RADIOMETRIC CALIBRATION OF FENGYUN-3D MERSI-II SATELLITE:
A CASE STUDY IN LAKE QINGHAI, CHINA

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ABSTRACT
In this paper, we describe a method for radiometric calibration of Fengyun-3D (FY-3D) MERSI-II TIR, bands 24 and 25 that combines vicarious and cross-calibration of the corresponding bands of Aqua MODIS, bands 31 and 32. A field campaign was conducted on lake Qinghai, China, on August 18, 2019. The surface measurements were performed before and after the passing time of Terra MODIS and FY-3D MERSI-II. Path radiance and transmittance were then calculated via the radiative transfer code MODTRAN 4.0, and the difference caused by the relative spectral response (RSR) of the sensors was eliminated by the spectral matching. Our experimental results indicate that the obtained radiometric calibration accuracy of FY-3D MERSI-II is stable during on-orbit operation.

Index Terms— Vicarious calibration, MODIS, FY-3D MERSI-II, cross-calibration.

1. INTRODUCTION

Thermal infrared channels provide information about Earth emission radiation, which plays an important role in cloud detection, surface temperature inversion, and heat budget. The radiometric calibration accuracy of satellite sensors changes with the degradation of the performance of their detectors, and also by the influence of outer space environment [1]. Therefore, it is essential to assess the status of satellite sensors during their on-orbit operations.

Vicarious calibration is an important approach to perform radiometric calibration of satellite sensors when the satellite is on-orbit. Different targets, such as deserts [2, 3], deep convective clouds (DCCs) [4, 5], and lakes [6, 7] have been used to perform radiometric calibration between satellite sensors. Lakes have proven to be an ideal target for radiometric calibration, especially for thermal infrared (TIR) sensors. Lake Qinghai is an important China radiometric calibration sites (CRCS) for TIR sensors. Due to its characteristics (large area, flat, and homogeneous), Qinghai Lake has been used since the 1990s to calibrate many satellite sensors in China, i.e., the Fengyun (FY) series [6, 7], the Huanjing (HJ) series [8], or the China-Brazil Earth resources (CBERS) series [9, 10].

In this paper, we describe a method for radiometric calibration accuracy of FY-3D MERSI-II. A field campaign was conducted from Aug 16, 2019 to Aug 22, 2019 at Lake Qinghai to support our methodology. The radiometric calibration of FY-3D MERSI-II TIR bands 24, 25 was performed through the vicarious and cross-calibration of the corresponding bands of Aqua MODIS, bands 31, 32, respectively. Our results confirm stable calibration accuracy of FY-3D MERSI-II during on-orbit operation.

2. CONSIDERED SATELLITES

2.1. FY-3D MERSI-II

The MERSI-II was launched on November 11, 2017 as the most important payload onboard the FY-3D satellite. An improved version of MERSI, MERSI-II is the first imaging instrument which can acquired infrared data of split-window regions with spatial resolution of 250m around the Earth. Moreover, the MERSI-II captures true color Earth images with 250m spatial resolution without any gaps every day. The MERSI-II has 25 spectral bands and uses detectors located on the focal plane that cover the solar spectrum from 0.412 µm to 12.0 µm. MERSI-II bands 4-7 and 15-25 cover the solar spectrum from 0.865 µm to 12.0 µm, producing TIR images, while bands 1-3 and 8-14 (covering 0.470 µm to 0.746 µm) produce images of visible and near-infrared (VNIR) solar radiation. The MERSI-II TIR bands are calibrated through a full-aperture onboard black-body (BB), space view and the moon, respectively. The specification of absolute radiometric accuracy for MERSI-II TIR band is 0.5K@270K.
2.2. Terra MODIS

MODIS (aboard the Terra satellite) was launched on 18 December, 1999. The MODIS sensor has 36 spectral bands and uses detectors located on the focal plane that cover the solar spectrum from 0.412 µm to 14.4 µm. MODIS bands 1-19 (covering from 0.412 µm to 2.1 µm) produce images of daytime solar radiation, while bands 20-25 and 27-36 (covering from 3.7 µm to 14.4 µm) collect thermal images which provide daytime and nighttime observation of Earth. The MODIS solar reflective bands are calibrated by on-orbit calibrators, including a solar diffuser and a solar diffuser stability monitor, whereas the thermal bands are calibrated by an on-orbit BB. The spatial resolution of MODIS bands 1 and 2 is 250 m. The resolution of bands 3 and 4 is 500 m, while the resolution of bands 5-36 is 1000 m.

