MCST Report

22
Barker

to the MODIS Science Team
by the MODIS Characterization Support Team (MCST)

MODIS
GSFC SBRC

MODerate **I**maging **S**pectroradiometer

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• Ken Brown • Joann Harnden • Brian Markham • Harry Montgomery • Steve Ungar

<u>Contributions</u>

•Paul Anuta - *Spectral Simulation* • Joan Baden - *Editor* • Tom Bryant - *Instrument Monitoring* • Jon Burelbach - *Image Processing* • Dan Knowles Jr. - *Database Development* • Ed Knight - *Instrument Engineer* • Geir Kvaran - *Algorithm Development* • Al McKay - *Technical Writing* • Jon Smid - *Sensitivity Studies* • Nicole White - *Editing*

30 September 1993
1100

Goddard Space Flight Center (GSFC), Greenbelt, MD, 20771
Building 8, 2nd Floor Auditorium

Outline

MODIS Level-1 Characterization and Calibration Algorithm

MODIS Instrument Characterization and Calibration

MODIS System Performance Simulation

Level-1
Characterization and Calibration Algorithm

Joann Harnden
Harry Montgomery

<u>Contributions</u>

- Paul Anuta - *Spectral Simulation*
- Joan Baden - *Editor*
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- Al McKay - *Technical Writing*
- Jon Smid - *Masking Development*
- Nicole White - *Editing*

MODIS Calibration Strategy

- **Use Alternative MODIS Calibration Methodologies**

  Several alternative calibration methodologies will be implemented throughout 15-year mission to provide a robust unique "official" calibration algorithm and to allow for its validation by independent methods

- **Characterize Precision on a Time-Scale of Months**

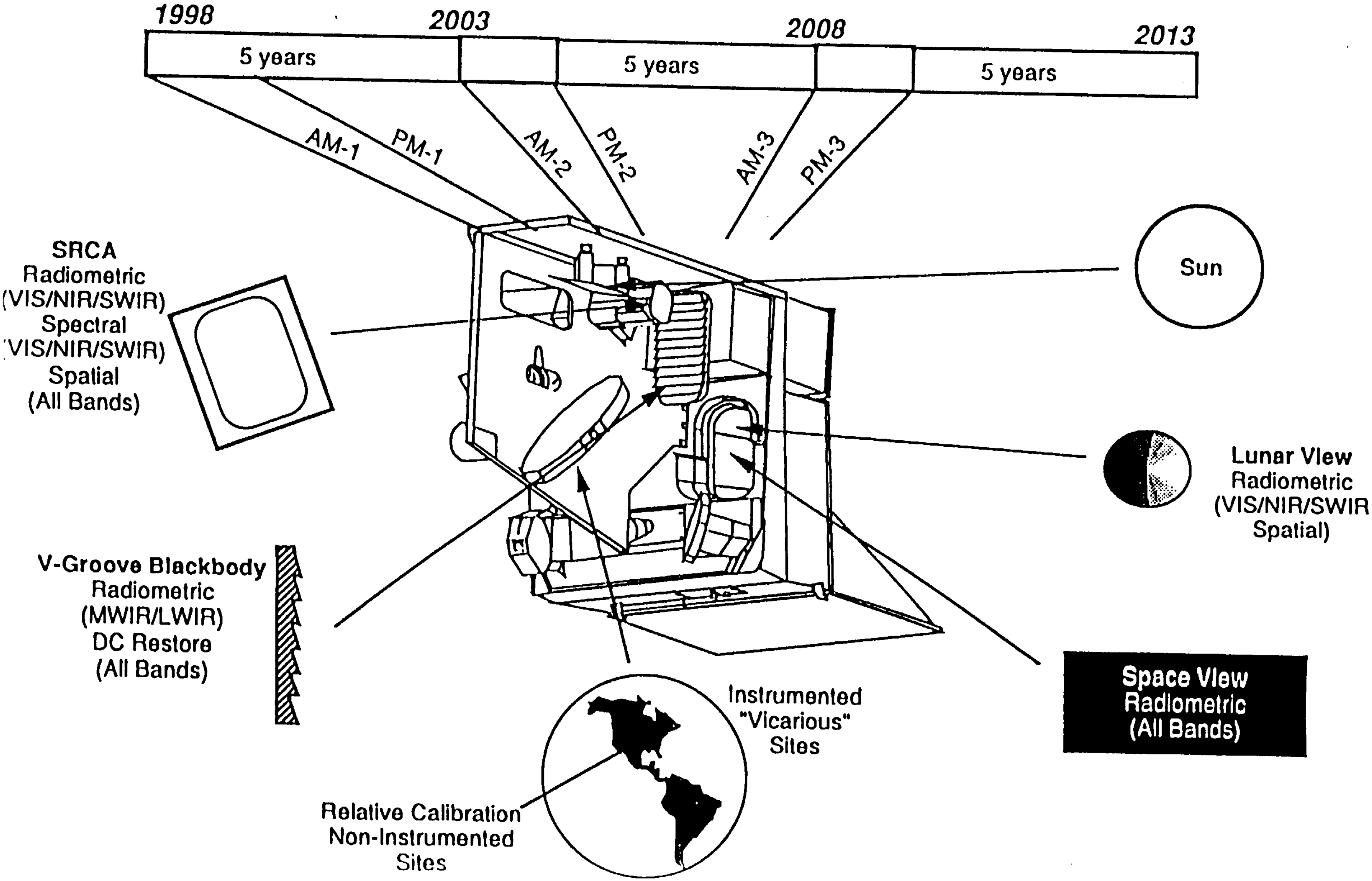
  Post-launch quantitative characterization and monitoring of the precision (repeatability) with which MODIS at-satellite radiances are measured by various methods will occur within 2 to 6 months

- **Characterize Accuracy on a Time-Scale of Years**

  Post-launch quantitative characterization and monitoring of the accuracy with which MODIS at-satellite radiances are measured by various methods and on two in-orbit instruments will occur within 3 to 5 years

EOS MODIS MISSION ELEMENTS

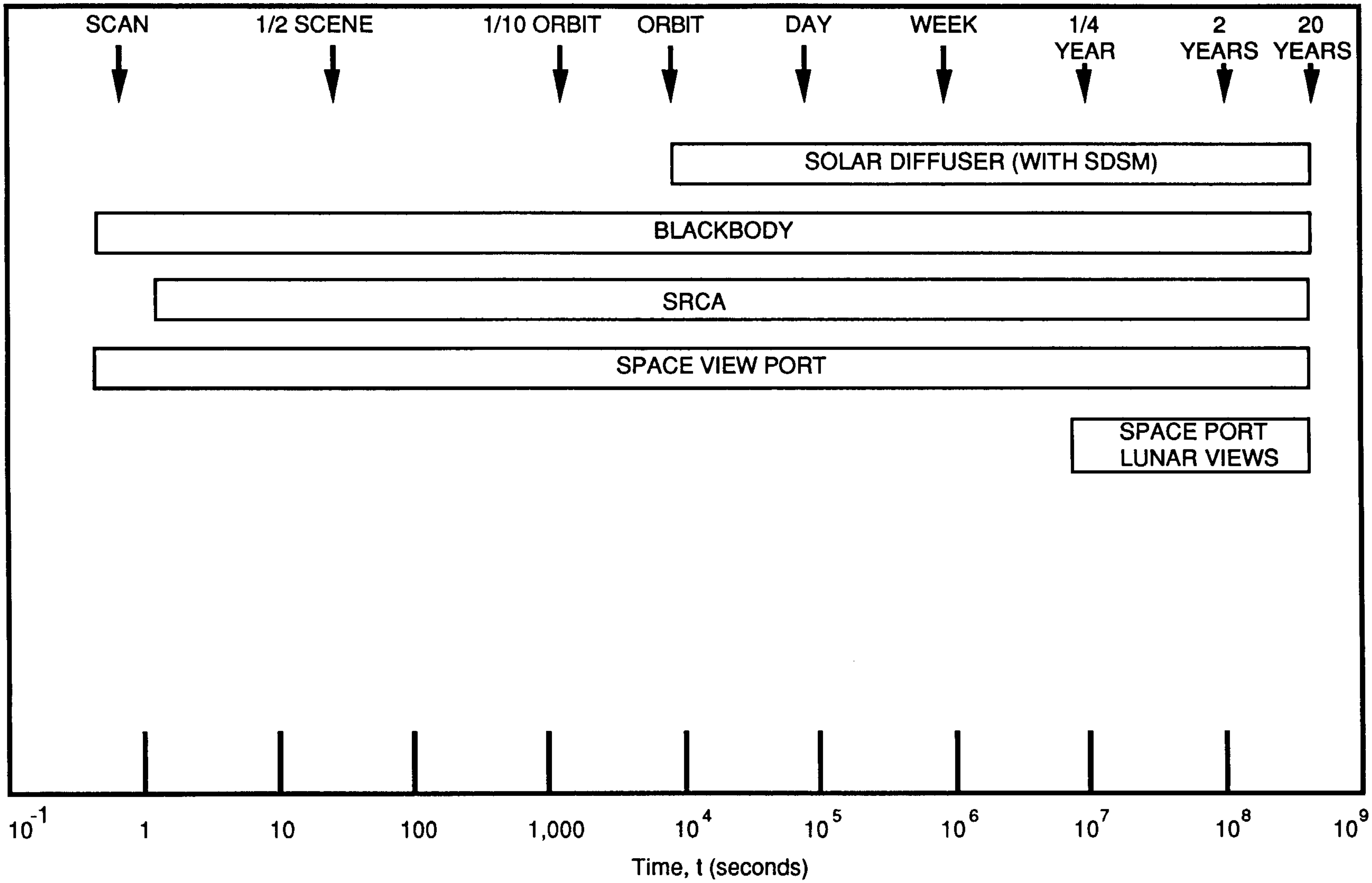
6 INSTRUMENTS
15 YEAR MISSION
6 CALIBRATION SOURCES



