Multi-angle imaging SpectroRadiometer (MISR) Ancillary Radiometric Product

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ABSTRACT

The in-flight calibration program for the EOS-AM 1 Multi-angle Imaging SpectroRadiometer (MISR) includes on-orbit calibration, characterization of instrument properties and a calibration integrity process. One of the primary activities of the In-flight Radiometric Calibration and Characterization (IFRCC) group responsible for the MISR calibration program at the Science Computing Facility (SCF) is to produce a data file called the Ancillary Radiometric Product (ARP). Radiance scaling and conditioning processing at the Distributed Active Archive Center (DAAC), as well as other science data product generation, proceed using ARP parameters. The parameters that make up the ARP include pre-flight data which give an account of the instrument radiometric response, along with other instrument descriptors. Radiometric response will be maintained and updated throughout the mission.

KEYWORD LIST

ARP, DAAC, EOS, MISR, Radiometric calibration, SCF, SDP, Spectral calibration

1. OVERVIEW

The MISR instrument has been designed and built by the Jet Propulsion Laboratory (JPL), to be launched in 1998 as one of five instruments on the first Earth Observing System platform (EOS-AM 1). MISR will acquire 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. Data from the MISR experiment will enable advances in a number of areas concerning global change:

- Clouds. High resolution bidirectional reflectances will be used in cloud classification, and the spatial and temporal variability of cloud hemispheric reflectance will be determined. Stereoscopic measurements will be used to retrieve cloud-top elevations. These data will help discern the role of different clouds types in the Earth's energy balance.
- Aerosols. Multi-angle radiance data will be used to determine aerosol optical depth, and to identify particle composition and size distribution. These data will enable a global study of the role of aerosols on the energy budget, and will provide data used for atmospheric correction of surface imagery.
- Land surface. Atmospherically-corrected surface bidirectional reflectances will be used to estimate surface hemispheric reflectance, an important climate variable, and to characterize vegetation canopy structures. These data will be important for investigating the effect of land surface processes on climate.
- Oceans. MISR will provide data to support ocean biological productivity studies in regions of low phytoplankton pigment concentrations, such as much of the tropical oceans.

It will fly in a 705 km (440 mile) sun-synchronous descending polar orbit, with an equatorial crossing time of 10:30 a.m. The instrument will be used to produce 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 448, 558, 670, and 858 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 overclock pixels, measure the video offset for each line of data.

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MISR will transmit the data it collects at a peak rate of 6.5 Megabits per second, By the time the raw data is processed a total of 258 Gigabytes per day will be generated as science products. A special system in being developed in order to be able to handle this quantity of' data. The MISR Science Data Processing System (SDPS) will produce science and pre-science data products from MISR instrument data. This system will be integrated into the Earth Observing System Data Information System (EOSDIS). The two components of the EOSDIS architecture where the primary functions of MISR science data processing occur arc the Science Computing Facility (SCF), located at the Jet Propulsion Laboratory in Pasadena, California, and the Distributed Active Archive C-eater (DAAC), located at the Langley research Center in Hampton, Virginia. One of the major activities the MISR SCF supports is carried out by the In-flight Radiometric Calibration and Characterization (IFRCC) group. This group provides instrument calibration and performance assessment, sensor quality control and data validation services and pursues development of MISR science algorithms and software. Much of this groups activities is to provide data and coefficients which are required for Level I B1 processing (radiance scaling anti conditioning) at the DAAC as well as other science data products. In order to get this information to the DAAC the IFRCC group will produce a set of 4 files called the Ancillary Radiometric Product (ARP). This product will be sent to the DAAC as a part of a pre-flight delivery of software and data from the SCF. Portions of the product will be updated throughout the mission and sent to the DA AC. monthly. The parameters that make up the ARP include pre-flight data and give an account of the instrument radiometric response along with other instrument descriptors. This paper will describe the origin, content, structure, the usc of the parameters in the ARP and the context in which the ARP delivers data to DAAC processing software.

2. MISR DATA PROCESSING

The MISR project is a component of the Earth Observing System (EOS) AM project, and the EOS Data Information System (EODIS), which are components of the NASA Mission To Planet Earth (MTPE). MISR Science Data Processing (SDP) exists to produce higher order science data products from raw M ISR instrument data. Typically, these products represent the retrieval of geophysical parameters such as column aerosol optical depth, atmospherically corrected hemispherical directional reflectance factor, and top-of-atmosphere bidirectional reflectance factor from CCD digital number (DN) measurements. This implies that MISR SDP must be able to:

1) ingest the instrument science and engineering data,
2) process quickly enough to stay ahead of the input data rates plus any reprocessing requests,
3) execute algorithms specified by the MISR science team,
4) provide flexibility to enable data quality improvements through algorithm or ancillary dataset upgrade, and
5) produce data sets that arc understandable and useful to the science community.

EOSDIS is a comprehensive earth science research information system which facilitates the extraction and exchange of scientific information from huge volumes of data and links a distributed science community to long-term data sets from E. OS, non-EOS earth probes, and in-situ measurements, .as well as to previous research results. It schedules and controls EOS instruments and observatories in accordance with investigator needs. It coordinates collection, processing and data exchanges with the international partners. It processes, maintains, and distributes the resulting data and information. The MISR SCF is a unique facility dealing only with MISR instrument issues. The MISR DAAC, which is shared with several other EOS instruments, will be the facility at which MISR science software will operate in a high volume, production mode. It will produce the standard science data products.

