Attachment F

ATBD for MODIS Level 1B Algorithm

Produced by members of the

MODIS Algorithm Team (MAT)

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11 OCT 94
Calibration Discipline Group Meeting

Acknowledgements

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Review Team

The Team thanks Bruce Guenther, John Barker, Bill Barnes, Phil Ardanuy, and Gerry Godden for reviewing this ATBD and providing many valuable comments.

ATBD for MODIS Level 1B Algorithm

AGENDA

• Introduction & Overview	Harry Montgomery
• Architecture	Peter Abel
• Verification	Peter Abel
• ATBD Risks, Status & Future Activities	Harry Montgomery
• Level 1B Software	Harry Montgomery
• Thermal Calibration	Dan Knowles
• Solar Diffuser Radiometric Calibration	Paul Anuta
• SRCA Radiometric Calibration	Nianzeng Che
• SRCA in Spectral Mode	Nianzeng Che
• SRCA in Spatial Mode	Nianzeng Che

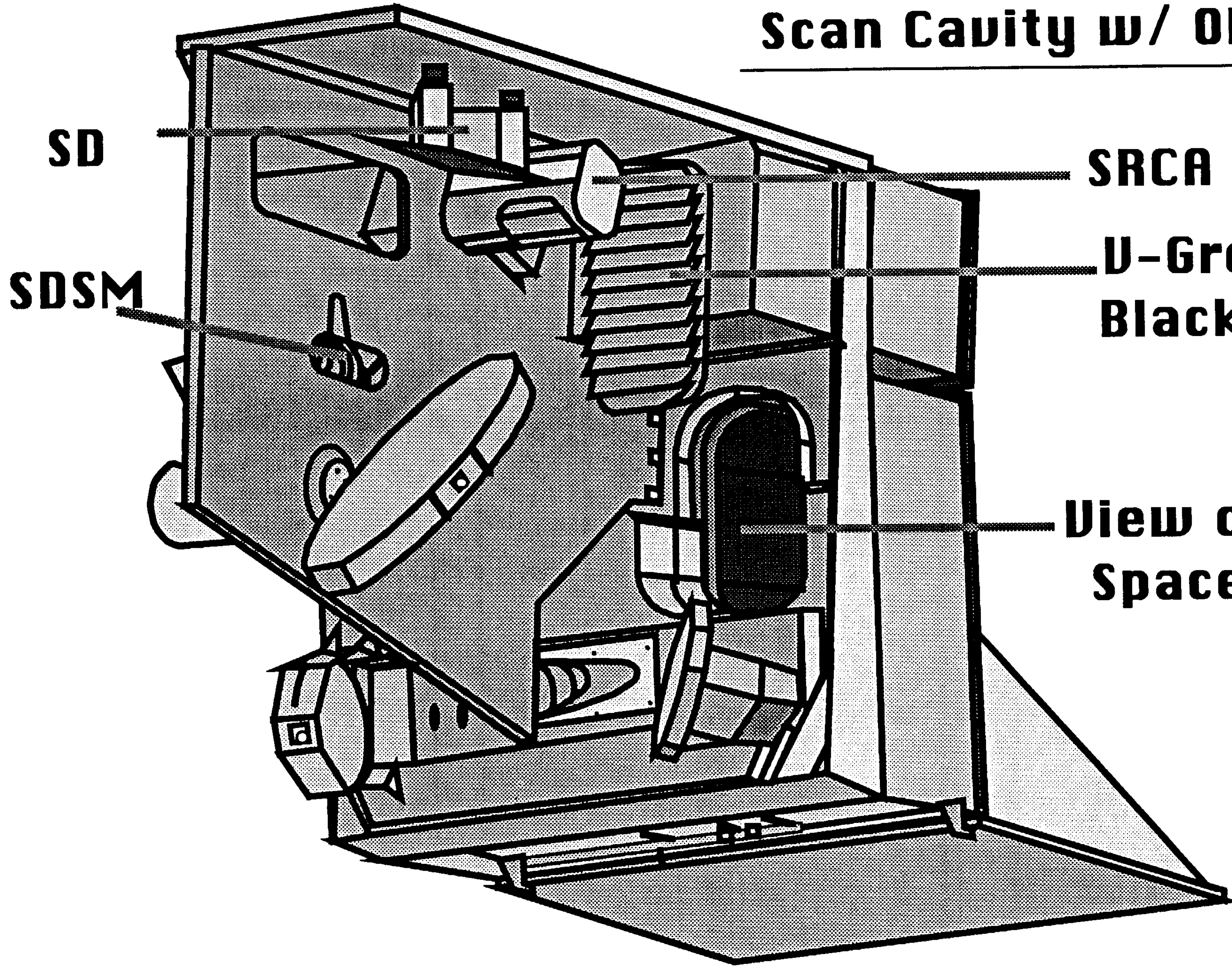
ATBD for MODIS Level 1B Algorithm

Introduction & Overview

Harry Montgomery

11 OCT 94
Calibration Discipline Group Meeting

Scan Cavity w/ OBCs



MCST Level 1B SW Milestones

ID	Name	Milestone (1994 Q3 – 1999 Q4)
1	Beta 2 Delivery	10/31
2	Engineering Model Testing Complete	2/1
3	Beta 3 Delivery	4/1
4	Version 1 Delivery	2/1
5	Protoflight Model Testing Complete	3/1
6	Version 2 Launch Ready Delivery	2/1
7	Version 2.1 Pre-Launch Update	2/1
8	Version 2.2 Post A&E (Launch + 6 months)	6/1

Functions of On-Board Calibrators

OBCs	FUNCTION	BANDS
BB	DN → L	Emissive
SV	DN → L= 0	Emissive Reflective
SRCA	DN → L DN → λ	Reflective
	DN → dx, dy	Emissive Reflective
SD/SDSM	DN → L DN → **BRDF**	Reflective

[**dx, dy**=FOV shift along-scan, along-track; **DN** = Counts; **L**= Radiance; λ=Wavelength]

•**SRCA** (Spectro-Radiometric Calibration Assembly)
•**SD/SDSM** (Solar Diffuser/Solar Diffuser Stability Monitor)
•**BB** (Blackbody) •**SV** (Space View)

MODIS Data

LEVEL	DESCRIPTION
0	Packed Raw Counts
1A	Unpacked Geolocated
***1B**	**Calibrated**
2	Science Products

*Subject of Today

Purposes for this ATBD

1 Give Formulae and Error Budget for Transformation

2 Describe Physical and Mathematical Basis of (1)

MODIS output counts —Characterization Data Sets→ Radiance at MODIS aperture

3 Describe Verification Procedures for (1)

4 Describe Internal and External Data Product Flows, Granules, Metadata, and Computer Requirements

5 Describe Exception Handling, QC, Diagnostics

6 ATBD is an evolving document, intended as the on-line reference for eventual attachment to EOSDIS Products

Building Blocks and their Time Sequence

Heritage	Take advantage of experience & lessons learned from other radiometers flown on Landsat, GOES, etc.	Now
Mathematical Models	Ongoing improvements for MODIS and its on-board calibrators.	Some Now
Subsystem Test	Used to verify and tune parts of models.	Some Now
Engineering Model (EM) TV Tests	First opportunity to tune & compare models of end-to-end system with real data for the MODIS and the on-board blackbody. SRCA and SD/SDSM will not be available for EM testing.	Feb 95
Protoflight Model (PF)	PF TV data will be used to tune/compare calibration algorithm. Complete MODIS/OBC system, with ghosting fixes incorporated, will be tested.	Mar 96
Activation & Evaluation (A&E)	Comprehensive evaluation & verification of calibration algorithm based upon on-orbit data.	Jun 98 Launch for 6 mos

Sequence of Events for the L1B Algorithm

- Examine & understand the physical principles & engineering details of the MODIS and its On-board Calibrators

- Derive the general form of the algorithms:

$$\text{Product} = f(DN, V_1, V_2, \ldots\ldots, C_1, C_2, \ldots.)$$

- **Product = MODIS input (eg. radiance, λ, FOV shift)** • **DN = Counts from MODIS/OBCs**
- **V_i = variables of the system, such as temperatures at monitored points** • **C_i = coefficients to be fitted**

- Determine and verify the optimal V_i and C_i based on System Level Ambient and Thermal Vacuum (TV) data. This process will be achieved using techniques that divide the TV data into statistically independent parts.

- Determine calibration uncertainty using TV data

- Incorporate the Algorithms into the Latest Software Design of the Level 1B Algorithm

- Verify algorithms during A&E (e.g. radiance, λ, FOV shift)

ATBD for MODIS Level 1B Algorithm

Architecture

Peter Abel

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Calibration Discipline Group Meeting

Architecture of the MODIS characterization & calibration algorithm

Peter Abel

1. Requirements (algorithm drivers)

2. Data & information flow

3. Overview of applications
   - Thermal infrared bands
   - Reflected solar bands
   - Spectral calibration
   - Spatial characterization

4. Summary

Goals of the Characterization & Calibration Algorithm:
Key Requirements in the MODIS Spec

Absolute radiometric calibration accuracy
(1σ @ L_{typ})

$<3\mu m$	± 5%
$>3\mu m$, except bands 20, 21, 31, 32	± 1%
Band 20 (3.75 μm)	± 0.75% (Goal ±0.5%)
Bands 31 (11.03μm) & 32 (12.02 μm)	± 0.5% (Goal ±0.25%)
"High" band 21 (3.96 μm) [New spec]	± 10% (Agreed w/SBRC)
"High" bands 31hi, 32hi	± 10%
Reflectance (Target BRDF at TOA)	± 2%

Stability of radiance ratio

Ratio of mean band responses	±0.5% @ full scale
(max change in two week interval)	±1% @ half scale

Spectral calibration accuracy

$\lambda \leq \lambda_0$, preflight	±0.5 nm	where
$\lambda > \lambda_0$, preflight	$\pm 0.5\ (\lambda/\lambda_0)$ nm	$\lambda_0 = 1.0\ \mu m$
$\lambda < \lambda_0$, inflight	$\pm 1.0\ (\lambda/\lambda_1)$ nm	$\lambda_1 = 0.412\ \mu m$

Goals of the Characterization & Calibration Algorithm:
Key Requirements in the MODIS Spec (continued)

Spatial calibration

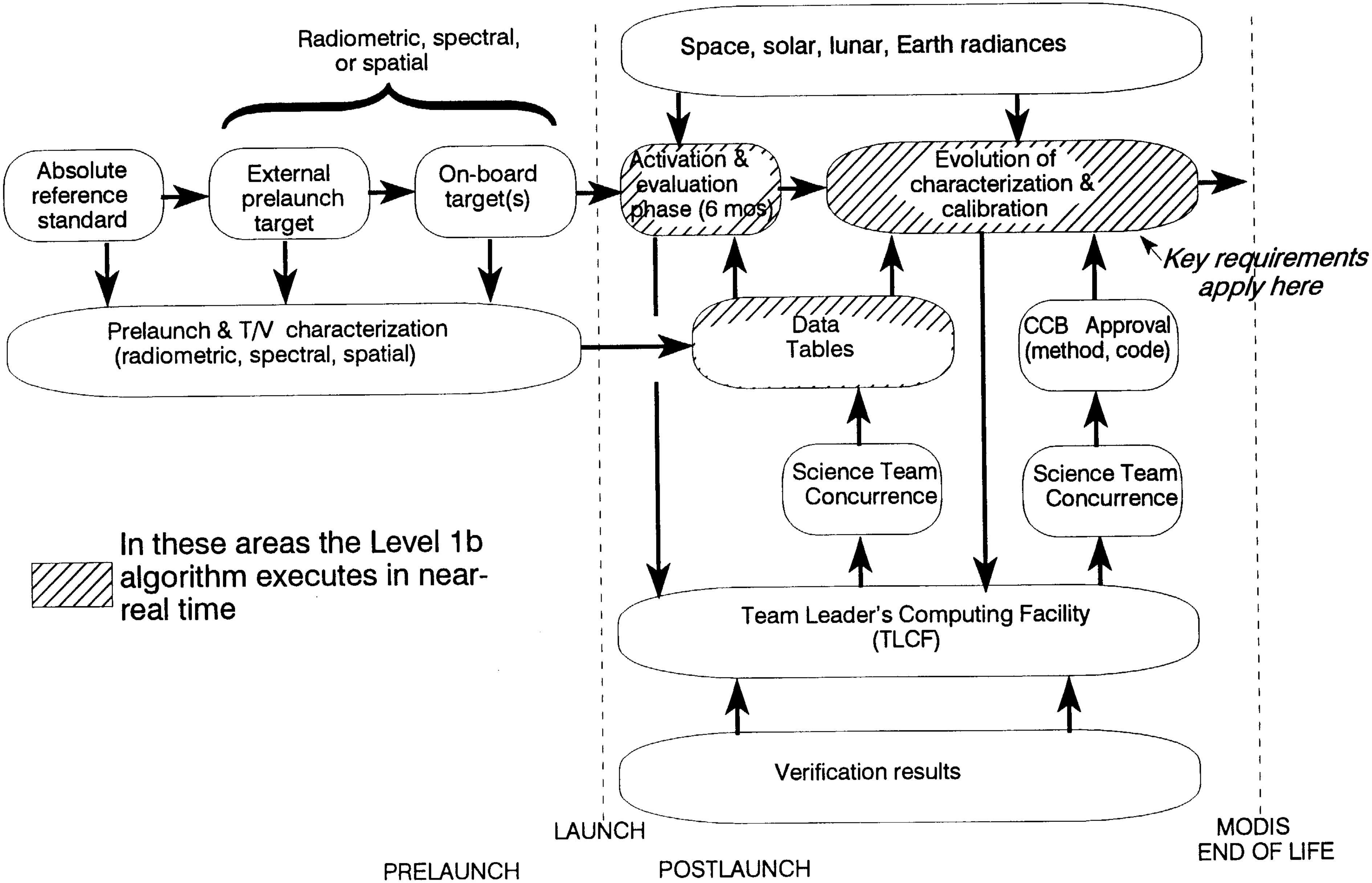
MODIS pointing knowledge with reference to EOS AM-1	±30 arcseconds, 1σ (±100 m at nadir)
Absolute AM-1 pointing knowledge	±30 arcseconds, 1σ (±100 m at nadir)

Coregistration

km → 1 km	±0.2 km (goal ±0.1 km)
0.5 km → 0.5 km	±0.1 km (goal ±0.05 km)
0.25 km → 0.25 km	±0.05 km (goal ±0.025 km)
1 km → 0.5 km	±0.2 km (goal ±0.1 km)
1 km → 0.25 km	±0.2 km (goal ±0.1 km)

Bright target recovery & associated optical effects

$L_{cloud} \rightarrow L_{typ}$ (Reflective bands) $L_{max} \rightarrow L_{typ}$ (Thermal bands)	Output settles to < ±0.5% within 2 km of entering L_{typ} regime



MODIS CHARACTERIZATION & CALIBRATION DATA FLOW

Acronyms:
CCB Configuration Control Board
TLCF Team Leader's Computing Facility

Absolute radiometric calibration - baseline TIR
(Thermal calibration - Dan Knowles)

Products

Level 1B :

Absolute radiance, L, at MODIS aperture

Metadata

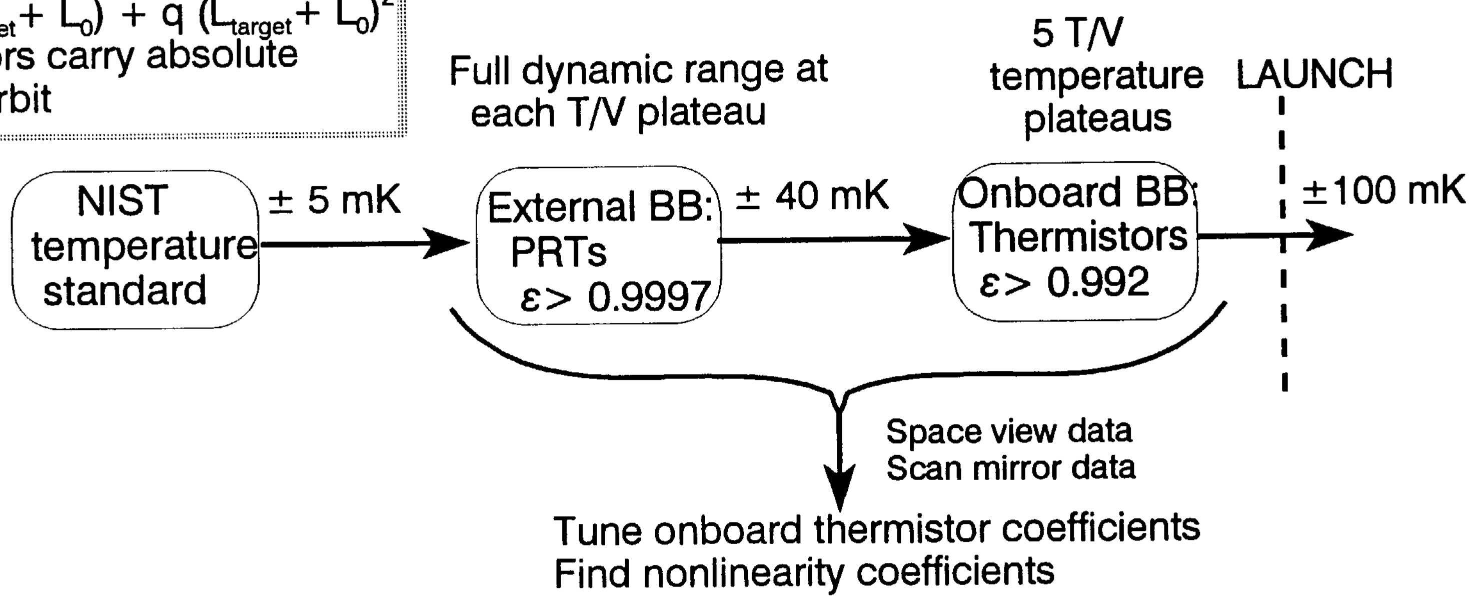
1σ uncertainties, quality indices

Baseline process

Quadratic transfer curve given by

$$V_{detector} = V_0 + m\,(L_{target} + L_0) + q\,(L_{target} + L_0)^2$$

Onboard BB thermistors carry absolute radiance scale into orbit



Data Table Examples

- $L(T_{onboard\ BB})$ for each detector
- Detector nonlinearity coefficients
- Scan mirror (both sides) reflectance or emittance as f(rotation angle)
- Onboard BB thermistor coefficients