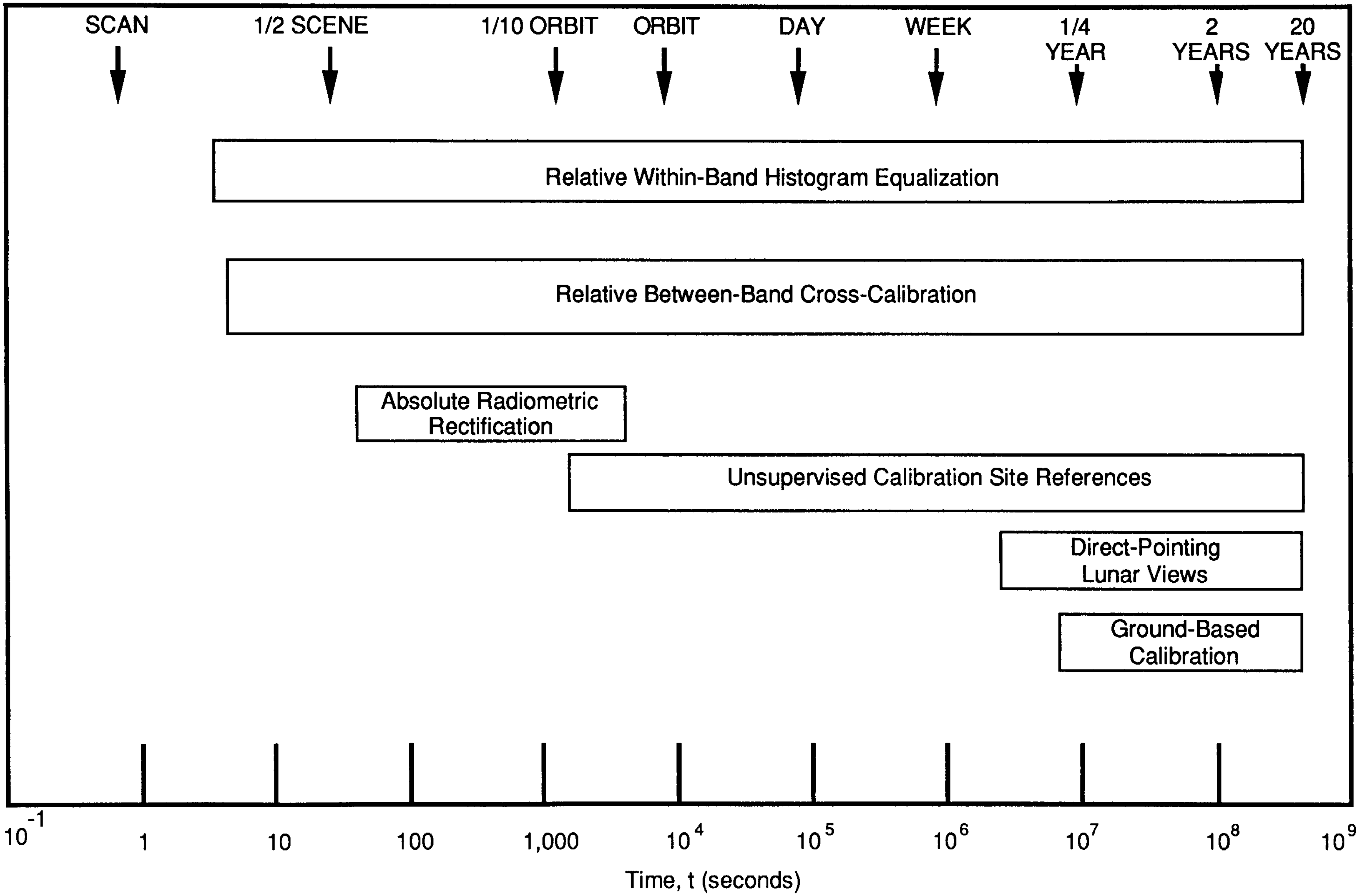
Time-Dependent Radiometric Calibration of the Reflective Bands

Time Scale	Calibration Technique	Availability
Within a Scan Line	Scene-dependent MTF inversion	Post-Launch
Within a Scan	Bias Offset measurements	At-Launch
	Blackbody as DC-restore	
	Space view	
	Relative cross-correlation of detectors both within and between bands	At-Launch
Within a Half Orbit	Radiometric rectification over known radiometrically homogeneous sites	Post-Launch
Between Orbits	SRCA in Radiometric mode	At-Launch
Between Days	Solar Diffuser	At-Launch
Between Months	Lunar Pointing	At-Launch
	Vicarious Measurement Methods aircraft and ground-based	Post-Launch
Between Years	Lunar Views	At-Launch
	Radiometric Math Model	Post-Launch

