2003 RAILROAD VALLEY VICARIOUS CALIBRATION EXPERIMENT

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ABSTRACT

The Multi-angle Imaging SpectroRadiometer (MISR) is one of five instruments on-board the EOS/ Terra spacecraft. The instrument has nine cameras, which view up to 70° forward and aft of the spacecraft track. MISR makes use of multiple calibration methodologies to meet its specifications of 3% absolute and 1% band and camera-relative. One of these pathways is provided by the on-board-calibrator (OBC), which consists of two Spectralon diffuse panels and six sets of photodiode detector standards (including one on a goniometric arm to measure panel angular reflectance stability). A blue-filtered photodiode is selected as the instrument's primary calibration standard, due to its stability. Neither of the diffuse panels nor the primary photodiode standard have degraded, to within the measured 0.5% uncertainty, after four years on-orbit. A once time Band-Adjustment of 3% in the Red and 1.5% in the NIR band is required to force MISR, as calibrated against the OBC, to agree with VC-derived radiances. This Band-Adjusted offset is applicable to all time measurements, as is demonstrated by the annual VC measurements. Presented here is the VC study conducted July 22, 2003 over Railroad Valley, Nevada. Cross-comparison studies with MERIS, MODIS, and Landsat are also provided, with MERIS and MISR agreeing to within 3%. Future MISR/ MERIS comparisons are desired, over a range of scene brightness and contrasts.

1 INSTRUMENT DESIGN

The Multi-angle Imaging SpectroRadiometer (MISR) [1],[2] is one of five instruments on-board NASA's Terra platform. Data products include cloud height and albedos, surface bi-directional reflectances, and aerosol parameters. These measurements are routinely provided over the globe, and are important in understanding Earth's radiation budget and climate change. Center wavelengths are at 447, 558, 672, and 867 nm, with bandwidths from 20-41 nm [3]. Each of 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 (26.1°), An (nadir), Aa (26.1° 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, with gain and offset terms establishing the translation between output digital numbers (DN), and incident radiances. A linear calibration equation is assumed. The spatial resolution of the MISR cameras is 275 m crosstrack (for the off-nadir cameras), or 250 m (for the nadir viewing camera). Downtrack instantaneous field-of-view increases due to view angle effects, ranging from 214 m in the nadir to 707 m at the most oblique angle. Downtrack sampling is 275 m for all cameras. In practice, most data are acquired in Global Mode, where pixel averaging is performed in order to reduce the data rate. Here 24 of the 36 data channels have been 4x4 sample averaged (to 1.1 km) before transmission from the instrument. The 9 Red bands and all bands of the An-camera (nadir viewing), are always in high-resolution. Local Mode targeting can temporarily provide high-resolution data in all data channels.

To support the geophysical retrievals, accurate radiometry is required throughout the dynamic range of the sensor. Top-of-atmosphere equivalent reflectance is defined here as $\rho\_toa = (\pi L/E_0)$, where L is the TOA radiance within a given MISR band, and E_0 is the MISR total-band-weighted exo-atmosphere solar irradiance, derived from the World Climate Research Program published values of solar irradiance [4]. Very low light levels, in the equivalent reflectance range below 7%, are typically found over dark water scenes having small aerosol burdens. Here the desired MISR radiometric calibration accuracy translates to a 10% absolute uncertainty at a scene equivalent reflectance of 0.02. For bright scenes, $\rho\_toa=1$, the requirement is for 3% accuracy. Relative accuracy of 1% is required between cameras, bands, and pixels.

2 THE CALIBRATION PROCESS

2.1 On-board calibrator

Radiometric data products include geo-located radiance images at nadir and off-nadir Earth view angles. These are total band-weighted camera-incident radiances, in units of W m^{-2} sr^{-1} μm^{-1}. The MISR radiometric response scale is established, in part, by its on-board calibrator (OBC). The strength of the OBC is its ability to provide camera, and pixel-relative calibrations, as well as to measure temporal stability. Experiments using the OBC are conducted once every two months. The bi-monthly frequency is desirable in that it is prudent to deploy the calibration panels only as needed to capture camera response changes. 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. Photodiodes are either of a light-trapped design called High Quantum Efficiency (HQE) diodes, or PIN photodiodes. The latter are constructed with a single diode per package.