Non-Baseline Options

Correction matrices for residual optical effects

Other methods for nonlinearity coefficients

Acronyms:

BB	Black Body
NIST	National Institute for Standards and Technology
PRT	Platinum Resistance Thermometer
TIR	Thermal InfraRed

Absolute radiometric calibration - baseline reflectance for $\lambda < 2.3\ \mu m$

(Solar diffuser - Paul Anuta)

Products

Level 1B :

Target BRDF

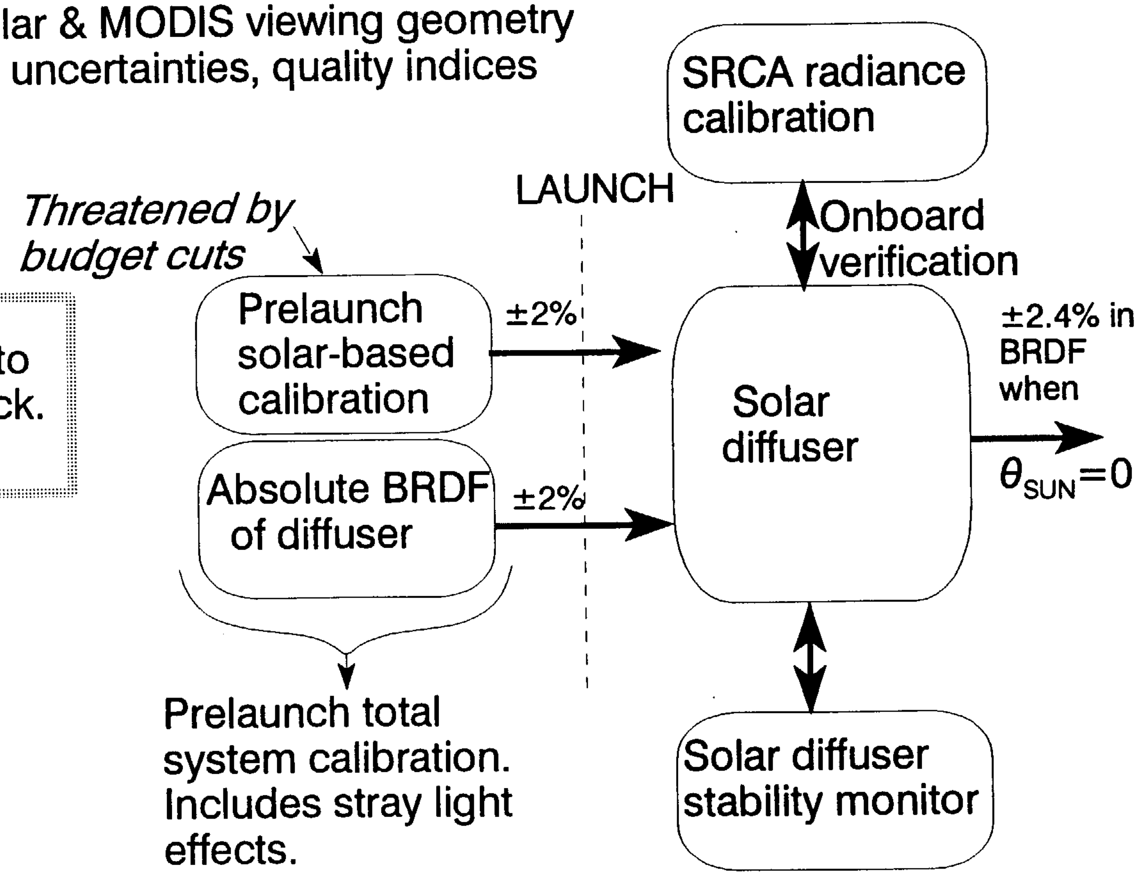
Metadata:

-Solar & MODIS viewing geometry

-1σ uncertainties, quality indices

Baseline process

Solar diffuser carries BRDF scale into orbit. SRCA gives consistency check.



Data Table Examples

-Absolute spectral BRDF of diffuser

-Prelaunch solar-based MODIS calibration

Non-Baseline Options

-Transfer to lunar BRDF standard

Acronyms:

SRCA SpectroRadiometric Calibration Assembly

BRDF Bidirectional Reflectance Distribution Function

Absolute radiometric calibration - baseline radiance for $\lambda < 2.3\ \mu m$

(SRCA in radiometric mode - Nianzeng Che)

Products

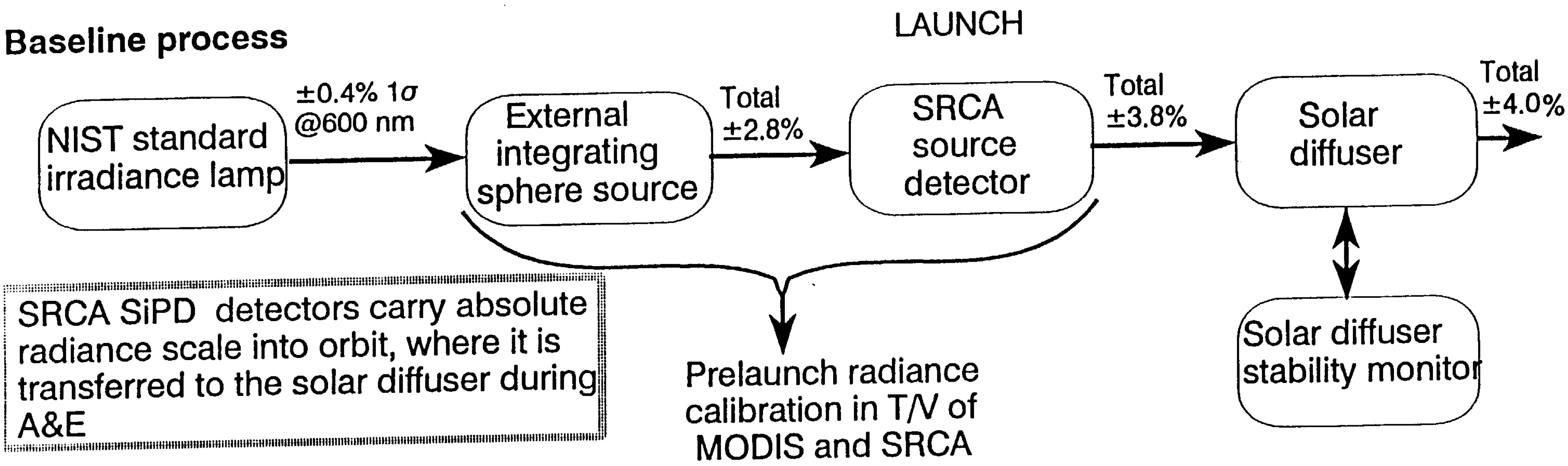
Level 1B :

Absolute radiance, L, at MODIS aperture

Metadata:

1σ uncertainties, quality indices

Baseline process



Data Table Examples

- -Spectral responsivity of SRCA source detector
- -SRCA prelaunch source radiance spectrum
- -MODIS prelaunch band responses to External Integrating Sphere Source
- -MODIS prelaunch band responses to SRCA source
- -Spectral BRDF of diffuser
- -Transfer to lunar radiance source (through space port)
- -Validation data for External Integrating Sphere Source (Round Robin results)

Non-Baseline Options

- -Major spacecraft maneuvers

Acronyms:

SRCA	SpectroRadiometric Calibration Assembly
SiPD	Silicon PhotoDiode
A&E	Activation & Evaluation phase (6 months)

Spectral calibration - baseline for $\lambda < 2.3\ \mu m$ ($\lambda < 1\ \mu m$ in orbit)

(SRCA in spectral mode - Nianzeng Che)

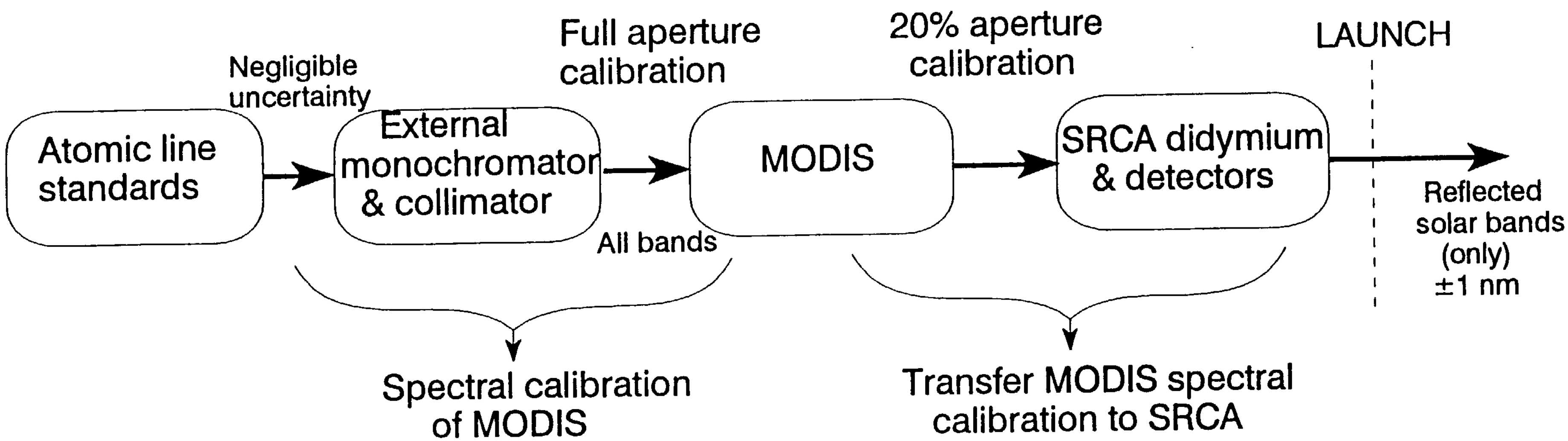
Products

Level 1B :
None

Metadata:
Band centers
1σ uncertainties, quality indices

Baseline process

> SRCA didymium glass spectral features and SRCA SiPD detector responsivities carry absolute spectral scale into orbit



Data Table Examples

- -Spectral responsivity of SRCA source detector
- -SRCA prelaunch source radiance spectra as f(# lamps)
- -Prelaunch band centers measured by External Collimator and by SRCA

Non-Baseline Options

- -In orbit measurement of band width
- -In orbit spectral calibration at $2.3\ \mu m > \lambda > 1\ \mu m$

Acronyms:
SRCA SpectroRadiometric Calibration Assembly
SiPD Silicon PhotoDiode

Spatial characterization - baseline
(SRCA in spatial mode - Nianzeng Che)

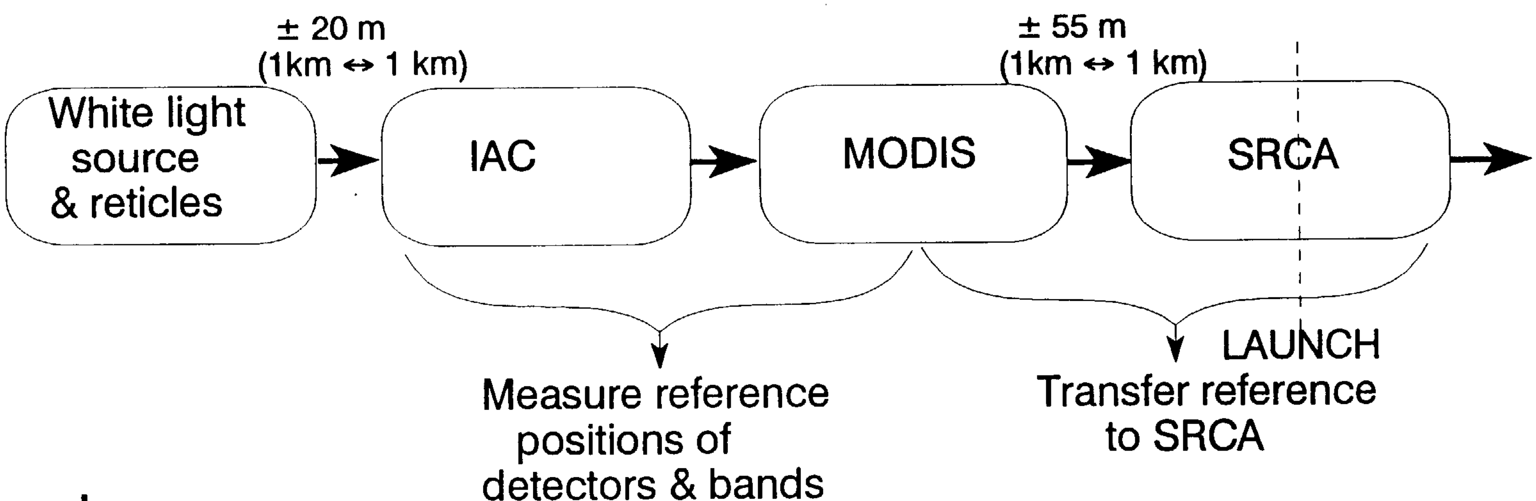
Products

Level 1B :
None

Metadata:
Detector offsets in scan direction
Band offsets in track direction
1σ uncertainties, quality indices

Baseline process

IAC measurements of relative detector & band positions are transferred to the SRCA prelaunch
SRCA in orbit measures detector & band shifts relative to prelaunch IAC measurements



Data Table Examples

-Prelaunch detector and band relative positions

Non-Baseline Options

-Lunar data analysis

Acronyms:
IAC Interface Alignment Collimator
SRCA SpectroRadiometric Calibration Assembly

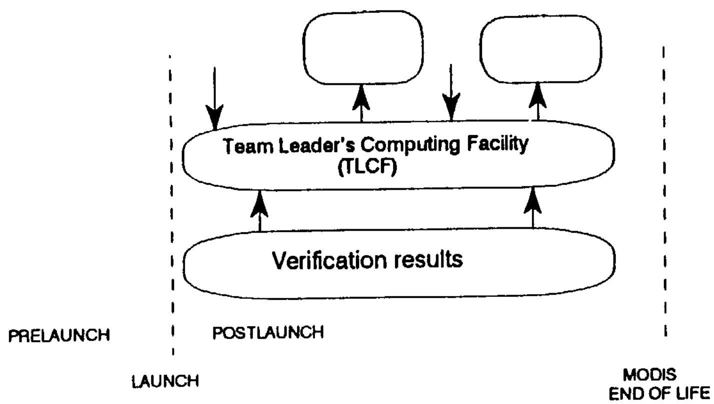
ATBD for MODIS Level 1B Algorithm

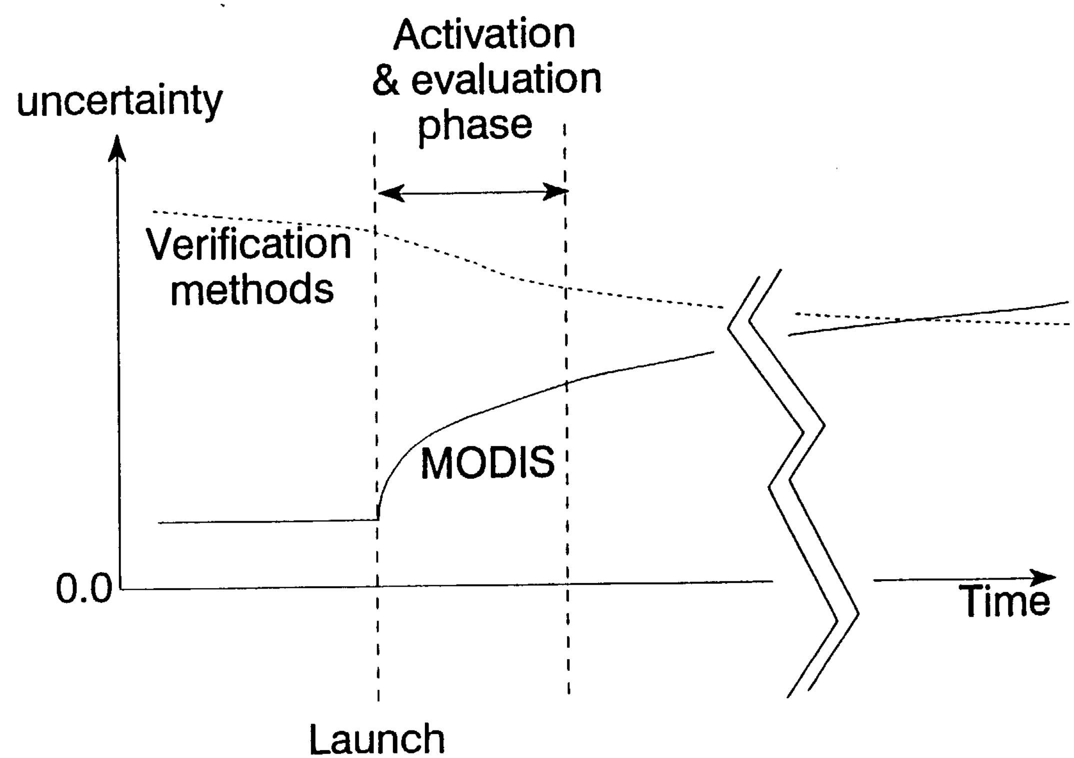
Verification

Peter Abel

11 OCT 94
Calibration Discipline Group Meeting

Verification philosophy





Premises:

1. MODIS foreoptics may degrade through the launch and insertion into orbit. Rate of degradation will rapidly decrease and stabilize after launch.