Time Domains for MODIS On-Board Calibration Methodologies

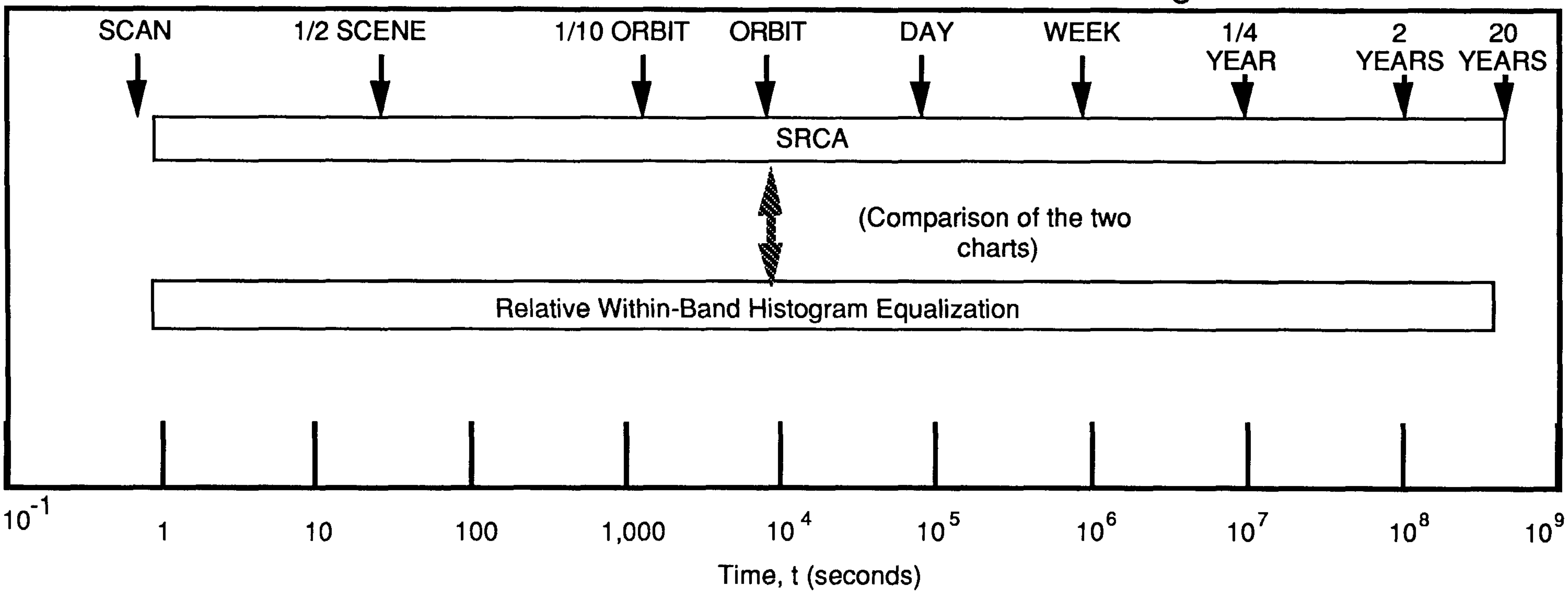


Time Domains for MODIS Image-Derived Calibration Methodologies



Example of Potentially Redundant Calibration

Time Domains for MODIS Calibration Methodologies



MODIS Level-1 Geolocation, Characterization and Calibration Algorithm Theoretical Basis Document (Cal ATBD)

Version 0 Preliminary DRAFT	June 30, 1993
Version 1 DRAFT	July 31, 1993
Version 1	September 7, 1993

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MODIS Cal ATBD

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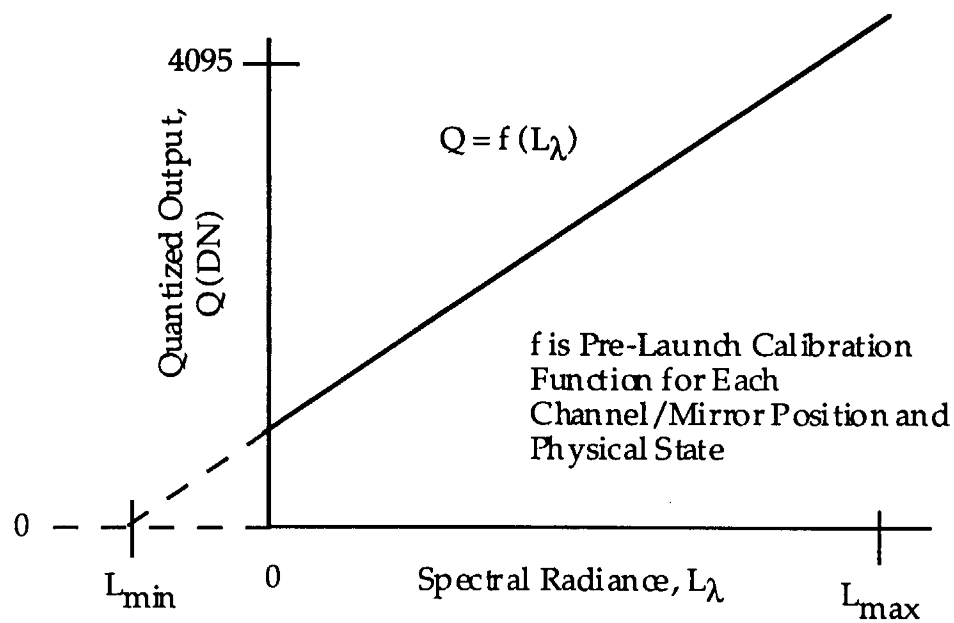
Pre-Launch SBRC Absolute Calibration of MODIS Channels

- Pre-launch calibration data relates 12-Bit counts to input spectral radiance for all MODIS channels.
- There will be at least two sets of 470 functions, one for each side of the scan mirror.
- LMax is the spectral radiance producing full scale output (4095 DN).
- LMin will be negative due to the intentional offset at zero radiance.

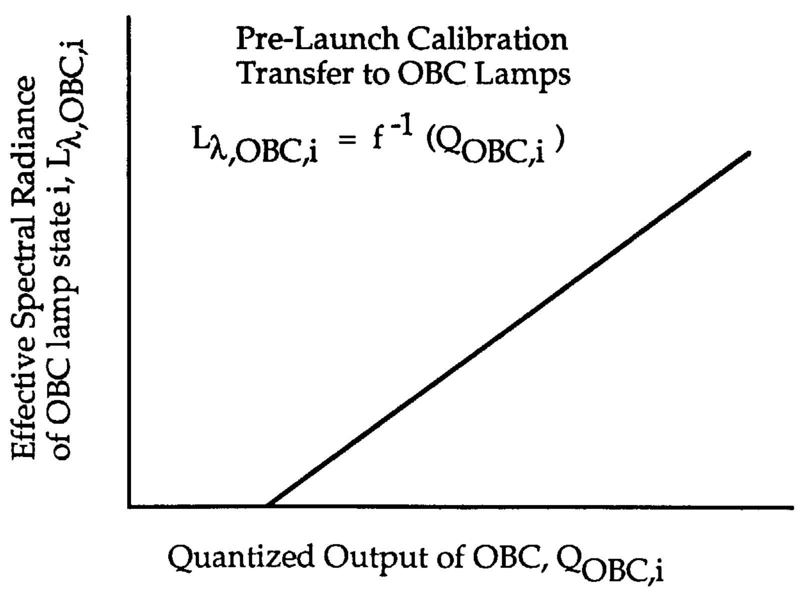


MODIS Channel to OBC Transfer & On-Orbit Use of OBC

• Pre-Launch Calibrattion produces a set of Quantized Output for each lamp state, $Q_{OBC,i}$, and a corresponding effective spectral radiance, $L_{\lambda,OBC,i}$ which is obtained from the inverse of the MODIS Calibration Function, f^{-1}.

• On-Orbit Observations of the SRCA at different lamp states produce current values of Q which are compared to pre-launch values.

• The pre-launch/post-launch count pair or the predicted/current pair for each lamp state become the basic input to the Calibration Algorithm.



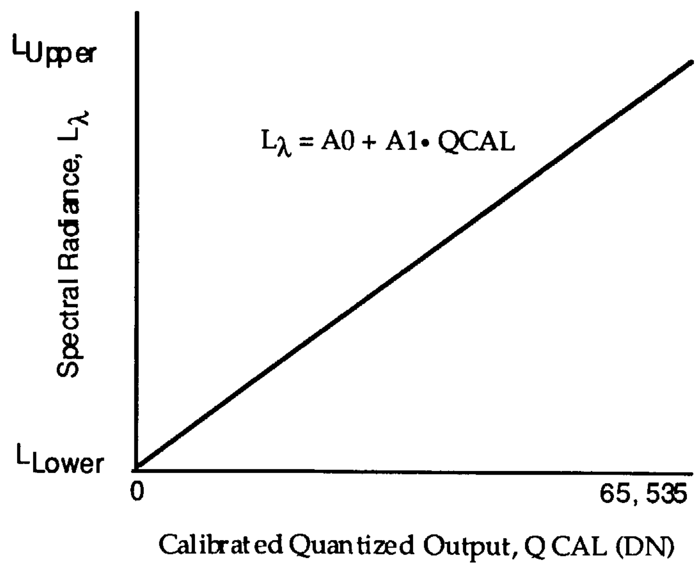
15-Year MODIS Calibration Strategy

• The overall calibration objective is to produce a 15 year MODIS data set which maintains a fixed relationship between "calibrated" Digital Values, QCAL, and At-Aperture Spectral Radiance L_λ, for all MODIS Instruments.

