Multi-angle Imaging SpectroRadiometer (MISR) Calibration and Test Program

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California Institute of Technology

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<th>Role and Responsibility</th>
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<tr>
<td>David Diner</td>
<td>MISR/ AirMISR Principal Investigator</td>
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<tr>
<td>Terry Reilly</td>
<td>Project Manager</td>
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<tr>
<td>Valerie Duval</td>
<td>Calibration Engineer</td>
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<tr>
<td>Carlos Jorquera</td>
<td>Photodiode assembly and test</td>
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<td>Nadine Chrien</td>
<td>Radiometric model, polarization, BRF analysis</td>
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<td>Barbara Gaitley</td>
<td>Radiometric and spectral data analysis</td>
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<td>Ghobie Saghri</td>
<td>Radiometric and spectral facility design</td>
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<td>Daniel Preston</td>
<td>Filters/ flight camera testing</td>
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<td>Teré Smith</td>
<td>Integration and test</td>
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<td>Eric Hochberg</td>
<td>Optical Characterization chamber</td>
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<td>Robert Korechoff</td>
<td>MTF, focus, special studies</td>
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<td>David Haner</td>
<td>Spectralon BRF testing</td>
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<td>Brian Chafin</td>
<td>In-flight data processing software</td>
</tr>
</tbody>
</table>
OUTLINE

The MISR/ AirMISR instruments

Detector-based calibration
  Manufacture of the laboratory and flight standards
  Traceability to Système International Units
  NIST verification (EOS round-robin experiment)

Test program
  "Optical Characterization Chamber": MTF, PSF, focus
  "Radiometric Characterization Chamber": Radiometric, Spectral Polarization
  Instrument level tests: image verification, camera pointing, data fidelity

Special studies
  Out-of-band spectral response, focal-plane scattering, offset video

In-flight calibration
  On-board calibrator, vicarious calibration
  Reconciling multiple calibrations

Data products
  The Ancillary Radiometric Product
Complete publication list is available via the Internet


IEEE’98 EOS Special issue


Calibration overview

Photodiodes


Diffuse panel studies


In-flight calibration


**Testing reports**


**IFRCC/ Level 1B1**

MISR OVERVIEW

Platform: Terra (EOS-AM1)
Launch: No earlier than August 27, 1999
  - recent TITAN IV/CENTAUR and DELTA III launch failures may cause a delay
Other EOS-AM1 instruments: MODIS, CERES, ASTER, and MOPITT

MISR capabilities: Multi-angle global view of earth
  - 9 cameras pointing nadir to ±70°
  - 4 spectral bands 446, 558, 672, and 866 nm
  - global coverage every 9 days
  - on-board pixel averaging (275 m - 1.1 km)
  - average data rate 3.3 Mb/sec
DEVELOPMENT TIMELINE

- Proposal submitted: July 15, 1988
- Preliminary design review (PDR): May 25, 1993
  - Calibration peer review: May 23, 1993
  - Preflight calibration plans: January 10, 1994
- Critical design review (CDR): December 6, 1994
  - Calibration peer review II: March 27-28, 1995
- Calibrate cameras
  - Engineering model: August 1994-August 1995
  - Calibrate flight cameras (10): August 1995-August 1996
- Instrument thermal vacuum testing: December 1996
- MISR arrives at spacecraft integrator: May 26, 1997
- Develop in-flight calibration processing capability: 1998
- Original launch date: June 1998
• Original proposal “Low-cost Airborne MISR Simulator” was submitted to the EOS Project Scientist (Dr. Michael King, GSFC) on 10 Nov 1995

• Objectives for AirMISR
  - collect MISR-like data sets in support of the validation of MISR products
  - underfly EOS-AM1 MISR to verify its radiometric calibration
  - enable scientific research utilizing high quality, well-calibrated multi-angle imaging data
  - enable the exploration of measurement enhancements (room reserved in instrument reserved as technology testbed for future cameras)

• MISR inheritance
  - implementation features a single pushbroom camera, gimbaled to nine view-angle positions during a 15 minute data acquisition run
  - camera comprised of a MISR brassboard lens (“A” lens design, shortest focal length), and MISR engineering model focal plane
  - spectral bands at 446, 558, 672, and 866 nm (widths of 20 - 40 nm)
  - spectral, radiometric, and point-spread-function (PSF) response measured using MISR-developed laboratories and analysis procedures
## PERFORMANCE COMPARISON