2. MODIS on-board calibrators will slowly lose absolute accuracy due to surface contamination, detector degradation, light bulb aging, etc.

3. Verification methods will improve their combined accuracy during A&E phase due to intensive data collection and comparison of results, and will thereafter maintain their absolute accuracy.

4. Combined absolute accuracy of verification methods may gradually overtake that of the onboard calibrators.

Examples of verification methods for radiance calibration (over land^L, ocean^o, clouds^c (TBD))

Thermal bands

Aircraft underflight:
- High resolution interferometer/spectrometer (HIS) [NOAA-Menzel*]^{L,o,c}
- MODIS Aircraft Simulator (MAS) [GSFC-King]^{L,o,c}

* May have potential for detecting spectral shifts

Surface truth & radiative transfer models:
- University of Arizona [Slater]^L
- Other MODIS Science Team members (TBD)

Relative methods:
- MODIS pixel overlap [GSFC-Ungar]^{L,o}

Reflective bands

Aircraft underflight examples:
- Aircraft-satellite instrument calibrator (NASIC) [GSFC-Abel]^{L,o,c}
- MODIS Aircraft Simulator [GSFC-King]^{L,o,c}
- AVIRIS [JPL-Rob Green]^{L,o,c}
- University of Arizona [Slater]^L

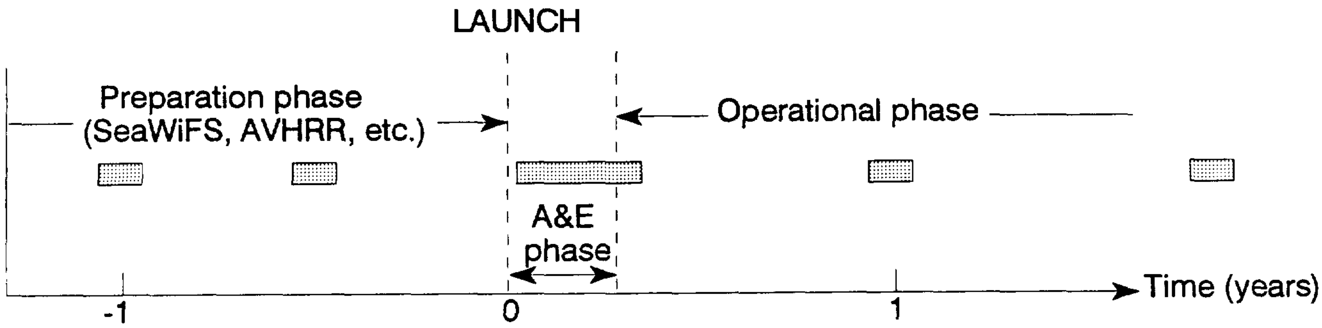
Surface truth & radiative transfer models:
- University of Arizona [Slater]^L (Radiance and reflectance)

Sensor-to-sensor transfer:
- MISR [JPL-Bruegge]^{L,o,c}
- SeaWiFS [GSFC-Esaias]^o
- MODIS-to-MODIS

Relative methods:
- Extended desert targets [NOAA-Rao]^L
- MODIS pixel overlap [GSFC-Ungar]^{L,o}

Verification campaign strategy

1. Campaign scheduling

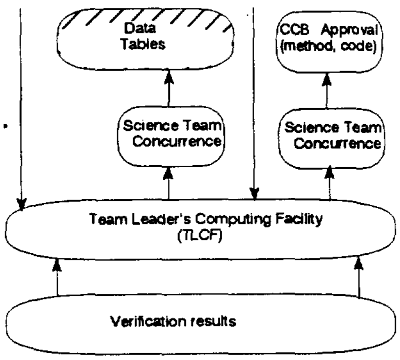


2. Representative absolute gain error budgets claimed for individual methods

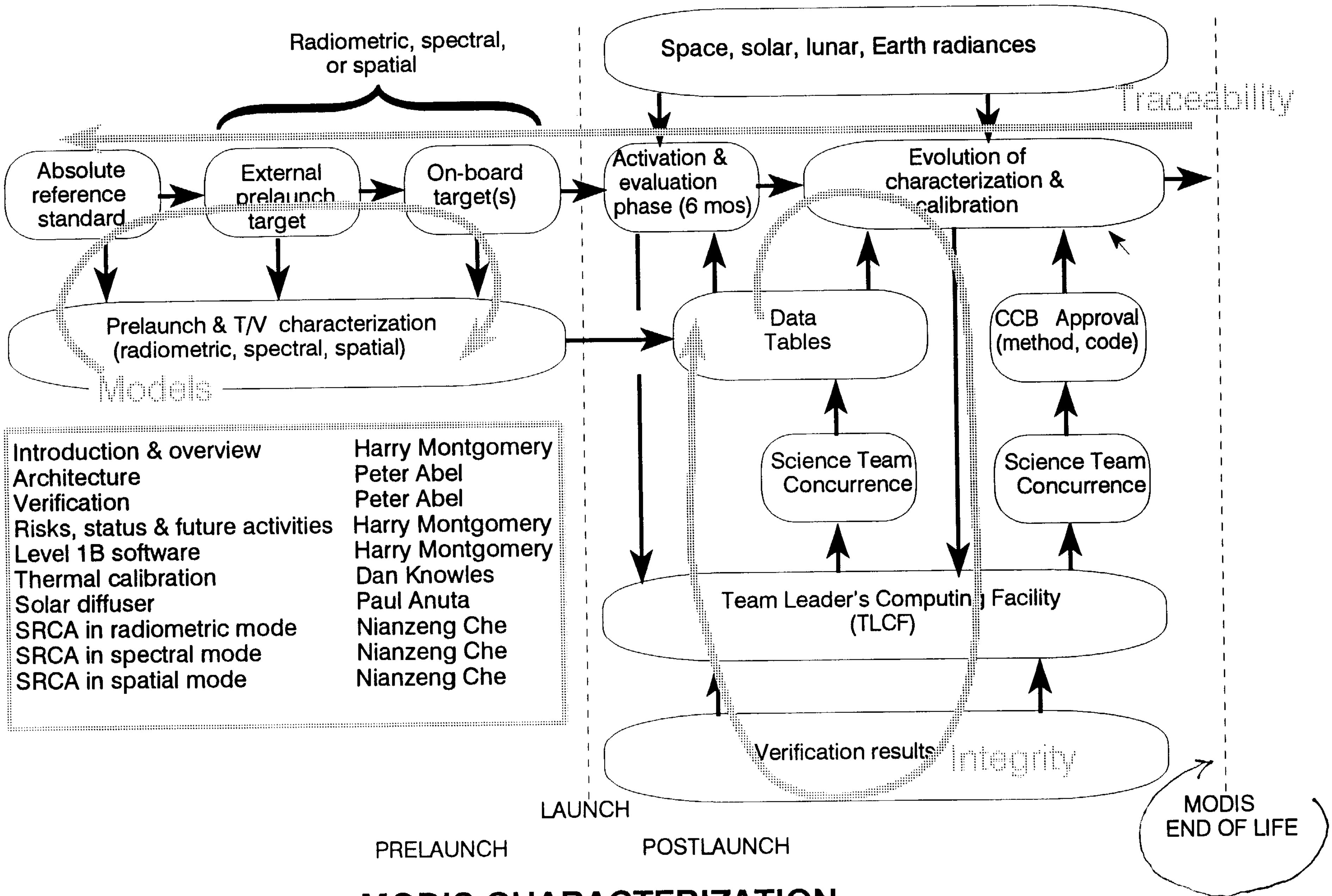
	Thermal bands	Reflective bands
Aircraft over ocean		
Abel	not applicable	±3.5%[A]
King	TBD	TBD
Aircraft over land		
Slater	TBD	±2.8%
Abel	not applicable	±3.5%[A]
Menzel	TBD	not applicable
King	TBD	TBD
Land surface based		
Slater	TBD	±3.5% (reflectance scale)
Sensor-to-sensor		
Bruegge	TBD	TBD

A. Reduces with future improvements such as in-flight calibration.

3. Data analysis



- For acceptance, all methods must meet TBD error budget requirements, and be peer reviewed by the Science Team.
- Prelaunch campaigns empirically establish the repeatability of each method, and gain field experience.
- Post-launch campaigns must be long enough to collect statistically significant amounts of verification data for preparation of realistic error budgets.
- As far as practicable, different methods will be applied at the same target for the same MODIS overpasses. This will allow direct comparison of results from different methods.
- Combined results for all methods, and MCST recommendations, will be reported to the Science Team for action.



Introduction & overview	Harry Montgomery
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Thermal calibration	Dan Knowles
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SRCA in radiometric mode	Nianzeng Che
SRCA in spectral mode	Nianzeng Che
SRCA in spatial mode	Nianzeng Che

MODIS CHARACTERIZATION & CALIBRATION DATA FLOW

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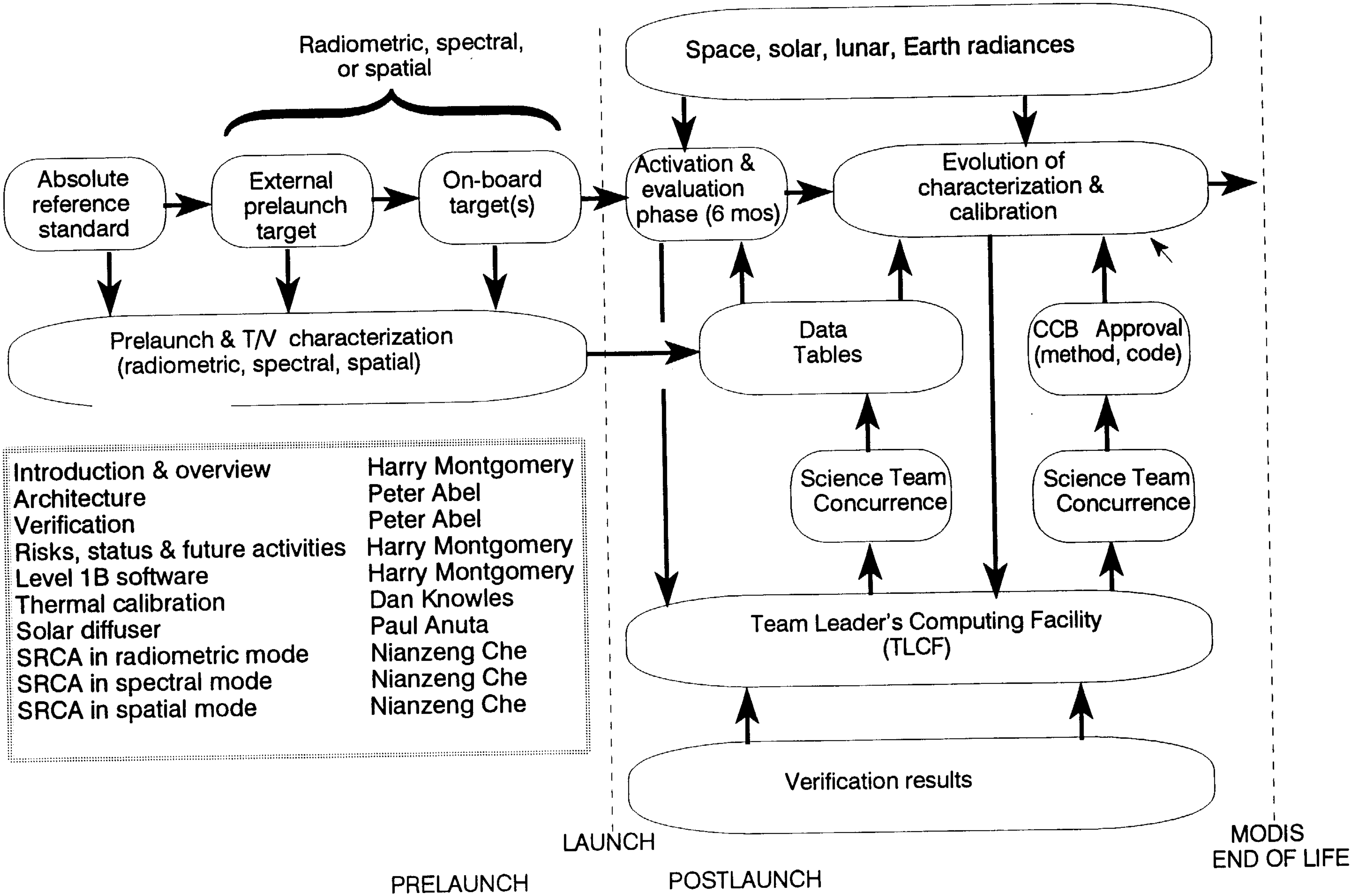

MODIS CHARACTERIZATION & CALIBRATION DATA FLOW

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ATBD for MODIS Level 1B Algorithm

Risks, Status & Future Activities

Harry Montgomery

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Calibration Discipline Group Meeting

Summary of Risks

1. Direct Calibration with the Sun not planned for class 10,000 clean room environment.

2. MODIS & SDSM view SD at about 20° on opposite sides of the normal.

3. SBRC move to Los Angeles will impact the Program.

4. Cost Constraints Limit Extent of Characterization:
   - Pre-launch Solar Calibration of SD/SDSM
   - Incomplete EM model (no ghosting fixes, SD/SDSM, or SRCA)
   - Truncated EM TV Testing (Universal curve for emissive bands not adequately characterized)
   - Limited MCST interaction with SBRC Personnel

5. Availability of Lunar Calibration
   - Funding/schedule to complete Keiffer characterization of Lunar radiance
   - Limited or No EOS manuevers to allow MODIS to scan the Moon

6. Limited or No EOS manuevers to allow MODIS to scan space for Characterizing Scan Mirror as a Function of Scan Angle

7. Unknown (due to incomplete test and analysis):
   Contamination Changes SD and Optical System Scatter, Blackbody Radiance and Optical System Transmission

ATBD Status & Future Activities

Status

- β_1 Version of Software Complete
- First Order Algorithm Defined
- ATBD Reviewed in Viewgraph Form
- GSFC TAC bought (clone of SBRC Test Analysis Console & Archiver)

Future Activity

- Obtain feed-back from Science Team, especially on Verification Activities
- Prepare written ATBD
- β_2 Version of Software Delivery — October 31, 1994
- β_3 Version of Software Delivery — April, 1995

ATBD for MODIS Level 1B Algorithm

Level 1B Software

Harry Montgomery

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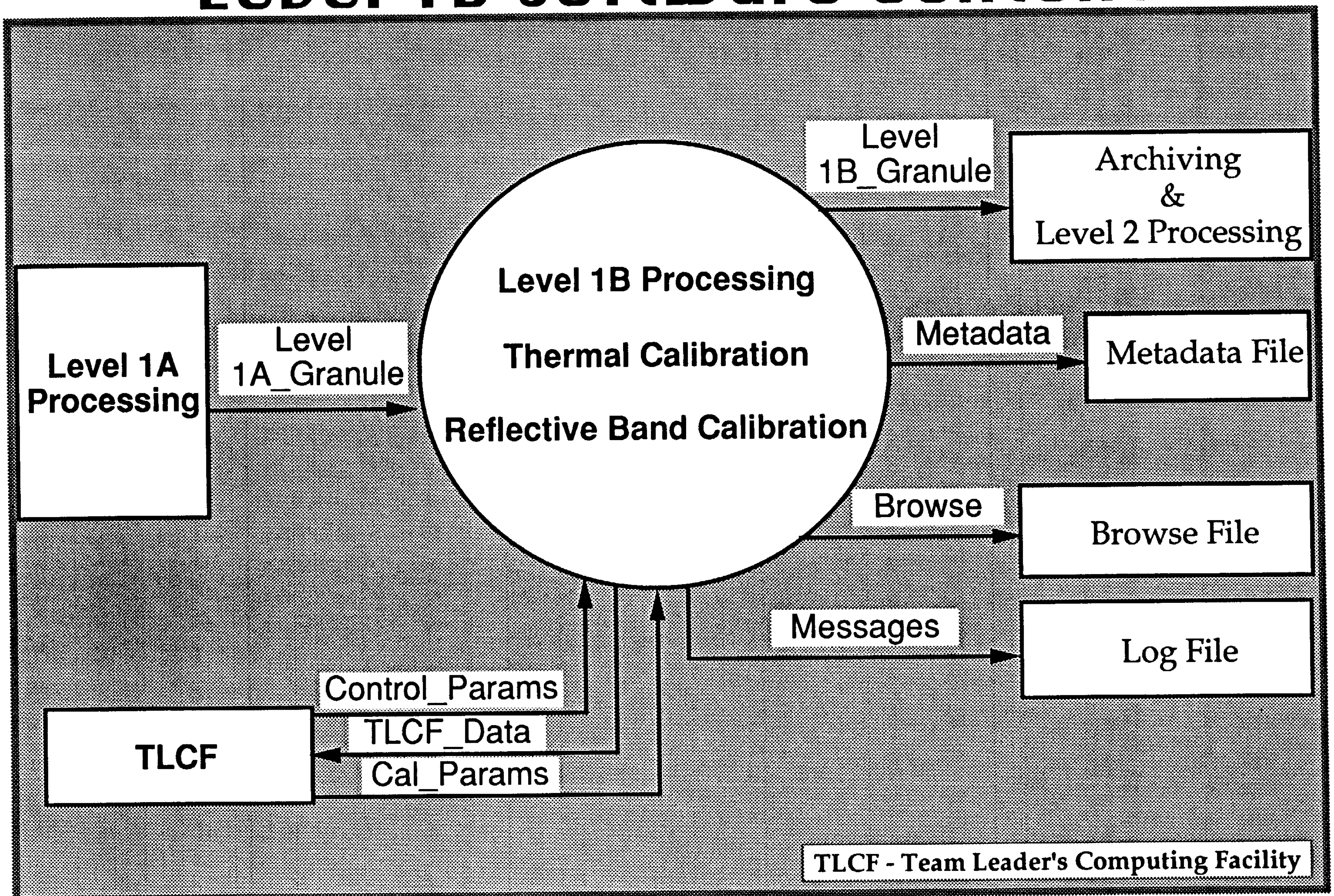
Calibration Discipline Group Meeting