• A Single, Linear Relationship will be maintained between L_λ and QCAL for all channels within each band.

• The dynamic range of QCAL for all Bands will be 0 to 65, 535 (2^{16}-1).

• The Post-Calibration Dynamic Range of L_λ for each Band will be specified by 2 values, L_{Lower}, and L_{Upper}.



MODIS Level-1 Data Products*

Level-1A Data (MOD01)

- Each Pixel Geolocated
- Calibration Coefficients Included as Ancillary Data

Level-1B Calibrated Data (MOD02)

- Each Pixel Geolocated
- Radiometric Dynamic Range of 1 to 65,535 Represents Spectral Radiance Range of L_{Lower} to L_{Upper} for each Band

Level-1B Utility Masks (MOD18)

- 1-Bit Binary Masks
- 3-Bit Fractional Masks

*Metadata for all Products

- Quality Assurance Data for Each Pixel
- Processing Applied to Each Band

MODIS Level-1 Core Algorithm Flow

Level-0 Data

Unpack & Geolocate Image Pixels

Level-1A Data & Metadata (MOD01)

Use Instrument-Based Techniques to Calculate Calibration Coefficients for Comparison to Trended Data

Generate Utility Masks

Initial Build

Subsequent Builds

Image-Derived Characterization

Use Image-Based Techniques If and When Developed & Accepted

Generate QA Metadata

Vicarious Data

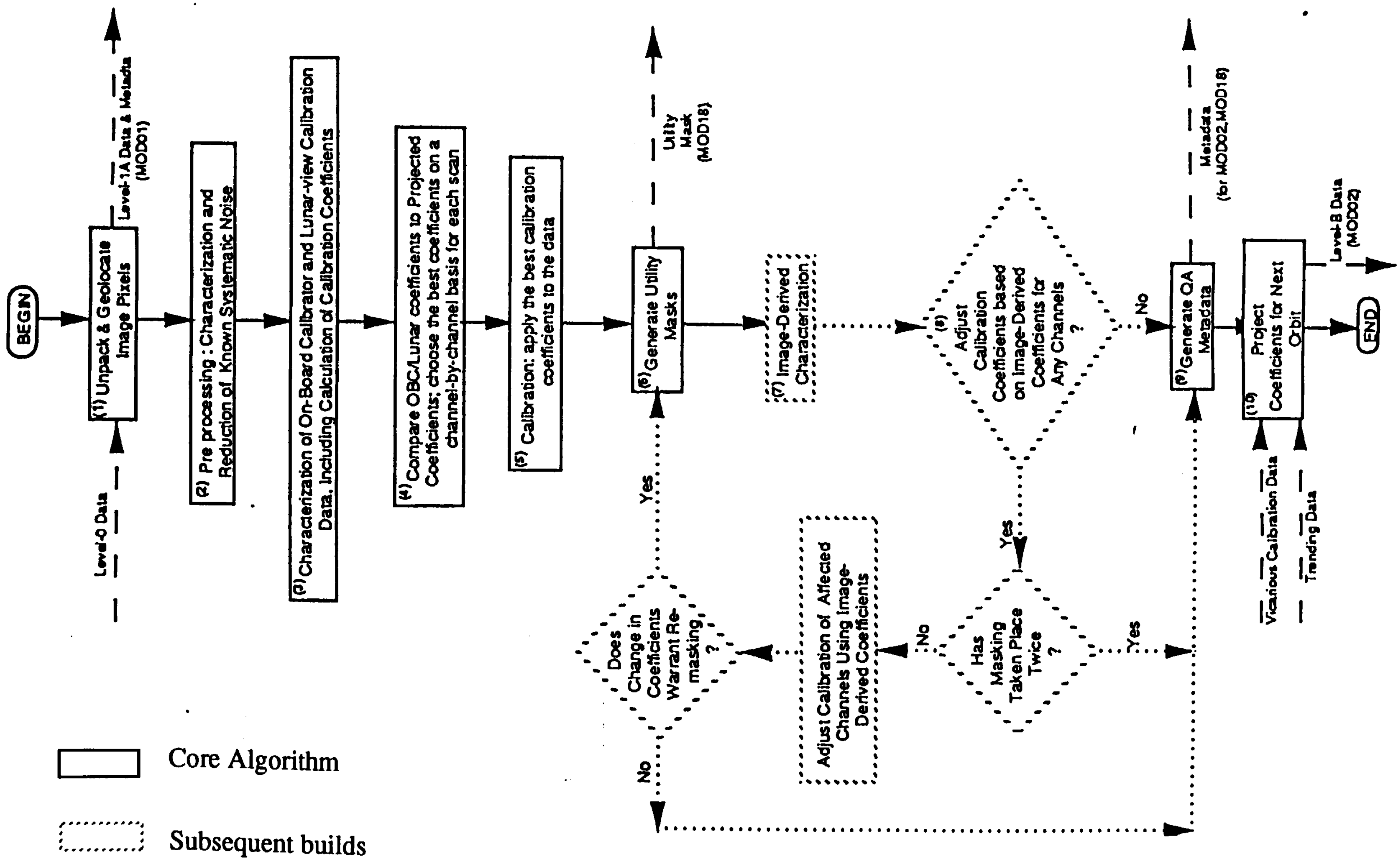
Project Coefficients for Next Orbit

Level-1B Data (MOD02)

Metadata MOD02 & MOD18

OVERVIEW: Level-1 Processing Flow

(From MODIS L-1 Geolocation, Characterization and Calibration Algorithm Theoretical Basis Document; Version 1; 9/7/93)



MODIS Utility Mask Product

- One of the standard MODIS Level-1B (MOD18) products will be a generic set of masks for all bands. It will be developed by MCST in collaboration with members of the MODIS science team.

- There will be three 64-bit Level-1B images, one for each of the different 250, 500 and 1000 m MODIS spatial resolutions.

- The bits in these images are each masks which will contain either binary or fractional information on each pixel. Binary masks will be for a "definite" presence or absence of an instrument state or target condition.

- There may be different discipline-dependent masks for some of these classes, e.g., cloud masks.

- There will be different algorithms for daytime and nighttime imagery.

- The MOD18 Product will be available for all MODIS datasets.