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MISR</th>
<th>AirMISR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute uncertainty</td>
<td>3% (1σ)</td>
<td>3% (1σ)</td>
</tr>
<tr>
<td>Number of detector elements</td>
<td>9 camera x 4 bands x 1504 pixels (~53,000)</td>
<td>4 bands x 1504 pixels (~6000)</td>
</tr>
<tr>
<td>Worst detector elements</td>
<td>10% &lt; response loss &lt; 1%</td>
<td>40%&lt; response loss</td>
</tr>
<tr>
<td>Number of detector anomalies</td>
<td>~12</td>
<td>~20 in blue ~ 20 in green</td>
</tr>
<tr>
<td>SNR</td>
<td>&gt; 900</td>
<td>same, excluding anomalous pixels</td>
</tr>
<tr>
<td>Spectral out-of-band</td>
<td>&lt;2%</td>
<td>4% in Band 3</td>
</tr>
</tbody>
</table>
**CALIBRATION PLAN**

- **System design:**
  - temporal stability achieved through radiation resistant components, contamination control, and flight UV blockers, lens shades, and cover
  - polarization insensitivity achieved through optical design
  - stray-light control within cameras calibrator subsystems

- **Detector-based standards** establish radiometric scale to ±3% (1σ; \( \rho_{eq} = 1.0 \)) uncertainty

- **Multiple methodologies** reduce systematic errors

- **Overflight campaigns** (semi-annual)
  - + On-Board Calibrator (monthly)

**Preflight:**
- laboratory standards provide measure of integrating sphere output

**In-flight:**
- flight standards provide measure of diffuser-reflected sunlight

**Detector-based standards** establish radiometric scale to ±3% (1σ; \( \rho_{eq} = 1.0 \)) uncertainty

**MISR team**
- generation of radiometric coefficients

**Level 1B product**
- production using recent ARP

**Level 2 science products**
- Monthly updates to ARP

**Radiance product reflects** best estimate of instrument responsivity
MISR REQUIRES RADIOMETRIC CALIBRATION AND STABILITY

SCIENCE REQUIREMENTS (68% CONFIDENCE)

• Absolute radiometric uncertainty: ±3% at signal $\rho_{eq}=100$
  - Required for accurate albedo and aerosol retrievals, change detection
• Relative angle-to-angle radiometric uncertainty: ±1% at signal $\rho_{eq}=100$
  - Required for accurate determination of angular signatures
• Stability (maximum change): 0.5%/ 1 month; 2%/ 1 year at signal $\rho_{eq}=100$
  - Required to maintain radiometric accuracy during intervals between calibrations

RAMIFICATIONS FOR INSTRUMENT

• High accuracy on-board calibrator
• Detector-based calibration using high quantum efficiency (HQE) and radiation resistant (PIN architecture) diodes
• High stability detectors, filters, and lenses
• Polarization insensitivity
• High signal-to-noise ratio
MISR REQUIRES SPECTRAL UNIFORMITY AND STABILITY

<table>
<thead>
<tr>
<th>REQUIREMENT</th>
<th>RATIONALE</th>
</tr>
</thead>
</table>
| Accuracy    | - Optimizes science  
- Avoids solar Fraunhofer lines and atmospheric water absorption 
- Provides synergism with other instruments |
| Knowledge   | - Necessary to avoid radiometric error |
| Uniformity  | - Minimizes complexity of science algorithms  
- Achieves consistent retrieval across the scene |
| Stability   | - Eliminates need for on-board calibration within instrument  
- Achieves consistent retrieval with time |

RAMIFICATIONS FOR INSTRUMENT

- Interference filter and blocker designs to provide high out-of-band rejection
- High stability filter coatings (Ion Assisted Deposition technology) to avoid need for on-board spectral calibrator
- Gaussian band profiles to provide polarization insensitivity
• MISR has stringent calibration requirements
  - Remote sensing systems flown prior to 1990 had very lax calibration requirements
  - Landsat program did not provide radiance data products
  - SPOT requires absolute calibration to only 10%
  - Conversely, MISR has very stringent (3%) absolute calibration requirements
  - Detector-based calibration elected to meet this challenge
  - Literature reports accuracies of 0.5%, using filtered trap detectors