Level 1B Software Context



Purpose of the Level 1B Software

Provide calibrated MODIS data which satisfies the requirements of the scientific community for analysis

Implement the Calibration Algorithm

Supply Metadata which Describes the Data

Identify Exceptions and Anomalies in the Data

Monitor MODIS Status and Report Data Quality

Level 1B Calibration Capabilities

Thermal Calibration
Uses Blackbody with along-scan interpolation

Reflective Band Calibration
Solar Diffuser Based (SRCA during A&E)

SRCA Characterization
Spectral, Spatial, Radiometric

Level 1B Issues

1. Undefined Portions of Algorithm
2. Major Changes to Defined Portion of Algorithm
3. Finalization of Interfaces
4. Quality Assurance
5. Exception Handling

Level 1B Software Milestones

Beta 2 Delivery	October, 1994
Beta 3 Delivery	April, 1995
Version 1 Delivery	February, 1996
Version 2 Launch Ready Delivery	February, 1997
Verson 2.1 Pre-Launch Update	February, 1998
Verson 2.2 Post A&E (Launch + 6 months)	June, 1998

ATBD for MODIS Level 1B Algorithm

Thermal Calibration

Dan Knowles

Absolute radiometric calibration - baseline TIR

(Thermal calibration - Dan Knowles)

Products

Level 1B :

Absolute radiance, L, at MODIS aperture

Metadata

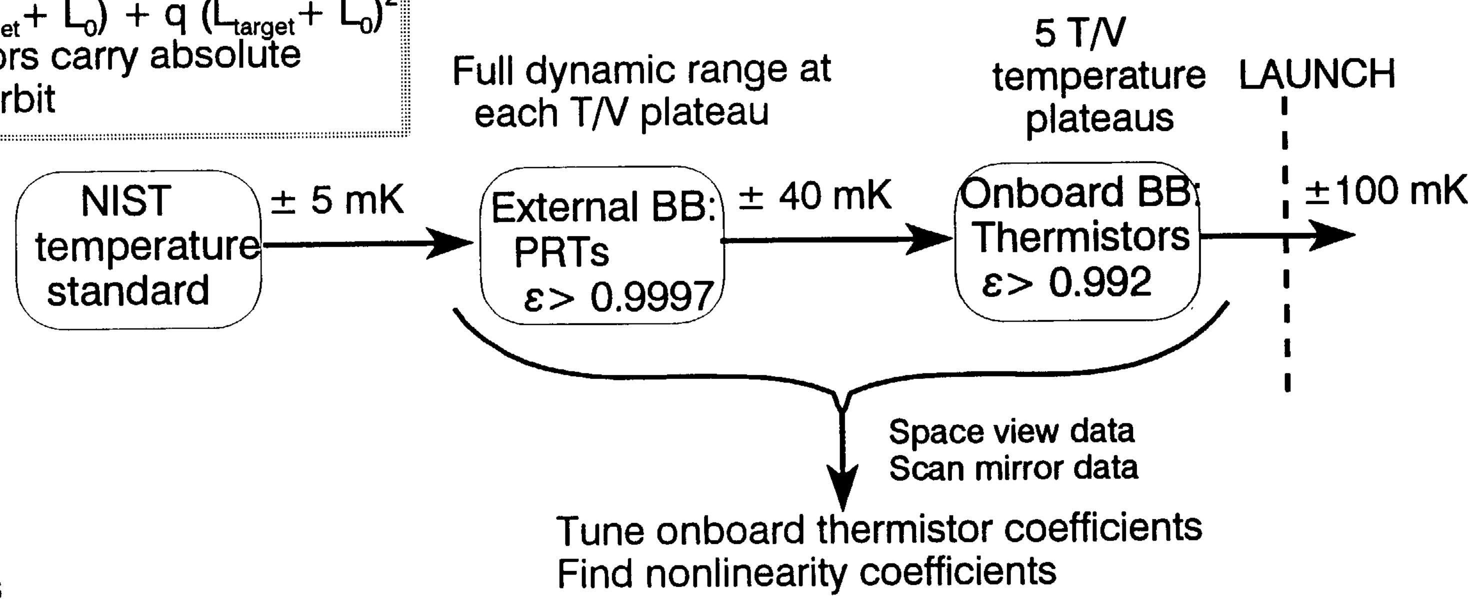
1σ uncertainties, quality indices

Baseline process

Quadratic transfer curve given by

$V_{detector} = V_0 + m\,(L_{target} + L_0) + q\,(L_{target} + L_0)^2$

Onboard BB thermistors carry absolute radiance scale into orbit



Data Table Examples

- $L(T_{onboard\ BB})$ for each detector
- Detector nonlinearity coefficients
- Scan mirror (both sides) reflectance or emittance as f(rotation angle)
- Onboard BB thermistor coefficients

Non-Baseline Options

Correction matrices for residual optical effects

Other methods for nonlinearity coefficients

Acronyms:

BB	Black Body
NIST	National Institute for Standards and Technology
PRT	Platinum Resistance Thermometer
TIR	Thermal InfraRed

Calibration of the MODIS Infrared Detectors (Bands: 20 - 25, 27 - 36)

Objective

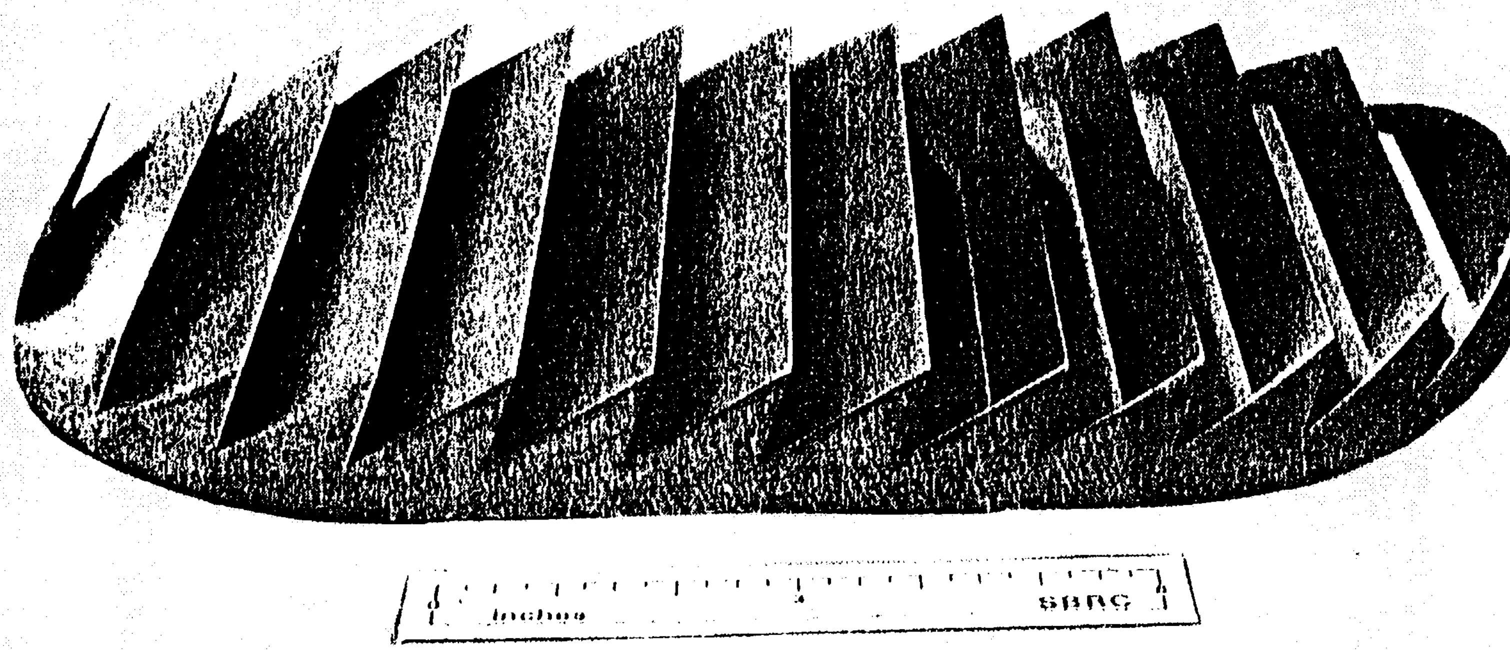
- Use the Space View, Blackbody, and other on-orbit telemetry to correct for changes since pre-launch thermal calibration
- Determine the spectral radiance at the MODIS aperture while observing the Earth target

Summary

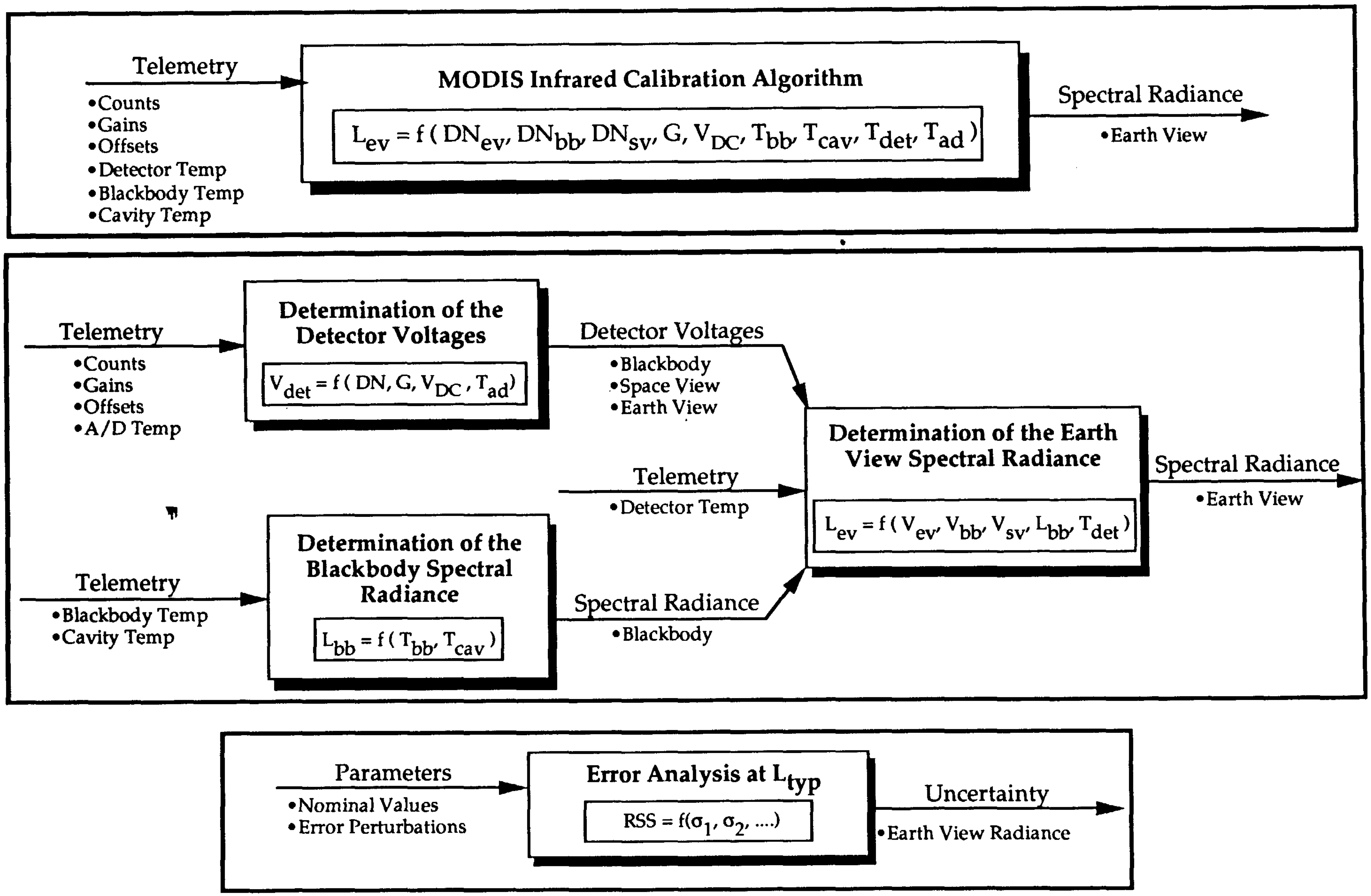
- Current analysis shows all infrared bands meet the specification except bands (20, 22, 23, and 24)*
- Center wavelength shift is the dominant source of error for the MWIR bands

* Bands 20, 22, 23, and 24 are .15%, .08%, .05%, and .05% out of spec, respectively

MODIS On-Orbit Blackbody



Overview


Telemetry
•Counts
•Gains
•Offsets
•Detector Temp
•Blackbody Temp
•Cavity Temp
MODIS Infrared Calibration Algorithm
$L_{ev} = f(DN_{ev}, DN_{bb}, DN_{sv}, G, V_{DC}, T_{bb}, T_{cav}, T_{det}, T_{ad})$
Spectral Radiance
•Earth View
Telemetry
•Counts
•Gains
•Offsets
•A/D Temp
Determination of the Detector Voltages
$V_{det} = f(DN, G, V_{DC}, T_{ad})$
Detector Voltages
•Blackbody
•Space View
•Earth View
Telemetry
•Detector Temp
Determination of the Earth View Spectral Radiance
$L_{ev} = f(V_{ev}, V_{bb}, V_{sv}, L_{bb}, T_{det})$
Spectral Radiance
•Earth View
Telemetry
•Blackbody Temp
•Cavity Temp
Determination of the Blackbody Spectral Radiance
$L_{bb} = f(T_{bb}, T_{cav})$
Spectral Radiance
•Blackbody
Parameters
•Nominal Values
•Error Perturbations
Error Analysis at L_{typ}
$RSS = f(\sigma_1, \sigma_2, ...)$
Uncertainty
•Earth View Radiance

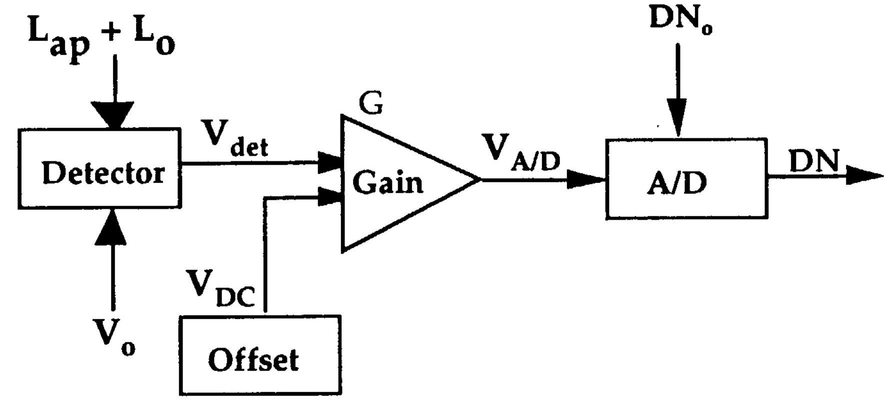
Determination of the Detector Voltages

Photovoltaic Circuit (Bands 20 - 25, 27- 30)

$$V_{det} = \frac{DN - DN_o}{G\,R_{ad}} - V_{DC}$$

PL3095-M00832

A/D = 12 bit
Offset = 8 bit

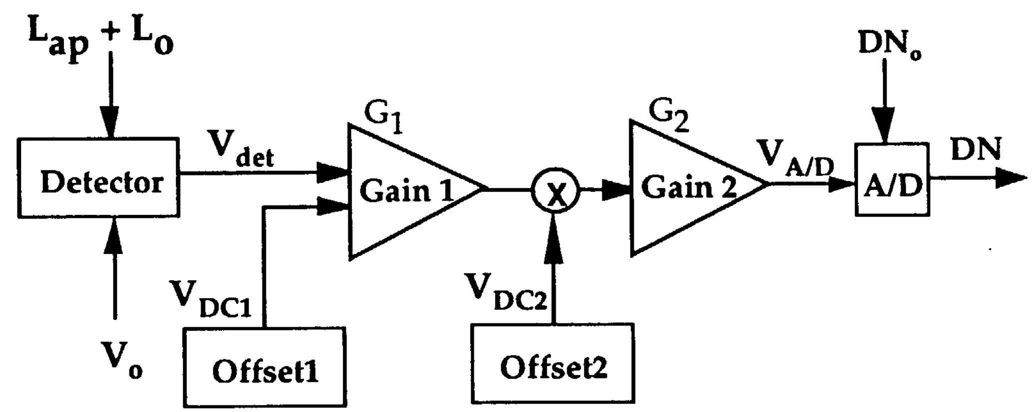


Photoconductive Circuit (Bands 31 - 36)

$$V_{det} = \frac{DN - DN_o}{G_1\,G_2\,R_{ad}} - \frac{V_{DC2}}{G_1} - V_{DC1}$$

PL3095-M00890

A/D = 12 bit
Offset1 = 8 bit
Offset2 = 8 bit



- V_{DC} is negative in value to place the target signal within the dynamic range of the A/D converter
- The digital numbers, gains, and offsets will vary from scan to scan
- The space view detector voltages and blackbody detector voltages will be averaged over 15 frames to obtain one value for each
- Linearity and temperature dependency of the responsivity of the A/D converter will be determined with the thermal vacuum test data
- R_{ad} will be checked with the electronic calibration (ECAL) on-orbit

Determination of the Blackbody Spectral Radiance

- The blackbody spectral radiance can be determined every scan as:

