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Examining the Calibration Performance of Communication, Ocean and Meteorological Satellite (COMS) Visible Channel Using Cloud Targets

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1. INTRODUCTION

Communication, Ocean and Meteorological Satellite (COMS) satellite is the first Korean geostationary satellite, which was launched on June 2010. COMS orbits the Earth at an altitude of 36,000 km, and its sub-satellite point is located at (128.2°E, 0°N). Meteorologial Imager (MI) aboard COMS has one solar channel and four emissive channels, and their spatial resolutions are 1 km and 4 km, respectively. Since onboard calibration system for COMS solar channel is not prepared, vicarious calibration is essential for the accurate monitoring weather and climate from space.

Inter-satellite calibration is a useful method that has been used in many studies (e.g., Minnis et al., 2002a, b). However, if spectral characteristics of the sensor response functions (SRFs) are considerably different, the spectral relation between the two sensors strongly depends on atmospheric conditions. Furthermore, in the case of polar-to-polar orbit satellites, inter-calibration is not practicable because the ray-matching conditions are not easy to find.

On the contrary, vicarious calibration based on the radiative transfer simulation of satellite-level radiance does not require that the two satellites match geometrically. This type of calibration instead requires other auxiliary data, such as surface, atmosphere, aerosol, and cloud parameters, which are needed for specifying inputs to the radiative transfer model (RTM). Compared to ocean or desert targets, the intended simulation accuracy can be more easily achieved using cloud targets because uncertainties induced by other input parameters are relatively small, compared to the high reflectance of cloud targets. Moreover, because of the strong reflection by the cloud layer, surface and atmospheric profiles have a negligible impact on the top-of-atmosphere (TOA) simulation, and thus climatological values can be used for specifying surface and atmospheric properties. This is particularly true for deep convective clouds (DCCs) (Sohn et al., 2009).

In this study, we explore the use of cloud targets to calibrate solar channels of satellite sensor using two modeling methods. Finally, the ray-matching method and the two cloud modeling methods are applied to examine the calibration status of visible sensor onboard COMS satellite.

2. METHODOLOGY

2.1. *Method 1: The ray-matching technique*

As a reference, measurements from well-calibrated Moderate Resolution Imaging Spectroradiometer (MODIS) 0.646-μm channels aboard Terra and Aqua are compared to COMS 0.677-μm channel measurements. Since pixel locations of MODIS and COMS are different, two satellite pixel measurements are averaged in a 0.5°×0.5° grid format. In addition, time differences of up to 5 minutes between COMS and MODIS measurements are permitted. The collocated targets

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are only collected over the ocean to minimize surface influences. Moreover, because visible reflectance is sensitive to both the viewing zenith angle (VZA) and the viewing azimuth angle (VAA), sensor viewing geometries are considered to satisfy thresholds of 5° for VZA differences and 15° for VAA differences. Limits of the solar zenith angle (SZA) ≤ 40° and VZA ≤ 40° are also applied to minimize navigation errors. Note that the collocation is made regardless of the presence of clouds.

Because the SRF determines the magnitude of gas absorption and scattering, cloud extinction, and surface reflectance for the given band, the spectral differences between COMS and MODIS should be considered for the intercomparison. To obtain theoretical relations between two sensors, radiative transfer simulations are performed using Santa Barbara Disort Radiative Transfer (SBDART; Ricchiazzi et al., 1998) model. In the simulation, various conditions of surface reflectance, atmospheric profile, SZA, VZA, cloud optical thickness (COT), and effective sizes are considered, as in Ham and Sohn (2010).

Regardless of RTM input parameters, strong linear relationships are shown between two channel reflectances (not shown), suggesting that the regression equation can be reliably used to convert MODIS channel reflectances into COMS channel reflectances. Eqs. (1) and (2) show regression equations between the COMS solar channel and MODIS 0.646-μm channel. In these regressions, two MODIS sensors aboard Terra and Aqua are separately related to the COMS channel reflectances

$$R_{COMS} = 1.0099\, R_{TERRA} - 0.0021 \qquad (1)$$

$$R_{COMS} = 1.0104\, R_{AQUA} - 0.0021 \qquad (2)$$

In Eqs. (1) and (2), R_{TERRA} and R_{AQUA} are the reflectances at the MODIS 0.646-μm channels aboard Terra and Aqua, respectively; and R_{COMS} is the reflectance at the MI 0.677-μm channel aboard COMS. Using Eqs. (1) and (2), the observed MODIS reflectances are converted to reflectances at the COMS solar channel, with a MODIS-equivalent accuracy. Therefore, if the given sensor is calibrated with the same accuracy as that of MODIS, the observed reflectances would be very similar to those obtained from the regression equations.

2.2. *Use of MODIS cloud products as inputs to RTM*

As in Method 1, all satellite measurements are converted into 0.5°-grid data for the collocation only over the ocean, and grid data are selected if the observation time difference is less than 5 minutes. Note that differences in sensor viewing angles are not counted, while threshold conditions of SZA ≤ 40° and VZA ≤ 40° are applied to minimize navigation errors and three-dimensional (3D) radiative effects. After applying MODIS cloud mask information, only the homogeneous 0.5° grid boxes that are filled entirely with cloud pixels are considered when standard deviation (STD) of visible reflectance ≤ 0.1. Finally, grid boxes showing a COT smaller than 5 are discarded to minimize ocean surface influences.