• Building flight detectors no easy task
  - assembly hermetically sealed to allow focal plane stability (protected from humidity, contaminants, filter shifts)
  - light-trap manufactured from using ceramic subcarriers
  - precision apertures manufactured using photolithography techniques (1 μm tolerance)
  - radiation testing required, simulating on-orbit environment
  - radiometric response verified by consistency checks with independent devices (laboratory standards and wedge standards)
ON-BOARD CALIBRATOR

Stowed diffuse panel

Deployed diffuse panel

67.5°
On-Board Calibrator (OBC)

- **High quantum efficiency (HQE) diodes**
  - Detector-based radiometric standard for the instrument
  - Configured in light-trap arrangement to give near 100% QE

- **Radiation resistant PIN diodes**
  - Secondary detector standard (longer lifetime than the HQEs)

- **Deployable Spectralon diffuse panels**
  - Relative BRF needed to transfer diode measurements into camera view angles
  - Absolute reflectance knowledge unnecessary (slow degradation permissable)

- **Mechanized goniometer diode (G-PIN)**
  - Verifies BRF stability of diffuse panels

Radiometric calibration

- Acquire monthly OBC data (6 minute interval at each pole)
- Conduct semi-annual overflight field campaigns
- Calibration coefficients computed from a time trend analysis considering the preflight, OBC, and overflight measurements
Panel design
- Panel difficult to frame, as Spectralon grows 0.29” beyond aluminum tray between survival temperatures -65 to 80°C.
- Panel design has feet protruding into frame to allow thermal growth without distortion and survive launch loads without yielding (yields at 200 psi).
- Spectralon can only be machined to a tolerance of 0.005”. Tray will be customized if necessary upon Spectralon delivery.

Handling specifications
- During manufacture all surfaces to contact resin or Spectralon to be wiped with 200 proof reagent grade Ethyl Alcohol.
- During transport within Labsphere or to JPL material stored in dry nitrogen purged aluminum transportation container with 9 integral witness samples. Spectralon will be housed in EM or PF container for BRDF testing.
- Following machining material baked out at 10-6 torr, 90°C for 48 hours.
<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge arcing evaluation</td>
<td>Frame/ housing configuration versus discharge damage (done)</td>
</tr>
<tr>
<td>Process verification tests</td>
<td>Cleaning and handling procedures (done)</td>
</tr>
<tr>
<td></td>
<td>BRDF study at in-orbit geometries</td>
</tr>
<tr>
<td></td>
<td>Polarization</td>
</tr>
<tr>
<td></td>
<td>Solar absorptance/ emittance</td>
</tr>
<tr>
<td>Environmental exposure tests</td>
<td>UV/ vacuum (repeat)</td>
</tr>
<tr>
<td>BRDF data will be acquired before and after to evaluate stability</td>
<td>Humidity</td>
</tr>
<tr>
<td></td>
<td>Thermal vacuum cycling</td>
</tr>
<tr>
<td></td>
<td>Charged particle, proton (done)</td>
</tr>
<tr>
<td></td>
<td>Atomic oxygen (analyses planned)</td>
</tr>
<tr>
<td>Mechanical and physical property testing</td>
<td>Tension strength</td>
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<tr>
<td></td>
<td>Compression strength</td>
</tr>
<tr>
<td></td>
<td>Modulus</td>
</tr>
<tr>
<td></td>
<td>Deformation under load</td>
</tr>
<tr>
<td></td>
<td>Flexural</td>
</tr>
<tr>
<td>Vibration testing</td>
<td>Launch vibration loads with particulate contamination evaluation</td>
</tr>
</tbody>
</table>
632 nm unpolarized
Reflectance Factor = 0.9893
MISR 12669–2, source at 8°

632 nm unpolarized
Reflectance Factor = 0.9968
MISR 12669–2, source at 40°

632 nm unpolarized
Reflectance Factor = 1.0180
MISR 12669–2, source at 45°

632 nm unpolarized
Reflectance Factor = 0.9997
MISR 12669–2, source at 50°

632 nm unpolarized
Reflectance Factor = 1.0015
MISR 12669–2, source at 55°
• North Pole: panel deployed for aft and nadir camera calibration
• One minute of night calibration
• Varying irradiance at sunrise
• Clear atmosphere interval is uncontaminated by Earth atmos (200 km solar tangent)
• Window end when Df data collection begins

IN-FLIGHT CALIBRATION: MISSION PLAN

Panel stow (0.25 min)

Flight direction

Clear atmosphere (3.3 min)