Three 8-Byte MODIS Level-1B Utility Masks

for 250, 500 and 1000 m Bands
of Instrument Channel, Data, and Scene Usefulness

Illustrative 1-bit Binary Level-1 Pixel Masks

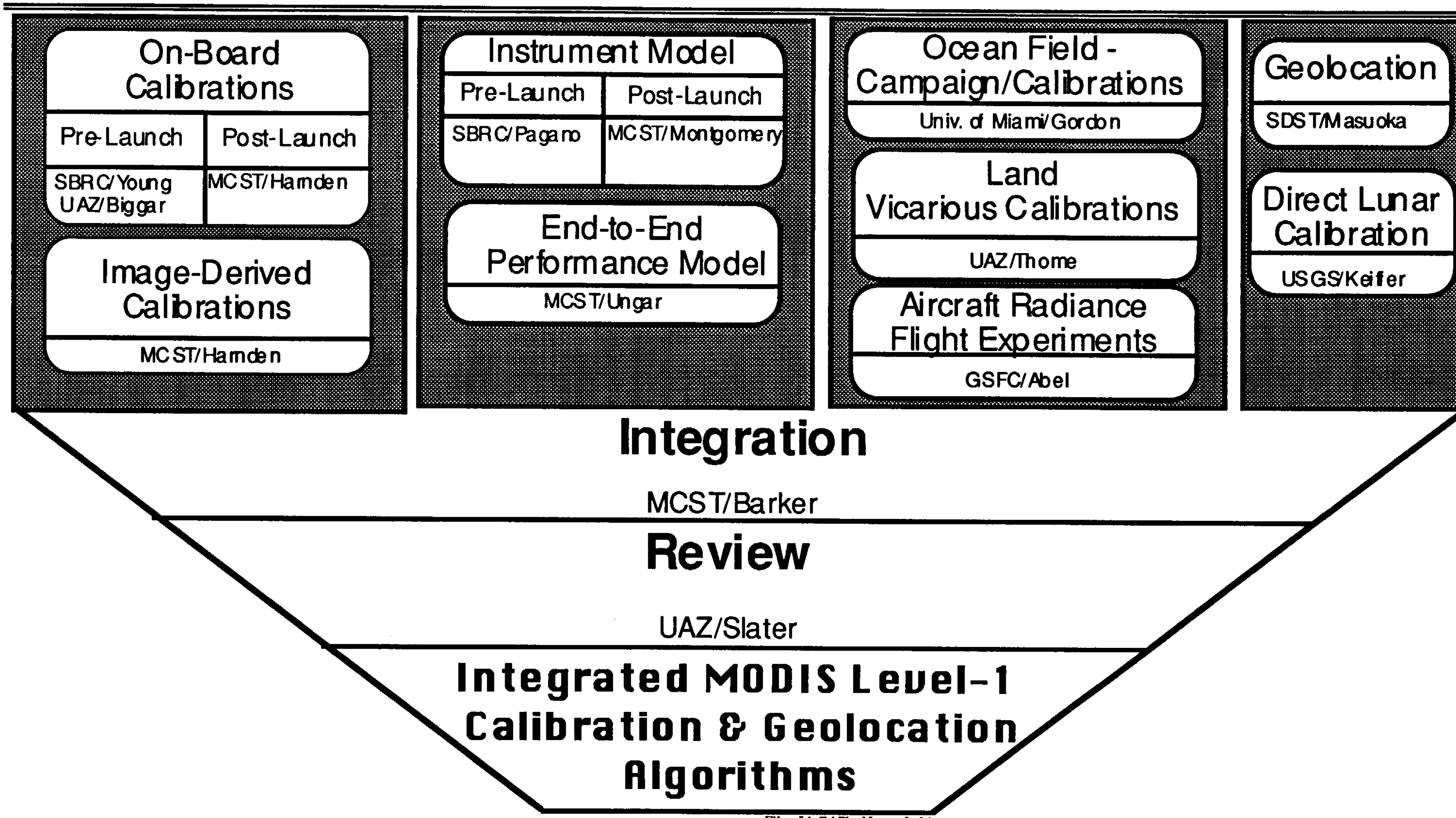
- Replaced Dead Channels*
- Overlapped with Adjacent Scan
- Opaque Clouds
- Calculated Cloud Shadow
- Spatially Homogeneous Pixels
- Land
- Calculated Potential Glint
- Unreplaced Noisy Channels*
- No Overlapped Ground Pixels
- Transparent Clouds
- Radiometric Outlier
- Mixed Pixel (Mixels)
- Water
- Actual Observed Glint

Illustrative 3-bit Fractional Level-1B Pixel Masks

- Pixel Area on Ground
- Opaque Cloud Fraction
- Water Fraction
- Snow/Ice Fraction
- Solar Irradiance at Top of Atmosphere
- Modular Transfer Function (MTF) Significance on Radiometry
- Size of Corrected (or Uncorrected) Systematic Errors

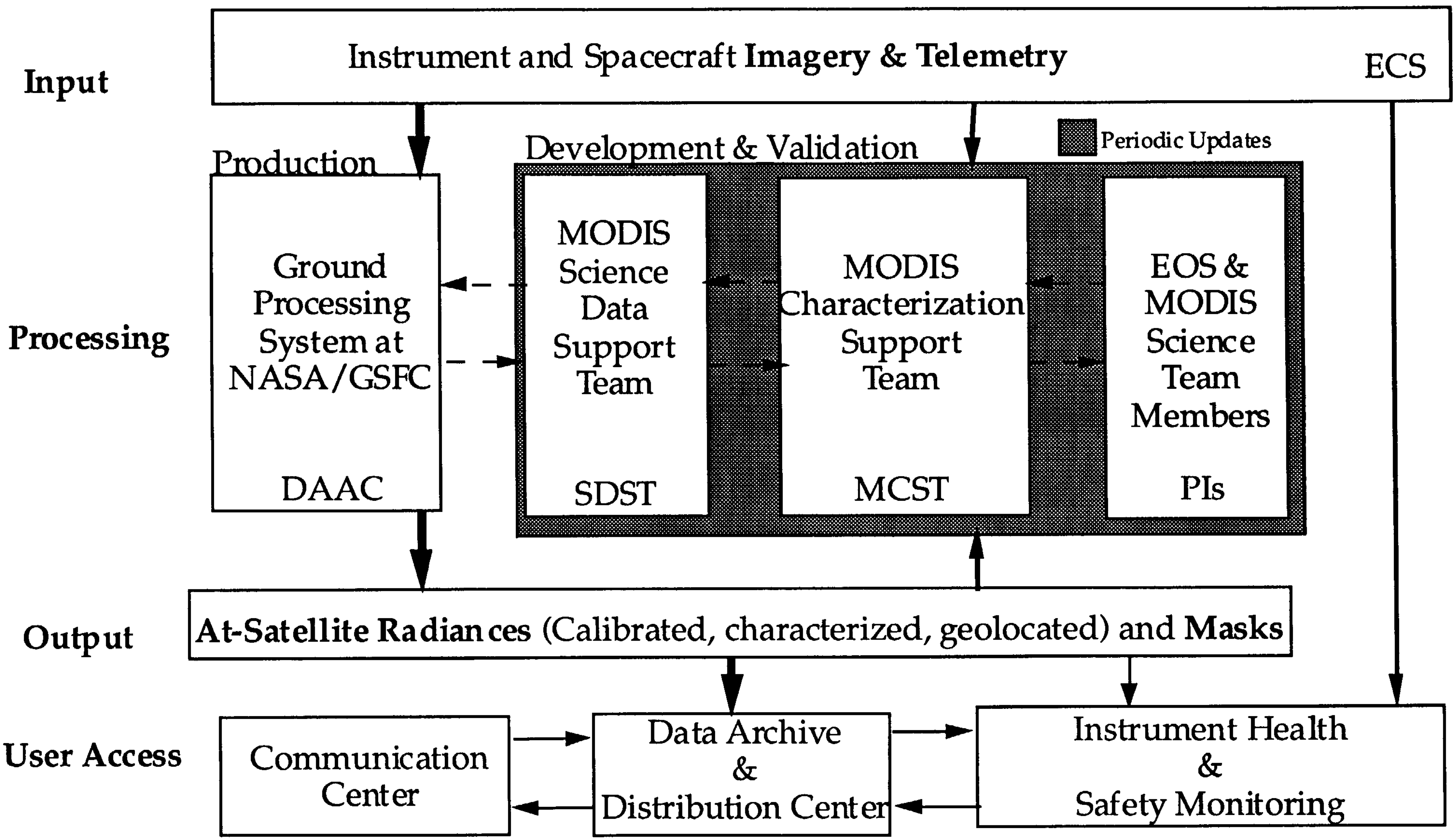
*Specific Channels identified in metadata files.

