunshor *et al.* 2004, 2006; Tobin *et al.* 2006). However, the large cold bias of ~1.3K in the Kalpana observations with respect to the AIRS measurements requires further study to find the underlying reason.

Table 1. Statistics of the Kalpana observed TIR brightness temperature with that obtained from AIRS

Dataset	No. of collocated pairs	RMSE	BIAS	Std. Dev.
Day (all β)	14034	0.71	0.33	0.63
Day (β<20°)	11285	0.58	0.33	0.48
Night (all β)	12123	1.43	1.29	0.62
Night (β<20°)	9495	1.45	1.32	0.61

References

Gunshor, M. M., T J Schmit, W. P. Menzel and D. C. Tobin, 2006: "Intercalibration of the newest geostationary imagers via high spectral resolution AIRS data", Preprints, *14th Conf. on Satellite Meteorology and Oceanography*, Atlanta, GA, Amer. Meteor. Soc., CD-ROM, P6.13.

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Wang, L., C Cao and P Ciren, 2007: "Assessing NOAA-16 HIRS Radiance accuracy using simultaneous nadir overpass observations from AIRS", *J. Atmos. Oceanic Technol.*, **24**, 1546-1561.

Tobin, D. C., H. E. Revercomb, C. C. Moeller, and T. Pagano, 2006: "Use of Atmospheric Infrared Sounder high-spectral resolution spectra to assess the calibration of Moderate Resolution Imaging Spectroradiometer on EOS Aqua", *J. Geophys. Res.*, **111,** D09S05, doi:10.1029/2005JD006095.

(M.V. Shukla, P. K. Thapliyal and P.K. Pal [Space Applications Centre, Indian Space Research Organisation (ISRO), Ahmedabad-380015, Email: pkthapliyal@sac.isro.gov.in])

Traceability Statement for IASI and AIRS

A key aspect to GSICS is to provide evidence to support applicability of the inter-calibration products we develop. A document has been prepared collaboratively by GSICS partners at EUMETSAT, NOAA, NIST and CNES to provide a statement demonstrating the suitability of the hyperspectral spectrometers, AIRS and IASI as inter-calibration references.

This discusses the various pre-flight and in-orbit tests that have been performed on these instruments. Particular attention is paid to their relative stability, as this is critical if they are to be used inter-changeably. Various methods are described which show that AIRS and IASI offer consistent radiometric calibration – each with uncertainties ~0.1K (k=1).

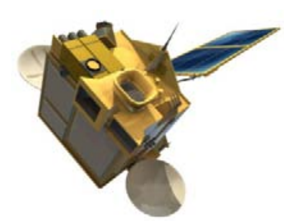
The statement also discusses the traceability chain of AIRS and IASI to the SI international reference standards, which is needed to achieve the long-term goal of GSICS.

The Traceability Statement is now available in PDF form from the website: http://www.eumetsat.int/groups/sir/documents/document/pdf_trace_stat_iasi_airs.pdf.

(By Dr. T. Hewison [EUMETSAT])

News in this Quarter

First Korean Meteorological Satellite COMS



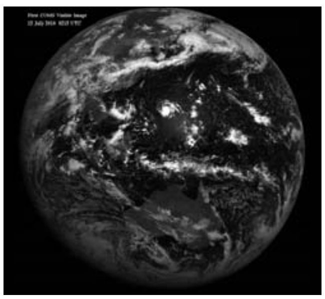
Communication, Ocean, and Meteorological Satellite (COMS), the first geostationary weather satellite of Korea has been launched successfully from the Ariane space launch site in Kourou, French Guiana at 21:41 GMT on June 26, 2010. It was in development for 7 years, under collaboration between four organizations including Korea Meteorological Administration (KMA). A mid-large sized satellite with a launch mass of 2,500 kg, COMS is located at 128.2˚E, 36,000km above the equator. Korea has become the world's 7th nation to have an independent meteorological satellite.

COMS observes the Earth using one visible channel and four infrared channels. COMS produces full disk imagery every three hours and extended Northern Hemisphere imagery every 15 minutes. In particular, COMS has been focusing on the Korean Peninsula eight times an hour for early detection of rapidly developing high-impact weather events such as typhoons and summertime heavy rains which are four times more frequent now than in the past.

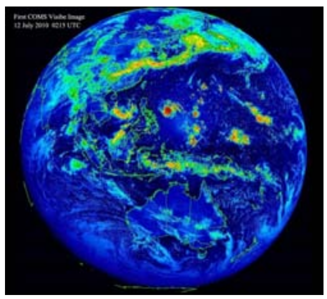
COMS on-orbit post launch test was started on July 5, 2010 and lasted until the end of January 2011. On-orbit tests ensure the satellite's operation and verify the integrity of the communications payload and the quality of the meteorological imagery prior to release of the public service. The first COMS visible image was received on July 12 at 0215UTC and confirmed the radiometric and geometric performance in flight. COMS IR images were taken on August 11 after outgassing.