Goniometer (2 min)

Sunrise (on panel) (1.3 min)

Night calibration (1 min)

North pole deploy (1.0 min)

Earth (day side)

Terminator

Earth (night side)
EOS CALIBRATION PANEL

• Membership
  - EOS project office lead
  - NIST representatives (Carol Johnson, Joe Rice)
  - Calibration scientist for each of 5 instrument teams
  - Calibration specialists:
    Vicarious calibration, Phil Slater, Univ. of Arizona
    Lunar studies, Hugh Kieffer, US Geological Survey

• Workshops (1 or 2 times a year)
• Peer reviews (2 reviews per instrument)
• Round-robin experiments
  - Radiometric (integrating sphere output verification)
  - Diffuse panel bi-directional reflectance function comparison
- EOS contractual agreement reads that MISR calibration must be NIST traceable
- In-house design does not come with a pedigree traceable to standards held at NIST
- MISR detector standards are traceable to the Système International (SI) radiance scale via traceable protocols of measuring current, voltage, and distances
- The internal quantum efficiency of these devices is well understood in the literature
- Verifications of our scale were provided by comparison to NIST-traceable lamps, and participation in EOS/ NIST sponsored round-robin experiments
Various transfer radiometers compared MISR integrating sphere output. Results give confidence in ability to achieve 3%(1σ) absolute requirement.

<table>
<thead>
<tr>
<th>Radiometer</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>550</td>
</tr>
<tr>
<td>MISR</td>
<td>0.4%</td>
</tr>
<tr>
<td>UofA</td>
<td>-1.0%</td>
</tr>
<tr>
<td>NRLM</td>
<td></td>
</tr>
</tbody>
</table>

Additionally, filter transmittance was measured by several instruments. MISR Cary establishes radiometric scale of Laboratory Standards.

<table>
<thead>
<tr>
<th>Filter $\lambda_c$,</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500</td>
</tr>
<tr>
<td>MISR Cary</td>
<td>baseline</td>
</tr>
<tr>
<td>JPL Beckman</td>
<td>+1.3%</td>
</tr>
<tr>
<td>UofA Optronics</td>
<td></td>
</tr>
<tr>
<td>GSFC Perkins and Elmer</td>
<td>+1.2%</td>
</tr>
</tbody>
</table>
Test date: AUG19

- NRLM
- GSFC
- UoA
- NIST (BoD)
- NIST (EaD)
NIST VS JPL BRDF MEASUREMENTS
SPECTRALON SAMPLE, 632.8 NM
**Subsystem verifications**

- **Optics**
- **Mechanisms**
- **Camera electronics**
- **Structures**
- **Analog electronics**
- **Command & Data**

**Assembly level verifications**

- Calibrate plate/mechanisms assembly
- Diode/goniometer assembly

**Camera assembly**

- Camera verifications

**Radiometric model**

- Component parameters

**Nine camera/optics bench assembly**

- Flight qualification testing

**System verification & shipping tests**

**Repeat for 9 cameras**

**Repeat for EM, protoflight**

**Thermal vacuum calibration**

**Calibration verification**
50x100 ft layout
x 30 ft height
Class 10,000 cleanroom

Optical Characterization Chamber
Features: Pinhole target, camera gimbal
Tests: EFT, MTF, PSF, Distortion, saturation

Radiometric Characterization Chamber
Features: 1.65 m sphere, monochromator
Tests: Radiometric and spectral calibration, polarization verification

Ground Support Equipment room
MISR RADIOMETRIC CALIBRATION FACILITY

- 65” Sphere
- 30 x 9” Exit port
- 4’ working distance
  - 12” external sphere with variable aperture

Power supplies

GSE & sphere controller

Vacuum chamber

Camera
MISR CALIBRATION EQUATION

- MISR will be calibrated in-flight by a regression of incident radiance against output DN.
  - Preflight data analysis has shown that the cameras are linear, except at extremely low inputs (scene reflectance < 5%).
  - The use of a linear or non-linear equation, e.g. the quadratic

\[
DN - DN_o = G_o + G_1 L_\lambda + G_2 L_\lambda^2
\]

has been investigated. This equation is linear at high radiances and quadratic at small radiances. This latter equation will be baselined, upon completion of the current study.

