A New Approach for Radiometric Cross Calibration of Satellite-borne Radiometers

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Abstract: *Approaches for establishing the absolute calibration of a newly deployed, satellite-borne radiometer have varied from aircraft under flights with previously calibrated sensors to vicarious calibration over known, benign backgrounds, utilizing radiative transfer models to generate top-of-atmosphere radiances. In this paper, we demonstrate the efficacy of this approach by presenting results of the cross-comparison of two sensors that are known to be well calibrated, Atmospheric Infrared Sounder (AIRS) and Moderate Resolution Imaging Spectroradiometer (MODIS). We focus on the results of the cross-comparison between MODIS and AIRS for the ranges of atmospheric and surface conditions embodied in a variety of common Earth scenes in this paper. We also investigate the dependence of the quality of the cross-calibration process as a function of the surface emissivity spectrum, phenomenology, and atmospheric conditions, identifying under what conditions the cross-calibration process is effective.*

I. INTRODUCTION

Establishing the long-term high quality the Earth System Data Records (ESDRs) with satellite remote sensing measurements will rely on the best efforts on instrument calibrations, so cross-sensor absolute radiometric calibrations are very critical and fundamental to ensure satellite measurements in the Climate Data Record (CDR) quality. Approaches for establishing the absolute calibration of a newly deployed, satellite-borne radiometer have run the gamut from aircraft under flights with previously calibrated sensors to vicarious calibration over known, benign backgrounds, utilizing radiative transfer models to generate top-of-atmosphere (TOA) radiances. Each of these approaches has its benefits and limitations. For example, in the former approach one must model the affect on the calibration from the intervening atmosphere between the aircraft and the satellite, while the latter approach requires an accurate validated radiative transfer model and detailed information on the atmospheric and surface conditions that the sensor is observing, either from insitu measurements or Numerical Weather Prediction (NWP) models. As a result, both approaches introduce errors into the calibration process that is difficult to quantify. Furthermore, limitations on geographic regions where aircraft measurements are available or ideal geophysical conditions for which radiative transfer models are reliable lead to a severe limitation on available data for analyses. Improving current cross-sensor calibration is an important issue.

George Mason University (GMU) has been working with scientists from Northrop Grumman Space Technology (NGST) on AIRS-MODIS band mapping algorithm and toolkit development for supporting the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and NPOESS Preparatory Project (NPP) missions. We develop spatial and spectral mapping technology and demonstrate the efficacy of this approach by presenting results of the cross-comparison of two-sensors: AIRS and MODIS. To enable this process, a number of tools have been developed to spatially match-up and aggregate the MODIS pixels to the AIRS Field-Of-View (FOV) and to perform the spectral simulation of the MODIS infrared bands using AIRS spectral radiances. A detailed description of these tools and their potential use for Cal/Val activities is provided in a companion paper (Hao, X. et al. "Development and enhancement of calibration/validation toolkit for

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supporting NPOESS/NPP missions", IGARSS05).

In this paper, we present an approach for cross-sensor calibration and focus on the results of the cross-comparison between MODIS and AIRS for the ranges of atmospheric and surface type conditions embodied in a variety of common Earth scenes. We used one-day (January 25, 2003) global AIRS and MODIS datasets to investigate the dependence of the quality of the cross-calibrations as a function of the surface types, surface emissivity spectrum and atmospheric conditions. We demonstrate that cross-calibrations are not simple approaches, they are can be done if we have valuable databases with calibration toolkits. We believe that this technology is useful for NPOESS and NPP mission and science support.

II. TECHNOLOGICAL STEPS

2.1. Spectral and Spatial Mapping

The AIRS and MODIS instruments are on boarded on Aqua satellite, so it provides a good chance to study the cross-sensor radiometric calibration of these two sensors. Because AIRS and MODIS have different spatial resolutions and scan geometries, for cross-calibration and cross-validation, we need to compare measurements from different sensors at co-located pixels, so spatial match-up is essential. Because AIRS is a satellite-borne high spectral instrument (with over 2300 wave numbers) designed for weather and climatic research, AIRS L1-B measurements can be also used to simulate broadband instruments, thus applied to cross-sensor validation and calibration. Both spectral and spatial mapping algorithms have been developed to support this approach. The MODIS related spectral response (RSR) functions were also used for mapping MODIS thermal infrared (TIR) radiances at AIRS footprints with AIRS high spectral measurements.

2.2 Database Designing

To study the cross-sensor calibration quality as a function of global geographic regions and phenomenology et al., we built a global database of simulated and aggregated MODIS at AIRS footprints with different surface types, geo-locations, scan angles, total precipitable water over air column, solar and satellite angles, surface and air temperatures, and cloud conditions. We used the 288 MODIS granules and 240 AIRS granules of one AIRS golden day, January 25, 2003. A wide range of problems requires reliable and accurate information on globe land cover, and in particular, the distribution and properties of vegetation. We used MODIS land cover datasets which include 17 International Geosphere-Biosphere Program (IGBP) surface types. Currently, the database includes 2916000 records over the AIRS foot prints on January 25, 2003, and 154 columns for simulated MODIS and aggregated MODIS thermal infra-red bands, and critical scene characteristics such as majority surface type, surface type percentage, solar and satellite view angles, atmospheric conditions. The database also includes simulated VIIRS thermal bands. We have developed a toolkit for database management and data analysis ([1]).