MODIS
Characterization & Calibration Data Sources



File: L1 CalPlanNames 2.61

MODIS Level-1 Product Flow



MODIS Instrument Characterization & Calibration

Harry Montgomery
Ken Brown

<u>Contributions</u>

- Joan Baden - *Editor*
- Tom Bryant - *Instrument Monitoring*
- Ed Knight - *Instrument Characterization*
- Dan Knowles Jr. - *Database Development*
- Nicole White - *Editing*

MODIS Instrument Calibration Requirements

Parameter	Requirement (Goal)	Predicted Pre-Launch	Predicted On-Orbit
Radiometric Calibration *	**%(+/-1σ)**		
Below 3000nm (Reflective)	5.0	4.0	
Above 3000nm (Emissive)	1.0		
Except 20,	0.75(0.50)		
31 & 32, and	0.50(0.25)		
31 High & 32 High	10		
Reflectance (Relative to the Sun)	2.0	4.0	2.0
Spectral Band-to-Band Stability			
Full Scale	0.5		
Half Scale	1.0		
Spectral Characterization	**nm**		
Center Wavelength			
Pre-Launch	0.5		
On-Orbit	1.0		
Geometric Characterization	**IFOV(+/-3σ)**		
Band-to-Band Registration			
Required	0.2 (0.1)	0.1	0.15

*Radiometric Accuracy is at specified typical radiance and can be 1% larger from 0.3 L_{typ} to 0.9 L_{Max} based on multiple samples of uniform, extended, non-polarized sources.

MODIS Stability Specification

Short-Term Radiometric Stability

(dt <= 2 weeks, corrected on the ground, including orbital perturbations)

Reflective Bands	+/- 1% (+/- 0.5% goal)
Emissive Bands	+/- 0.5%

Long-Term Radiometric Stability

(2 weeks <= dt <= 5 years, corrected on the ground, including orbital perturbations)

Below 3000 nm	+/- 2%
Above 3000 nm	+/- 1%

Spectral Band-to-Band Stability

(dt <= 2 weeks, corrected on the ground, including orbital perturbations)

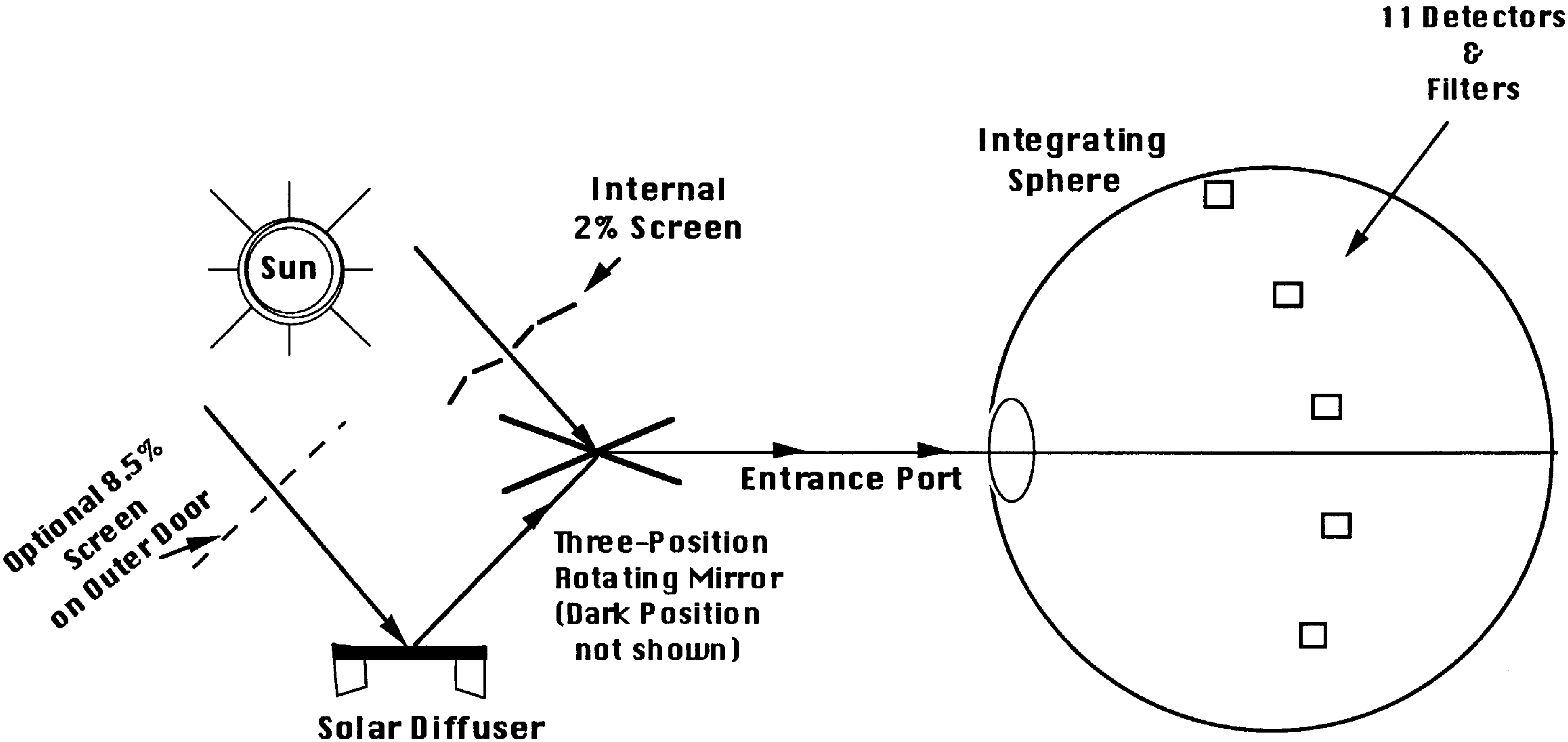
+/- 0.5% (at full scale)

Wavelength Stability

(dt <= 5 years, corrected on the ground, including orbital perturbations)

VIS Bands	+/- 2nm
Other Bands	+/- 1%

MODIS Solar Diffuser Stability Monitor (SDSM)



Use SDSM and SD Data to Create (L_λ, Q) Calibration Point

SDSM Calculations for Stability of SD:

$$Q_{SD}(\lambda,t) = R'(\lambda)\, K' K(\theta)'\, f(\lambda,\theta,\phi,\theta',\phi',t) \cos\theta\, S(\lambda)$$

$$Q_S(\lambda,t) = R'(\lambda)\, K(\lambda)\, S(\lambda)\, K(\theta)$$

$$K(\lambda) = \frac{Q_s(\lambda,t_0)\, f(\lambda,\theta,\phi,\theta',\phi',t_0)\, K' K'(\theta) \cos\theta}{Q_{SD}(\lambda,t_0)\, K(\theta)}$$

$$f(\lambda,\theta,\phi,\theta',\phi',t_1) = \frac{K(\lambda)\, Q_{SD}(\lambda,t_1)\, K(\theta)}{Q_S(\lambda,t_1)\, K' K'(\theta) \cos\theta}$$

$$C(\lambda,t_1) = \frac{f(\lambda,\theta_1,\phi_1,\theta_1',\phi_1',t_1)}{f(\lambda,\theta_1,\phi_1,\theta_1',\phi_1',t_0)}$$

$$\langle C(\lambda,t_1)\rangle = 1/N \sum_{i=1}^{N} C_i(\lambda,t_1)$$

Solar Diffuser Calculations:

$$L(\lambda) = \langle C(\lambda,t_1)\rangle f(\lambda,\theta_1,\phi_1,\theta_2',\phi_2',t_0) S(\lambda)$$

$$\langle L(\lambda)\rangle = 1/N \sum_{i=1}^{N} L_i(\lambda)$$

L_λ for Solar Diffuser

t_0, t_1	= Time Before, After Launch
N	= Number of Data Points
Q_{SD}	= Solar Diffuser Counts from SDSM minus offset
Q_S	= Sun Counts from SDSM minus offset
$R'(\lambda)$	= Spectral Responsivity of SDSM
offset	= offset from dark position of SDSM
$f(\lambda,\theta,\phi,\theta',\phi',t)$	= BRDF of Solar Diffuser
$S(\lambda)$	= Solar Spectral Irradiance
$K(\lambda)$	= Attenuation of SDSM sun-screen
K'	= 1 for no solar diffuser screen = 0.085 for solar diffuser screen
$K(\theta)'$	= obliquity factor for solar diffuser screen
$K(\theta)$	= obliquity factor for SDSM solar screen
$C(\lambda,t_1)$	= Degradation of SD panel
$\langle C(\lambda,t_1)\rangle$	= Average Degradation Value
$L(\lambda)$	= Spectral Radiance
$\langle L(\lambda)\rangle$	= Average Spectral Radiance