- \( L_\lambda \) is the sensor band-averaged spectral incident radiance, averaged over both in-and-out-of-band wavelengths and reported in units of \([W \, m^{-2} \, sr^{-1} \, \mu m^{-1}]\):

\[
L_\lambda = \frac{\int L_{source} R_\lambda d\lambda}{\int R_\lambda d\lambda}
\]

- \( R_\lambda \) is the relative pixel spectral response; DN is the camera output digital number; \( G_0, G_1, \) and \( G_2 \) are the pixel response coefficients; \( DN_o \) is the DN offset, unique for each line of data, as determined by an average over the first eight "overclock" pixel elements.
MEASURED CAMERA SNR

Input file: 11feb98_2.Jong1
Camera: AirMISR Nadir
Temp: -5C
Band 2: 555 nm
Integration time: 18.9 ms
Repetition 1
Pixels: 13 to 1516
Number reps: 64

Signal to noise ratio at Req = 0.070
SNR: 267, +/- 25.
SNR requirement: 156.

Signal to noise ratio at Req = 0.938
SNR: 993, +/- 98.
SNR requirement: 679.
MEASURED CAMERA SATURATION LEVELS

Diamonds: An, Af, Aa, Bf, Ba
Boxes: Cf, Co, Df, Da

Band 1

Band 2

Band 3

Band 4
COMPOSITE RESPONSE PROFILE:
- Measured data 400 to 900 nm
- In-band at 2.6 nm resolution, 0.5 nm sampling, 7 field position
- Out-band at 19.5 nm resolution, 5 nm sampling, 3 field positions
- Spectral model includes focal-plane measurements to 1100 nm, and Code V lens model 365 to 400 nm.

IMPROVED TESTING:
- Obtained by use of an integrating sphere at monochromator exit slit. Spectral uniformity of illumination improved reduced from several nm to several tenths of nm.
Separate in- and out-band measurements allowed us to cover $10^{-4}$ sensitivity range.

In-band spectral response measurements:
- 400 to 900 nm wavelength range
- 2.6 nm spectral resolution
- 0.5 nm sampling

Out-band spectral response measurements:
- 400 to 900 nm wavelength range
- 19.6 nm spectral resolution
- 10 nm sampling

Radiometric model utilized to extend response region from 365 nm to 1100 nm.
- Lens model using CODE V at 5 field positions.
- Focal plane measurements of quantum efficiency (350-1100 nm)
- Analog-to-digital gain using camera response to varying integration time (while viewing the integrating sphere)

Both measured and band-averaged spectral response measurements published within the ARP.
MEASURED SPECTRAL PARAMETERS

Band 1, In-Band Data
- Gaussian FWHM: 26.99 nm
- Gaussian Center Wavelength: 442.45 nm

Band 2, In-Band Data
- Gaussian FWHM: 18.04 nm
- Gaussian Center Wavelength: 557.20 nm

Band 3, In-Band Data
- Gaussian FWHM: 14.79 nm
- Gaussian Center Wavelength: 671.66 nm

Band 4, In-Band Data
- Gaussian FWHM: 27.06 nm
- Gaussian Center Wavelength: 864.87 nm
SUMMARY

• MISR testing of 10 cameras (9 flight and 1 spare) has been successfully completed after 1 year development and 1 year testing and analysis.

• 6 weeks per camera required to provide OCC (EFL, distortion, PSF), RCC (radiometric, spectral calibration, polarization verification), hot and cold margin, dynamics, and magnetics testing.

• Several verification failures appear to have little impact on the mission:
  - Swath overlap meets requirements, though camera boresight failures noted.
  - Response uniformity meets requirement for all but a handful of pixels. Only 8 pixel zones (4 pixel block) out of 13,536 have a local uniformity exceeding 10%.

• Several verification failures result from unprecedented camera specifications, driven by 3% radiometric requirement. Successful test program allows mission objectives to be met, following ground processing:
  - Out-of-band errors can be reduced from 4% to 0.5% when needed. No correction necessary for Band 1, or bright targets.
  - PSF deconvolution requires minimal processing: 1D, 51 pixels PSF, 20 iterations (no FFT required).