2.1. SCF IFRCC Processing

A subset of the activities which take place at the MISR SCF arc carried out by the IFRCC team[1,3,5] anti has the objectives of:

- providing for the in-flight radiometric calibration of the sensor and validate that this calibration meets the absolute and relative accuracy requirements;
- delivering this calibration to the DAAC in the form of the Ancillary Radiometric Product (ARP), and update this product as needed to maintain the accuracy of calibration;
- developing the radiance scaling and conditioning algorithms, used in Level1B1 standard product generation at the DAAC;
- providing for the characterization of the sensor, as needed to define the impact of hardware performance on the scientific products; and

• validating radiances produced from the radiance sealing and conditioning algorithms.

A high-level summary of these activities, the input data types, output products and deliverables are depicted in Figure 1. The IFRCC team will develop SCF algorithms and processing codes to explore MISR performance and provide the needed radiometric calibration and characterization products and reports. Non-MISR input data sets include the vicarious (ground truth) in-situ measurements, used in vicarious calibration processing. and cross-sensor data, used for calibration verification. The development of the Level 1 B1 Radiance Product algorithms is primarily a pre-launch activity, with post-launch updates as needed. The calibration, characterization, anti calibration integrity activities at-c on-going processes in the post-launch era.

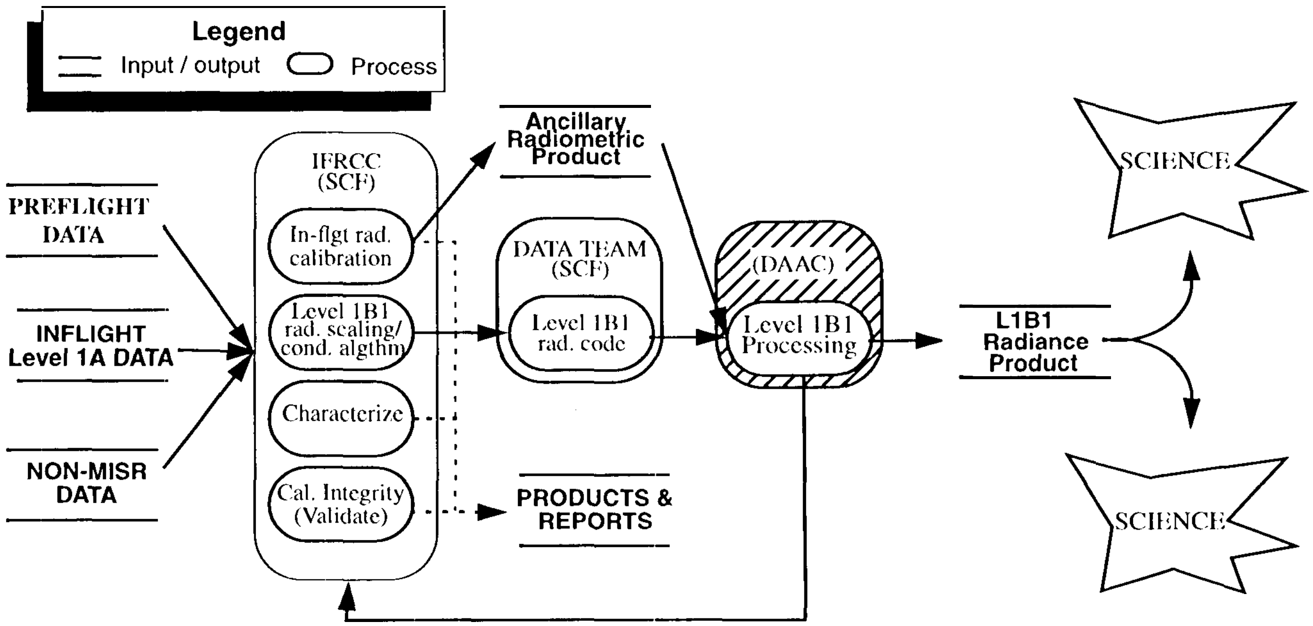

Figure i. IFRCC program elements.

Four calibration methodologies arc weighted to produce the ARP radiometric coefficients anti radiance uncertainty tables. These are On-Board Calibrator (OBC), vicarious calibration (VC), histogram equalization (HE), and data trend methodologies. Characterizations will include noise analyses, anti radiometric uncertainties as quantified for a variety of specific scenes types (having high spatial or spectral contrast). The ARP aiso provides an estimate of radiance uncertainty (assuming a uniform scene) at several radiometric levels. Finally, calibration integrity and Level i B i validation will be accomplished using cross-sensor comparisons and MISR desert scene data. Lunar calibration data will be additionally analyzed for stability verification purposes.

Characterization is the measurement of the typical behavior of instrument propel-tics which may affect the accuracy or quality of the derived data products. The in-flight characterization includes a determination of the noise and spatial frequency response of the sensor. It determines the potential for radiometric errors as may occur for specific scene types, including those of high spatial or spectral contrast. Finally, the in-flight characterization program will attempt to confirm that many instrument properties arc as measured in the pre-launch laboratory environment. 'i'his includes spectral response stability, hysteresis, saturation recovery, and modulation transfer function (MTF).

Calibration integrity is the process of validating and certifying the Level i B i Radiometric product, One component of calibration integrity is the determination of any radiometric biases between the M ISR radiometric scale and that used by other remote sensing instrument (particularly EOS sensors). Periodic cross-comparisons with Moderate Resolution Imaging Spectroradiometer (MODIS), Système Probatoire ci'Observation de la Terre (SPOT), and Landsat Thematic Mapper (TM) sensor calibrations will be made, as data become available. As an added check on the radiometric calibration, there will be a routine analysis of MISR imagery over desert sites. Likewise, response stability may be verified using lunar observation data, ii' available.

MISR is routinely calibrated in flight to account for anticipated degradations in sensor response with time. Pre-flight calibration data arc used to establish a prediction of the initial on-orbit response. The in-flight calibration activities of the IFRCC team arc discussed in the companion paper following this one.