RPT92-0618 pg. 5-8

$$L_{bb} = \frac{\sum_{\lambda lower}^{\lambda upper} \varepsilon_{\lambda bb} B_{\lambda bb} R_{\lambda} \Delta\lambda}{\sum_{\lambda lower}^{\lambda upper} R_{\lambda} \Delta\lambda} + \frac{\Omega_{cav} \sum_{\lambda lower}^{\lambda upper} (1-\varepsilon_{\lambda bb}) B_{\lambda cav} R_{\lambda} \Delta\lambda}{\pi \sum_{\lambda lower}^{\lambda upper} R_{\lambda} \Delta\lambda} + \frac{\Omega_{Earth} \sum_{\lambda lower}^{\lambda upper} (1-\varepsilon_{\lambda bb}) B_{\lambda Earth} R_{\lambda} \Delta\lambda}{\pi \sum_{\lambda lower}^{\lambda upper} R_{\lambda} \Delta\lambda}$$

Blackbody Term — Cavity Term — Earth Term

- Blackbody term is at least 98% of the total value of L_{bb}

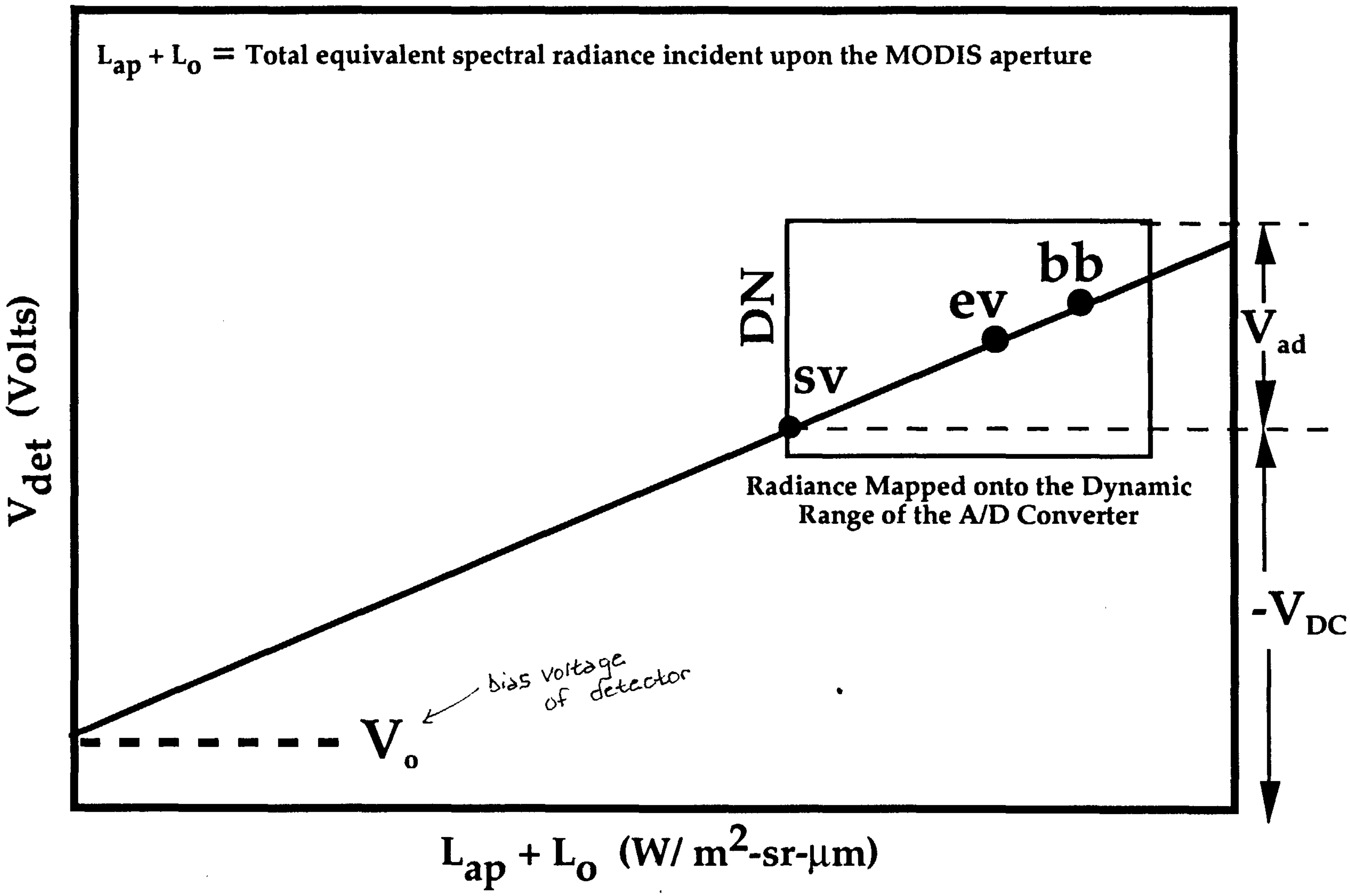
Where $$B_{\lambda} = \frac{2hc^2}{\pi\lambda^5 (e^{(hc/\lambda kT)} - 1)}$$

- The result of the above integral will be stored in detector dependent tables which relate radiance to target temperature. The blackbody spectral radiance can then be determined as:

$$L_{bb} = \frac{L_{emiss(T_{bb})}}{R_{filter}} + \frac{\Omega_{cav} L_{reflect(T_{cav})}}{\pi R_{filter}} + \frac{\Omega_{Earth} L_{reflect(T_{Earth})}}{\pi R_{filter}}$$

- The range of the emissive tables will be from 280K to 320K with a resolution of .05K.
- The range of the reflective tables will be from 200K to 400K with a resolution of 1K.
- The 12 blackbody thermistors will be averaged to determine one effective blackbody temperature. The thermistors may be weighted to obtain an effective temperature located towards the center of the blackbody.
- A thermister failure determination algorithm will be developed.
- The blackbody temperature will be elevated periodically to 315K

Universal MODIS Infrared Calibration Curve



Determination of the Earth View Spectral Radiance

The detector voltage can be expressed in terms of the total equivalent spectral radiance incident upon the MODIS aperture as follows, where, L_0 and m are unknowns:

$$V_{det} = q(L_{ap}+L_o)^2 + m(L_{ap}+L_o) + V_o$$

Applying the blackbody and space view data to this equation and accounting for mirror emissivity variations with scan angle, the Earth View spectral radiance can be determined as:

$$L_{ev} = A(L_{ev/uncorrected}) + B$$

$$L_{ev/uncorrected} = \frac{V_o - \overline{V}_{sv} - q_{(T_{det})} L_o^2 + \sqrt{(\overline{V}_{sv} - V_o - q_{(T_{det})} L_o^2)^2 + 4 q_{(T_{det})} L_o^2 (V_{ev} - V_o)}}{2 q_{(T_{det})} L_o}$$

Where:

$$A = \frac{\sum_{\lambda lower}^{\lambda upper} (1 - \varepsilon_{mirror(bb)}) R_\lambda \Delta\lambda}{\sum_{\lambda lower}^{\lambda upper} (1 - \varepsilon_{mirror(ev)}) R_\lambda \Delta\lambda}$$

$$B = \frac{\sum_{\lambda lower}^{\lambda upper} (\varepsilon_{mirror(bb)} - \varepsilon_{mirror(ev)}) B_{\lambda mirror} R_\lambda \Delta\lambda}{\sum_{\lambda lower}^{\lambda upper} (1 - \varepsilon_{mirror(ev)}) R_\lambda \Delta\lambda}$$

$$L_o = \frac{\overline{V}_{bb} - \overline{V}_{sv} - q_{(T_{det})} \overline{L}_{bb}^2 - \sqrt{(\overline{V}_{sv} - \overline{V}_{bb} + q_{(T_{det})} \overline{L}_{bb}^2)^2 + 4 q_{(T_{det})} \overline{L}_{bb}^2 (V_o - \overline{V}_{sv})}}{2 q_{(T_{det})} \overline{L}_{bb}}$$

- The value of the non-linear term, q, will be determined pre-launch at three detector set points and treated as a constant on-orbit

Current Absolute Error Analysis

- **Analysis based on perturbations of nominal values through the calibration equation**

$$RSS = \sqrt{\sigma_1^2 + \sigma_2^2 + \ldots \sigma_n^2}$$

$$\sigma_i = \frac{L(\rho_1, \rho_2, \ldots \rho_i + \Delta\rho_i, \ldots, \rho_n) - L(\rho_1, \rho_2, \ldots, \rho_n)}{L(\rho_1, \rho_2, \ldots, \rho_n)} 100$$

Band 20 Itemized Root Sum Squared List

Parameters	Peturbation	Band 20 Error
Non-linear Coefficient	1%	.01%
CavityTemp	1K	.04%
Blackbody Temp	.1K	.48%
Blackbody Emissivity	.004	.00%
Signal Digitization	1DN	.24%
Detector Bias Variation	.01%	.01%
Scan Mirror Emissivity Variation	.001	.05%
Center Wavelength Shift	.1%	.87%
NIST Tracability (absolute error)	~~~~~~~	.52%
RSS		1.15%

Absolute Spectral Radiance Error at Ltyp

	RSS	RSS*	Spec
Band 20	*1.15%*	0.75%	0.75%
Band 21	6.93%	6.89%	10.00%
Band 22	*1.08%*	0.72%	1.00%
Band 23	*1.05%*	0.71%	1.00%
Band 24	*1.05%*	0.87%	1.00%
Band 25	0.90%	0.66%	1.00%
Band 27	0.74%	0.70%	1.00%
Band 28	0.64%	0.61%	1.00%
Band 29	0.58%	0.57%	1.00%
Band 30	0.57%	0.57%	1.00%
Band 31	0.28%	0.28%	0.50%
Band 31hi	0.32%	0.32%	10.00%
Band 32	0.28%	0.27%	0.50%
Band 32hi	0.32%	0.31%	10.00%
Band 33	0.55%	0.54%	1.00%
Band 34	0.55%	0.54%	1.00%
Band 35	0.56%	0.55%	1.00%
Band 36	0.58%	0.57%	1.00%

- **RSS* has center wavelength shift of .01% instead of .1% (Spec value)**
- **Errors underlined do not meet specification**
- **NIST tracability is: .52% for bands 20-25, 27-30, and 33-36,**
  .22% for bands 31 and 32.
  ref: RPT94-0234 pg. 1-10

Thermal Calibration Nomenclature

A	=	Reflective correction factor of the MODIS scan mirror
B	=	Emissive correction term of the MODIS scan mirror
bb	=	MODIS blackbody
$B_{\lambda,T}$	=	Planck function
$B_{\lambda,T_{bb}}$	=	Planck function evaluated at T_{bb}
$B_{\lambda,T_{Earth}}$	=	Planck function evaluated at T_{Earth}
$B_{\lambda,T_{cav}}$	=	Planck function evaluated at T_{cav}
DN	=	Digital Number output of the A/D converter
DN_{bb}	=	Digital Number output of the A/D converter while viewing the MODIS blackbody
DN_{ev}	=	Digital Number output of the A.D converter while viewing Earth
DN_o	=	Pre-set digital offset of the A/D converter (DN_o = 100)
DN_{sv}	=	Digital Number output of the A/D converter while viewing the space
$\varepsilon_{\lambda bb}$	=	Wavelength dependent emissivity of the MODIS blackbody
ev	=	MODIS Earth View
G	=	Amplifier Gain
L_{ap}	=	Spectral radiance incident at the MODIS aperture while viewing any target
L_{bb}	=	Spectral radiance incident at the MODIS aperture while viewing the MODIS blackbody.
$L_{emiss(t)}$	=	Table of MODIS blackbody emitted radiance
L_{ev}	=	Spectral radiance incident at the MODIS aperture while viewing the Earth target.
$L_{ev/uncorrected}$	=	Spectral radiance at the MODIS aperture while viewing the Earth target assuming no angle dependent emissivity of the MODIS scan mirror
L_o	=	Equivalent optical background spectral radiance referenced to the MODIS aperture
$L_{reflect(T)}$	=	Table of MODIS blackbody reflected radiance
L_{sv}	=	Spectral radiance incident at the MODIS while viewing space.
L_{typ}	=	Typical earth radiance used in MODIS instrument specification.
m	=	First order calibration coefficient
$q(T_{det})$	=	Second order (non-linear) calibration coefficient determined pre-launch and treated as a constant on-orbit
R_{ad}	=	Responsivity (Counts/Volts) of the A/D converter
R_{filter}	=	Integrated spectral response of the MODIS optical system
R_λ	=	Wavelength dependent spectral response of the MODIS optical system
sv	=	MODIS space view
T_{ad}	=	Temperature of the A/D converter
T_{bb}	=	Mean temperature of the MODIS blackbody
T_{cav}	=	Mean temperature of the MODIS cavity
T_{det}	=	Temperature of the detector
T_{Earth}	=	Temperature of the Earth segment of Ω_{Earth}
V_{DC}	=	DC restore voltage applied by the analog electronics module
V_{det}	=	Voltage across the detector
λ_{lower}	=	Lower limit of filter spectral response data
λ_{upper}	=	Upper limit of filter spectral response data
Ω_{cav}	=	Projected solid angle of MODIS cavity subtended by the MODIS blackbody
Ω_{Earth}	=	Projected solid angle of the Earth subtended by the MODIS blackbody

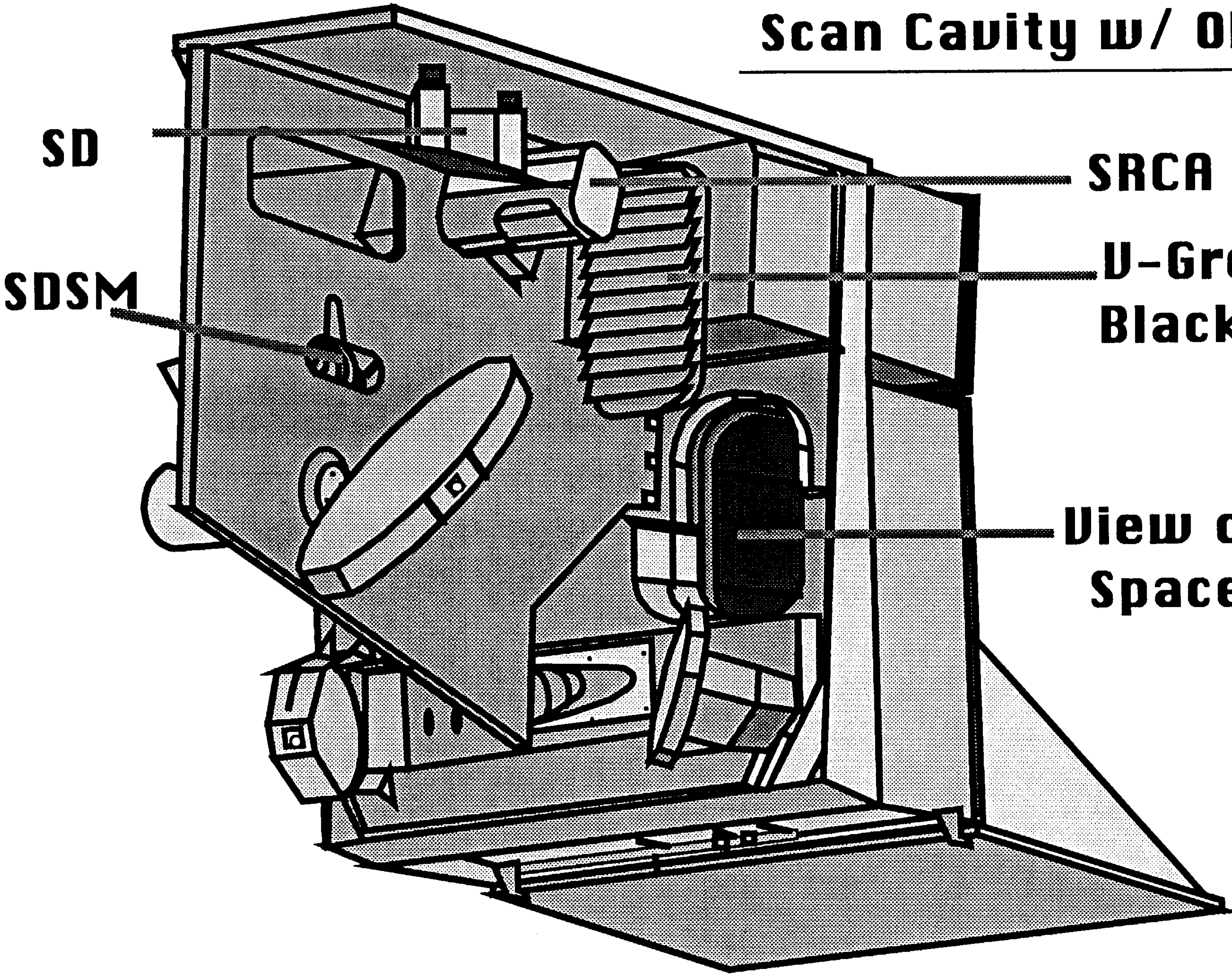
ATBD for MODIS Level 1B Algorithm

Solar Diffuser Radiometric Calibration

Paul Anuta

11 OCT 94
Calibration Discipline Group Meeting

Scan Cavity w/ OBCs



Absolute radiometric calibration - baseline reflectance for $\lambda < 2.3\ \mu m$

(Solar diffuser - Paul Anuta)