• Saturation appears to affect many pixels within the line array:
  - Saturation unlikely on orbit. Data Quality Indicators will identify affected pixels.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Cause</th>
<th>Solution</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>White light leaks in filter</td>
<td>Bondlines between bands</td>
<td>Masks added to filter</td>
<td>Fixed</td>
</tr>
<tr>
<td>Interference fringes in flat-field data</td>
<td>Fabry-Perot interference between CCD and filter</td>
<td>Increase spacing between filter and CCD</td>
<td>Fixed</td>
</tr>
<tr>
<td>Spurious signal in CCD</td>
<td>Illumination of silicon around CCD bond pads</td>
<td>Addition of light shield to focal plane package</td>
<td>Fixed</td>
</tr>
<tr>
<td>Insufficient out-of-band rejection</td>
<td>Spattering in filter coatings</td>
<td>Higher quality flight filter Spatter side down</td>
<td>Improved flight performance</td>
</tr>
<tr>
<td>Low-level “halo” around point-source image</td>
<td>Reflection between CCD and filter</td>
<td>See above. Correction in data processing if needed</td>
<td>Improved flight performance</td>
</tr>
<tr>
<td>Excess power needed to cool CCD to -10°C</td>
<td>Thermal leaks</td>
<td>Focal plane temperature changed to -5°C</td>
<td>Fixed</td>
</tr>
<tr>
<td>Complex assembly procedure to achieve repeatable focus</td>
<td>Lens to camera head interface flanges</td>
<td>Interface redesigned and simplified</td>
<td>New design breadboarded</td>
</tr>
<tr>
<td>Low-level inter-band electrical crosstalk (0.07%)</td>
<td>Suspected inadequate grounding</td>
<td>Additional grounding or correction in data processing</td>
<td>Options being investigated</td>
</tr>
</tbody>
</table>
Unsat. and sat. green band PSFs at 5C; files 08apr96-120 and -126

average unsat. max d_n = 10930
average of first 8 overclock = 332.2
Filter scatter sites and CCD/filter reflections determined to be cause of finite width PSF and out-of-band performance, see:

FOCAL PLANE SCATTERING

Component of 1% out-of-band budget

Component of 2% delta contrast target budget and MTF specification
• MISR will make use of four calibration methodologies, in order to assess calibration uncertainty and reduce systematic errors.

  - On-Board Calibrator (OBC) hardware are used to establishes an absolute and relative calibration for each pixel. The OBC consists of solar-reflecting diffuse panels (Spectralon), detector standards, and a goniometer to verify there is no degradation in the reflectance shape. Data are acquired monthly.

  - Vicarious calibration (VC) can be one of three types:
    1) High-altitude sensor (e.g. AirMISR) VC
    2) Surface-radiance VC
    3) Surface reflectance VC

  - Histogram equalization statistics are used to provide a relative-calibration of the pixels within an array.

  - Trend analysis are used to fold other calibration data into the coefficient algorithm (e.g. preflight). Retrospective data are weighted less with time.

• A weighting algorithm will combine the multiple data in order to achieve the most accurate sensor calibration.
IFRCC PROGRAM ELEMENTS

MISSION OPS
- Acquire MISR calibration mode data
- Acquire MISR local mode data

PREFLIGHT
- MISR preflight radiometric calibration
- Scene studies
  - PSF
  - Spectral in-band scaling

LEVEL 1A
- Updated params.
  - Radiometric calibration coefficients and uncertainties
  - SNR
  - Pixel nonuniformity
  - Quality thresholds

ARP

IN-FLIGHT RAD. CALIBRATION
- OBC
- Vicarious cal.
- Histogram eq.
- Cal trend

LEVEL 1B1 ALGORITHMS
- Rad. scaling algorithm
- Radiance conditioning algorithm

CHARACTERIZATION
- Data anomalies
- Noise studies
- Scene rad. errors
- Contrast target
- Spectral content
- Pixel non-uniformity
- Polarization

CALIBRATION INTEGRITY
- Traceability
- Quality assessment
- Lev. 1B1 rad. prod. validtn
  - Sensor cross-comp.
  - Desert scenes
  - Lunar observ.