Sensor calibration data arc used in the production of the MISR standard radiance product, termed the Level i B i Radiometric Product. Although processing occurs at the DAAC, it is the responsibility 01 the IFRCC team to provide the algorithms, which the MISR Science Data System Team turns into production software. The algorithms arc broken down into two types. In the radiance scaling processing step, DN values arc converted to band-weighted spectral radiances. The second process is termed radiance conditioning. Here, tile radiances arc adjusted to spectrally scale tile measured radiance, predicting tbc value measured by a nominal passband. In addition, image sharpening is performed using PSF data. Out-of-band spectral response subtraction is also performed on select Level 2 (Top-of-atmosphere/Cloud anti Acrosoi/Surface) products.

The Level 1 B i (Radiometric scaling and conditioning) anti Level 2 (Top-of-atmosphere/Cloud anti Acrosoi/Surface) processing algorithms require calibration data sets. Several parameters arc available oniy through the pre-flight test and analysis program. Examples are the spectral calibration anti point- spread function parameters. These parameters arc treated as static, as they arc believed to be temporally invariant, although on-orbit characterizations wiii be done to test these assumptions.

The radiometric calibration data will be updated throughout the mission. 'l'his is accomplished through the delivery of a new ARP file to the DAAC. Monthly updates arc planned, but updates can occur as needed to maintain an accurate record of the instrument performance.

2.2. ARP Role in Processing

The processing flow for the portion of generation of tile Level i A (Reformatting anti Annotating) Product dealing with radiometric image data and for the Level 1 B I Radiometric Product is shown in Figure 2, along with a symbol convention [']. They arc shown as part of a combined flow because it is currently envisioned that the Level 1A product wiii be archived, whereas the Level 1 B i product wiii be hcid temporaril y oni y until the complet ion of Level i B2 (Aerosol/Surface) processing. Users interested in the Level i B i product will be able to obtain it "on-demand". The scene-dependent data quality assessment parameters report on loss of radiometric integrity duc to saturation, or other anomalous conditions. Radiance scaling uses coefficients, generated at the MISR Science Computing Facility (SCF) and reported in the Ancillary Radiometric Product, to convert digital numbers to radiances. These coefficients represent our latest understanding of each pixel's response function, and arc derived as described in IFRCC documentation[1,5]. Radiance conditioning consists of point-spread function (PSF) deconvolution to provide an image restoration step to compensate for low-level halos in the camera impulse response. The rationale behind the radiance conditioning process arises from an understanding of the actual camera performance characteristics, obtained during pre-flight testing. The output product consists of radiance values corresponding to cacb Level i A input value. Additionally, data integrity metrics arc reported with the Level i A product.

3. ARP

The ARP purpose is to convey calibration, characterization and verification products from MISR instrument data, as well as external data sources, to the DAAC where the information is used to correct and produce science data products.

The ARP uses the Hierarchical Data Format (HDF). HDF is a mult-object file format for sharing scientific data in a distributed environment anti was created at the National Center for Supercomputing Applications to serve the needs of diverse groups of scientists working on projects in many fields. It is designed to address many requirements for storing scientific data including:

- Support for the types of data anti metadata commonly used by scientists.
- Efficient storage of anti access to large data sets.

- Platform independence.
- Extensibility for future enhance nts and compatibility with other standard formats.

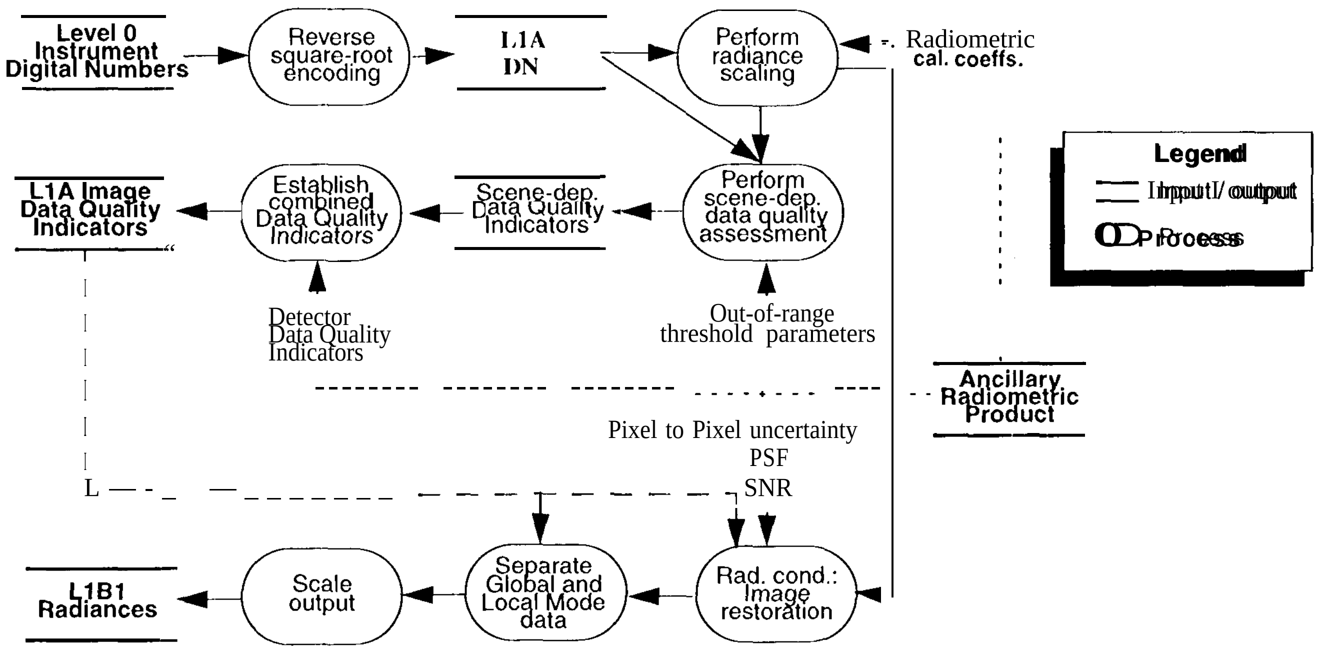

Figure 2. ARP role in the generation of the science data in the Level I A and Level I B 1 products

HDF also consists of supporting software that make it easy to store, retrieve, visualize, analyze and manage data in HDF files.