Although OBC system degradation can occur in principle, MISR experiment accuracy has benefited from the stability of the calibrator with time. Prelaunch testing [5], [6] established Spectralon preparation and handling procedures that would reduce the risk of on-orbit degradation. Hydrocarbon contaminants introduced during manufacture or testing, such that due to machining oils, 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 project elected to swap out the panels present during instrument integration and spacecraft-level testing. Prior to launch the original panels were removed and replaced with panels that had been kept in a nitrogen-purged container, following vacuum baking. Degradation analysis on the on-board calibrator [7] has demonstrated the success of this plan. The flight Spectralon panels have degraded, on-orbit, by no more than a total of 0.5% for the four-years on-orbit.

Degradation of the Spectralon panels would be of concern if the panel bi-directional reflectance factor (BRF) were to change in shape, or if the relative spectral reflectance were to change at MISR wavelengths. Since MISR makes use of in-flight detector standards, a decrease in the panel's hemispheric reflectance would otherwise be inconsequential. The blue-filtered High Quantum Efficient (HQE) device, a light-trapped three detector radiometer, has remained stable to better than 0.5% throughout the mission [7]. This diode is therefore used as the primary standard. Not all of the monitoring photodiodes have remained stable on-orbit. For this reason, all other photodiodes are re-calibrated against this standard prior to the bi-monthly data analysis.

2.2 Vicarious calibration

Radiometric validation is accurately done over homogeneous desert playa, as is traditional for vicarious calibration (VC) campaigns. These are intensive field campaigns, conducted at uniform desert sites such as Railroad Valley, Nevada. They are performed annually for MISR by the Jet Propulsion Laboratory (JPL) staff. Unique tools for this JPL operation include AirMISR [8], an ER-2 based aircraft prototype for MISR, and the PARABOLA instrument [9], a surface based radiometer that 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%. In the case of MISR, the June 2000 vicarious campaign [10] was used to calibrate the on-board-calibrator, which in turn produces radiometric gain coefficients for the cameras on a bi-monthly basis. In addition, a 3%, 1.5% adjustment in the Red and NIR bands is required to force the OBC-derived calibration coefficients to agree with VC observations [3]. This change has only been in place since November 2003, although all MISR data acquired to date will be reprocessed using this adjustment. The VC methodology, therefore, is used to define MISR's absolute and band-relative scales. With this scale adjustment, MISR and VC radiances agree to within 2-4% [11], for 6 field campaigns, where Terra was directly overhead on these dates.

The MISR VC objectives each year call for acquisitions of MISR, AirMISR, and in-situ measure of radiance for a target within the center of a MISR swath, as well a second date where the same target is the swath edge. The successful 2003 campaigns were conducted on June 13, July 11, and July 22. The first objective (target at MISR swath center) was fulfilled using data acquired on July 22. On this date MISR flew nearly overhead (1.2° offset) and thus a MISR near-center pixel imaged the site. (MISR overpass information is: Path 40, Block 60, Orbit 19112, 18:34 UT, target 15.2 km west of Terra, 1.2° view, 190.3° heading.) Likewise, MERIS and Landsat acquired data on this same date, although a half-hour earlier in each case.

Table 1 shows the differences in orbital parameters for MERIS, as compared to MISR and Terra/ MODIS. It is these orbital differences that makes the identification of near-co-incident scenes problematic. This scene identification remains an unresolved obstacle in the comparison of future MERIS and MISR data sets. Table 2 compares the spectral parameters for several instruments. For the case of MISR, MODIS, and Landsat, the solar irradiances were re-computed by the MISR team, using the spectral response functions provided by each instrument and the Wehrli 1986 solar model [4]. MERIS wavelength and exo-atmosphric data were obtain from their project.

Table 1. MERIS, MISR, and Terra/ MODIS Ground track differences

Parameter	MERIS	MISR	MODIS
Platform	Envisat	Terra	
Orbit	Sun-synchronous	Sun-synchronous	
Orbit inclination	98.5°	98.2°	
Altitude	800 km	705 km	
Repeat cycle	35 days	16 days	
Node	Ascending	Descending	
Local time	10:00 a.m.	10:30 a.m.	
Cross-track swath (km)	68.5° (1150 km)	28.6° (360 km)	117.6° (2330 km)
Spatial resolution (full-resolution mode)	300 m	275 m	Channel dependent: 250, 500, 1000 m

Table 2. Center-wavelengths, band-weighted exo-atmospheric solar irradiances, W m^{-2} μm^{-1}, and radiances, W m^{-2} μm^{-1} sr^{-1}, from the data products (before cosine-theta adjustment).

