

# Ancillary Radiometric Product (ARP) usage in the EOS/ MISR Level 1B radiance product generation

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## ABSTRACT

The radiometric response of the EOS-AM1 Multi-angle Imaging SpectroRadiometer (MISR) is to be measured throughout the six-year mission. To accomplish this task, MISR makes routine use of an on-board calibrator, aircraft flyovers, field exercises, and comparisons to other on-orbit and aircraft sensors. Analyses of these data results in a deliverable called the Ancillary Radiometric Product (ARP). This file contains the radiometric response parameters for all nine cameras and four spectral bands. The instrument on-board calibrator is exercised bi-monthly, and the next ARP time-series file is created shortly thereafter. This file is used in MISR standard product generation to convert the sensor output into a measure of the incident radiance, and is used to process all MISR data acquired in the subsequent two months. Thereafter the process is repeated and the new ARP time-series file is utilized. Due to improvements in the processing algorithms, updates are allowed to the inactive ARP data files. These revisions would be used should a previously generated MISR data product be reordered and reprocessed, as would be the case should an investigator desire to make use of all science software algorithm upgrades. This paper discusses the investigations and algorithm changes that have occurred in the production of the ARP since launch, and discusses changes to the Level 1B data that might be expected should data be reprocessed.

## KEYWORD LIST

Radiometric calibration, EOS, MISR, DAAC, ARP

## 1. OVERVIEW

The MISR instrument<sup>1</sup> has been designed and built by the Jet Propulsion Laboratory (JPL), and launched in 1999 as one of five instruments on the first Earth Observing System platform (EOS-AM1). MISR acquires systematic multi-angle imagery to monitor top-of-atmosphere and surface reflectances on a global basis, and to characterize the shortwave radiative properties of aerosols, clouds, and surface scenes. With ground data processing, MISR produces registered global data sets from nine cameras, spanning a range of view angles from nadir to 70.5° forward and aftward of nadir. The time separation from observation of a single ground target from the forward most camera to the aftmost view is 7 minutes. Within this time the spacecraft covers a ground track 2800 km in length, with a swath width of 378 km. Each of the nine cameras images in four spectral bands, measured to be 446, 558, 672, and 866 nm (termed respectively Bands 1-4). A charge-coupled device (CCD) line array, 1504 active elements per line, underlies each of the four interference filter strips. At the Earth's surface each detector element produces a data pixel with a cross-track spatial sampling interval of 275 m (250 m for the nadir camera). Additional samples of the video signal chain, termed overlock pixels, measure the video offset for each line of data.

The EOS/ MISR project is a component of NASA's Mission To Planet Earth (MTPE), as are the Distributed Active Archive Centers (DAACs). MISR uses the DAAC at the Atmospheric Sciences Data Center, Langley Research Center, to produce and distribute radiance and higher order science data products. The latter include column aerosol optical depth and atmospherically corrected surface reflectance parameters. Data products are produced using software which has been

developed for processing efficiency and robustness, and operates in a high-volume production mode. Software updates are infrequent, and follow a rigorous testing phase. Requisite for processing is a data file called the Ancillary Radiometric Product (ARP), which includes the MISR instrument radiometric response coefficients. This file is used to manufacture Level 1B (radiance) data, from which all other data products are derived. The ARP time-series files are not produced at the DAAC, but rather delivered there bi-monthly, following each MISR in-flight calibration experiment. The production of the ARP is done at the Jet Propulsion Laboratory (JPL) in a completely different processing environment, where accuracy, not speed, is the driving criteria. The JPL/ MISR calibration team is responsible for this activity, and continues to validate the algorithms and hardware associated with the process. As a result, many changes to the ARP generation code (called ARPGen) have occurred since launch. These changes, and impacts to the MISR radiance data, are summarized in this manuscript, and on-line (see the calibration results page, at <http://www-misr.jpl.nasa.gov>). Details of the OBC validation, Vicarious calibration (VC) experiments, and sensor cross-comparison studies are the subject of future publications.

