MODIS Solar Diffuser Earthshine Modeling and Analysis

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ABSTRACT

MODIS's solar diffuser is one of the key calibration sources for its reflective bands. Geometric optical modeling shows that Earthshine illuminating the solar diffuser contaminates measurements of the direct solar irradiance. Before launch, a simple model was used that did not consider the non-diffuse component and the atmospheric transfer of the Earthshine contamination. Recently, a more detailed Earthshine model has been recently developed to better determine the magnitude and characteristics of Earthshine contamination. The model includes a geometric optical model of the instrument, a model of the Earth/Sun/instrument geometry during the calibration interval, an atmospheric model, and various bi-directional models of Earth surface types. Several types of vegetation and open-ocean with different wind speeds are modeled. Analysis was performed of the solar diffuser data with particular emphasis on the surface type at the Earth locations where specular reflections (glint) might occur, i.e., where the solar and view zenith angles are almost the same and the relative azimuth angle is near 180º. The new model compares well with detailed analysis of the solar diffuser data, both over open-ocean with glint, and over vegetation. Both the modeling and analysis show a spectral dependence in the non-diffuse radiation that increases with wavelength. The modeling and analysis give lower and upper bounds on the Earthshine contamination and suggest approaches for minimizing its impact on the MODIS calibration.

Keywords: MODIS, EOS, Earthshine, calibration, solar diffuser

INTRODUCTION

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments [1] are on-board NASA's Earth Observing System (EOS) Terra spacecraft launched in December 1999 and Aqua spacecraft launched in May 2002. MODIS has 36 spectral bands with center wavelengths ranging from 0.41μm to 14.2μm and nadir spatial resolutions of 0.25km (bands 1-2), 0.5km (bands 3-7), and 1.0km (bands 8-36). The 36 bands are configured on four focal plane assemblies: visible, near infrared (NIR), short- and mid-wave infrared, and long-wave infrared. These bands are calibrated and characterized on-orbit using three on-board calibrators: a solar diffuser (SD), a spectro-radiometric calibration assembly, and a blackbody. Another on-board device, a solar diffuser stability monitor, is used to track SD degradation.

The SD is the key calibration source for the reflective bands with wavelengths below 2.2μm [2]. Geometric optical modeling of the MODIS SD system (e.g. diffuser, aperture) clearly shows pathways by which Earthshine illuminates the SD during radiance/reflectance calibration. This undesired Earthshine contribution to the solar irradiance on the diffuser always increases the incident irradiance and has varying spectral content. Before launch, a simple Earthshine model was used that did not consider the non-diffuse (specular) component and the atmospheric transmission of the Earthshine contamination. As seen in Figure 1, the Earth's surface is very complicated and there can be a significant specular component depending on the land surface conditions. In the pre-launch MODIS radiance/reflectance calibration error budget generated by the sensor vendor, Raytheon Santa Barbara Remote Sensing (SBRS), the presence of Earthshine in MODIS SD calibrations was estimated to be ±0.3% for all bands and was included in the overall budget as a random error.

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Figure 2 illustrates how the Earthshine contaminates the SD measurement. In addition to the Sun's direct illumination of the diffuser, sunlight reflected from the Earth's surface, clouds and atmosphere also illuminates the SD. The SD aperture limits the amount of contamination, but does not eliminate it entirely. For regularly scheduled MODIS SD calibration, care has been taken to make the measurements before Earthshine becomes visible through the nadir telescope aperture.

This paper shows examples of Earthshine as seen in the MODIS calibration data and describes a more detailed Earthshine model that was developed to better characterize the Earthshine contamination. The model includes a geometric optical model of the instrument, a model of the Earth/Sun/instrument geometry during the calibration interval, an atmospheric radiative transfer model, and bi-directional models of several Earth surface types. The results from this work suggest potential approaches for minimizing existing Earthshine impact on the MODIS SD calibration.

Frame ISS007E 10805

Figure 1. Earthshine over the Pacific Ocean from the International Space Station on July 21, 2003.

Earthshine Contamination

MODIS SD calibration coefficient, m_1, which is proportional to 1/gain, can be used to identify the magnitude of the variation of the Earthshine effect in SD calibrations. Figure 3 shows the MODIS band averaged m1 values as a function of day for bands from 412nm (band 8) to 869nm (band 16) over one week. The fluctuations seen in the figure have magnitude greater than 0.4 % and are predominantly in the negative direction, consistent with additional irradiance on the diffuser due to Earthshine. Examination of longer time series of m_1 values has revealed fluctuations of up to 0.5%. The identification of Earthshine as the source of these fluctuations can be performed by considering their spectral dependence and temporal behavior. The largest fluctuations are seen in band 16 in the near infrared at 869nm. They decrease at lower wavelengths towards band 8 (412nm). It should also be noted that the fluctuations in band 16 can be as large as 0.4% over the course of one day. The correlation of the fluctuations between bands is a dramatic indication of the change of Earthshine contamination from orbit to orbit. Temporal evidence for Earthshine as the source of the m_1 fluctuation is provided by the fact that several downward spikes in Figure 3 (e.g. the first three spikes) occur approximately once every 14 orbits, once per day, when the satellite is over the same geographic region.

Additional evidence for the existence of Earthshine can be seen in the MODIS band 7 (2.1μm) SD data acquired over polar scenes shown in Figure 4. The orbital SD data, shown as band value in percent versus instrument elevation, clearly show an out-of-family curve for the transition from ice to open-ocean. The magnitude of the effect is on the order of 0.5%, increasing through the transition from ice (i.e. Greenland) to open-ocean. The effect is consistent with the predicted increased specular (glint) reflectance of open-ocean over ice. In this case the increased reflectance of the open-ocean is seen as Earthshine contamination on the MODIS SD.

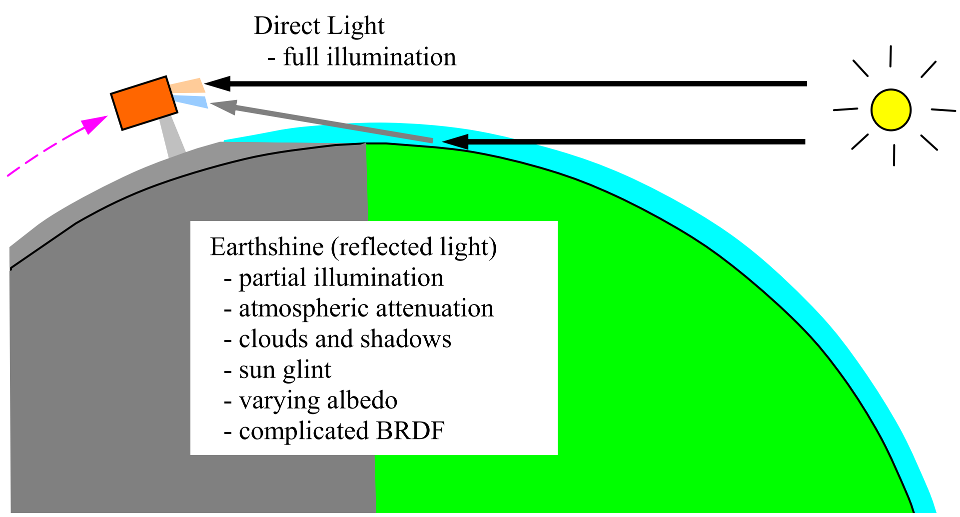

Figure 2. Solar diffuser measurement contaminated by Earthshine.