MERIS			MERIS			MISR			MODIS			Landsat		
λ	E_0	L	λ	E_0	L	λ	E_0	L	λ	E_0	L	λ	E_0	L
413	1731	106.7	709	1396	140.2	447	1871	129.9	466	2015	128.6	478	1966	129.8
443	1867	119.8	754	1258	138.0	558	1851	158.5	554	1858	153.1	561	1841	143.4
490	1895	131.3	761	1240	50.5	672	1525	159.9	646	1601	148.5	661	1552	139.9
510	1923	134.6	779	1192	130.4	867	969.6	110.9	856	989.8	108.2	832	1054	104.0
560	1841	147.0	865	971	106.4				442	1865	sat.	1650		25.70
620	1696	147.0	885	953	101.8				547	1870		2200		6.69
665	1555	148.6	900	915	67.2				677	1505				
681	1488	147.8							866	969.7				

As MISR radiances change with processing algorithm updates the ratio of MISR to VC radiances may also change. It is for this reason that it is important to identify the calibration heritage of any data. The VC results presented here used the "Band-Adjusted, T21-2" algorithm. For all other sensors the data were extracted from data products made available shortly following the experiment. Radiances were averaged over a 1 km^2 area centered about the VC experimental site. In the case of MERIS and Landsat, a factor of 1.04 was also applied to the data product radiances, to estimate the radiances that would have been measured had all satellites flown over the target at the same time. This factor was derived simply by taking the ratio of cosines for the respective solar illumination angles, at the time of overpass. The VC radiances were then computed using the campaign-measured top-of-atmosphere reflectances, multiplied by the band-weighted exo-atmospheric solar irradiances for that sensor. For each sensor, the difference between the cosine-theta adjusted radiances, as compared to the VC measured radiances for that sensor's passband were compared. Fig. 1 (left) shows the Nevada desert region, and experimental results (right). Tables 3 and 4 show the in-situ derived atmospheric parameters.

The results shown in Figure 1 show excellent agreement between MISR and MERIS, using their respective vicarious calibrations. MISR's agreement is within 1%. Close agreement is expected, in that it is these previous VC campaigns that have determined the calibration of the OBC, and in-turn provided the calibration for MISR. Exo-atmospheric solar model differences could be removed in future studies, by comparing top-of-atmosphere reflectances.

The University of Arizona has conducted vicarious calibrations of MODIS and Landsat for many years. Discrepancies between these sensor and VC results have been reported by this group (private communication) to be -1.4, -0.9, -3.4, -2.5, and -3.4% respectively, for the MODIS 412, 469, 555, 645, 858 nm bands, and to be -4.5, -4.8, -1.9, -1.8 for the first four Landsat channels. These instruments have made use of an on-board-calibrator and preflight calibration testing, respectively, to establish their scales, and thus are not in agreement with these July 22, 2003 results. Differences between the University of Arizona and JPL results may be attributed to differences in the band-weighted exo-atmospheric solar irradiances.