The ARP is composed of four HDF files each containing different sets of data classified by use and origin. Within these four files are two sets of parameters, updated and static. Updated parameters are recomputed and incorporated in the ARP to be delivered to the DAAC on a monthly basis. The information used to update these parameters comes from instrument science and calibration data as well as ground calibration data. The static parameters are expected to never change and are generated during pre-launch calibration efforts. The file that will be updated most frequently is the ARP in-flight calibration file.

The first file making up the ARP is tbc Pre-flight Characterization Data file and contains pre-flight instrument characterization parameters supplied for data user reference. Examples include the measured spectral response functions, and the instantaneous fields-of-view. These parameters are not used by DAAC processes. It is unlikely that this file will be modified once delivered. However, a version number wiii be tracked for all ARP files should this be the case.

The second fiic in the ARP is the Pre-flight Calibration Data file anti contains pre-flight calibration data, It is distinguished from the Pre-flight Characterization Data file, in that these data are used as input to DAAC processes. Parameters include spectral band parameters, spectral in-band nonuniformity correction factors, spectral-out-of-baa(i correction matrix, the point-spread functions, exo-atmospheric spectral solar irradiances and the PAR integration weights. Radiometric gain coefficients are not included here, as they are updated on-orbit. It is unlikely that this file will be modified once delivered.

The third file making up the ARP is the In-flight Calibration Data file which contains in-flight calibration data. It is also used as input to DAAC standard product generation. It is distinguished from tbc Pre-flight Calibration Data file, in that these instrument parameters are monitored on-orbit. At-i aunch values are initialized by tbc pre-flight calibration data. Monthly updates to this file allow processing to continue with current performance metrics. Parameters include radiometric calibration coefficients, absolute radiometric calibration coefficient uncertainties, relative radiometric calibration coefficient uncertainties, signal-to-noise ratios, data quality indicators and quality assessment threshold parameters. A date range revision number will indicate a revision has been made to the parameters, should this occur.

The fourth file making up the ARP is the Configuration Parameters file which contains threshold parameters and process control limits used by DAAC processes. Examples arc the average digital number (DN) value of a line above which data integrity is reduced, and the number of iterations performed for point-spread function (PSF) deconvolution. They are expected to change only at the discretion of the Principal Investigator, Instrument Scientist, and the Science Team. Such a change would reflect a relaxation of stricter tolerance of specific data anomalies. A version number will reflect any such changes.

4. ARP DATA ORIGIN - PRE-FLIGHT TESTING OVERVIEW

Much of the ARP contents are obtained from pre-flight testing of the instrument components and systems. Testing of MISR flight hardware is done at the component, camera, and system levels, as well as after integration onto the spacecraft. The bulk of the science performance data, however, are collected at the camera level of assembly[2,4,8]. By characterizing each camera individually, testing can be spread over time and the test hardware is simplified.

After assembly a camera first goes to the Optical Characterization Chamber (OCC). A xenon lamp source external to this chamber feeds a chamber-internal target wheel. At the target wheel a pinhole is selected according to the focal length of the camera under test. The pinhole target is at the focus of a collimator. allowing the camera to image the pinhole which produces a subpixel Airy disk when well focused. The camera is attached to a two-axis gimbal and this pinhole image can be scanned across the focal plane in either the downtrack or crosstrack directions. With this set-up the OCC is used to provide the boresight modulation transfer function (MTF), point-spread function (PSF) (See Figure 3.), camera boresight location, effective focal length, and pixel pointing (distortion mapping) of the sensor[7,9].