For selected cloud grid targets, sensor-reaching reflectances are simulated using collocated MODIS-derived cloud products, such as COT, cloud effective radius, cloud top pressure (CTP), and cloud top temperature (CTT). To determine the dominant cloud phase at a 0.5°-grid box, grid-averaged CTT is used, i.e. pure ice clouds are assumed for CTT ≤ 227 K, whereas water clouds are assumed for CTT ≥ 273 K. The cloud top height is obtained from the MODIS CTP, and then the cloud geometrical depth is set 1 km. In addition, standard tropical profiles are used to specify the atmospheric conditions. Surface reflectance is specified using the oceanic bidirectional distribution function (BRDF) model since cloud targets are chosen over the ocean.

With the given inputs, the SBDART model is used to calculate the channel reflectances. The SBDART model considers multiple scattering by atmospheric particles under the assumption of a plane-parallel atmosphere. Therefore, errors caused by the neglect of 3D radiative effects may be included in the simulation of 0.5°-grid reflectances. We investigate 3D effects of the cloud on the simulation by dividing the 3D effects into two parts: the effect associated with horizontal variations, i.e. plane parallel homogeneous (PPH) bias, and the effect associated with horizontal interactions, i.e. independent column approximation (ICA) bias. Finally, the PPH bias is avoided using the approach of Oreopoulos and Davies (1998). The ICA bias is included in this calculation because its contribution appeared negligible for large-scale (0.5° box) simulation of homogeneous clouds (STD of reflectance ≤ 0.1), under relatively small SZAs (≤ 40°).

2.3. *Method 3: Use of deep convective clouds (DCCs)*

A detailed description of this method is provided by (Sohn et al., 2009). Briefly, DCCs overshooting the tropical tropopause layer are selected from MODIS observations when the observed IR brightness temperatures at 11-μm channel (TB_{11}) ≤ 190 K. Moreover, two types of homogeneity checks are applied to exclude targets extending to the cloud edge. Pixels are selected when (1) STD of the visible reflectance normalized by their mean value in the surrounding 10 km x 10 km area is less than 0.03, and (2) STD of TB_{11} for the same area is less than 1 K.

Once DCC targets are selected, ice cloud phase is assumed since the uppermost part of clouds overshooting the TTL mostly contains nonspherical ice particles. In addition, for the radiative transfer simulation for DCCs, their COT and effective radius are assumed to be 200 and 20 μm, respectively. In addition, cloud altitude is assumed to be located between 1 km and 15 km, based on the fact that overshooting clouds are thicker than 10 km. Expecting insignificant influence of the atmosphere and surface on the DCC simulation, standard tropical atmospheric profiles and oceanic BRDF model are used, same as in Methods 1 and 2. Note that DCC targets are collected regardless of the land surface types, even though the oceanic BRDF model is used for the calculation of surface reflectance.

The SBDART RTM is used to calculate the visible channel reflectances of DCC targets, which may result in simulation biases by 3D effects, as in Method 2. However, considering that PPH bias is produced by a nonlinear relationship between COT and reflectance, and such a nonlinearity of reflectance mostly vanishes in the range of COT > 100, the PPH assumption appears to introduce only minor errors in the DCC simulation. Moreover, since horizontally homogeneous targets are only used for the calculation and the results are daily averaged, it is expected that ICA biases have negligible influences by smoothing out. The daily averaging is performed only if the number of selected DCC targets is greater than 10 per day.

3. Results

The measurements of COMS solar channel are compared against MODIS 0.646-μm channel measurements by applying Method 1. MODIS-equivalent COMS 0.677-μm channel reflectances are obtained by applying Eqs. (1)−(2). In Fig. 1, comparison is made for each month between measured COMS and MODIS-equivalent COMS reflectances. Except March 2011, the regression slopes are between 0.899 and 0.903, while intercepts are nearly zero (< 0.01). This suggests about 10% of low bias of COMS measurements against MODIS measurements. For the case of Mar 2011, it seems that some outliers near zero point reduce regression slope, but the general pattern is similar to those shown in other months.

COMS 0.677-μm channel reflectances are simulated using MODIS cloud products as inputs to an RTM, and these serve as references for examining COMS solar channel measurements (Method 2). In Fig. 2, comparisons are made between simulated and measured COMS solar channel reflectances for each month. In Fig. 2, regression lines are given as blue lines. Regression slopes are between 0.878 and 0.907, while regression intercepts are slightly larger than those shown in Method 1. In Fig. 2, regression lines from Method 1 are also given as red lines for comparing with Method 2 (blue lines). Although Method 2 generally produces smaller slopes and larger intercepts than Method 1 for overall periods, red and blue lines are mostly overlaid with each other. Therefore, it is concluded that Method 2 also provides a similar degree (10%) of low measurement biases of COMS 0.677-μm channel, in comparison to MODIS measurements. Slight differences in regression results between Methods 1 and 2 are likely due to the target reflectances larger than about 0.2 in Method 2, causing larger uncertainties in the regression intercepts.

