Calibration refinements in support of MISR

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ABSTRACT: The Multi-angle Imaging SpectroRadiometer (MISR) is one of five instruments on-board the EOS/Terra spacecraft, and has collected science data since March 2000. A multi-angle capability is provided by nine cameras, which view up to 70° forward and aft of the spacecraft track and enable unique geophysical retrievals. Throughout its mission, a calibration team has made periodic refinements to the process used to calibrate MISR. These have resulted in improved absolute, and band and camera-relative calibrations, as well as in derived geophysical data products. Data reprocessing is on-going, such that these refinements also improve previous data acquisitions. The calibration process is believed to be mature at this time, with no other changes anticipated. Bi-monthly deployments of the on-board-calibrator continue to monitor instrument response degradations, and provide correction coefficients needed to maintain the accuracy of the radiance products.

I. OVERVIEW

The Multi-angle Imaging SpectroRadiometer (MISR) (Diner et al., 1998) is one of five instruments on-board NASA's Earth Observing System (EOS). With a 340 km swath width, MISR produces global data sets at nine day intervals or less, depending on latitude. The effective center wavelengths are 447, 558, 672, and 867 nm, as computed using a moments (centroid) analysis within the region delimited by the 1% response points (Bruegge et al., 2002). Each of the nine cameras has a unique name, and is associated with a specific view angle. The cameras view a target consecutively in the order Df (70.5° fore), Cf (60.0°), Bf (45.6°), Af (61.1°), An (nadir), Aa (61.1° aft), Ba (45.6°), Ca (60.0°), and Da (70.5°), with 7 minutes from first to last acquisition of a target. MISR has 14-bit quantization, and therefore has roughly 16,384 gray levels. The finite video offset and square-root encoding reduces this by about 300 counts.

In addition to the nine science cameras, MISR makes use of an on-board-calibrator (OBC). The OBC consists of two Spectralon diffuse panels, and six sets of photodiode detectors. The latter measure solar-reflected light from the panels, and provide a measure of the camera-incident radiance. These are regressed against the camera 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 set is on a goniometric arm, and allows panel bi-directional reflectance factor (BRF) degradation to be monitored. The OBC has been stable with time. This is attributed to the Spectralon handling and preparations procedures established preflight (Bruegge et al. 1993, Stiegemann et al. 1993). A key step was the panel vacuum baking following BRF testing, thus removing volatile contaminants. Additionally, test panels were replaced with flight panels following spacecraft-level testing. These steps proved to be effective, in that Spectralon panels have degrade, on-orbit by only 0.5% (Chrien et al. 2002).

II. PROCESS UPDATES

MISR requirements for bright targets include 3% absolute, and 1% band- and camera-relative calibrations. MISR radiometric accuracy has previously been documented (Bruegge et al., 2002) for homogeneous desert targets. Here vicarious calibration (VC) experiments, in conjunction with sensor cross-comparison studies and on-board-calibrator (OBC) error assessments, have demonstrated MISR radiometric accuracy for targets which fall mid-range in the sensor's dynamic range - 0.3 to 0.4 in top-of-atmosphere (TOA) reflectance. Vicarious calibration experiments are intensive field campaigns, located at uniform desert sites such as Railroad Valley, Nevada. These are conducted annually for MISR, by the Jet Propulsion Laboratory (JPL) staff (Abdou et al. 2002). Unique tools for this JPL operation include AirMISR (Diner et al. 1998), an ER-2 based aircraft prototype for MISR, as well as the PARABOLA instrument (Bruegge et al. 2000, Abdou et al. 2000), a surface based radiometer.
which measures upwelling and downwelling radiance in 5° samplings. For these desert VC experiments the surface reflectance term dominates the TOA radiance. Under clear sky and low aerosol conditions, typical for southwestern sites, radiances are measured within an uncertainty of 3%. Vicarious calibrations are used to validate the radiometric scale of some sensors. In the case of MISR, the June 2000 vicarious campaign was used to calibrate the on-board-calibrator, which in turn produces radiometric gain coefficients for the cameras on a bi-monthly basis.

The utilization of the 2000 VC campaign to set the absolute scale for MISR was the first of five process improvements, summarized in Table 1. In 2001 the team began to conduct vicarious calibration experiments both at swath center and swath edge. The results indicated an agreement was within the VC precision for the swath center results, but a few percent higher at the edges. A review of the calibration processing code disclosed an indexing error and resulting inversion of the BRF database used to correct for differences between the photodiode and camera view angles of the panel. This was quickly corrected.