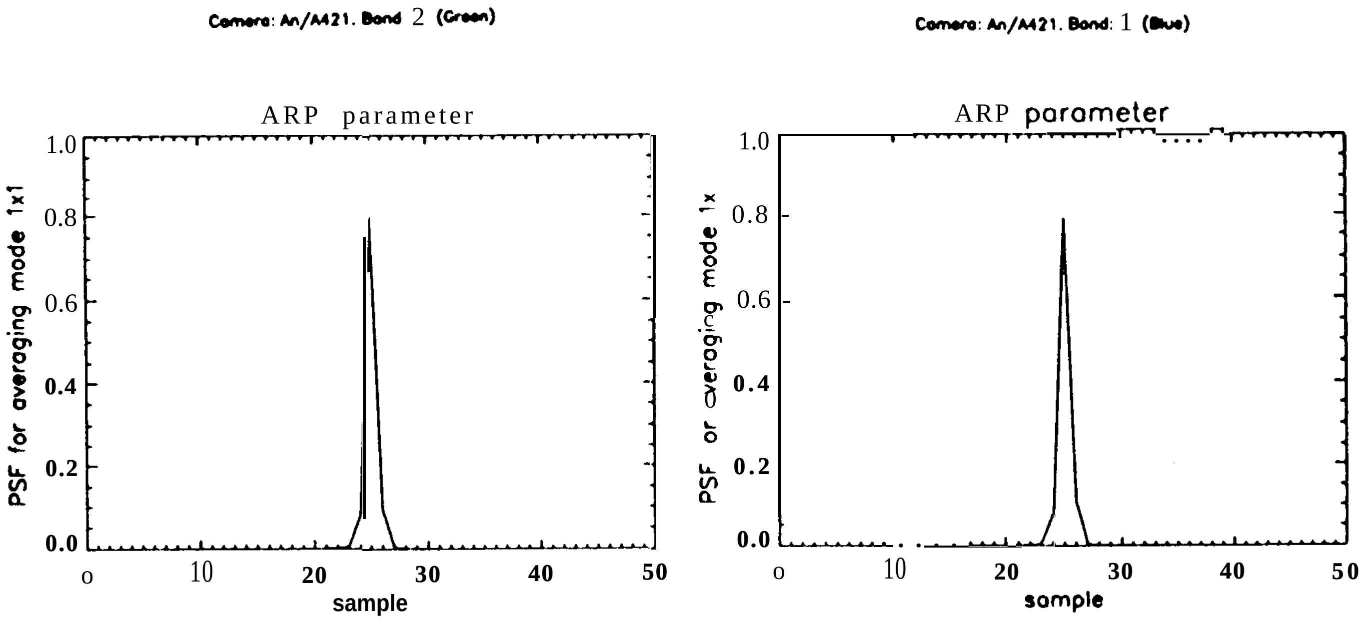

Figure 3. PSF for the Nadir Camera (An). Examples of the PSF functions for the **blue and** green bands.

Following completion of OCC testing, cameras are moved to the Radiometric Characterization Chamber (RCC). This chamber has a window within its door. Either a monochromator or integrating sphere arc wheeled in front of the chamber, illuminating the camera through this window. Radiometric and spectral calibration camera data arc acquired while in this chamber. Radiometric testing makes usc of a 1.65 m (65”) integrating sphere, calibrated with high quantum efficiency light-trapped photodiodes. Twelve radiometric levels, unique [o each spectral band and spanning the detector dynamic range, arc used.

Each photoactive pixel element stimulated with incident radiation responds with an output measured in DN. The plot of incident radiance versus DN is the radiometric transfer curve. The objective of radiometric calibration is to develop a calibration equation which best represents the observed radiometric transfer curve, and to provide both a quantitative determination of the gain coefficients to this equation, as well as the uncertainties in measuring radiances using these coefficients. The most appropriate source to use for radiometric calibration is full-aperture (one that overfills the sensor's field-of-view), as well as, spatially and spectrally homogeneous. Multiple radiometric levels are used which span the portion of the sensor dynamic range that is of interest 10 the data community. Radiometric uncertainties due to specific scene features (e.g., high contrast targets) arc also reported as part of the IFRCC characterization program.

The gains associated with the individual detector elements can change with time, due to polymerization of contaminants on lens surfaces, lens browning, and the effects of radiation on the electronics. Because of this anticipated degradation with time, the radiometric response is monitored during the mission.

Pre-flight calibration determined that a quadratic calibration best represents the radiometric transfer curve for each of the cameras. Although the CCD response is nearly linear (the second order coefficient is quite small), inclusion of this term improves the radiance retrieval at the lower end of the detector transfer curve. The equation MISR will use is:

$$DN - DN_o = G_0 + G_1 L_\lambda + G_2 L_\lambda^2$$

where:

L_λ is the sensor band-averaged spectral incident radiance, averaged over both in-anti-out-rrf-hand wavelengths, reported in units of [W m^{-2} sr^{-1} µm^{-1}], and defined by the equation:

$$L_\lambda = \frac{\int L_{source} S_{\lambda,b} \lambda d\lambda}{\int S_{\lambda,b} \lambda d\lambda}$$ where $S_{\lambda,b}$ is the standardized spectral response function for band b created from averaging over all the measured values $R_{\lambda,b}$ and λ within the integral converts from units of photon counts to energy;

DN is the camera output digital number,

G_0, G_1, and G_2 arc 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 deter-mincci by an average over the first eight "overclock" pixel elements (shielded pixels at the cad of the sensor array).

Gain coefficients arc available for every active pixel measured at the specified camera integration time. A convenient way to summarize this large number of coefficients is by using the channel averaged gain responses (G_1) Table 1.

Table 1: Channel averaged gain response (Wm^{-1}µm^{-1}sr^{-1}/DN). Cameras arc designated from A through D spanning a range of view angles from nadir to 70.5° forward (f) and aftward (a) of nadir (An).

Camera	G_1			
	Band 1 / Blue	Band 2 /"Green	Band 3 / Red	Band 4 / NIR
Df	23.7	23.s	28.1	44.1
Cf	23.2	24.1	29.5	45.0
Bf	23.7	22.6	29.5	45.7
Af	23.4	23.6	29.3	43.8
An	20.9	21.9	30.2	43.7
Aa	23.2	24.3–"	28.9	42.7
Ba	26.1	23.x	27.5	47.9
Ca	23.0	23.1	27.9	44.7
Da	23.1	22.K	27.5	42.4

Spectral calibration is conducted using a single-pass gt-sting monochromator, xenon arc lamp, and variable width exit slit. Both in-band scans, at 0.5 nm sampling and 2.6 nm resolution, and out-of-band scans, at 19.6 nm resolution and 10 nm sampling, arc made of each CCD line array. Testing covers the 400 to 900 nm range, but the response characterization is extended from 365 to 1100 nm through component-level studies.

in-band spectra] calibration data arc taken at seven field-angle locations across the array; out-of-band calibration data arc taken at three field-angle locations. Parameters reported in the ARP use three field positions for both the in- and out-of-band data. Out-of-band response beyond the limits of the monochromator (less than 400 or greater than 900 nm) is determined by using the measured focal plane spectral response data (CCD, filter, and window), collected to 1000 nm, and a lens transmittance model. Tbc spectral response of the MISR cameras arc known to be limited to above 365 nm, due to lens transmittance, and below 1100 nm, due to the bandgap of the silicon detectors (See Figure 4, 5, 6, and 7).

