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ScienceDirect
Remote Sensing of Environment 107 (2007) 2 – 11
Remote Sensing of Environment
www.elsevier.com/locate/rse

The MISR radiometric calibration process

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Received 8 March 2006; received in revised form 14 July 2006; accepted 17 July 2006

Abstract

One important objective of the Multi-angle Imaging SpectroRadiometer (MISR) is retrieving global aerosol loading and microphysical properties. Accuracy depends on many factors, including the availability of a complete catalog of particle types with their associated size distributions, shapes, single-scattering albedos, vertical profiles, and spectral radiative characteristics. Co-equal to this need is the availability of a well-designed, well-characterized instrument, with a calibration that is maintained post-launch. This allows accurate radiance and retrieval products to be made, adjusting for instrument changes. MISR performance has been intensively studied throughout the design, pre-flight, and post-launch mission phases. To establish the absolute radiometric scale, annual vicarious calibration (VC) exercises have been conducted. In addition, an on-board-calibrator (OBC) allows more frequent testing of camera degradations. Together, the VC and OBC processes have allowed MISR to achieve an absolute calibration uncertainty of 4% or better (1σ confidence level) for bright land targets. Additional fine-tunings have been made following analysis of lunar-view campaign data, and from a statistical analysis of Earth observations. These studies led to slight camera-to-camera adjustments, which are important in improving the aerosol retrieval process. Validation of the response at the lower end of the dynamic range has also been accomplished using a dark-water study. With these studies complete, MISR calibration is now in an operational mode, and data users can be assured the resulting data products are stable with time. Such records meet the needs of a program designed to support climate change and provide long-term monitoring of the Earth's atmosphere and radiative fluxes.

Keywords: Radiometric calibration; MISR

1. Introduction

1.1. Science drivers to accurate radiometry

MISR aerosol optical depth uncertainty requirements have been specified as 0.05 or 20%, which ever is larger, under average, cloud-free viewing conditions. Further, there exists a goal to achieve 0.01 to 0.02 uncertainty in the future. The latter is comparable to the best surface-based instrument uncertainties, but can be reached in some cases by creating monthly averages that reduce instantaneous retrieval noise. MISR measurements distinguish spherical from non-spherical particles, separate two to four compositional groups based on indices of refraction, and identify three to four distinct size groups between 0.1 and 2.0 μm characteristic radius at most latitudes (Kahn et al., 1998, 2001; Kalashnikova & Kahn, in press). Over deep water, the MISR aerosol retrieval algorithm uses the 672 and 866 nm bands, similar to other sensors that take advantage of the very low surface reflectance at these wavelengths. At high optical depths, data from the 446 and 558 nm bands are also incorporated. An advantage of multi-angle observations is that aerosol retrievals over water are possible even when some cameras are affected by sun glint. Over land, aerosol retrievals are complicated by the large variability in surface bidirectional reflectance factor (BRF), and that ground-reflectance is high for much of the Earth, including desert and urban areas that are major aerosol source regions. The MISR land aerosol algorithm models the shape of the surface BRF as a linear sum of angular empirical orthogonal functions derived directly from the image data, making use of spatial contrasts to separate the surface and atmospheric signals (Diner et al., 2001, 2005; Martonchik et al., 2002). Aerosols are

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doi:10.1016/j.rse.2006.07.024

detected by virtue of their effect on the angular variation in the observed spectral radiance, rather than by their effect on absolute brightness (which does play a role in the dark-water algorithm).

To achieve the scientific objectives, MISR calibration requirements specify 3% absolute and 1% band and camera-relative calibrations, for bright targets (at equivalent reflectances of one). Here we define top-of-atmosphere equivalent reflectance as $\rho = \pi L / E_0$, where L is the top-of-atmosphere radiance within a given MISR band, and E_0 is the MISR total-band-weighted exo-atmosphere solar irradiance. Requirements at the low end of the dynamic range specify a 10% absolute uncertainty at a scene equivalent reflectance of 0.02. For dark-water scenes having aerosol optical depths on the order 0.2 or less at mid-visible wavelengths, the equivalent reflectance typically falls below 7%. The aerosol optical depth calibration uncertainty requirement is 0.02 or better, in all channels. This is the more demanding of the two requirements, and is at the cutting edge of current capabilities.

