Evaluating the calibration of MTSAT-1R infrared channels using collocated Terra MODIS measurements

Hye-Sook Park and Byung-Ju Sohn

School of Earth and Environmental Sciences, Seoul National University, Mail Code NS80, Seoul, 151-747, Korea
E-mail: parkhs@eosat.snu.ac.kr

Abstract

The calibration of four MTSAT-1R infrared channels was evaluated by comparing MTSAT measurements with Terra/MODIS inferred MTSAT-equivalent brightness temperatures during 13 months since August 2005. Theoretical relationships converting MODIS brightness temperatures to MTSAT-equivalent values were obtained and used for the comparison. Results indicate that MTSAT two split window channels are well calibrated and no serious systematic errors or biases are found; and the MTSAT water vapor channel shows a good linear relationship but with a positive bias of around 1.7 K. The significant cold bias of about -7.8 K shown before February 2006 is found to be much removed into about -0.6 K in July 2006, after correction of the electrical crosstalk between MTSAT-1R SWIR channel and WV channel starting from March 2006. Since then calibration performances of MTSAT-1R split window channels and shortwave IR channel seems to be comparable to MODIS calibration while water vapor channel shows more uncertainties around 1.7 K bias.

1. Introduction

The Multi-functional Transport Satellite (MTSAT) 1R (hereafter MTSAT-1R) of Japan Meteorological Agency was launched on 26 February 2005. MTSAT-1R carries a 5-channel imager called Japanese Advanced Meteorological Imager (JAMI) providing nominal half-hourly images. The JAMI consists of one visible channel with a 1 km field of view (FOV) and four infrared (IR) channels (i.e. two split window channels, one water vapor channel, and one shortwave infrared channel) with about 4 km FOV at the nadir. Accurate measurements of meteorological/geophysical parameters from satellite radiometric data require absolute calibration. The calibration establishes a functional relationship to transform satellite-estimated digital counts into physically meaningful quantity, i.e. radiance. In principle, the radiometric performance characterized before the launch can be used for the calibration during the flight. However, it is in practice not much useful because of various undetected performance anomalies and sensitivity changes of the detector due to the aging processes, leaving frequent update of calibration status (Weinreb et al., 1997).
Absolute calibration in the shortwave infrared and thermal infrared channels is possible using onboard blackbody calibration facility. The MTSAT-1R onboard calibration system provides calibration coefficients for four infrared channels by combining looks to the space and to the blackbody source (Puschell et al., 2002). MTSAT-1R calibration accuracies for infrared channels are claimed to be 0.18 K at 300 K for the two split window channels and the shortwave infrared channel, and 0.15 K at 300 K for the water vapor channel (Puschell et al., 2002; CGMS, 2005). However, considering that radiometric responses and blackbody optics may change during the flight, assessment of those performances is necessary using alternative (or vicarious) calibration methods for the better understanding of "what degree of accuracies the MTSAT-1R possesses". Calibration can be achieved with success through the radiative transfer calculation (van de Berg et al., 1995) or the intercomparison with other well-calibrated satellite sensors (König et al., 1999; Sohn et al., 2000; Bréon et al, 2000; Tjemkes et al., 2001 among others).

In this paper we intend to assess calibration accuracies of MTSAT-1R infrared channels by comparing MTSAT-1R measured brightness temperatures with ones from other satellite sensors that have similar spectral response functions and are well calibrated. In doing so, we use the Moderate-resolution Imaging Spectrometer (MODIS) on the sun synchronous polar orbiting NASA’s Earth Observing System (EOS) Terra platform that carries similar spectral channels and has high radiometric accuracy performance (Moeller et al., 2003).

2. MTSAT-1R and MODIS data

The MTSAT-1R satellite observes earth-atmospheric conditions with four infrared channels whose response functions are centered at 10.8, 12.0, 6.8 and 3.8 µm. Here those four channels are referred to as split window channel 1 (WIN1), split window channel 2 (WIN2), water vapor channel (WV), and shortwave infrared channel (SWIR), respectively.

Assessing the accuracies of MTSAT-1R IR channel calibration, MODIS measurements at the similar bands are used. Amongst 36 spectral channels in the 0.405-14.385 µm spectral range, Terra/MODIS level 1B radiances at band 20 (3.75 µm), 27 (6.72 µm), 31 (11.03 µm), and 32 (12.02 µm) are used as a reference for assessing the calibration performance of MTSAT-1R IR channels. Sensor response functions of MTSAT-1R and corresponding MODIS channels of interest are given in Figure 1. It is indicated that the spectral response functions of MTSAT-1R infrared channels and Terra/MODIS channels are in similar spectral bands. The MODIS in-orbit calibration and characterization were performed using its on-board calibrators. MODIS has a typical radiance prelaunch specifications of 0.75%, 1%, 0.5%, and 0.5% for SWIR (3.75 µm), WV (6.72 µm), WIN1 (11.03 µm), and WIN2 (12.02 µm) band, respectively, whose corresponding brightness temperatures are about 0.18 K, 0.27 K, 0.34 K, and 0.37 K (Xiong et al. 2005). Based on the comparison of Terra MODIS with contemporaneous measurements by NASA ER-2 underflights it was reported that the absolute accuracies of MODIS measurements should not be worse than claimed radiometric
accuracies (Moeller et al. 2003). Thus with those accuracies MODIS measurements can be used for evaluating other instruments when they are carefully intercompared.