MISR will not need to apply a soLlrcc-correction scaler to the pre-flight-determined calibration coefficients. This is sometimes done by other programs, to account for the source-color differences between the laboratory calibration (using a sphere source), and Sun color temperature. The argument for using these correction factors is that the Sun-illuminated target provides a different out-of-band target, which affects the gain constant. As MISR is reporting band-weighted radiances, this correction is not needed. [1]

Analyses of the spectral response functions can lead to descriptor parameters which arc approximations to the actual functions. These derived parameters are a mathematical convenience, and additionally useful in defining specifications, in comparing pixel-to-pixel or camera-to-camera response differences, or in assigning a wavelength to which a geophysical parameter (e.g., surface reflectance, or atmospheric transmittance) is reported. The moments analysis provides an equivalent squat-c band representation of the profile, and is convenient in summarizing the total-hand response spectral performance of the sensor array.

The total-band weighted solar irradiancc, $\mathcal{E}_{0,b}^{std}$ is given by: $\mathcal{E}_{0,b}^{std} = \left(\int_{365}^{1100} E_{0\lambda} S_{\lambda,b} \lambda d\lambda\right) / \left(\int_{365}^{1100} S_{\lambda,b} \lambda d\lambda\right)$, where $E_{0\lambda}$ is the exo-atmospheric solar irradiancc at 1 A. U., $S_{\lambda,b}$ is the standardized spectral response profile for band b created from averaging over all the measured values $R_{\lambda,b}$, and λ within the integral converts from units of photon counts to energy. This irradiancc is associated with an equivalent band that is characterized by the moments equations:

$$\lambda_{m,solar,b}^{std} = \int_{365}^{1100} \lambda \cdot E_{0\lambda} S_{\lambda,b} d\lambda / \int_{365}^{1100} E_{0\lambda} S_{\lambda,b} d\lambda$$

$$\sigma^2 = \int_{365}^{1100} \lambda^2 \cdot E_{0\lambda} S_{\lambda,b} d\lambda / \int_{365}^{1100} E_{0\lambda} S_{\lambda,b} d\lambda - (\lambda_{m,solar,b}^{std})^2$$

$$\lambda_{u,l} = \lambda_{m,solar,b}^{std} \pm \sqrt{3} \cdot \sigma$$

$$\Delta\lambda_{m,solar,b}^{std} = 2\sqrt{3} \cdot \sigma$$

The in-band and total-band (385 - 1100 nm) weighted solar irradiancc parameter values arc reported on the figures for the standardized spectral response functions for each band. $\mathcal{E}_{0,b}^{std,in-band}$, over each of the MISR bands is given by:

$$\mathcal{E}_{0,b}^{std,in-band} = \left(\int_{in-band} E_{0\lambda} S_{\lambda,b}^{in-band} \lambda d\lambda\right) / \left(\int_{in-band} S_{\lambda,b}^{in-band} \lambda d\lambda\right)$$

where the in-band region is defined as $\lambda_{l,b}^{std} < \lambda < \lambda_{u,b}^{std}$, $E_{0\lambda}$ is the exo-atmospheric solar spectral irradiance at 1 astronomical unit (AU) and $S_{\lambda,b}^{in-band}$ is the standardized spectral response function. Tbc multiplication by λ within the integrals is for the purpose of converting from units of photon counts 10 energy, as the CCD detectors are photon-recording devices. This irradiance is associated with an equivalent band that is characterized by the moments equations:

$$\lambda_{m, solar, b}^{std, in-band} = \int_{in-band} \lambda \cdot E_{0\lambda} S_{\lambda, b}^{in-band} d\lambda / \int_{in-band} E_{0\lambda} S_{\lambda, b}^{in-band} d\lambda$$

$$\sigma^2 = \int_{in-band} \lambda^2 \cdot E_{0\lambda} S_{\lambda, b}^{in-band} d\lambda / \int_{in-band} E_{0\lambda} S_{\lambda, b}^{in-band} d\lambda - (\lambda_{m, solar, b}^{std, in-band})^2$$

$$\lambda_{u, l} = \lambda_{m, solar, b}^{std, in-band} \pm \sqrt{3} \cdot \sigma$$

$$\Delta\lambda_{m, solar, b}^{std, in-band} = 2\sqrt{3} \ .6$$

The values for these wavelength parameters arc reported on the plots for the band weighted solar irradiance profiles and arc used in the description of any product for which out-of-band correction has not been performed.

Also displayed on the plots arc specification levels and moment analysis square band results. The dotted lower horizontal line on the band profiles is the average out-of-band specificat ion of 0.000 I in transmittance for data averaged over 100 nm; the upper dotted horizontal line is the maximum out-of-band specification of 0.001 in transmittance; the vertical dotted lines arc the wavelength locations which is considered to be in-band; the broader, lower square dashed rectangle is the total-band moment analysis band anti the narrow dashed rectangle is the in-band moment analysis band.

The gaussian representation is also useful to approximate the MISR in-band region. This is because the MISR filters were designed to be gaussian in shape, allowing a polarization insensitive camera design when used in conjunction with a Lyot depolarizer. The gaussian best-fit analysis has been done anti is reported in the AI-W, but are not presented here.