3. PROPOSED METHOD

3.1. Theory

The at-sensor radiance measured by the FY-3D MERSI-II satellite at TIR bands contains three parts: i) the radiance reflected from the target after the interaction with the atmosphere, ii) the radiance scattered from the atmosphere itself, and iii) the radiance emitted from the target after the attenuation by the atmosphere. Hence, the radiance received by the sensor can be modeled as follows:

\[ L_s(\lambda) = \tau_\alpha(\lambda)L_t(\lambda) + L_{path}(\lambda) + \tau_\alpha(\lambda)L_d(\lambda)\rho_e(\lambda), \]  

where \( L_s(\lambda) \) is the spectral radiance received by the sensor, \( \tau_\alpha(\lambda) \) is the spectral transmittance of the atmosphere, \( L_{path}(\lambda) \) is the path radiance scattered from the atmosphere, \( L_d(\lambda) \) is the radiance emitted by the target, and \( \rho_e(\lambda) \) is the surface emissivity. In our work, the spectral transmittance \( \tau_\alpha(\lambda) \) and the path radiance, \( L_{path} \) were calculated with MODTRAN 4.0 using simultaneous measurements when the FY-3D MERSI-II overpassed Lake Qinghai on Aug. 18, 2019.

3.2. Spectral Matching

The difference between the relative spectral response (RSR) of the satellite sensors when performing cross-calibration should be eliminated, because they can result in different radiance or reflectance (even if they are observing the same target at the same time). Ratios such as spectral band adjustment factor (SBAF), and matched-image adjustment factor (MIAF) are applied to reduce mismatches between RSRs based on the measured or simulated hyperspectral radiance or reflectance profile of the target, i.e., the MODTRAN simulated radiance (or reflectance) profile [11, 12]:

\[ \rho_{ME} = \frac{\int RSR_{ME}(\lambda)\rho(\lambda)d\lambda}{\int RSR_{ME}(\lambda)d\lambda}, \]  

\[ \rho_{MO} = \frac{\int RSR_{MO}(\lambda)\rho(\lambda)d\lambda}{\int RSR_{MO}(\lambda)d\lambda}, \]  

where \( \rho_{MO} \) and \( \rho_{ME} \) are the simulated top-of-atmosphere (TOA) reflectance of MODIS and MERSI-II, respectively. \( RSR_{MO} \) and \( RSR_{ME} \) respectively represent the relative spectral response (RSR) of MODIS and MERSI-II. \( \rho(\lambda) \) is the TOA reflectance profile simulated by MODTRAN 4.0. Due to the lack of a hyperspectral emissivity profile of Lake Qinghai, SBAF or MIAF are not suitable for spectral matching between the CE312, FY-3D MERSI-II and Aqua MODIS. Hence, in this work, the \( \rho(\lambda) \) is calculated based on six built-in atmosphere profiles (i.e., tropical, mid-latitude summer/winter, sub-arctic summer/winter included in 1976 U.S. Standard), two observing geometries (vertical and 10°), and nine temperature scenarios (278K, 283K, 288K, 293K, 298K, 303K, 208K, 212K, 320K) via the MODTRAN 4.0. Linear fitting was performed once the simulated TOA reflectance was calculated for the two sensors. Fig. 1 and Fig. 2 respectively show the spectral matching results for MERSI-II bands 24 and 25 with the corresponding bands of MODIS.
Table 1. Input parameters of MODTRAN4.0 for path radiance and transmittance calculation.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>FY-3D MERSI-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>2019/08/18</td>
</tr>
<tr>
<td>Overpassing Time (UTC)</td>
<td>06:34:00</td>
</tr>
<tr>
<td>Solar Zenith (°)</td>
<td>28.4740</td>
</tr>
<tr>
<td>Solar Azimuth (°)</td>
<td>219.2028</td>
</tr>
<tr>
<td>Satellite Zenith (°)</td>
<td>21.3344</td>
</tr>
<tr>
<td>Satellite Azimuth (°)</td>
<td>261.5048.00</td>
</tr>
<tr>
<td>Ground Altitude (km)</td>
<td>2.360</td>
</tr>
<tr>
<td>AOD@550nm</td>
<td>0.360</td>
</tr>
</tbody>
</table>

As we can see from these figures, the MERSI-II simulated TOA reflectance is in good agreement with that of MODIS in the corresponding TIR bands.

3.3. Method

Our methodology for calibration of FY-3D MERSI-II TIR, bands 24 and 25 combines vicarious and cross-calibration based on Aqua MODIS. Fig. 3 shows the flowchart of our calibration strategy for FY-3D MERSI-II TIR bands. The vicarious calibration is based on simultaneous measurements during overpasses of FY-3D, including surface temperature, aerosol optical depth (AOD) and atmospheric profiles.