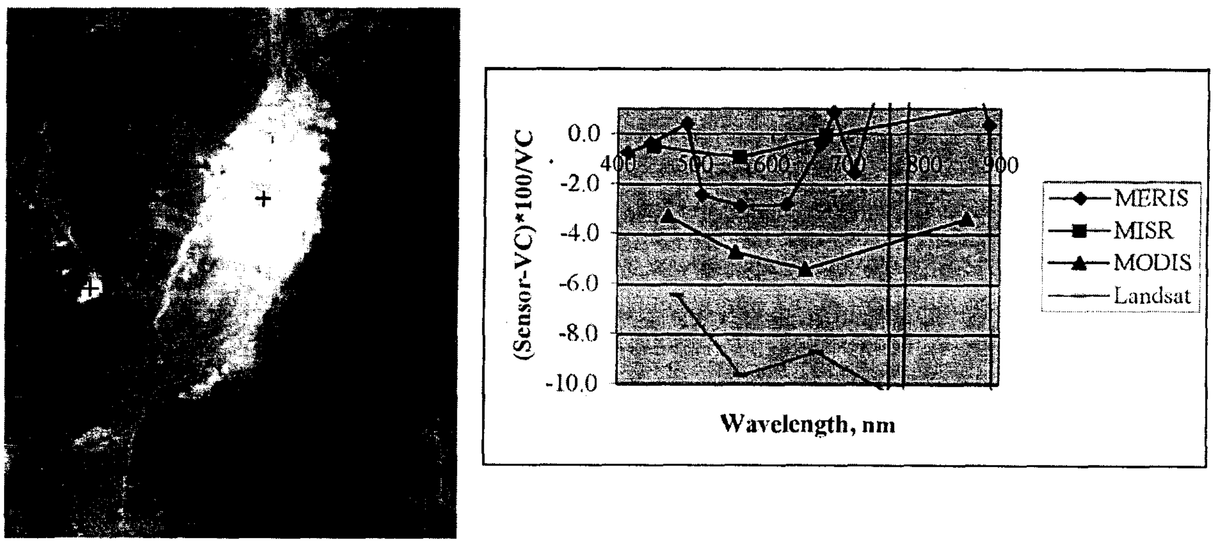

Fig. 1. Left) Lunar Lake and Railroad Valley targets, Nevada. Area shown is approximately 84x84 km^2. The Lunar Lake site is uniform to within 1% only over an area of 1x1 km; the Railroad Valley site is uniform over an 8x8 km region. Right) Difference between measured radiances from MERIS, MISR, MODIS, Landsat, as compared VC data sets over the Railroad Valley site.

Table 3. Scalar VC input parameters

Earth-Sun distance: 1.015996
Longitude/ Latitude: -115.69013 W, 38.49703 N
Surface elevation, m: 1434
Pressure, mbar: 870.02
Junge nu: 3.47
Local time: -7 hours_ from UT
Ozone column, Dobson units = 284.77
Overpass times in UT for Terra, ENVISAT, Landsat: 18:36:02, 18:06:37, 18:09:29
Sun elevation in degrees, for Terra, ENVISAT, Landsat.: =24, 28.8, 28.37

Table 4. VC measured atmospheric parameters

Channel	Wavelength	τ_total	τ_Ray	τ_ozone	τ_aer
0	380.5	0.49	0.38	0.	0.114
1	399.0	0.42	0.31	0.	0.110
2	441.0	0.31	0.21	0.0001	0.098
3	519.5	0.19	0.10	0.0142	0.074
4	609.1	0.15	0.055	0.0344	0.057
5	669.0	0.097	0.038	0.0134	0.047
6	781.0	0.064	0.020	0.0030	0.040
7	869.0	0.048	0.013	0.0008	0.035
8	938.5	0.37	0.010	0.	0.032
9	1028.	0.037	0.007	0.	0.030

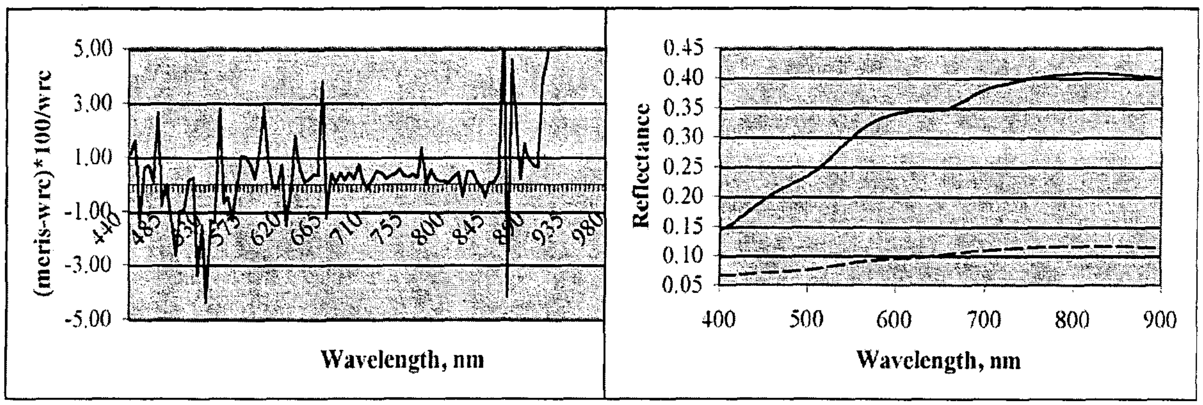

Fig. 2. Left) Difference between the MERIS exo-atmospheric solar-irradiance values, and Wehrli 1986. Right) Surface-measured reflectance (solid line) and VC measured top-of-atmosphere equivalent reflectances (dashed line) at time of Terra overpass.

3 CONCLUSIONS

MISR and MERIS data sets are consistent to July 22, 2003 vicarious calibration results, within 3%. MODIS and Landsat discrepancies are higher, possibly due to differences in solar models, as well as standards used to establish these scales.

Validation over bright desert targets is not in itself sufficient, as the validity of data products must also be demonstrated for cloud/ snow and ice scenes, contrast scenes, and dark target scenes, such as found over dark ocean sites, and dense dark vegetation. Instrument artifacts, such as additive stray-light or electronic biases, if present, would lead to large radiometric errors in the measure of incident radiance, but might not be detected except under low-light conditions.. MERIS/ MISR cross-comparisons are desired in future studies over a range of scene brightness and contrasts.

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