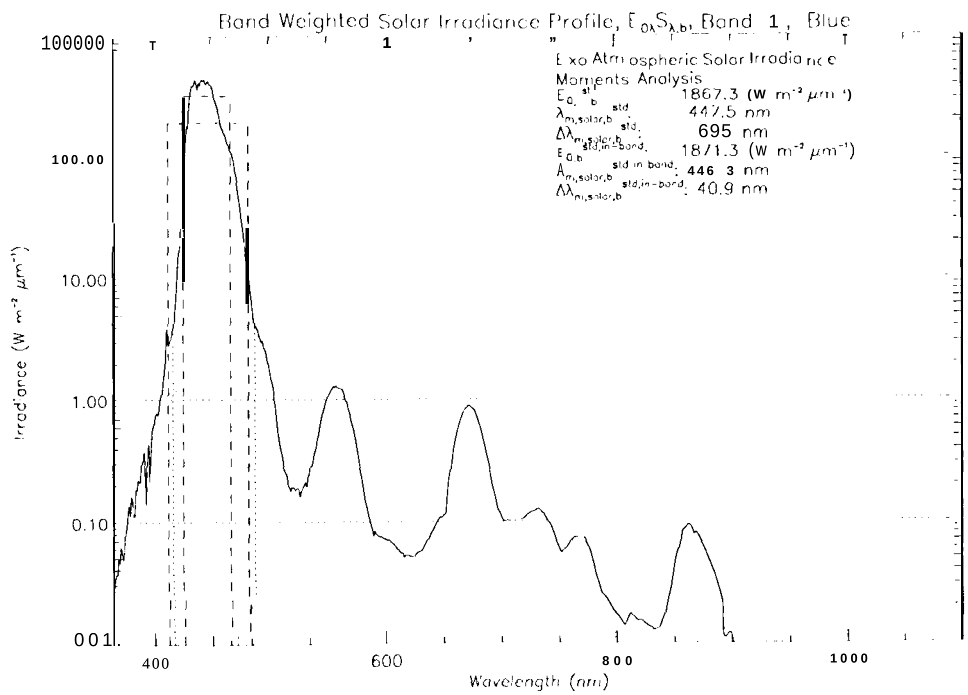

Figure 4. Standardized Spectral Response Function for the Blue Band

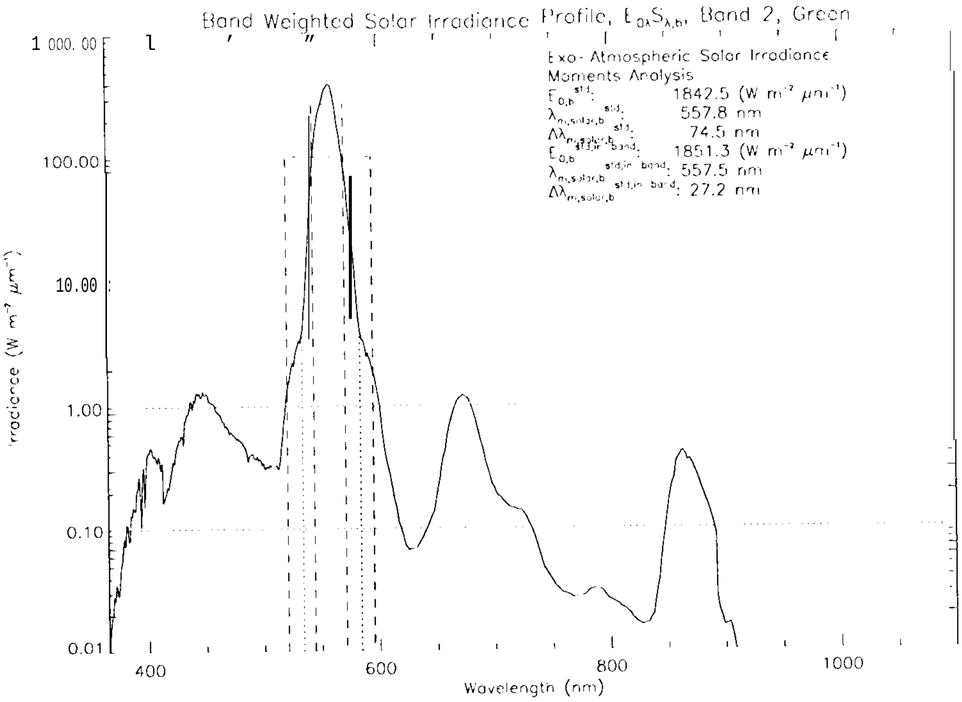

Figure 5. Standardized Spectral Response Function for the Green Band.

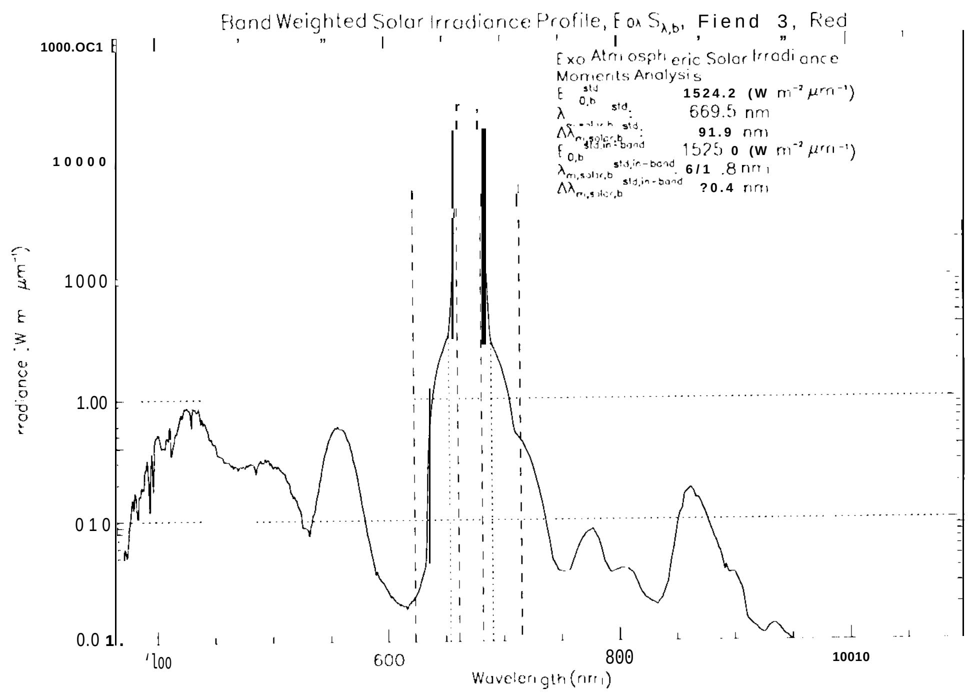

Figure 6. Standardized Spectral Response Function for the Red Band.