Calculate the MODIS SD Data

For all detectors for which the current solar diffuser mode will provide values within those detectors' dynamic ranges.

$$\langle Q\rangle = 1/N \sum_{i=1}^{N} Q_i$$

Q from Solar Diffuser

$\langle Q\rangle$	= Average Solar Diffuser Value for MODIS
N	= Number of Solar Diffuser Values for MODIS
Q_i	= i^{th} Solar Diffuser Values for MODIS

On-Orbit SRCA Acquisitions

- 4 of 10 SRCA Frames per Scan
- ~800 Scans per Orbit
  (Assuming 20% Duty Cycle)
- One Lamp State at a Time

	TIME (min)	BAND
Radiometric Calibration	17	Reflective
Spectral Characterization (Center Wavelength)	75	Reflective
Spatial Registration*	37	ALL

*Both Along Scan and Along Track

SBRC
Documentation Tracking by MCST

- SBRC Deliverables Database

  Software: EXCEL

- SBRC Deliverables Library

  Location: Bldg 22, Rm 354, GSFC, Greenbelt, MD

Contact: Dan Knowles Jr. 301-286-1378 for more information.

MODIS System Performance Simulation

Stephen Ungar
Brian Markham

Contributions

- Paul Anuta - *Spectral Simulation*
- Joan Baden - *Editor*
- Jon Burelbach - *Image Processing*
- Ed Knight - *Instrument Engineer*
- Jon Smid - *Sensitivity Studies*
- Nicole White - *Editing*

MODIS System Performance Simulation Task

Objective

- Provide for spectral, spatial, and temporal simulation of MODIS Imagery End-to-End Performance for developing and testing Level-1 Calibration/Masking Algorithm and Performing Product to Instrument Calibration Sensitivity Studies.

Approach

- Obtain, maintain, and enhance SBRC MODIS Radiometric Math Model

- Provide for Simulation of MODIS Imagery From TM Imagery, including retention of TM reference composition in each MODIS pixel for evaluation of algorithm effectiveness.

- Use PRA (Photon Research Associates) GCI (Global Change Toolkit) Toolkit as user-friendly software shell to allow insertion of user developed Models of Atmosphere, Target and Instrument Characteristics, including synthetic scenes.

MODIS Scientific Calibration-Related Requirements

Radiometric Requirements

for Solar Reflective Bands (#1-19, 26)

Scientific Discipline Requirements	At-Satellite Radiance used in Identification of Scientific Products		Signal Accuracy Required to Support 5-10% (±1σ) Modeling of Scientific Products		Instrument Precision Required for 2X Verification of Signal Accuracy		Monitoring Precision Required for 2X Verification of Instrument Precision	
	min (%)	max (%)	min (%)	max (%)	min (%)	max (%)	min (%)	max (%)
Radiance								
• Atmosphere-Leaving	10	100	0.5	10	0.2	5	0.1	2
• Land-Leaving	50	90	2.0	10	1.0	5	0.5	2
• Water-Leaving	10	50	0.5	5	0.2	2	0.1	1
Net Radiance (Signal)								
• Atmospheric	1	100	0.05	10	0.02	5	0.01	2
Components	5	20	0.20	2	0.10	1	0.05	0.5
• Reflections by Land Class	1	5	0.05	0.5	0.02	0.2	0.01	0.1
• Oceanic Components								

Conclusion: The Ocean Group has the highest Radiometric Requirement.

MODIS Scientific Calibration-Related Requirements

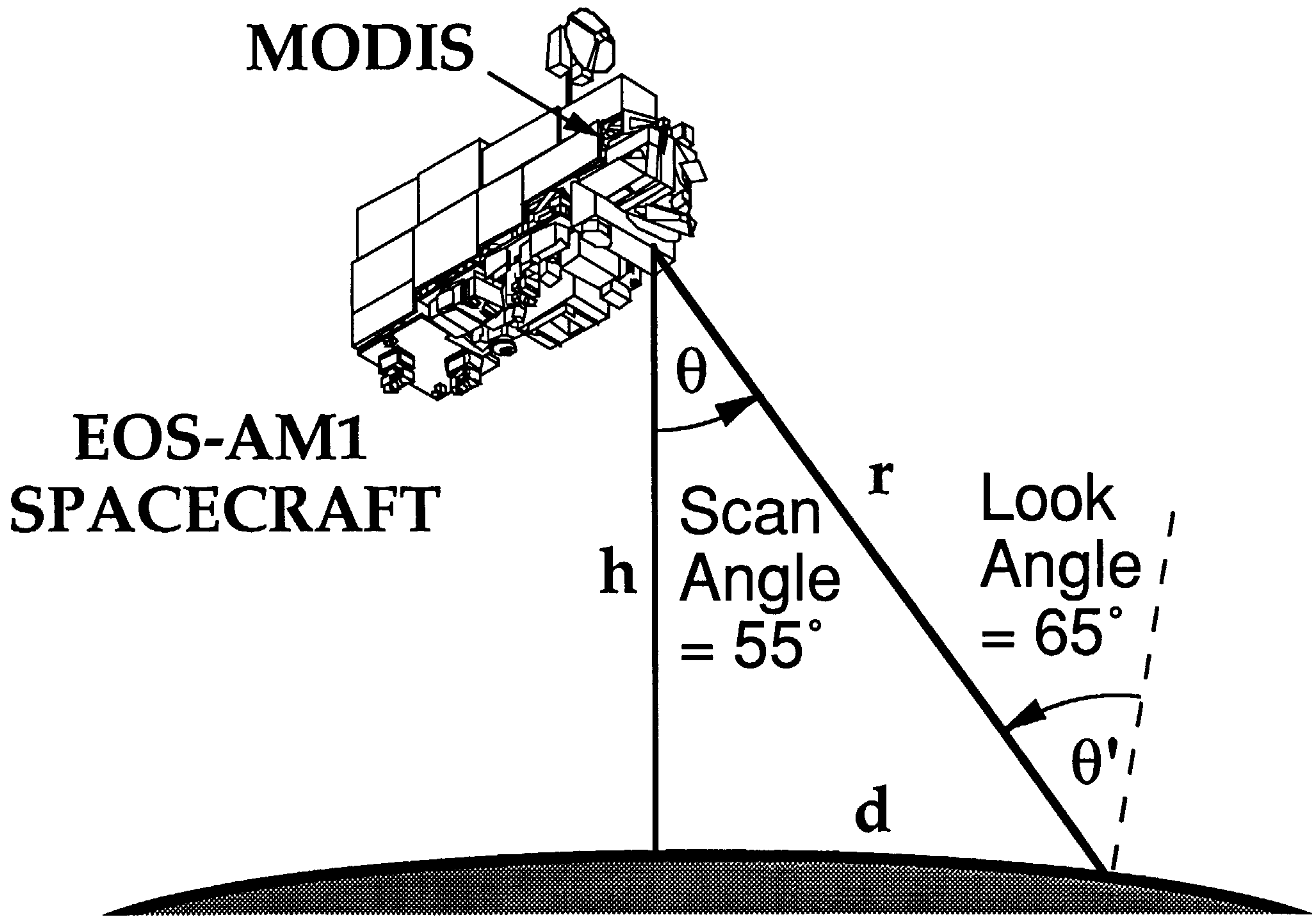
Geometric Requirements

Scientific Discipline Requirements	IFOV		Geolocation		Band-to-Band Registration	
	min (Km)	max (Km)	min (Km)	max (Km)	min (pixels)	max (pixels)
Atmospheric Products	0.1	10	10	10	2	5
Land Products	0.1	10	0.02	0.5	0.05	0.15
Ocean Products	2	10	2	5	2	5

Conclusion: The Land Discipline Group has the highest Spatial Requirement.

Feedback to MCST is requested from Discipline Representatives and others as to the appropriate range for these requirements. Specifically, identify the key calibration-critical MODIS data products & the approximate Band-Dependent Algorithms To Be Used in Developing Sensitivity Studies for Deriving Requirements, Including Key People With Whom to Work.