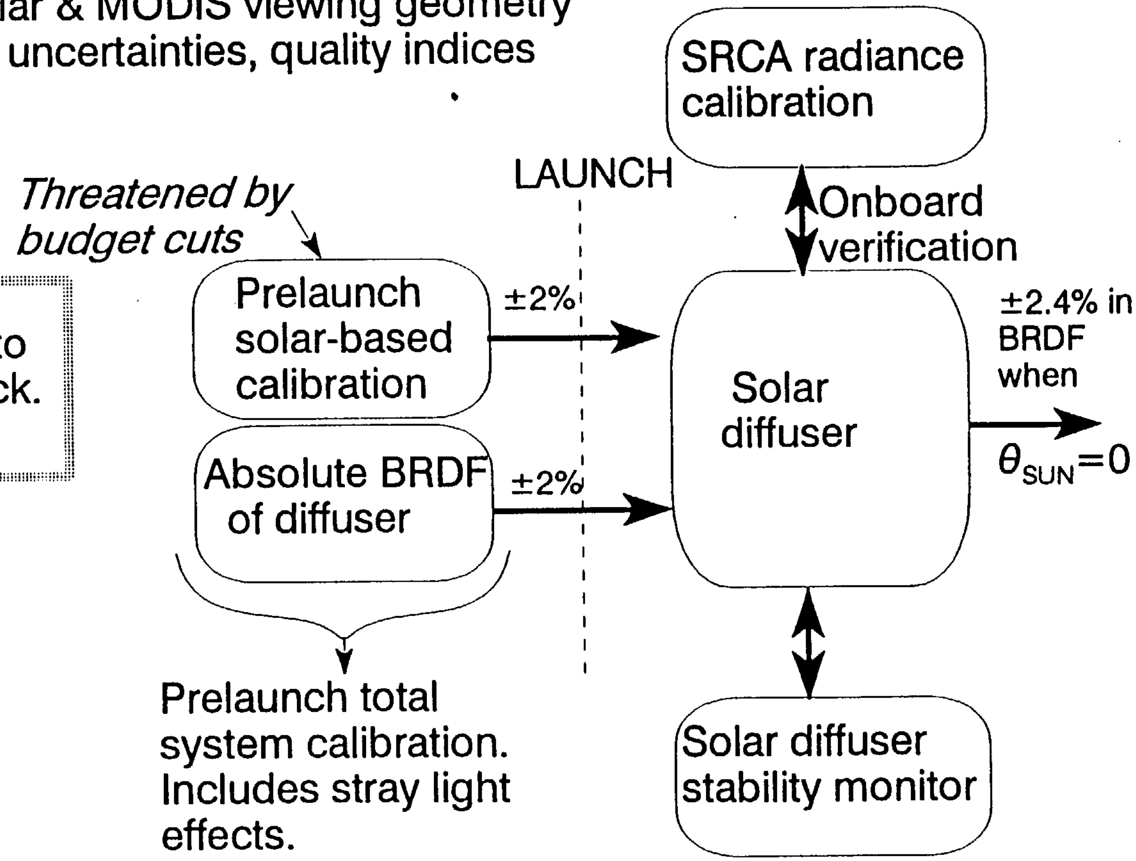
Products

Level 1B :
- Target BRDF

Metadata:
- -Solar & MODIS viewing geometry
- -1σ uncertainties, quality indices

Baseline process

Solar diffuser carries BRDF scale into orbit. SRCA gives consistency check.



Data Table Examples
- -Absolute spectral BRDF of diffuser
- -Prelaunch solar-based MODIS calibration

Non-Baseline Options
- -Transfer to lunar BRDF standard

Acronyms:
SRCA SpectroRadiometric Calibration Assembly
BRDF Bidirectional Reflectance Distribution Function

SD/ SDSM Calibration Summary

Objective:

- Track MODIS reflective band gains using the SD/SDSM to correct for changes since pre-launch calibration.

Baseline:

- Absolute accuracy - 4 %
  - NIST standard transferred from SRCA to SD
- BRDF accuracy - 2.4 %
  - Based on pre-launch SD measurements

Solar Model-Based SD Radiometric Accuracy:

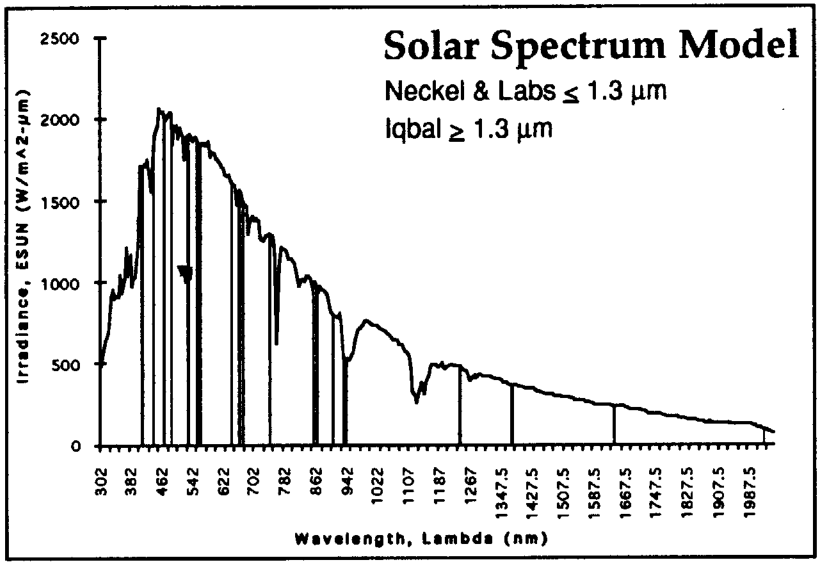
- Absolute accuracy - 4%
  - Based on pre-launch SD measurements and knowledge of Solar Irradiance

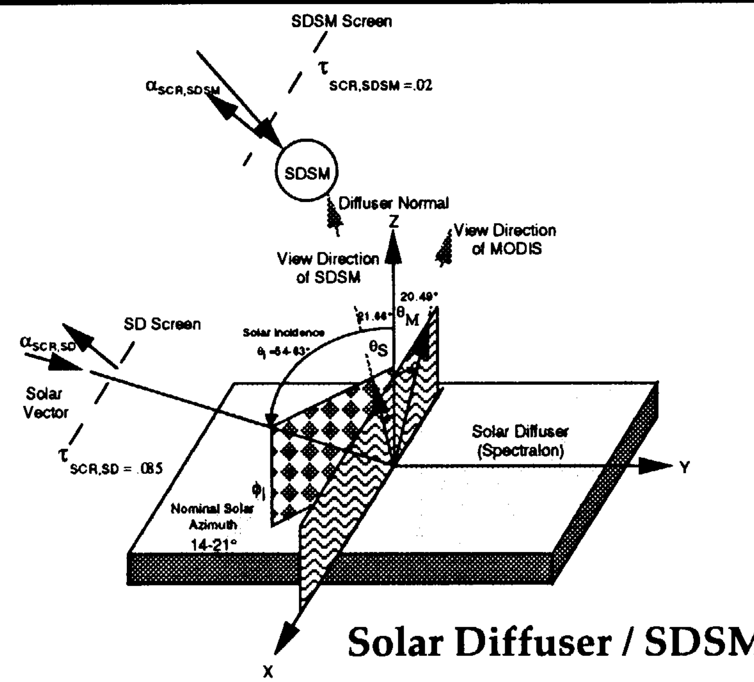
---

BRDF of Scene is called Reflectance Calibration in MODIS Specification

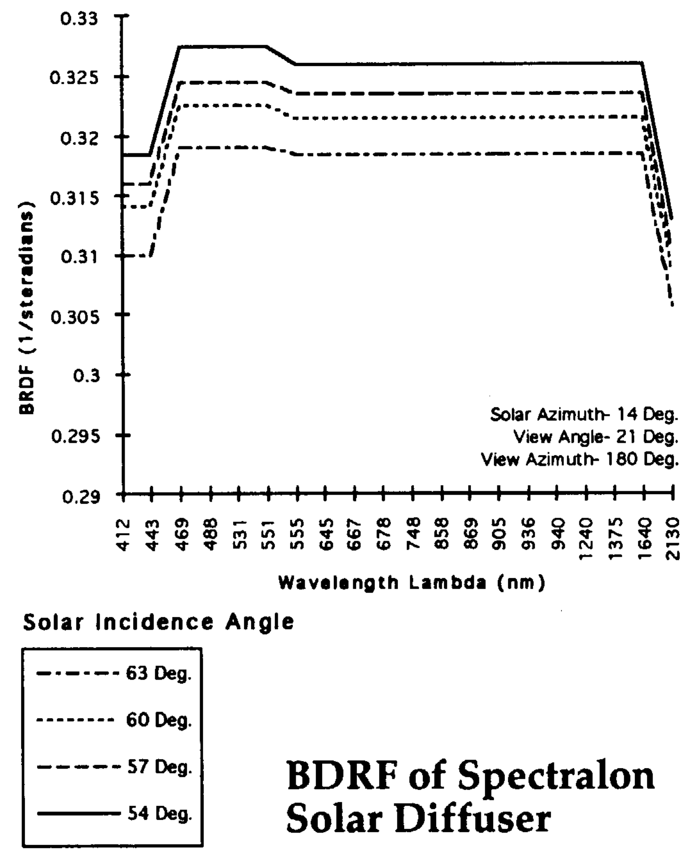
SRCA	-	Spectro-Radiometric Calibration Assembly
SD	-	Solar Diffuser
SDSM	-	Solar Diffuser Stability Monitor

Key SD/SDSM Elements





Solar Diffuser / SDSM



BDRF of Spectralon Solar Diffuser

SD Calibration Overview

When MODIS views the SD

$$DN_{SD} = \underbrace{G^L E_{SUN}}_{G^Q} \overbrace{\underbrace{\tau_{SD}\Delta_{SDSM} BRDF_{0,SD} COS(\theta_{SD})}_{Q_{SD}}}^{L_{SD}}$$

When MODIS views the scene:

$$DN_{SCENE} = \underbrace{G^L E_{SUN}}_{G^Q} \overbrace{\underbrace{BRDF_{SCENE} COS(\theta_{SCENE})}_{Q_{SCENE}}}^{L_{SCENE}}$$

To obtain scene spectral radiance:

$$G^L = \frac{DN_{SD}}{L_{SD}} \qquad L_{SCENE} = \frac{DN_{SCENE}}{G^L}$$

To obtain scene BRDF:

$$G^Q = \frac{DN_{SD}}{Q_{SD}} \qquad Q_{SCENE} = \frac{DN_{SCENE}}{G^Q}$$

$$BRDF_{SCENE} = \frac{Q_{SCENE}}{COS(\theta_{SCENE})}$$

Where:

DN	-	Counts
G	-	Gain
L	-	Spectral Irradiance
E	-	Solar Irradiance
τ	-	Screen Transmission
θ	-	Solar Incidence Angle
Δ	-	Degradation Factor

VIS, NIR, SWIR Calibration Algorithm

Responsivity Estimation:

$$G^{L}_{B,Ch}(t) = \frac{\overline{D}N^{SD}_{B,Ch} - \overline{D}N^{SP}_{B,Ch}}{L_{SD}(\lambda_B, t)} \qquad G^{Q}_{B,Ch}(t) = \frac{\overline{D}N^{SD}_{B,Ch} - \overline{D}N^{SP}_{B,Ch}}{Q_{SD}(\lambda_B, t)}$$

$\overline{D}N$ is the average over one MODIS scan

Trend the Responsivity Values:

Piecewise linear and quadratric least squares trend functions track, smooth and predict the responsivities over time:

$$\hat{G}^{L,Q}_{B,Ch} = f_{TREND}(\overline{G}^{L,Q}_{B,Ch}(t_i), \overline{G}^{L,Q}_{B,Ch}(t_{i-1}), \overline{G}^{L,Q}_{B,Ch}(t_{i-2}), \ldots, p_1, p_2, p_3, B, Ch, t) \bullet \delta(\varphi)$$

$\delta(\varphi)$ is the intra-orbit variability factor determined from the SRCA as function of orbit angle φ.

Compute Calibration Coefficients:

$$c^{L,Q}_{0,B,Ch} = \frac{-\overline{D}N^{SP}_{B,Ch}}{\hat{G}^{L,Q}_{B,Ch}} \qquad c^{L,Q}_{1,B,Ch} = \frac{1}{\hat{G}^{L,Q}_{B,Ch}}$$

Compute scene radiance and Q values for each pixel:

$$L^{SCENE}_{B,Ch} = c^{L}_{0,B,Ch} + c^{L}_{1,B,Ch} DN^{SCENE}_{B,Ch} \qquad Q^{SCENE}_{B,Ch} = c^{Q}_{0,B,Ch} + c^{Q}_{1,B,Ch} DN^{SCENE}_{B,Ch}$$

Error Analysis for Solar Diffuser Calibration Mode

Absolute Accuracy

Parameter	Nominal Value	Estimated Error*	Radiance Error (%) Screen Closed	Radiance Error (%) Screen Open	Reflectance Error (%) Scr. Closed	Reflectance Error (%) Scr. Open
τ_{SCR}	.085	1% (2x SBRC)	1	0	.99	
SD BRDF	.318	1%	1	.99	.99	.99
θ_i Solar Incidence	58 Deg.	.1Deg.	.24	.24	.24	.24
ϕ_i Solar Azimuth	15 Deg.	.1Deg.	≈ 0	≈ 0	≈ 0	≈ 0
θ_M MODIS View Angle	20.49 Deg.	.1Deg.	≈ 0	≈ 0	≈ 0	≈ 0
ϕ_M MODIS View Azimuth	180 Deg.	.1Deg.	≈ 0	≈ 0	≈ 0	≈ 0
E_{SUN} Solar Irradiance	1817 W/m^2-sr-µm (Band 10, 488 nm)	3 % **	3 %	3 %		
Source	BRDF Cal.	1.53 %			1.53	1.53
KMODIS - Radiance Mode	Includes all MODIS system errors	2.32%	2.32	2.32		
KMODIS - Reflectance Mode	Excludes WL shift and OOB	1.23%			1.23	1.23
		RSS	4 %	3.9 %	2.4%	2.2%

* From SBRC Error Budget Document 93-0868-139

** From analysis of Neckel &Labs, Kurucz, Wehrli

Accuracy of knowledge of Solar variability ≈ .5 %

SD System Calibration Using External Sources

• Transfer of calibration from other sources will be used to calibrate the SD system in-flight. In each case the resulting SD radiance reference calibration accuracy is directly determined by the radiance accuracy of the source:

1. MODIS during A&E. 4-10%
2. Baseline SRCA transfer in-flight 4%
3. Terrestrial Verification 3-5%
4. Lunar Verification 1-15%

• BRDF* of the SD is obtained from the ratio of the radiance from the SD given by the external calibration via MODIS to the Solar spectral irradiance: In this case the 1 sigma error in Q is the RSS combination of the Solar spectral irradiance model absolute error (3%) and the error from 1,2,3 or 4 above.

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*Baseline 2.4%

SD/SDSM System Risks

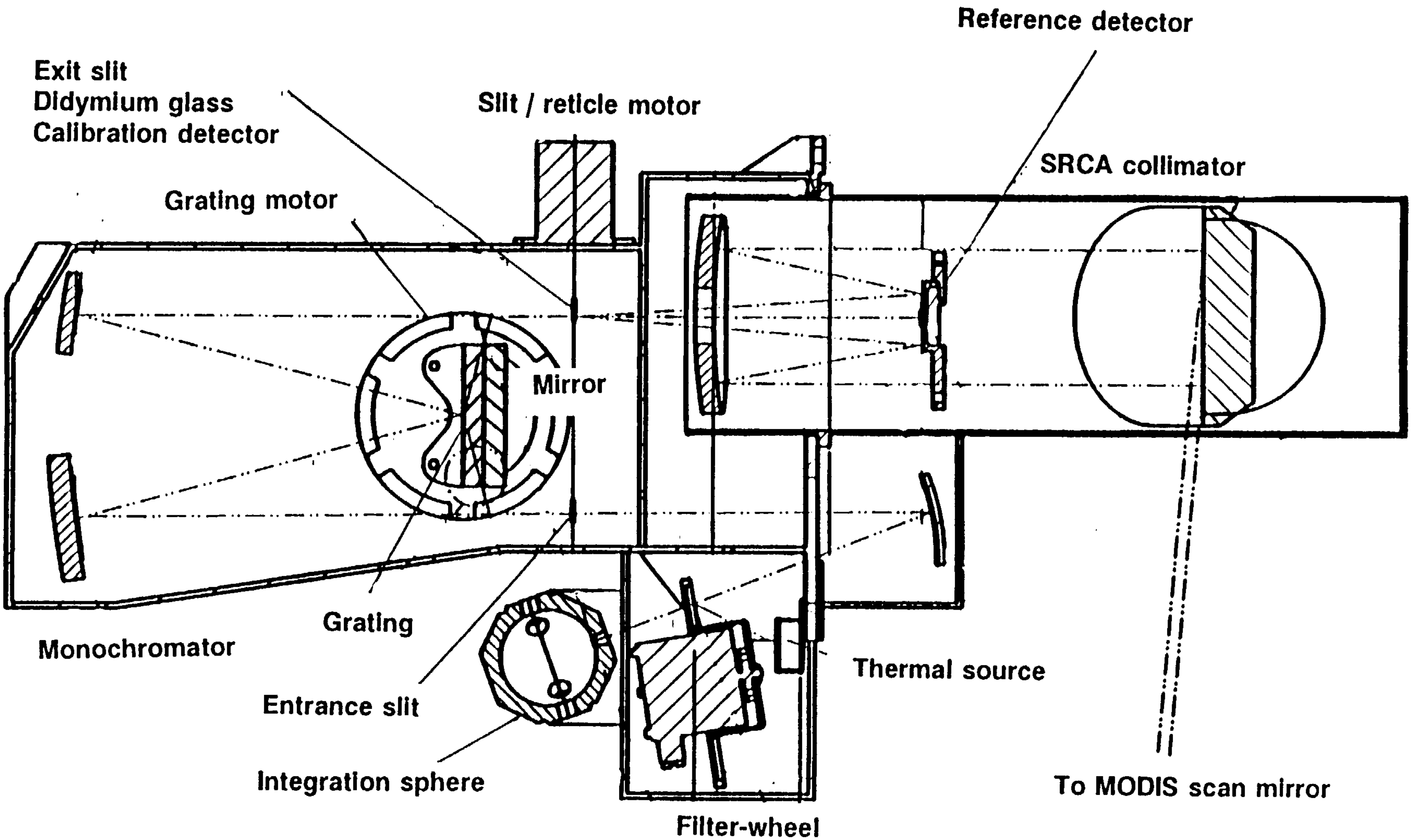
Risk	Implication	Mitigation Strategy
No Solar-Based pre-launch calibration of the SD	Radiance and BRDF models used in calibration algorithm cannot be validated	On-Orbit transfer of radiance calibration and knowledge of Solar Spectrum
Scattered light component in the SD mode is unknown	Radiometric error due to scattered light is unknown	Model estimates from ongoing studies
SDSM does not view SD at the same angle as MODIS	Changes in the SD BRDF in backscatter direction (SDSM) may not be proportional to changes in the forward scatter (MODIS) direction	Use laboratory measurements of SD material after exposure to Solar radiation (e.g. SSBUV experiments)