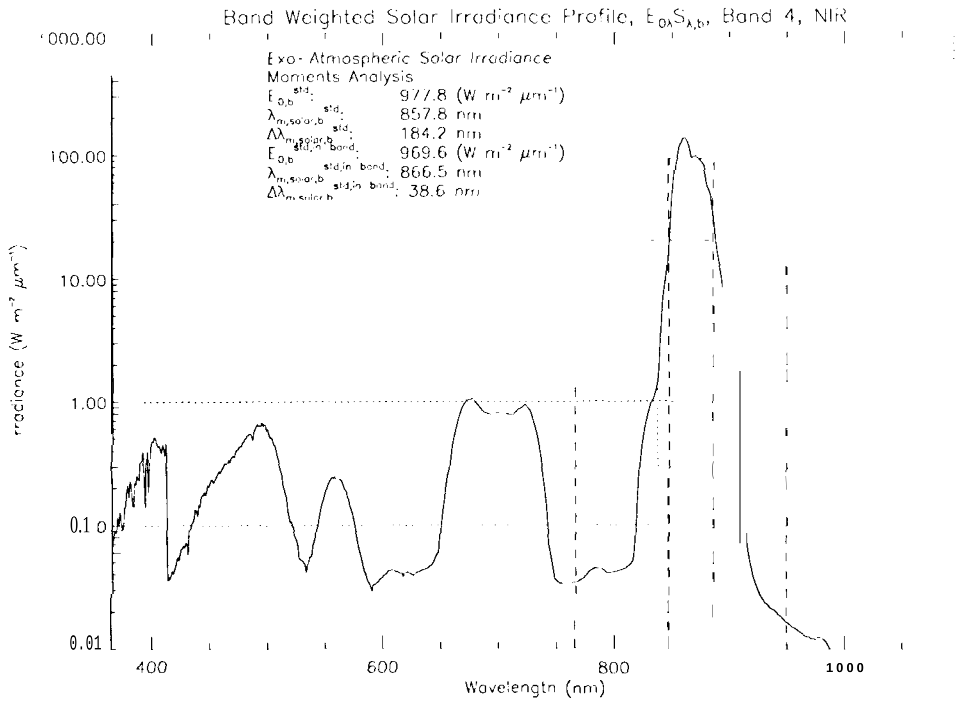

Figure 7. Standardized Spectral Response Function for the Near Infrared Band.

10 general the cameras were found to meet their design specifications. Exceptions, such as slight boresight and local non-uniformity errors, arc believed to be small enough such that there is no effect on the science data products. Saturation blooming affects arc larger around the saturated pixel than originally anticipated. The cause may partially be explained by PSF, which appears broader bemuse of the intense signal strength. This halo cannot be effectively removed by PSF deconvolution, as the amount of energy to remove from neighboring pixels is unknown (the radiance falling on the saturated pixel is unknown). An electronic noise is additionally noted on pixels clocked out following the saturated clement. This noise is negligible (~5 DN out of the 16,384 DN range) for a single saturated pixel, but begins to be discernible when a large fraction of the array is saturated (the noise is additive with number of saturated pixels). This extended saturation scenario, however, is unlikely to occur on orbit.

A sophisticated data quality assessment algorithm will identify all pixels which arc radiometrically affected by saturation or other specification errors. Pixels for which the specifications fail will not be used in science data product generation. Other data quality checks are for detector failures (e.g., poor signal-to-noise), or for pixels which have a low DN when the data line has an atypically high average DN. The latter is tracked, as at high illumination levels it is noted that there is an uncertainty in the measured video offset. That is determined in that the overclock samples arc not stable throughout the line read. This electronic noise is also small (-25 DN for an average DN of 12,000 for the line), and therefore will seldom be problematic.

Two performance violations that arc more consequential and have resulted in added ground processing. 'I'hat is, as a result of camera performance testing, MISR now plans to make usc of an out-of-band correction algorithm to certain Level 2 science products[6]. Additionally, an image restoration algorithm will use the measured PSF response to remove the effects of light scattering within the focal plane. These effects result from scattering within the filter, and between the detector and filter (separated by 38 μm)[6]. It should be kept in mind that M ISR is calibrated to an unprecedented radiometric calibration accuracy (3%/1σ confidence level for uniform bright scenes). These added processing steps will allow spectrally or spatially inhomogeneous scenes to be measured within the radiometric specifications defined for more homogeneous scenes. Conversely, without this processing the radiometric requirement would still be met for most scenes, however certain scene types would have radiance errors between 3 and 10%. This information has to be added to the ARP to be passed to the processing algorithms at the DAAC.

5. SUMMARY

The Ancillary Radiometric Product provides a key link between the science product production activities at the Distributed Active Archive Center and the calibration and characterization activities at the Science Computing Facility. The Ancillary Radiometric Product consists of four Hierarchical Data Format files which contain pre-flight calibration, pre-flight characterization, in-flight calibration data and configuration parameters. The pre-flight information is never expected to change. Configuration parameters would only change if the algorithms used for science product processing arc altered. In-flight information will be regularly updated to provide the most up to date calibration parameters to the science product processing software. The pre-flight calibration information the Ancillary Radiometric Product contains reflects much of the work done to meet the demanding requirements set for the Multi-angle Imaging SpectroRadiometer, especially the 3% radiometric calibration accuracy specification.

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