COMS Meteorological Data Processing System (CMDPS) is the product of independent and domestic technology. The development project, which started in 2003, brought together 10 experts from 8 universities for a partnership between industry, academia, and the research community. CMDPS provides 16 baseline products including information on atmospheric motion vectors, Asian dust, sea-surface temperature and land-surface temperature over the East Asian region. These products will help improve the performance of NWP models for weather analysis and forecast. In the long run, they will be used in the analysis and prediction of climate change around the Asian region.

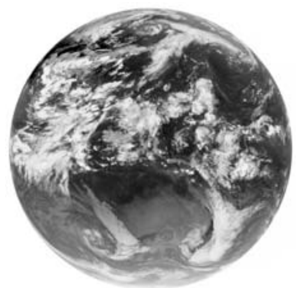
Starting in April 2011, National Meteorological Satellite Center (NMSC) will be providing COMS data free of charge to countries in the Asia Pacific region. It will also actively deploy the satellite receiving system support project for the countries in Southeast Asia for improving the utilization of satellite data. In particular, KMA National Meteorological Satellite Center (NMSC) has been providing a training program for about one month for the forecasters and satellite imaging analysis experts in the Asia Pacific region including the Philippines, Vietnam, Mongolia and Papua New Guinea every year since 2007.



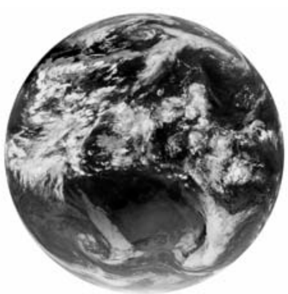
Visible (original)



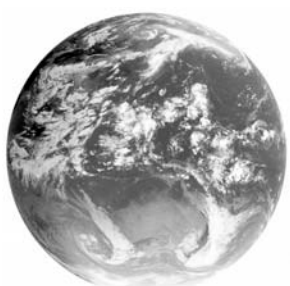
Visible (colored)



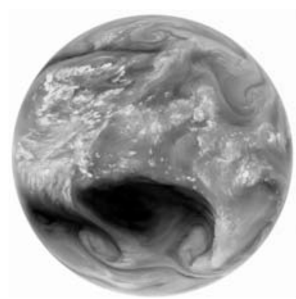
IR1 (11μm)



IR2 (12μm)



SWIR (3.5μm)



WV (6.7μm)

The first COMS VIS image from July 12, 2010 at 0215 UTC, and IR images from August 11, 2010 at 1014 UTC.

(by J. Park [KMA])

Just Around the Bend …

GSICS-Related Meetings

- **CALCON Technical Conference, 29 August to 1 September 2011, Logan, UT. High-level Agenda:**
  - Pre-launch testing and post-launch performance
  - Inter-calibration and validation of operational sensors
  - Radiometric sensor calibration uncertainty and error analysis
  - Calibration methods using celestial objects
  - Calibration of microwave radiometers and other microwave instruments
  - Calibration data analysis methods and software
  - Calibration methods for climate change measurements and modeling

- **Third GSICS Users' Workshop, 6 September 2011, Oslo, Norway (held in conjunction with the 2011 EUMETSAT Satellite Conference). High-level Agenda:**
  - GSICS status on activities and existing products
  - GSICS strategy for inter-calibration of solar channels
  - GSICS strategy for LEO to LEO products, especially µwave inter-calibration - an outreach to possible beta-testers
  - MODIS Product Uncertainty Index
  - Need for common reference channels
  - GSICS Work on the Chinese instrument MERSI
  - GSICS relation to GRUAN

GSICS-Related Publications

Eplee, R. et al., 2011: Cross calibration of SeaWiFS and MODIS using on-orbit observations of the Moon. *Applied Optics*. **50**, 120-133.

Heidinger, A. et al., 2010: Deriving an inter-sensor consistent calibration for the AVHRR solar reflectance data record. *Intl. Journal of Remote Sensing*, **31**, No. 24, 6493-6517.

Jupp, F. L. et al., 2010: An Evaluation of the Use of Atmospheric and BRDF Correction to Standardize Landsat Data. *IEEE Journal of Selected Topics in Applied Earth Obs. and Remote Sensing*. **3,** No. 3, 257.

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

GSICS Classifieds

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With Help from our Friends:

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

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