![Figure 1. Spectral response functions of four infrared channels of MTSAT-1R (solid line) and MODIS (dotted line).](image)

3. Construction of match-up data

Collocated match-up data are constructed from hourly MTSAT-1R HiRiD IR images and MODIS measurements for 13 months from August 2005 to August 2006 over the 40°N-40°S and 100°E-180°E analysis domain. For the SWIR channel, only nighttime images are used to exclude solar reflection effect during the daytime.

The intercomparison method compares the observations from two satellites in which sensor spectral response functions are similar to each other over the defined bands. Even so, since two instruments are mounted on different satellite platforms the time-space resolution and viewing geometry are quite different from each other. In order to remove effects of different spatial and temporal resolutions and viewing geometry differences, tight collocation criteria are set as follows. As the atmosphere is constantly in motion and clouds particularly vary rapidly within a short period, simultaneous observations at the same target must be compared for the inter-satellite calibration. Taking different spatial resolutions caused by different satellites into account, we project measurements from different sensors onto one common reference. Brightness temperatures from each satellite are averaged and reformatted into the 0.2 x 0.2° grid to mitigate effects of different spatial resolutions. Brightness temperatures were averaged only when all pixels within the 0.2° grid are entirely filled with clear pixels to mitigate effect of cloud contamination. MODIS level 2 cloud mask products (MOD35_L2) were used to ensure the removal of cloud-contaminated scenes. Also applied was the homogeneity criterion which can remove the targets contaminated by clouds or coastal line. If there is any pixel within a 0.2° x 0.2° target whose brightness temperature difference from the grid mean is larger than 1K, then the grid target was discarded. As a second step, grid data are selected when observations from two satellites are within the ±5 minute time difference.

Data are further processed for the construction of match-up data when an absolute difference in viewing angle between two observations is less than 5° because the satellite zenith angle can have a
large effect on measured brightness temperatures and the effect is dependent upon wavelength (Gunshor et al., 2004).

4. Development of conversion function

The radiance measured by a satellite detector \( (N_{\Delta \lambda}) \) is the integrated value of spectral radiance \( (N_{\Delta \lambda}) \) at the top of atmosphere (TOA) over the wavelength interval \( (\lambda_1, \lambda_2) \), but weighted and normalized by the response function for the channel, i.e.:

\[
N_{\Delta \lambda} \equiv \frac{\int_{\lambda_1}^{\lambda_2} \Phi(\bar{\lambda}, \lambda) N_{\Delta \lambda} d\lambda}{\int_{\lambda_1}^{\lambda_2} \Phi(\bar{\lambda}, \lambda) d\lambda}
\]

(1)

where \( \Phi(\bar{\lambda}, \lambda) \) is the instrumental response function and \( \bar{\lambda} \) is the mean wavelength of the band.

Since the radiance measured by satellite varies with the instrumental response function as shown in equation (1), differences in response function must be accounted for the comparison of measurements from different sensors. Given different spectral response functions (Figure. 1), we develop conversion functions based on radiative transfer calculations to convert MODIS brightness temperature into MTSAT-1R equivalent brightness temperature.

Conversion functions are obtained from simulated MODIS \( (TB_{MODIS}) \) and MTSAT-1R brightness temperatures \( (TB_{MTSAT}) \) by considering that brightness temperature at one channel can be linearly expressed by other similar spectral channel, i.e.:

\[
TB_{MTSAT} = a + b TB_{MODIS}
\]

(2)

where \( a \) and \( b \) are interception and slope, respectively. For the simulation of brightness temperatures we use the RTTOV-7 radiative transfer model (Saunders, 2002) with Thermodynamic Initial Guess Retrieval 2000 (Chédin et al. 1985; Chevallier et al. 1998) profile data as inputs. TIGR 2000 data set contains climatological 2311 temperature, water vapor and ozone profiles over the globe. Instrumental noise was added to the simulated brightness temperatures by assuming a normal distribution of the noise with a mean of zero and one standard deviation equal to the \( \text{NEAT} \).

Coefficients \( a \) and \( b \) are determined by regressing the simulated MODIS brightness temperatures to simulated MTSAT temperatures. Since viewing geometry and surface type also affect the TOA radiance, simulations and regressions are made at every 5° viewing angle, and over land and ocean, respectively. It is noted that correlation coefficients from each regression appear to be close to 1, manifesting a nearly perfect linear relationship between paired two channels.

5. Results

Using Eq. (2) with obtained coefficients \( a \) and \( b \), the MTSAT-1R IR brightness temperatures are predicted from corresponding MODIS channel brightness temperatures. Figure 2 displays the scatterplots of observed versus predicted brightness temperatures of MTSAT-1R WIN1, WIN2, WV,
and SWIR channels for 13 months from August 2005 to August 2006. Dashed lines represent regression lines while solid lines are for the perfect matches.