DCC targets are selected using COMS window channel measurements, and the reference reflectances for those selected DCC targets are produced from simulations with characteristic cloud optical properties (Method 3). Results from Method 3 are directly compared with results from Methods 1 and 2, as shown in Fig. 3. Monthly regression lines from Methods 1 and 2 (shown in Figs. 1 and 2) are given as red and blue lines, respectively, while Method 3 results are given with crosses. Each cross in Method 3 results represents a daily average. DCC results are in near agreement with what predicted from two regression results, suggesting the measurement biases of COMS solar channel to be –9% and –10%.

4. Summary

In this paper we examined the performance of operational calibration of COMS 0.677-μm channel using three calibration methods. The first method is based on the ray-matching technique for inter-satellite calibration. MODIS 0.646-μm channel is used as a reference, and reflectances are compared between MODIS and COMS only over oceanic regions. The results obtained from the ray-matching technique indicate that COMS calibration coefficient is biased low by 10%.

The COMS channel reflectances are simulated using collocated MODIS cloud products, such as COT, particle effective radius, CTT, and CTP as inputs for the radiative transfer model. In the simulation, the method of Oreopoulos and Davies (1998) is adopted to describe the subgrid variability because the plane-parallel assumption at each grid box could generate simulation errors by 3D radiative effects. Suggested biases in COMS visible channel calibration from Method 2 appear to be consistent with results from the ray-matching technique (Method 1) since regression results from two methods are mostly overlapped.

Results from these two methods are compared with those derived from the DCC method (Method 3). It is shown that results from DCC method are consistent with results from other two methods, showing two regression lines going through a bundle of DCC-derived points. Overall, all three calibration methods show good agreement and suggest that the current COMS 0.677-μm channels underestimate reflectances by 9-10%.

Acknowledgments

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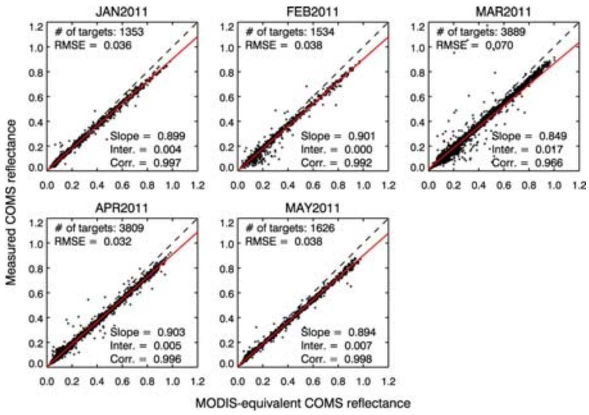

Fig. 1. Comparison between MODIS-equivalent COMS reflectances and measured COMS Level 1B reflectances.

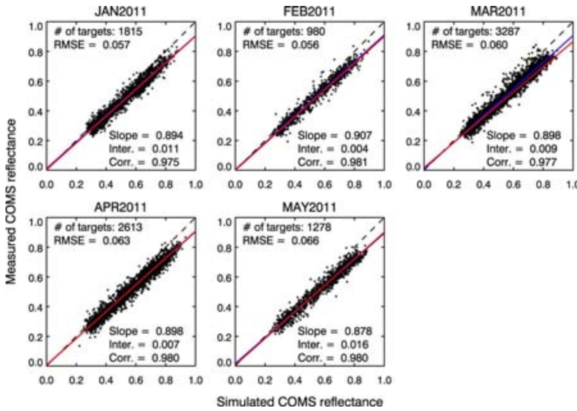

Fig. 2. Comparison between simulated COMS reflectances and measured COMS Level 1B reflectances. Regression lines from Methods 1 and 2 are given with red and blue lines, respectively.

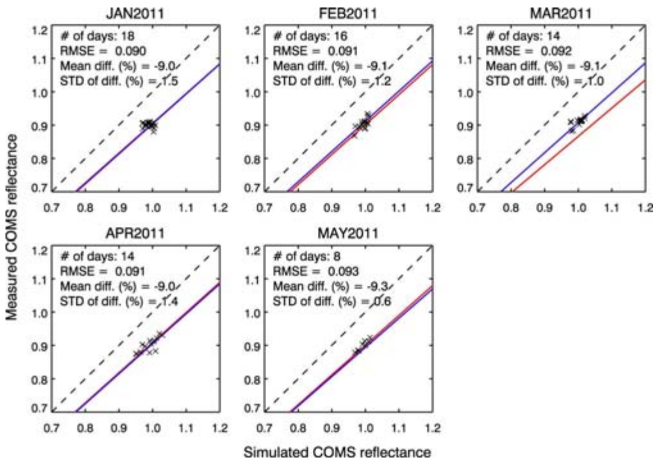

Figure 3. Comparison of Method 3 (crosses) against Method 1 (red line) and Method 2 (blue line). For Method 3, the daily average is calculated when the number of selected DCC targets is greater than 10.