2. MISR instrument

MISR was launched into polar orbit on December 18, 1999 aboard the NASA Earth Observing System (EOS) Terra spacecraft. MISR makes near-simultaneous measurements at nine view angles spread out in the forward (f) and aft (a) directions along the flight path, using nine separate push-broom cameras observing Earth at 70° (cameras Df and Da), 60° (Cf and Ca), 46° (Bf and Ba), 26° (Af and Aa), and nadir (An). Each camera contains four spectral bands centered at 447, 558, 672, and 867 nm. For each of these the spectral band is Gaussian in shape. This profile, used in conjunction with a Lyot depolarizer, provides depolarization of the incoming light to within an uncertainty of ±1%. MISR obtains global coverage between ±82° latitude in 9 days, with spatial sampling per pixel between 275 m and 1.1 km, depending on channel and data acquisition mode. The instrument systematically covers a range of airmass factors from 1–3, and in mid-latitudes, samples scattering angles extending from about 60–160°. The analog readouts from the charge-coupled device (CCD) detectors in the camera focal planes are digitized to 14 bits. Thermoelectric coolers and focal plane heaters are used to maintain stable detector temperatures of -5.0 ± 0.1 °C.

2.1. On-board calibrator

The MISR radiometric response scale is established using an on-board calibrator (OBC), as well as by vicarious calibration experiments (Abdou et al., 2002; Bruegge et al., 2002). The strength of the OBC is its ability to conveniently and frequently test the camera response. Calibrations using the OBC are conducted once every 2 months. The OBC, depicted in Fig. 1, consists of two Spectralon diffuser panels, and six sets of photodiode detectors. The latter measure solar-reflected light from the panels, and provide the camera-incident radiance. These are regressed against the camera digital number (DN) output, in order to provide the radiometric response for each of the 1504 CCD detector elements per line array, nine cameras, and four spectral bands per camera. One such photodiode is set on a goniometric arm to monitor changes in panel bidirectional reflectance factor (BRF).

Although OBC system degradation can occur, MISR experiment accuracy has benefited from the stability of the calibrator with time. Pre-launch testing (Bruegge et al., 1993, 2001; Stiegman et al., 1993) established Spectralon preparation and handling procedures that would reduce the risk of on-orbit degradation. Hydrocarbon contaminants, such as machining oils introduced during manufacture or testing, were shown to cause degradation when exposed to on-orbit vacuum ultraviolet light. With this information at hand, the MISR Spectralon panels were vacuum-baked, following laboratory reflectance testing, to remove any such contaminants. In addition, the original panels, in place during instrument integration and spacecraft-level testing, were removed and replaced with panels that had been kept in a nitrogen-purged container. Degradation analysis of the on-board calibrator demonstrated the success of this plan (Chrien et al., 2002). The flight Spectralon panels have degraded on-orbit by no more than a total of 0.5%.

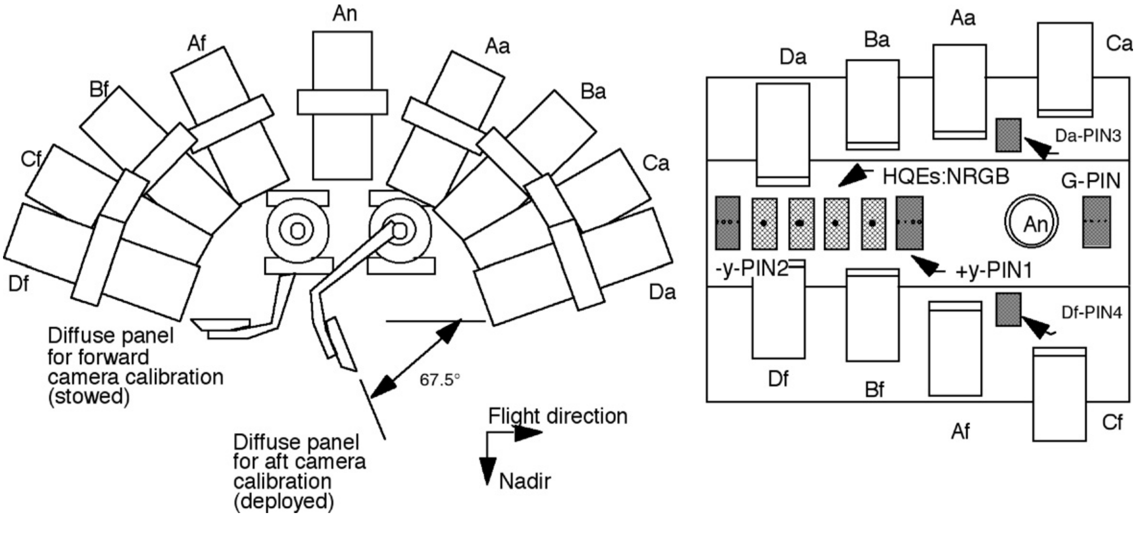

Fig. 1. Schematic of MISR on-board calibrator. Left: Foreward cameras Df–Af and nadir camera, An, view one panel; Aft-cameras Da–Aa and nadir camera, An, view a second panel. Right: Six sets of photodiodes measure panel-reflected sunlight. Each photodiode set has four photodiodes filtered to the MISR passbands.