![Scatterplots](image)

**Figure 2.** Scatterplots of measured MTSAT-1R and MODIS equivalent MTSAT-1R brightness temperatures during 13 months from August 2005 to August 2006 for (a) split window channel 1, (b) split window channel 2, (c) water vapor channel, and (d) shortwave infrared channel. For figure (d), black, cyan and pink dots represent the results before, during and after crosstalk correction.

The measured MTSAT WIN1 brightness temperatures are in good agreement with predicted TBs from MODIS data (Figure. 3a). A correlation coefficient of 0.99 is shown with a mean bias of -0.19 K. The slope of 0.98 is smaller than unity and intercept is 4.62 K, indicating that measured MTSAT WIN1 TBs at the warmer targets are slightly larger than those inferred from MODIS and vice versa.

Scatterplot for the measured versus predicted MTSAT-1R WIN2 brightness temperatures is given in Figure 3b. Correlation coefficient, mean bias, slope, intercept point resulted from 58032 data points are 0.99, 0.23 K, 0.99, and 1.73 K, respectively, with a root mean square error (RMSE) around 0.67 K. Similar to the WIN1, statistics suggest that the current calibration for MTSAT-1R WIN2
channel is as good as the corresponding MODIS channel.

The measured MTSAT-1R WV channel brightness temperatures are compared with predicted values (Figure 3c). A good linear relationship is also shown with a slope of 1.03 and an intercept point of -9.58 K. The mean bias up to 1.7 K with RMSE of 1.8 K is noted, indicating that MTSAT-1R WV channel slightly overestimates brightness temperature in comparison to the MTSAT-equivalent MODIS WV channel values.

Scatterplot for the SWIR channel is given in figure 3d. In Figure 3d, the black dots represent the intercomparison results from August 2005 to 18 on February 2006. In comparison to other three IR channels, the MTSAT-1R SWIR channel (shown in black dots) shows a much larger cold bias about -7.8 K, indicating a significant underestimate of brightness temperature compared to what suggested from MODIS measurements. Furthermore, the RMSE of about 7.93 K appears to be much larger than other three IR channels. It has been reported that there existed an electrical crosstalk between MTSAT-1R SWIR channel and WV channel and corrections were made after March 2006 (Puschell et al. 2006). In order to examine what extent of improvement has been made for the SWIR channel, we analyzed the SWIR channel by dividing before and after crosstalk correction periods in the same way as in generating figure 3 and results are given in figure 3d in cyan and red colors. The cyan and pink dots are the results during and after crosstalk correction periods, respectively. The crosstalk periods are from 19 on February to 30 on June in 2006. In comparison to results before electrical crosstalk, the Scatterplots (shown as pink dots) after correction show a much better agreement of MTSAT-1R SWIR brightness temperatures with MODIS-inferred brightness temperatures, with correlation coefficient of 0.99, mean bias of -0.59 K, and slope of unity. A much small RMSE of 0.65 K is noted after crosstalk correction periods, in comparison to an RMSE of 7.9 K before Mid of February 2006. Also noted is that the abnormal large errors shown in SWIR channel is no longer present after July in 2006, suggesting that the calibration of SWIR channel has been much improved after the crosstalk correction. Thus, the MTSAT-1R calibrations after the correction of SWIR/WV channel crosstalk appear to be as good as those of MODIS measurements although the WV channel shows an overestimate around 1.7 K.

6. Conclusions

We assessed the calibration performance of four MTSAT-1R infrared channels by converting the corresponding MODIS measurements to the MTSAT-equivalent values by applying theoretically developed transfer functions. In doing so, collocated brightness temperatures from MTSAT-1R and Terra/MODIS for 13 months from August 2005 to August 2006 over the 40°N-40°S and 100°E-180°E domain were used in conjunction with MODIS cloud mask products for selecting clear-sky and homogeneous targets.

As shown in the summarized results in Figure 2, two split window channels appear to be well calibrated and no serious systematic errors or biases are found, when MODIS values are considered as references. The water vapor channel also shows a well-calibrated behavior, but with a warm bias...
around 1.7 K. On the other hand, the large negative bias around -7.8 K in SWIR channel became much smaller after the electrical crosstalk correction done in February 2006. Taking the statistical results obtained for 13 months since August 2005, we conclude that calibration performances of MTSAT-1R split window channels and shortwave IR channel seems to be comparable to MODIS calibration while water vapor channel shows more uncertainties.

7. Acknowledgments
This research has been supported by the Korean Geostationary Satellite Program (COMS) funded through Korean Meteorological Administration (KMA) and by the BK21 Project of the Korean Government.

8. References
CGMS, 2005: Long-term satellite activities of JMA to materialize a robust satellite observing system. The 33rd CGMS, 1-4 Nov., Tokyo, Japan, Paper No. CGMS-XXXIII JMA-WP-06.