2.3 Filter Approaches

The database has a huge amount of records over various situations; it's quite difficult to analyze the data efficiently. To identify the primary factors that affect the difference between simulated MODIS and aggregated MODIS, we used filter approaches by setting constraints with parameters in the database. With successive filters, we can discover the relations of simulated MODIS and aggregated MODIS over various constraints.

For case study, we selected MODIS water vapor bands (27 and 28) and land surface temperature bands (22, 31 and 32). Table 1 shows pixel numbers used for compressive analysis for both cloud fraction ≤ 5% and all sky conditions. We defined cloud fraction ≤ 5% pixels as:

Cloud fraction (layer 1) >=0 & <=0.05 (1)
&
Cloud fraction (layer 2) >=0 &<=0.05 (2)

Generally speaking, the ratio between good quality cloud fraction ≤ 5% pixels and all sky conditions is less than 13%. There are around 357 thousands pixels with cloud fraction ≤ 5%. Under both all sky conditions and small cloud fractions, we analyzed data with filters over surface types, total precipitable water, solar zenith angles, etc..

III. PRELIMARY RESULTS

Based on our compressive analysis, we found that the qualities of cross calibration for MODIS mid-tropospheric water vapor sounding bands (27 and 28) are very good. The mean differences (biases) and standard deviations of simulated and aggregated BTs for water vapor bands (27 and 28) and surface temperature bands (22, 31 and 32) shown in table 1. The standard deviations are much small with could filters than all sky pixels. Figure 1 shows the difference between simulated and aggregated MODIS band 27 brightness temperature (BT) for all sky conditions (about 2.9 million pixels). The bias for band 27 is 1.467 degree K. The dynamic range of band 27 BTs is about 200-280 degree K. The histogram for band 27 shows in figure 2. The bias for band 27 is between 1 and 2 degree K, which is caused by an AIRS spectral measurement gap. When we apply cloud fraction filters, we can find more detailed information about bias distribution for "clear sky" conditions, and the standard deviation is much smaller in small cloud fraction conditions than that in all sky cases. Figure 4 shows the MODIS band 28 BT histogram. The bias is only 0.12 degree K for all sky conditions.

Table 1. Global one day AIRS golden day pixels (all vs. cloud fraction ≤ 5%)

Band	All pixel Standard deviation	Cloud ≤ 5% pixels standard deviation	All pixel biases	Cloud ≤5% pixel biases
27	1.4367K	0.6436K	1.467K	1.687K
28	2.1778K	0.7133K	0.120K	0.080K
22	4.2243K	2.2753K	0.166K	0.010K
31	4.6716K	2.1026K	0.149K	0.252K
32	4.6453K	2.1478K	0.086K	0.125K

We take one more step to study MODIS band 27 bias as a function of surface types. Figure 4 shows the biases as function of different IGBP surface types using MOD12C1 0.05 degree datasets. It suggested that these biases are smaller over snow/ice and deciduous needle-leaf forest while they are larger in permanent wetlands and evergreen broadleaf forest regions. The magnitude of this bias may depend by the amount of moisture in atmosphere. Figure 5 shows MODIS band 27 bias as a function of the total precipitable water (TPW). Evergreen broadleaf forests mostly locate in tropical or subtropical regions, the TPW range is about 0-50 mm for clear sky conditions, and larger in cloudy conditions. The Deciduous Needleleaf forests are restricted to a small region at high latitudes, the atmosphere at these locations is very dry. The moisture content of the pixels associated with the Evergreen Broadleaf IGBP types are much larger than that associated with the Deciduous Needleleaf type. It may suggest that TPW is a critical factor that affects the bias of band 27. For band 28, there are no spectral gaps in spectral simulation, the bias of band 28 is quite small. And band 28 bias doesn't show significant dependence on TPW.

We analyzed the surface temperature bands (band 22, 31 and 32). Figure 6 shows the correlation between simulated and aggregated for one day all sky over 2.8 million pixels while clear sky conditions show in figure 6. It suggested the global BT variations for cloud fraction ≤ 5% condition

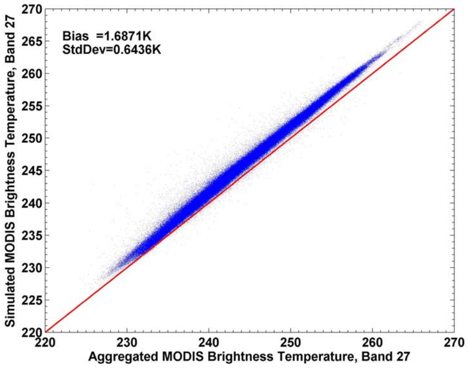

Figure 1. Simulated and aggregated MODIS band 27 BTs for cloud fraction ≤ 5% sky conditions.