ATBD for MODIS Level 1B Algorithm

SRCA Radiometric Calibration of Reflectance Bands

Nianzeng Che

11 OCT 94
Calibration Discipline Group Meeting



Reference detector
Exit slit
Didymium glass
Calibration detector
Slit / reticle motor
SRCA collimator
Grating motor
Mirror
Grating
Monochromator
Thermal source
Entrance slit
Integration sphere
To MODIS scan mirror
Filter-wheel

SRCA LAYOUT

Absolute radiometric calibration - baseline radiance for $\lambda < 2.3\ \mu m$

(SRCA in radiometric mode - Nianzeng Che)

Products

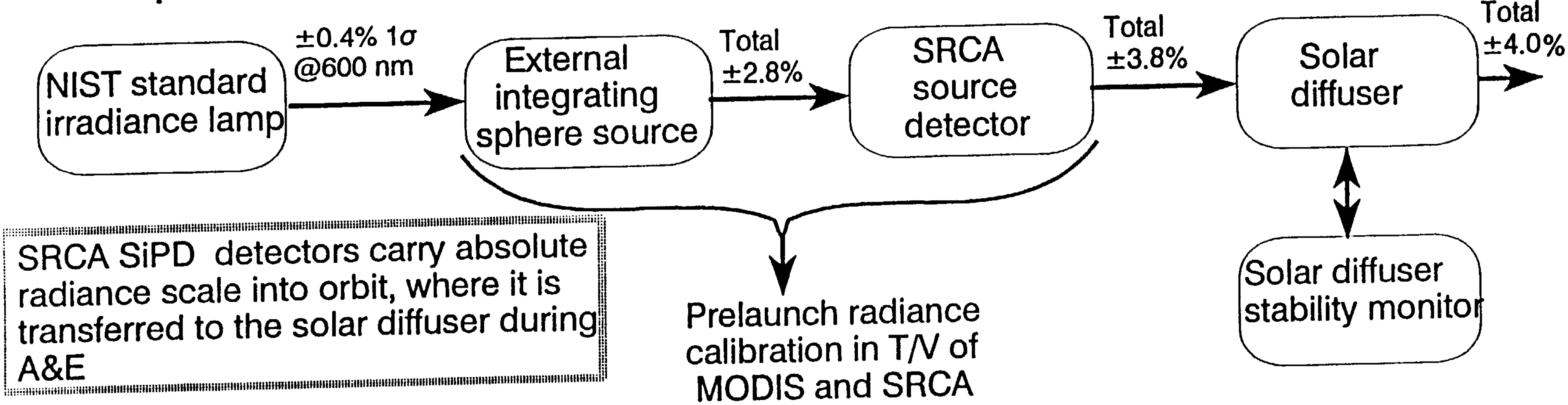
Level 1B :

Absolute radiance, L, at MODIS aperture

Metadata:

1σ uncertainties, quality indices

Baseline process



Data Table Examples

- -Spectral responsivity of SRCA source detector
- -SRCA prelaunch source radiance spectrum
- -MODIS prelaunch band responses to External Integrating Sphere Source
- -MODIS prelaunch band responses to SRCA source
- -Spectral BRDF of diffuser
- -Transfer to lunar radiance source (through space port)
- -Validation data for External Integrating Sphere Source (Round Robin results)

Non-Baseline Options

- -Major spacecraft maneuvers

Acronyms:

SRCA	SpectroRadiometric Calibration Assembly
SiPD	Silicon PhotoDiode
A&E	Activation & Evaluation phase (6 months)

Summary of SRCA in Radiometric Mode

- Absolute Uncertainty of ground Spherical Integration Source, SIS(100) of 2.8%.
- SRCA is radiometrically calibrated by SIS (100) with an absolute uncertainty of 3.5%.
- SRCA carries the calibration to space in Activation & Evaluation (A & E) phase with an absolute uncertainty of 3.8%.
- SRCA transfers the calibration to SD/SDSM System with an absolute uncertainty of 4%.
- SRCA output radiance can be corrected on-orbit using the SD/SDSM after A & E.

SRCA -- Spectro-Radiometric Calibration Assembly
SD/SDSM -- Solar Diffuser / Solar Diffuser Stability Monitor

SRCA in Radiometric Mode (Design)

1. **Objectives:**

   (1) Track changes in radiometric calibration from prelaunch to on-orbit.

   (2) Maintain the radiometric calibration accuracy intra-orbit after SRCA is radiometrically calibrated against SD/SDSM.

2. **Calibration frequency:**

   100 times in during A/E phase; once per week with 10W & 1W bulb and once per month for full radiometric calibration in operation (to be reviewed post-launch).

3. Six light levels are available by combination of bulbs on & off (3-10W, 2-10W, 1-10W, 1-10W w/ ND, 1-1W, 1-1W w/ND).

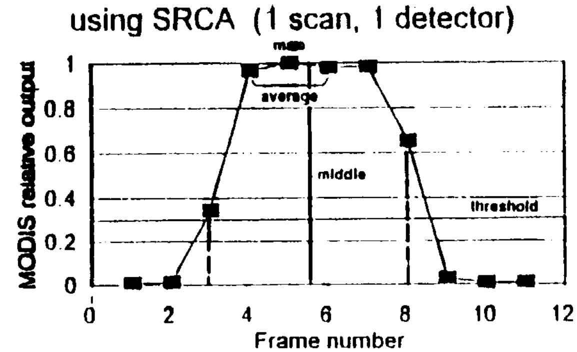
4. **Operational mode:**

   (1) Normal mode - Constant Radiance

   (2) Redundant mode - Constant Current

SRCA in Radiometric Mode (Algorithms)

The algorithm determines the digital counts when MODIS detectors are fully illuminated by SRCA under stable operational condition.



Signal response of MODIS detector

Algorithms:

(1) Find the maximum DN over frames.

(2) Set threshold DN = 0.3 $DN_{max,b,ch}$ (sc#).

(3) Determine the left & right frame no. that the DNs are greater than $DN_{threshold}$.

(4) Find middle frame no.

(5) Average three DNs centered around the middle frame no., $DN_{AV,b,ch}$(sc#).

(6) Average over scan no.

$$DN_{b,ch} = 1 / N_{scan} \cdot \Sigma_{i=1,Nscan} DN_{AV,b,ch} (sc\#)$$

(7) Calculate the standard deviation for the scans.

Radiometric gain values:

If the SRCA output radiance, $L_{SRCA,b}$ is known or is calibrated against other sources such as SD or verification results. The radiometric gain value is:

$$Kb,ch,L = (DN_{MODIS,b,ch} - DN_{o,b,ch}) / L_{SRCA,b}$$

b -- band number

ch -- channel number

sc# -- scan number

DN_{MODIS} -- digital counts when MODIS viewing

$DN_{o,b,ch}$ -- space counts

L_{SRCA} -- Radiance output from SRCA

SRCA in Radiometric Mode (error estimation)

#	Description	Uncertainty
	Requirement	5.0%
(1) SRCA carries calibration into space		
1	Calibration preflight at T / V environment	3.5%
2	Carrying into space	1.0%
3	Instability during radiometric calibration by SRCA	0.3%
4	Possible MODIS band shift by 0.5 nm	1.0%
	Summary	3.8%
(2) Transfer calibration from SRCA to SD/SDSM in A/E phase		
1	SRCA radiance uncertainty	3.8%
2	Instability during radiometric calibtaion by SRCA	0.3%
3	Transfer from SRCA to SD/SDSM	1.0%
	Summary	4.0%
(3) SRCA radiometric uncertainty by referring to SD/SDSM in operation		
1	SD/SDSM radiance uncertainty	4.0%
2	SD/SDSM uncertainty in space	1.5%
3	Transfer from SD/SDSM to SRCA	1.0%
4	Instability during radiometric calibration by SRCA	0.3%
5	Instability between two radiometric calibration by SRCA	1.5%
	Summary	4.6%

Risk: Reference Silicon Photodiode signal may be saturated in several MODIS bands.

ATBD for MODIS Level 1B Algorithm

SRCA in Spectral Mode

Nianzeng Che

11 OCT 94
Calibration Discipline Group Meeting

Spectral calibration - baseline for $\lambda < 2.3\ \mu m$ ($\lambda < 1\ \mu m$ in orbit)

(SRCA in spectral mode - Nianzeng Che)

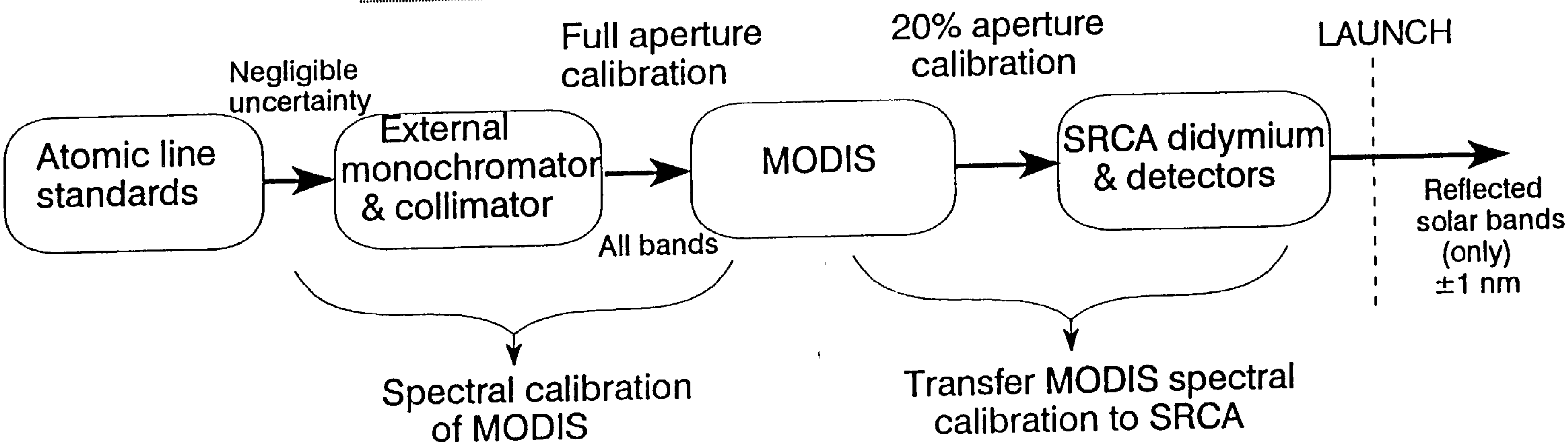
Products

Level 1B :
None

Metadata:
Band centers
1σ uncertainties, quality indices

Baseline process

SRCA didymium glass spectral features and SRCA SiPD detector responsivities carry absolute spectral scale into orbit



Data Table Examples

- Spectral responsivity of SRCA source detector
- SRCA prelaunch source radiance spectra as f(# lamps)
- Prelaunch band centers measured by External Collimator and by SRCA

Non-Baseline Options

- In orbit measurement of band width
- In orbit spectral calibration at $2.3\ \mu m > \lambda > 1\ \mu m$

Acronyms:
SRCA SpectroRadiometric Calibration Assembly
SiPD Silicon PhotoDiode

Summary of SRCA in Spectral Mode

- Prelaunch spectral calibration accuracy for MODIS is less than 0.5 nm for wavelength less than 2.3 μm.

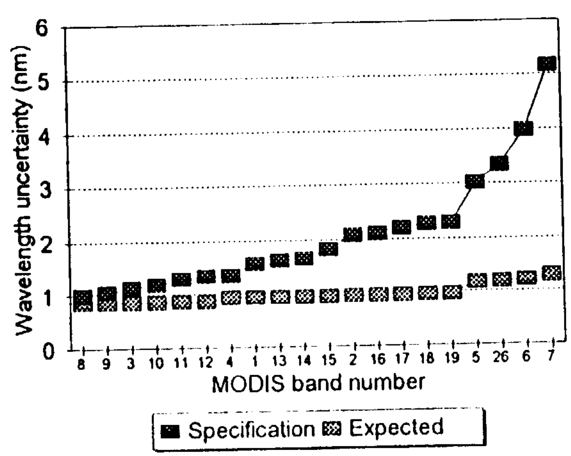
- Establish the center wavelength relationship between MODIS and the SRCA during ground testing.

$$\lambda_{c,\ MODIS}\ (b\#,ch\#) = K(b\#,ch\#) \bullet \lambda_c\ (b\#,ch\#)$$

- Specification requires that the spectral calibration accuracy on orbit is less than 1.0 nm for 0.412 μm and (λ / 0.412) nm for $0.412 < \lambda < 2.3$ μm.

- SRCA is a spectral self-calibrator using didymium glass.

- The on-orbit calibration accuracy is expected to meet the specification.



SRCA in Spectral Mode (Design)

1. **Objective:** Track on-orbit changes in the MODIS center wavelengths (for $\lambda < 2.3\mu m$) from prelaunch.

2. **Preflight requirement:** 0.5 nm ($\lambda < 1\mu m$) and 0.5 nm • λ/λ_0 ($\lambda > 1\mu m$), where $\lambda_0 = 1\mu m$.
   On-orbit: 1 nm • λ/λ_1, where $\lambda_1 = 0.412\mu m$. No requirement beyond $1\mu m$.

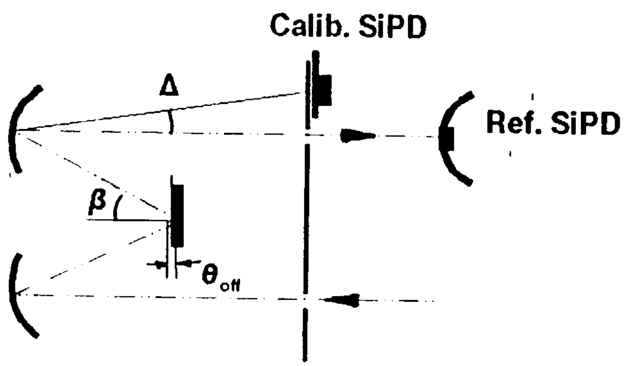
3. **Output:**
   (1) MODIS center wavelength shift, $\Delta\lambda_c$, is detected by SRCA.
   (2) $\lambda_{c,MODIS} = K \bullet (\lambda_{c,original} + \Delta\lambda_c)$

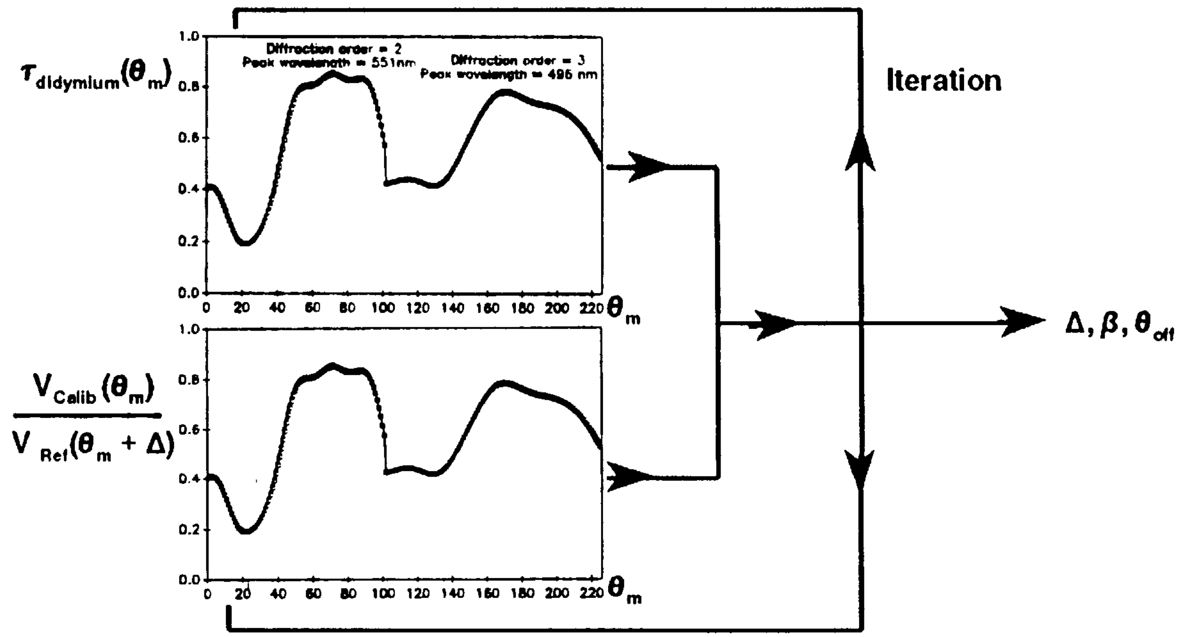
4. **Calibration frequency:** 100 times during A/E phase and once per month in operation (to be reviewed post A&E)

SRCA in Spectral Mode

- Three SRCA monochromator parameters, Δ, ß, and θ_{off}, need to be re-measured in space for wavelength self-calibration.