Table 1. MISR calibration process updates. The date the algorithm was first implemented is given in Column 4, and the Level 1B radiance product version which captures this change given in Column 5.

<table>
<thead>
<tr>
<th>Correction name</th>
<th>Description</th>
<th>Analysis technique</th>
<th>Implementation date</th>
<th>subsequent L1B2 version</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC adjust</td>
<td>On-board calibrator tuned to ground truth</td>
<td>Vicarious Calibration, Lunar Lake 2000</td>
<td>2/24/2001</td>
<td>7</td>
</tr>
<tr>
<td>Linear offaxis</td>
<td>Coding error: Indices reversed in Spectralon BRF database</td>
<td>Vicarious Calibration at swath edge</td>
<td>10/24/2001</td>
<td>10</td>
</tr>
<tr>
<td>PSF correction</td>
<td>Edge enhancement</td>
<td>Preflight measurements, on-orbit edge analysis</td>
<td>11/12/2002</td>
<td>16</td>
</tr>
<tr>
<td>Band adjust</td>
<td>3% decrease in the Red, 1.5% in the NIR.</td>
<td>Vicarious Calibration, 2000-2004 campaigns</td>
<td>12/5/2003</td>
<td>22</td>
</tr>
<tr>
<td>Camera adjust</td>
<td>Channel adjustments</td>
<td>Symmetry and lunar studies</td>
<td>11/30/2004</td>
<td>23</td>
</tr>
</tbody>
</table>

In 2002 a correction for instrument point-spread function effects was implemented (Bruegge et al., 2004). Preflight testing had indicated that a point source of light would be smeared across the line array. Cross-pixel attenuation was less than 0.1 for adjacent pixels, decreasing sharply to $10^{-5}$ within 25 pixels distance. This small light smearing is not sufficient to cause radiometric errors except under extreme conditions (such as over dark ocean targets in the vicinity of bright cloud or ice targets). The implementation of a PSF correction scheme thus improves radiometry for contrast target cases.

A band-relative adjustment has been made to MISR data beginning December 2003. The need for this change was again revealed through vicarious calibration experiments. An analysis of three years of data has shown the radiances from the Red Band to be consistently high. Subsequent to this study the radiances for this band were reduced by 1.5% (Bruegge et al., 2004).

The final response adjustment has come about from a symmetry study where the response of the fore- vs. aft-pointing cameras was compared (Diner et al., 2004). This, and supporting evidence from lunar observations,
resulted in camera-to-camera response changes that were typically less than 1%, but as large as 2.5% for one camera. The nadir calibration response has not changed as a result of this study.

These process changes have been validated by cross-comparison studies using MERIS, and MODIS, and by dark water vicarious calibration studies. These studies are made using the MISR nadir camera, in that only AirMISR is capable of viewing at the extreme down-track view angles observed by MISR. These studies have shown MISR radiances to be about 3% higher than MODIS radiance products, due to a difference in the radiometric standard used to calibrate the instrument. MODIS makes use of their on-board calibrator to establish the scale, including knowledge of the diffuse panel reflectance, determined via a solar ratiomiageradiometer; as stated earlier, MISR relies upon vicarious calibration as its radiometric standard. Agreement among MISR and MERIS radiances are within 2%. Dark water VC studies have confirmed MISR’s radiometric response over dark targets (Kahn et al, 2005). The final validation of MISR calibration has come from the science community. Sensitivity studies have shown that a few percent correction in band or camera relative calibration can change the reported aerosol optical depth by 0.02. With the current system it is believed that MISR aerosol products are typically accurate to ±0.03 (Diner et al., 2004). These accuracies rival those obtained from surface sun photometers, such as those used within the AERosol RObotic NETwork (AERONET).

III. ACKNOWLEDGMENTS

The work described in this paper is being carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. MISR data products are processed and made available by the The Atmospheric Sciences Data Center, Langley Research Center.

A number of support individuals have assisted in the acquisition and analysis of MISR calibration data, including Wedad Abdou, Nadine Chrien, Barbara Gaitley, Mark Helmlinger, Ralph Kahn, Mike Smyth, David Nelson, Kyle Miller, Tom Thaller, and Tom Nolan.

IV. REFERENCES