The MISR instrument has been characterized and calibrated preflight<sup>2</sup>. In addition, an extensive on-board calibrator (OBC) has been built in order to monitor instrument degradation during the mission<sup>3</sup>. The OBC consists of two Spectralon panels, which when deployed reflect solar light into the cameras and silicon photodiodes. The photodiodes are used as detector standards, and provide a measure of the incident light to the cameras. A correction for the reflectance properties of the diffuse panels with viewing angle is included. This is accomplished by knowledge of the Spectralon bi-directional reflectance function (BRF), which was measured preflight<sup>4</sup>. The OBC is exercised bi-monthly, followed by packaging of the resulting radiometric response coefficients into a data file called the Ancillary Radiometric Product (ARP). Each file is valid for the subsequent two months, and together form a series labelled T1 (preflight), T2 (first post-launch analysis), through Tx, where x is the time-series counter. More specifically, the ARP in-flight calibration file name follows the format:

$$\text{MISR\_AM1\_ARP\_INFLTCAL\_Txxx\_Fyy\_zzzz.hdf} \quad (1)$$

where xxx is the time-series number, yy the file format identifier, and zzzz the revision number for a given time-series file. Through out the remainder of this paper we will use an abbreviation such as Tx, or Tx\_z, to denote a specific in-flight, time-series file.

At the time of this publication nine ARP In-flight calibration files have been produced and delivered. For completeness, it should be mentioned that there are actually four ARP files<sup>5</sup>, named preflight characterization, preflight characterization, in-flight calibration, and configuration parameters. Each is written in Hierarchical Data Format (HDF). Combined, these provide parameters such as the radiometric uncertainty values, signal-to-noise, and pre-flight measured data, including the instrument spectral response, and band-weighted exo-atmospheric solar irradiance values. These latter parameters are considered invariant with time and, in contrast to the in-flight parameters, reside in one of the three temporally-invariant files.

## 2. ARP ALGORITHM BASIS

The ARP processing algorithm is discussed in this section, as it exists to date, and as was used to create ARP\_T9. Both pre-flight and post-launch studies have determined that a quadratic calibration equation has the lowest residuals as compared to the measured incident radiance versus output digital numbers (DN). Although the CCD response is nearly linear (the second order coefficient is quite small), inclusion of this term reduces the residuals at the lower end of the detector transfer curve. The equation MISR uses is:

$$DN - DN_o = G_o + G_1 L_b + G_2 L_b^2 \quad (2)$$

where:

$L_b$  is the sensor band-averaged spectral incident radiance, averaged over both in-and-out-of-band wavelengths, reported in units of  $[W m^{-2} sr^{-1} \mu m^{-1}]$ , and defined by the equation:

$$L_b = \frac{\int L_{source} S_{\lambda, b} \lambda d\lambda}{\int S_{\lambda, b} \lambda d\lambda} \quad (3)$$

where  $S_{\lambda, b}$  is the standardized (photon) spectral response function for band b created from averaging over all the measured values. In the MISR algorithms the product  $S\lambda$  always appear in combination, to convert from units of photon counts to energy. This is done only for consistency with our earlier documents and analyses, rather than an approach of storing the product directly in our data archive and referring to the response with a single parameter  $R=S\lambda$ . Continuing the parameter definition,

DN is the camera output digital number,

$G_0$ ,  $G_1$ , and  $G_2$  are the response coefficients which, once determined, provide the radiometric calibration of a specific pixel,

$DN_0$  is the DN offset, unique for each line of data, as determined by an average over the first eight “overclock” pixel elements (shielded pixels at the end of the sensor array).

Gain coefficients are available for every active pixel measured at the operational camera integration time. For the ARP\_T9 algorithm, the coefficient  $G_0$  is constrained to zero during the data regression. This physical constraint has been applied, as by definition the dark-current output (that is the camera output DN when there is no incident illumination) is equal to the video offset measured under these same light conditions. If left unconstrained the regression analysis would compute a  $G_0$  parameter which fluctuates sinusoidally across the line-array, with a channel mean value anywhere between 40counts. As the cameras have 14-bit output, this offset is considered negligible, thus validating the approach.

As the OBC consists of 24 photodiodes (six wavelength sets), a decision as to which to use as the radiometric standard must be made. One of the photodiode sets is in a trapped detector configuration, yielding 100% external quantum efficiency in theory. We have observed that the blue-filtered high quantum efficient (HQE) photodiode has been extremely stable since launch, and is therefore used as the primary OBC standard. Other wavelength-filtered photodiodes have demonstrated varying stability. For this reason the green, red, and nir-HQE photodiodes (and all other photodiodes) are re-calibrated against the HQE-blue during each calibration experiment. This is done by assuming the Spectralon panel to be spectrally neutral, then assigning a response to each of the diodes such that the ratio of the computed radiances (diode to the HQE-blue diode) equals the ratio of their measured currents. Variants to the present algorithm are summarized in Table 1.