LEGEND
- IFRCC activity
- Other activity
- Input or output
<table>
<thead>
<tr>
<th>File name</th>
<th>Description</th>
</tr>
</thead>
</table>
| Preflight Characterization Data          | • preflight instrument characterization parameters  
• unlikely to be modified once delivered  
• measured pixel spectral response functions (7x36), standardized spectral response functions (1 per band), instantaneous fields-of-view |
| Preflight Calibration Data               | • input to DAAC processes  
• unlikely to be modified once delivered  
• spectral descriptors relevant to Level 1B1 and Level 2 standard products  
• band weighted solar irradiances       |
| In-flight Calibration Data               | • parameters updated monthly on-orbit  
• at-launch values are initialized by the preflight calibration data  
• radiometric calibration coefficients, calibration uncertainties, signal-to-noise ratios, and Detector Data Quality Indicators. |
| Configuration Parameters                 | • threshold parameters and process control limits used by DAAC processes                                                                   |
• **Data conditioning**
  - Resamples photodiode data to CCD data time acquisition
  - Removes corrupt data

• **Regression**
  - Regresses CCD DN data against photodiode measured incident radiances
  - Quadratic fit produces $G_0$, $G_1$, and $G_2$ coefficients for every pixel
  - Data weighted inversely by the DN variances (noisy data weighted less)
  - Process repeated using 3 independent on-board standards (HQE, PIN nadir, PIN at closest view angle to camera being calibrated)

• **Coefficient trending**
  - Uses historical coefficients and present coefficient
  - Performs a quadratic fit to the data
  - Reported coefficient comes from fit. This smooths gain coefficients, in case of noise in the retrieval

• **Coefficient weighting**
  - Final coefficients come from a weighted average of the multiple determinations (vicarious and 3 detector standards)
  - Weighting is inversely proportional to the methodology uncertainty
• Performance summary
  - SNR computed from residuals of CCD DN against photodiode radiances
  - sliding window does local fit of the data, to determine local variances
  - SNR used to update radiometric uncertainty tables
  - CCD element response uniformity updated as part of detector data quality metric
RADIOMETRIC SCALING AND CONDITIONING

Level 1A (MIS01) → Radiance scaling → Radiance (W m\(^{-2}\) μm\(^{-1}\) sr\(^{-1}\)) → Radiance conditioning → Level 1B1 (MIS02)

Instrument DNs

Resampling and projection to Space Oblique Mercator grid

Geo-rectified and registered radiances

Out-band correction

Image enhancement via PSF deconvolution

Level 1B2 (MIS03) → some Level 2 products

Geophysical parameters
**RADIANCE SCALING**

- Radiometric calibration coefficients are used to retrieve a band-averaged spectral radiance. Total-band response is included.

**RADIANCE CONDITIONING**

- PSF deconvolution to sharpen the image, compensating for focal-plane scattering;
- A standardized spectral response function is assumed.
• Data Quality Indicators (DQI) are assigned to each Level 1B pixel. These are assigned the values:

<table>
<thead>
<tr>
<th>DQI value</th>
<th>significance</th>
<th>Error component radiance uncertainty contribution</th>
<th>Level 1B2 resample weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>within specification</td>
<td>None</td>
<td>full</td>
</tr>
<tr>
<td>1</td>
<td>reduced accuracy</td>
<td>1-3%</td>
<td>half</td>
</tr>
<tr>
<td>2</td>
<td>unusable for science</td>
<td>3-50%</td>
<td>none</td>
</tr>
<tr>
<td>3</td>
<td>unusable</td>
<td>&gt;50%</td>
<td>none</td>
</tr>
</tbody>
</table>

• Saturation blooming (Note: in average mode pixel is sat. if sat. in red band)
  - DQI=0 if no. saturated pixels (nsat)=0
  - else DQI=1 if specific pixel under test has < 0.5% radiometric error
  - else DQI=1 if specific pixel under test has < 3.0% radiometric error; else DQI =2

• Video offset uncertainty
  - DQI=0 if line average DN less than threshold (~12,000 DN)
  - else DQI=1 if specific pixel under test has < 0.5% radiometric error
  - else DQI=1 if specific pixel under test has < 0.5% radiometric error; else DQI=2
• Detector anomaly
  - Values can be predetermined and stored in ARP
  - SNR used as DQI criteria

<table>
<thead>
<tr>
<th>SNR</th>
<th>DDQI value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;100</td>
<td>0, else</td>
</tr>
<tr>
<td>&gt;90</td>
<td>1, else</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>2, else</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

- Detector response uniformity used as DQI criteria

<table>
<thead>
<tr>
<th>Uniformity, 4x4 average mode</th>
<th>DDQI value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10%</td>
<td>0, else</td>
</tr>
<tr>
<td>&lt;15%</td>
<td>1, else</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>2, else</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Uniformity, 2x2 average mode</th>
<th>DDQI value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10%</td>
<td>0, else</td>
</tr>
<tr>
<td>&lt;15%</td>
<td>1, else</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>2, else</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>