- Didymium peak positions and curve match to determine the three parameters.





- MODIS detector signal under SRCA Illumination is used to determine
  (1) Center wavelength shift, $\Delta\lambda_c$, for each MODIS band ($\lambda < 2.3\ \mu m$).
  (2) Center wavelength, λ_c, corrected for SRCA partial aperture illumination effect using prelaunch coefficient K.

SRCA in Spectral Mode (Error Sources)

The MODIS center wavelength error sources are listed below. The error is evaluated by averaging over the spectral range from 0.4 to 1.0 μm.

Error budget of spectral calibration by SRCA

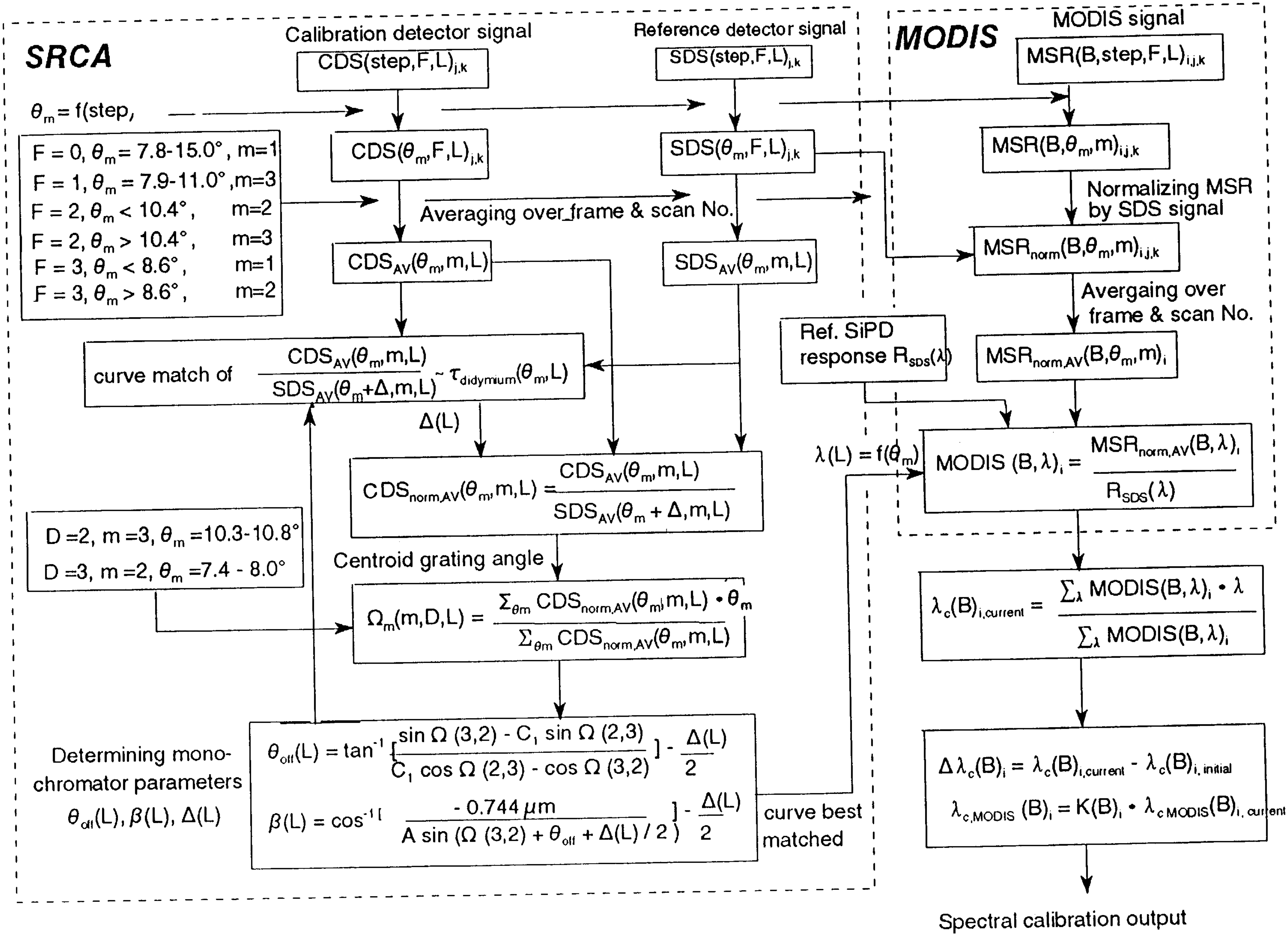
Item	Description of error sources	Wavelength uncertainty (nm)		
		m = 1	m = 2	m = 3
1	Motor angle repeatability & non-linearity for ±6" (1)	0.21	0.13	0.08
2	grating motor offset error of 6 ±0.006	0.60	0.45	0.30
3	half included angle error of 0.025 ±0.105	0.48	0.36	0.24
4	grating width error of 0.10nm in manufacturing (1)	0.06	0.05	0.04
5	grating width error due to temperature change of 10K	0.04	0.03	0.02
6	difference in responsivity of std. & calib. detectors by 2%	0.24	0.18	0.12

Note: (1) From SBRC.

Risk:

Grating motor fails or is worn out.

SRCA in spectral mode (calibration flowchart)



Nomenclature:

MSR -- MODIS detector signal
Step -- Grating step number
m -- Grating diffraction order
j -- Scan number
$\tau_{didymium}$ -- Didymium transmittance
Δ -- Angular displacement between main exit slit and didymium slit
C_1 -- a constant
$R_{SDS}(\lambda)$ -- Spectral response of the reference detector
$\Delta\lambda_c(B)_i$ -- wavelength shift for band B and channel i
$\lambda_{c,\,MODIS}(B)_i$ -- Center wavelength for MODIS band B and channel i

SDS - Reference detector signal
F -- Filter number
B -- MODIS band number
k -- Frame number
D -- Didymium peak number
λ -- Wavelength

CDS -- Calibration detector signal
L -- Lamp configuration
i -- Channel number
θ_m -- Grating motor rotating angle
β -- Half-included angle
θ_{off} -- Grating motor offset angle

ATBD for MODIS Level 1B Algorithm

SRCA in Spatial Mode

Nianzeng Che

11 OCT 94
Calibration Discipline Group Meeting

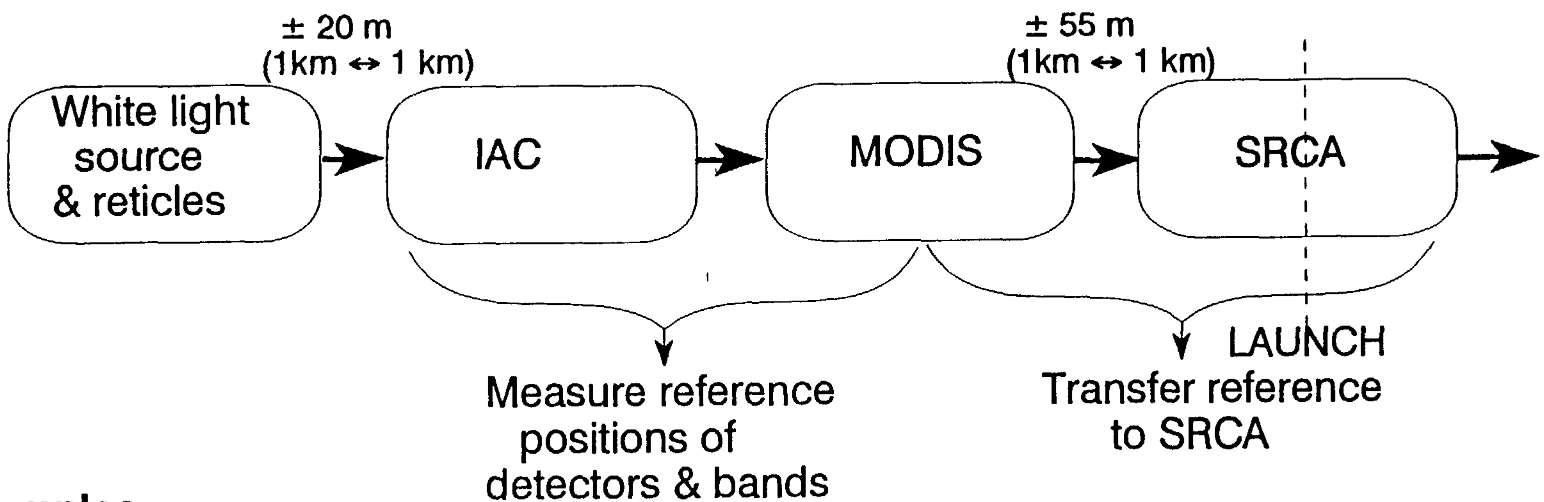
Spatial characterization - baseline
(SRCA in spatial mode - Nianzeng Che)

Products
- Level 1B :
  - None

Metadata:
- Detector offsets in scan direction
- Band offsets in track direction
- 1σ uncertainties, quality indices

Baseline process

IAC measurements of relative detector & band positions are transferred to the SRCA prelaunch
SRCA in orbit measures detector & band shifts relative to prelaunch IAC measurements



Data Table Examples
- -Prelaunch detector and band relative positions

Non-Baseline Options
- -Lunar data analysis

Acronyms:
- IAC Interface Alignment Collimator
- SRCA SpectroRadiometric Calibration Assembly

Summary of SRCA in spatial registration mode

- SDST provides geolocation of 10 nominal 1-km IFOV in a single band with location accuracy of

  At launch (1σ) 97m along-scan, 75 m along-track
  After A & E (1σ) 51m along-scan, 28 m along-track
- The relative position along-scan & track is measured prelaunch for all detectors (490 in 4 focal planes).
- On-orbit SRCA measures the relative position shifts along scan direction for each detector and the centroid shifts along track direction for each band.
- The shift uncertainty (m)

	1km - 1km	0.5km - 0.5km	0.25km - 0.25km	1km - 0.25km	1km - 0.5km
Prelaunch (1)	20	10	5	60	80
on-orbit	55	24	15	80	90

(1) SBRC, A-11323-151868

- Data can be combined to determine the geolocation of each pixel along-scan and each band along-track.
- The relative co-registration (m)

	1km - 1km	0.5km - 0.5km	0.25km - 0.25km	1km - 0.25km	1km - 0.5km
Specification	200	100	50	200	200
Goal	100	50	25	100	100

SRCA in spatial registration mode (Design)

1. Objective:

(1) Track the position shift of each MODIS detector along-scan and the centroid position shift of each band along-track.

(2) MODIS project may utilize along-scan shifts to adjust sampling phase to allow registration of the four focal planes along-scan.

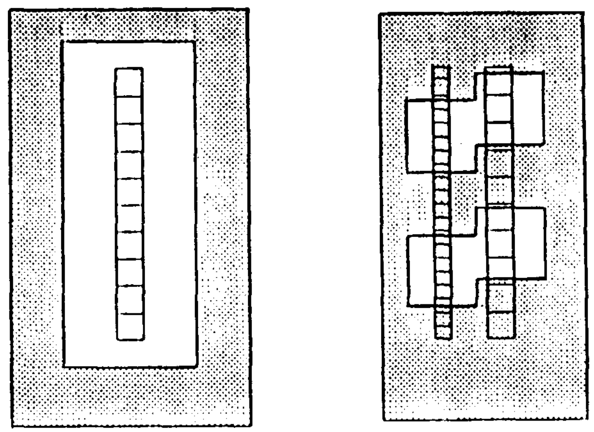
2. Output : position shift for each MODIS detector along-scan.
centroid position shift for each MODIS band along-track.

This information provides the data base for determining how well the detectors are registered focal plane-to-focal plane, band-to-band, and pixel-to-pixel (along-scan only).

3. Calibration frequency: 100 times during A/E phase and four times per year in operation (to be reviewed after A&E).

4. Spatial calibration procedure

The along-scan and along-track reticles are alternatively in position. The reticle image scans across the detectors when MODIS scan mirror is rotating. MODIS detector sampling takes samples over frames in different phase delay setting. Processing the entire sampled signal collected by MODIS detectors provides the data base for spatial calibration of each detector (along-scan). The calibration in along-track quantifies only the centroid position change for each MODIS band.



a. Along-scan reticle b. Along-track reticle
Fig. 6.1 Reticle patterns

SRCA in spatial registration mode (Algorithms)

1. Spatial center value for each MODIS detector in along-scan direction

$$<X>_{b,ch} = \frac{\sum_x CARFS_{b,ch}(X)\ X_{b,ch}}{\sum_x CARFS_{b,ch}(X)}$$

where

$$CARFS_{b,ch}(X) = \frac{\sum MSR_{b,ch}(sc,df,pds,t)}{Number\ of\ scan}$$

where X = [pds + N_{PDS1} · (df - 1)] · pdl.

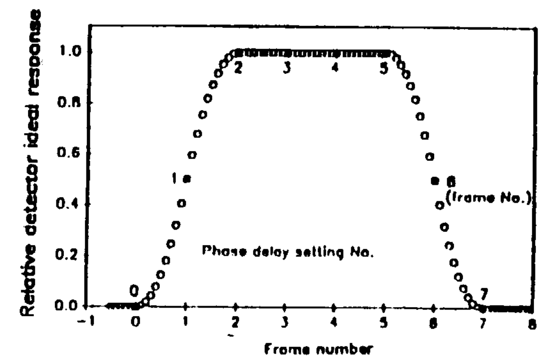
2. Spatial centroid value for each MODIS band in along-track direction

$$<Y>_{b} = \frac{\sum_{Y_{ch}} \sum_x CARFT_{b,ch}(X)\ Y_{b,ch}}{\sum_x CARFT_{b,ch}(X)}$$

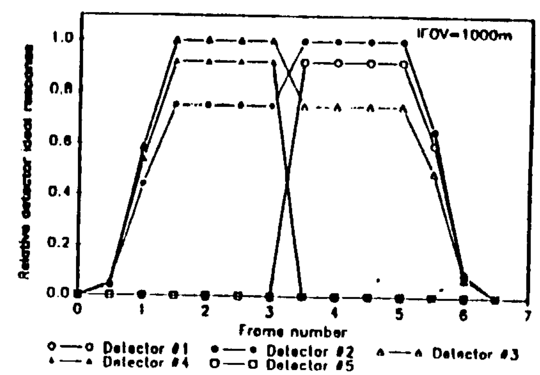
$$CARFT_{b,ch}(X) = \frac{\sum MSR_{b,ch}(sc,df,pds,t)}{Number\ of\ scan}$$

where X = [pds + N_{PDS2} · (df - 1)] · pdl

CARFS = Combined Aperture Response Function (along-scan)
CARFT = combined Aperture Response Function (along-track)
b = MODIS band number MSR = MODIS spatial response (digital counts)
ch = Channel number df = Data frame number sc = Scan number
pds = Phase delay setting number pdl = Phase delay step length
N_{PDS} = Number of phase delay setting t = Date & time Y = Ordinate value of MODIS detector center



a. Along-scan



b. Along-track

Fig. 6.2 Combined Aperture Response Function

SRCA in spatial registration mode (Error estimation)

<u>Requirement: < 0.2 IFOV (goal 0.1 IFOV)</u>

Table 1. Error budget of spatial calibration in along-scan direction (in IFOV unit)
(Detector-based calibration)

Item	Description of error sources	Band 1-2 (250m)	Band 3-7 (500m)	Band 8-36 (1000m)
Crosstalk (1)	Asymmetric response along cross-track direction	0.006	0.012	0.024
Phase-delay	± 0.01 IFOV unit	0.006	0.006	0.006
Noise	1 / SNR / √ sample No.	negligible		
Radiance output	0.08% variation & 0.07% draft max.	negligible		
Partial aperture filling	Transmittance reduction by 0.4% at both ends	0.009	0.008	0.007
Non-uniform slit illumination	3% reduction at both of slit ends, shift 2 1000m-IFOV in orbit	negligible		
Slit inclination (2)	Max 0.05° along-slit direction and displacement of 0.0125 for 1km IFOV	0.045	0.022	0.011
	Summary	0.047	0.027	0.028

Note: The actual error values should be revised according to the measurement.

(1) The following electronic integrator response is assumed:

left side: (sin (1 / size * 0.2 π * (x + size / 8))) ^ 2

right side: (sin (1 / size * 0.2 π * (x + size / 8))) ^ 2.2

where size = 4, 2, 1 for 250m, 500m, 1000m IFOV, respectively.

(2) This item may be partially corrected in signal processing.

SRCA in spatial registration mode (Error estimation (cont'd))

Requirement: 0.2 IFOV (goal 0.1 IFOV)

Table 2. Error budget of spatial calibration in along-track direction (IFOV unit)
(Centroid-value-based calibration for MODIS bands)

Item	Description of error sources	Band 1-2 (250m)	Band 3-7 (500m)	Band 8-36 (1000m)
Phase-delay	± 0.01 IFOV unit	negligible		
Noise	1 / SNR / √ sample No.	negligible		
Radiance output	0.08% variation & 0.07% draft max.	negligible		
Non-uniform slit illumination	3% reduction at both of slit ends, shift 2 1000m-IFOV in orbit	0.010	0.010	0.009
reticle image motion	displacement of 0.0125 for 1km IFOV and inclination of 0.05° in cross-track direction	0.001		
	displacement of 0.0125 for 1km IFOV and inclination of 0.05° in along-track direction	0.022	0.033	0.044
Spurious crosstalk	reduction by 0.01 IFOV unit at reticle edge	0.011	0.015	0.023
out-of-focus	0.05 mm	0.026	0.013	0.005
	Summary	0.037	0.040	0.051

Note: The actual error values should be revised according to the measurement.

The calculation is based on the assumption that the minimum phase-delay is one. The error will be significantly increased with no phase-delay.

3.3.6.4 Risk

Signal saturation may occurs for MODIS Band 24 & 25.