**Table 1. ARP algorithm change history**

<b>First implementation</b>	<b>Algorithm change</b>
T001 (preflight)	Preflight, laboratory calibration
T002_003	Mean G1 coefficient for each channel constrained to preflight channel mean. Pixel-to-pixel relative response determined from response to OBC diffuse panel. A linear calibration equation was utilized for simplicity ( $G_0=G_2=0$ ).

**Table 1. ARP algorithm change history**

<b>First implementation</b>	<b>Algorithm change</b>
T002_0004	Use was made of the Blue HQE photodiode (with its preflight determined response) to establish the radiometric scale for all MISR channels.
T002_0005	Use was made of the June 11, 2000, vicarious calibration experiment to re-calibrate the Blue HQE photodiode. This was done in that the VC results were consistent with Landsat and AVIRIS. This adjustment lowered the MISR reported radiances by 10%.
T008_0001	The quadratic calibration equation was re-introduced.
T009_0001	Separate calibration coefficients have been developed for the photodiodes as they view the North panel (used for aft and AN-red, nir channels) and the South panel (used for the fore- and AN-blue, green channels). This change is expected to improve fore-aft camera biases

For the first post-launch calibration T2, the pre-flight channel-mean response was maintained, but the pixel-relative response was altered. This algorithm, and a linear calibration equation, were utilized for simplicity in the early mission time frame. In this era the OBC hardware and ARPGen algorithms were undergoing their first validations. Even through the pre-flight channel-mean response was maintained, use of the flat-field view proved useful. With ARP file T2 vignetting of the Af and Aa cameras (the cameras at a 26 view) was removed, as compared to scenes processed with the pre-flight determined response file. In addition, rippling, (down-track striping) of the imagery is improved using more recent calibrations. This rippling may be due to slight changes within the camera filters, or filter/ detector separations.

A summary of the active ARP files is presented in Table 2. Beginning in the T7 era (March 2001), ARP file production has become routine, with shorter delivery times between calibration and ARP construction. Even so, revisions to all nine time-series files are planned for the future, as improved camera-to-camera and band-to-band relative calibration schemes are solidified. MISR data will need to be reprocessed, to take account of these algorithm improvements.

**Table 2. ARP activation dates**

<b>Time period</b>	<b>To be used for data acquired beginning:</b>			<b>File name</b>	<b>Date first use in production</b>
	<b>Date</b>	<b>Time (UT)</b>	<b>Orbit</b>		
T2	Feb 24, 2000	16:41:00	995	T002_F02_0005	February 15, 2001 Orbit 6169
T3	Jun 12, 2000	4:13:51	2575	T003_F02_0001	
T4	Aug 29, 2000	14:18:37	3717	T004_F02_0001	
T5	Nov 1, 2000	20:53:25	4653	T005_F02_0001	
T6	Dec 19, 2000	19:13:59	5351	T006_F02_0001	

**Table 2. ARP activation dates**

Time period	To be used for data acquired beginning:			File name	Date first use in production
	Date	Time (UT)	Orbit		
T7	March 7, 2001	01:17:44	6476	T007_F02_0001	Same (1)
T8	May 17, 2001	01:19:09	7510	T008_F02_0001	Same (1)
T9	July 11, 2001	01:27:11	8311	T009_F02_0001	Same (1)

(1) These files were produced in time to be used in the processing of MISR data acquired at the same date and orbit as the calibration experiment was conducted.

A summary of the Af time-series response is given in Figure 1. That is, the incident radiance is plotted which would produce a given DN output of 10,000 counts. This is done using the response coefficients from the ARP files listed in Table 2, and normalized against the radiance which would have been incident in the early mission time frame, T2.. It is shown that there is a large (>10%) discontinuity between the preflight calibration, and initial post-launch response determination. The cause of this discrepancy is not well understood, but is the combined affect of instrument degradation in storage, plus the difference in the preflight radiance scale (laboratory photodiode detector standards), and the in-flight radiance standard (vicarious calibration analysis). The reliance on the vicarious calibration was unplanned in the pre-flight era. The decision to make use of the VC results followed when close agreement between this scale, and that of the Landsat and AVIRIS sensors, was shown.