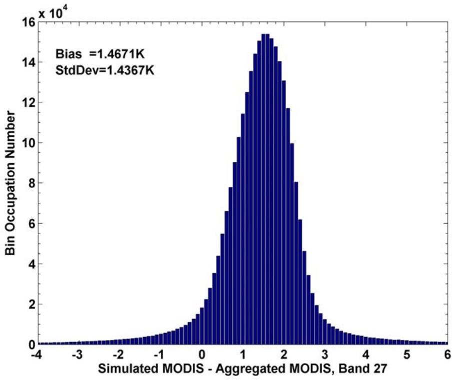

Figure 2. Band 27 Simulated and aggregated MODIS BT histogram for all sky conditions.

IV. CONCLUSION AND DISCUSSIONS

In this study, we demonstrate the efficacy of cross-calibrating AIRS and MODIS instruments. The dependence of the quality of the cross sensor calibration shows as a function of solar and satellite, atmosphere and land surface conditions, such as surface types, cloudy fractions et al. We found that cross-calibrating quality is a function of critical scene parameters such as surface type,

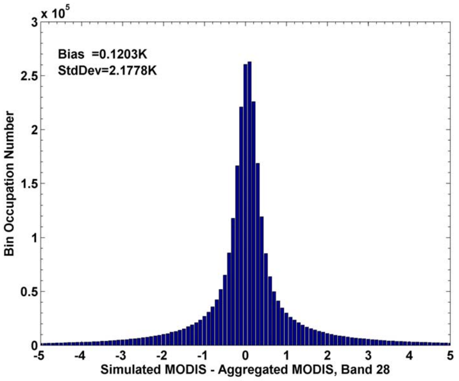

Figure 3. MODIS Band 28 Simulated and aggregated histogram for all sky conditions

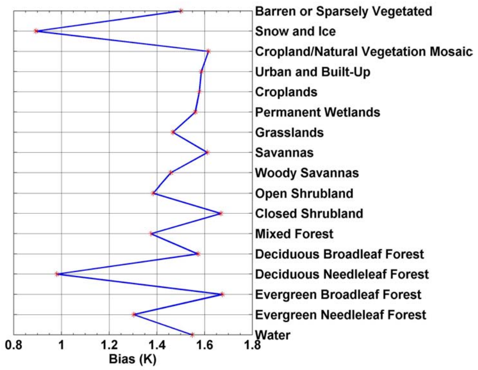

Figure 4. Band 27 biases as a function of surface types show the variations between simulated and aggregated BTs all pixels.

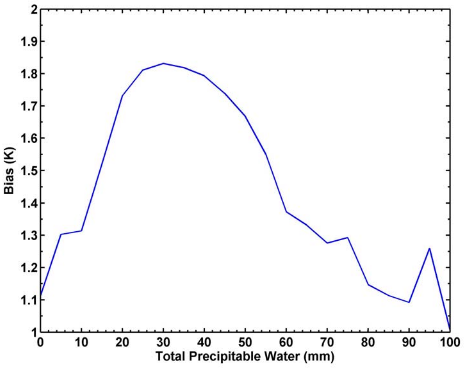

Figure 5. MODIS Band 27 bias as a function of TPW over all pixels.

atmospheric conditions and phenomenology. Global BT dynamic range can be identified band by band for all MODIS thermal IR bands. By comprehensive analysis of global datasets over various situations, a look-up-table can be constructed for the differences between simulated and aggregated MODIS as function of the critical scene parameters.

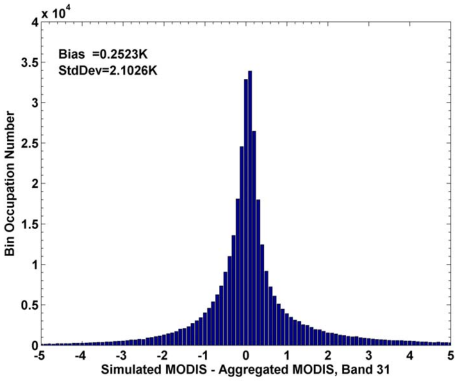

Figure 6. MODIS Band 31 Simulated and aggregated BT histogram for cloud fraction ≤ 5% conditions

Our new approach for radiometric cross-calibration of satellite radiometers can be used to improve current absolute radiometric calibrations and provide timely, cost effective, and technically appropriate cross sensor calibration data and information. This approach can be used to support NPOESS/NPP pre-launch and post-launch missions.

Current, only one AIRS golden day (January 25, 2003) has been selected for comprehensive analysis. To investigate the dependence of the cross-sensor calibration variation with seasonal variations, we need to test more datasets for different seasons in the near future.

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