Moreover, an atmospheric profile was measured by a radiosonde equipment located near the shore of Lake Qinghai. The balloon, manufactured by the Vaisala, was released to measure the vertical temperature, relative humidity, and pressure one hour before the overpass of FY-3D MERSI-II. The aerosol optical depth (AOD) was measured simultaneously at the same location where the radiosonde balloon was released. The input parameters of MODTRAN 4.0 for path radiance and transmittance calculation are listed in Table 1. Fig. 4 shows the simulated profiles of path radiance and transmittance, along with the RSR of the corresponding bands.

4. RESULTS

4.1. Surface Measurements

One of the most important aspects in our vicarious calibration process is the measurement of the surface temperature of lake Qinghai. In our ground campaign, the surface temperature was measured by the CE312 IR radiometer (the benchmark precision instrument for measurements of spectral luminance in 4 to 6 thermal infra-red bands) after rigorous laboratory calibration. Two bands of CE312, i.e., those at 10.8 and 12.0 microns, were used to match the corresponding bands of FY-3D MERSI-II and Aqua MODIS, respectively. During the overpass of the satellite sensors, the CE312 was attached to an unmanned boat about 1.5m from the surface of the lake.

4.2. Calibration Results

Table 2 shows the obtained calibration results based on the simultaneous measurements conducted on Aug. 18, 2019. As we can see from Table 2, the differences for FY-3D MERSI-II are -0.2631K for band 24, and -0.4.000K for band 25, respectively. However, the results of the cross-calibration for these two corresponding bands are -2.5663K, and 2.9027K, respectively. Compared with the vicarious calibration, such large difference in cross-calibration may be caused by the sharpen variation of atmosphere in the overpassing time of MERSI-II and MODIS. Hence, our results combining vicarious calibration and cross-calibration exhibit the potential to achieve stable calibration accuracy of FY-3D MERSI-II during on-orbit operation.

5. CONCLUSIONS

In this paper, we present a new method for calibration of FY-3D MERSI-II satellite that combines vicarious calibration (based on simultaneous measurement results during a field campaign) and cross-calibration via Aqua MODIS. The field
campaign was conducted on lake Qinghai, China, to evaluate the radiometric calibration accuracy of FY-3D MERSI-II from Aug. 16, 2019 to Aug. 22, 2019. Surface measurements, including surface temperature, AOD and atmospheric profiles were input to MODTRAN 4.0 to generate the path radiance and transmittance when the FY-3D MERSI-II overpassed lake Qinghai. Moreover, the RSR mismatches between the corresponding bands of CE312, MERSI-II, and MODIS were reduced by linear fitting by means of simulations under different scenarios. The results obtained by combining vicarious calibration and cross-calibration indicate that the obtained calibration accuracy results of FY-3D MERSI-II are stable during on-orbit calibration.

### 6. REFERENCES


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**Table 2.** Obtained calibration results.

<table>
<thead>
<tr>
<th>Band</th>
<th>Rad_Raw</th>
<th>Rad_Vic</th>
<th>BT_Raw(K)</th>
<th>BT_Sim(K)</th>
<th>Diff (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERSI-II Band 24</td>
<td>8.1794</td>
<td>8.2373</td>
<td>290.7020</td>
<td>289.9699</td>
<td>0.2631</td>
</tr>
<tr>
<td>MERSI-II Band 25</td>
<td>7.5515</td>
<td>7.5439</td>
<td>289.6797</td>
<td>288.7132</td>
<td>0.9665</td>
</tr>
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</table>

**Cross-calibration result:**

<table>
<thead>
<tr>
<th>Band</th>
<th>Rad_Raw</th>
<th>Rad_Coss</th>
<th>BT_Raw (K)</th>
<th>BT_Sim (K)</th>
<th>Diff (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERSI-II Band 24</td>
<td>8.1794</td>
<td>8.5206</td>
<td>290.7020</td>
<td>293.2683</td>
<td>2.5663</td>
</tr>
<tr>
<td>MERSI-II Band 25</td>
<td>7.5515</td>
<td>7.2369</td>
<td>289.6797</td>
<td>286.7770</td>
<td>-2.9027</td>
</tr>
</tbody>
</table>

1. Radiance calculated from the raw image.
2. Radiance calculated from vicarious calibration.
3. Bright temperature calculated from the raw image.
4. Radiance calculated from vicarious calibration.
5. Radiance calculated from cross-calibration.
6. Radiance calculated from cross-calibration.