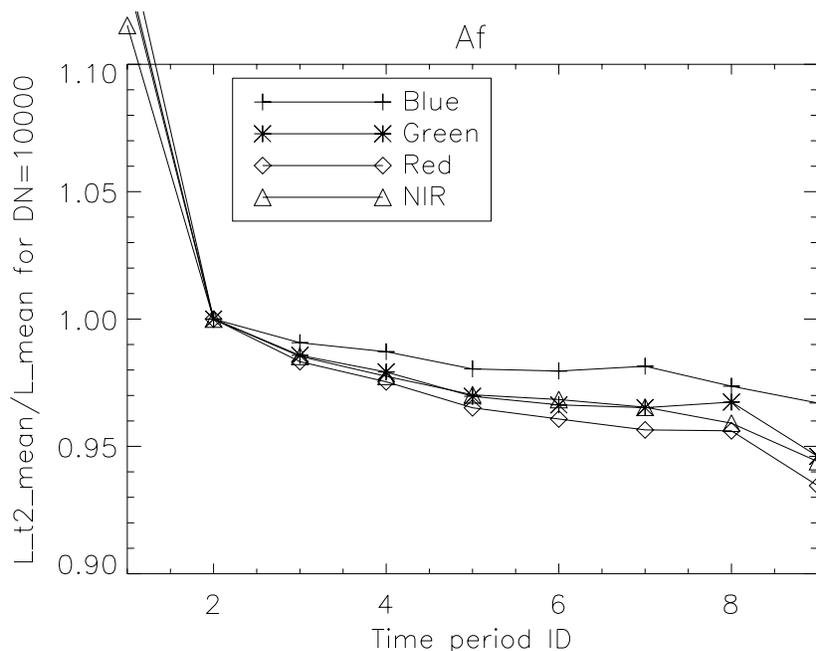


Figure 1. Time-series of channel mean G1 coefficient for Af camera, four bands.

### 3. ARP ALGORITHM CHANGES

A few investigators may wish to determine radiances that would have been computed if a specific ARP had been used in the L1B1 or L1B2 data production. As an example, say that a L1B2 data product was produced with ARP\_T002\_0001, but it is now recommended that ARP\_T002\_0002 be used for any data that is reprocessed. A procedure is described below which will give the investigator a crude feel of the radiance changes that result from a given algorithm update.

We will define the ARP coefficients that were used in the data processing as  $G_{1\_old}$  coefficient, and the updated coefficients as  $G_{1\_new}$ . The DN that the instrument recorded can first be computed:

$$DN = G_{0\_old} + G_{1\_old} * L_{old} + G_{2\_old} * L_{old}^2 \quad (4)$$

then the radiances which would have been computed had the updated ARP been used is determined:

$$L_{new} = -2[G_0-DN]/\{G_1 + \sqrt{G_1^2 - 4*G_2*(G_0-DN)}\} \quad (5)$$

The above equation is a variant to the usual quadratic inversion. It is preferred for instances where  $G_2$  is small. We have found that each of our algorithm changes have produced small radiance changes (on the order of a few percent), for all but the change implemented for T2\_4. This is the time era when the MISR radiometric standard was transferred from the HQE-blue preflight scale, to the VC scale.

In summary, any MISR data user should be cognizant of the ARP files used to produce their data product. Ideally each investigator desires to have a data products derived from the latest revision to a coefficient file. To determine which ARP file was used to develop a given data product, you would use an HDF browser, such as HDF\_Scan. (This software is available from the Langley DAAC, and was written to view MISR data as well as generic HDF files.) Using this or other data browser software, one can read the metadata published within the HDF data product. The ARP file name can be found under Annotation Text: Input Data files. This file name can be compared to the latest delivered ARP file name, for a given time period.

### 4. SUMMARY

The Ancillary Radiometric Product is a key data file used a the Langley Distributed Active Archive Center to produce MISR data products. As the Level 1B data product is still in the beta phase of maturity, updates to the ARP files are to be expected. A data user can consult the MISR web page (<http://www-misr.jpl.nasa.gov>) to determine if all such ARP revisions have been completed. Should this be the case, the change in radiances between the files on-hand, and those that would be produced with the updated ARP files, can be computed using the procedure discussed above. Reprocessing of early mission data is planned for the future.

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