MODIS Scan Edge Geometry



Parameters Influencing MODIS Scan Pattern

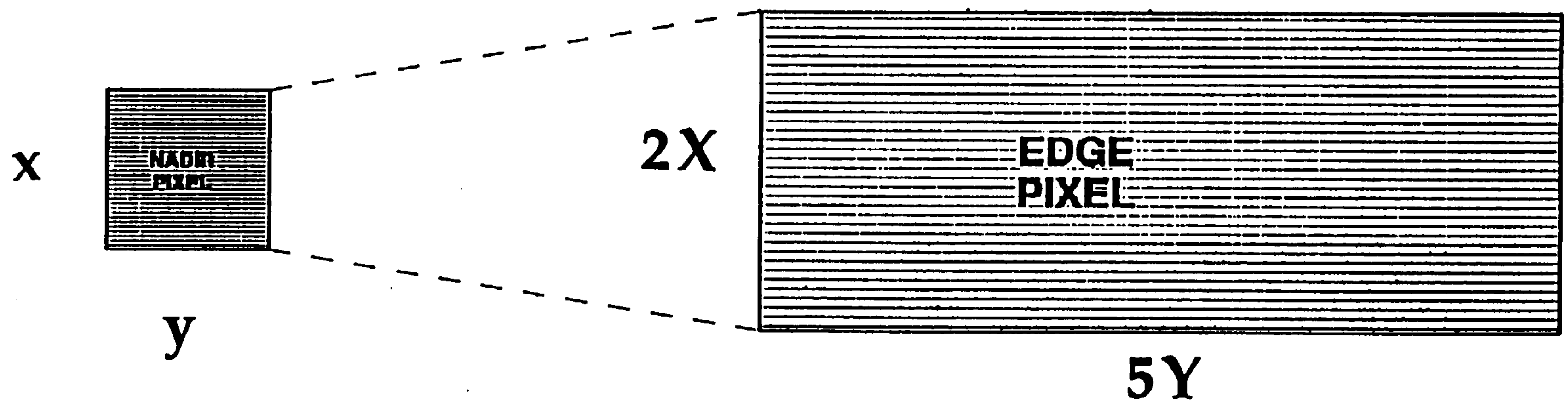
PARAMETER	SIMPLIFIED	RIGOROUS	UNITS
platform altitude		705	kilometers
maximum scan-angle		55	degrees
angular IFOV		1.41844	millirad's
number if array elements		10	
orbital period		98.80299	minutes
subsatellite velocity		6.760355	KM/sec
sweep scan period		1.479241	seconds
swath width at nadir	10	10.00017	kilometers
half swath distance	1006.844	1164.77	kilometers
range to swath edge	1229.13	1414.032	kilometers
range/height		2.005719	
great circle arc		10.46289	degrees
nadir x-pixel size	1000	1000	meters
nadir y-pixel size	1000	1000	meters
The following measurements refer to the edge pixel			
edge stretch	4.829771		
look angle	55	65.46289	degrees
x-pixel size	4829.771	4829.783	meters
y-pixel size		2005.719	meters
lead/trail ranges	1411.839	1416.232	kilometers
trapazoidal distortion		6.23182	meters
refractive distortion		127.5133	arc-sec's
refractive distortion		0.6182019	millard's

SIMPLIFIED refers to small angle and/or flat earth approximation

x = along-scan direction ..... y = along-track direction

MODIS Pixel Size Range

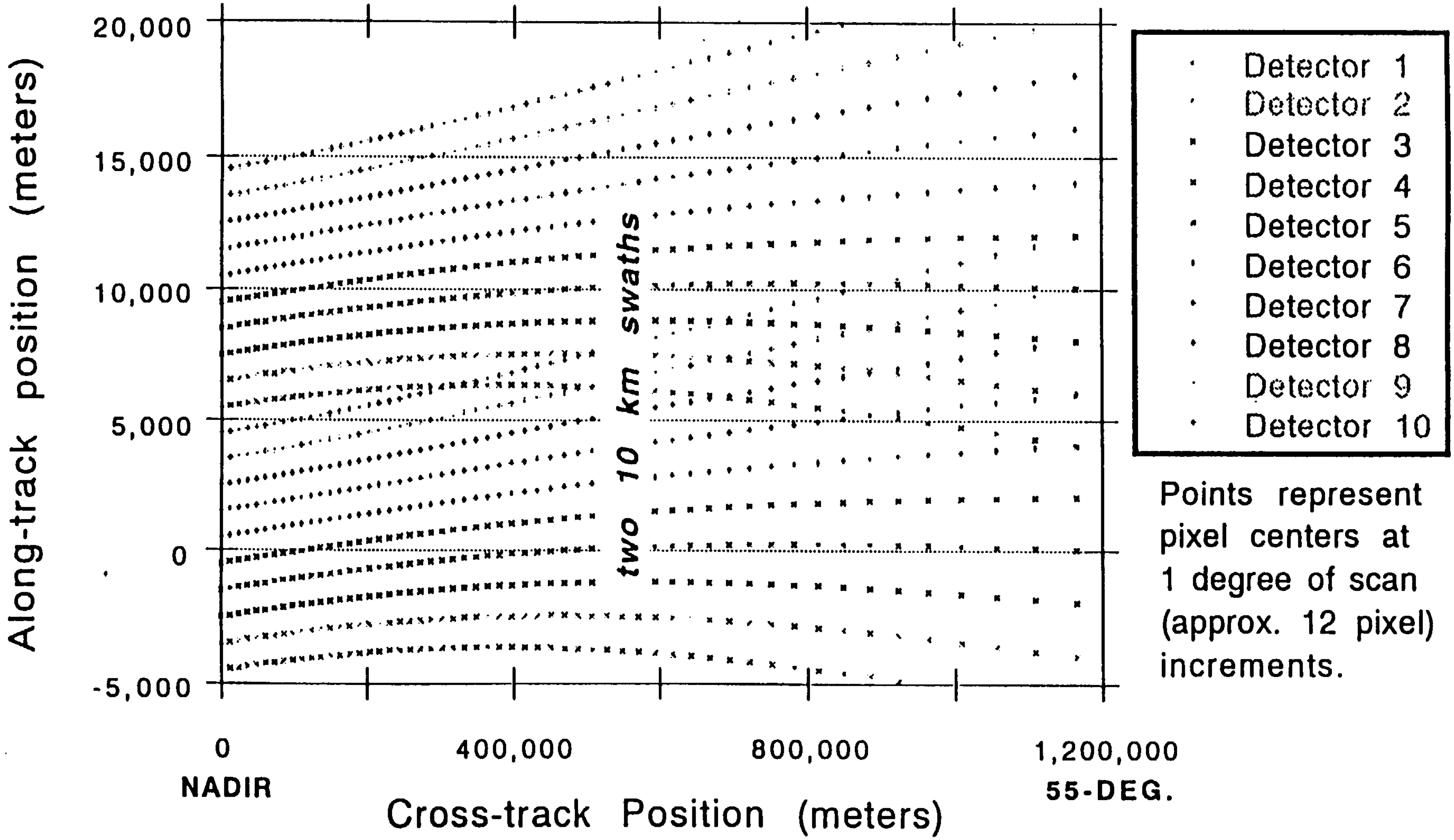
(drawn to the scale of 1" = 1 km)



Edge distortion in the along-track direction is due to doubling of the satellite distance from target at slant angle of 55 degrees. The along-scan distortion is further exaggerated by obliqueness of view and curvature of the earth.

MODIS Scan Pattern

(10 element array, 1 km GFOV)



Points represent pixel centers at 1 degree of scan (approx. 12 pixel) increments.

BAND 29 STUDY

TASK

Evaluate acceptability of 2 different filter wafers for Band 29

Wafer A: Center Wavelength 5 nm beyond Specification tolerances,
Lower Edge Range 31.5 nm beyond Specification

Wafer B: Lower Edge Range 66 nm beyond Specification

METHOD

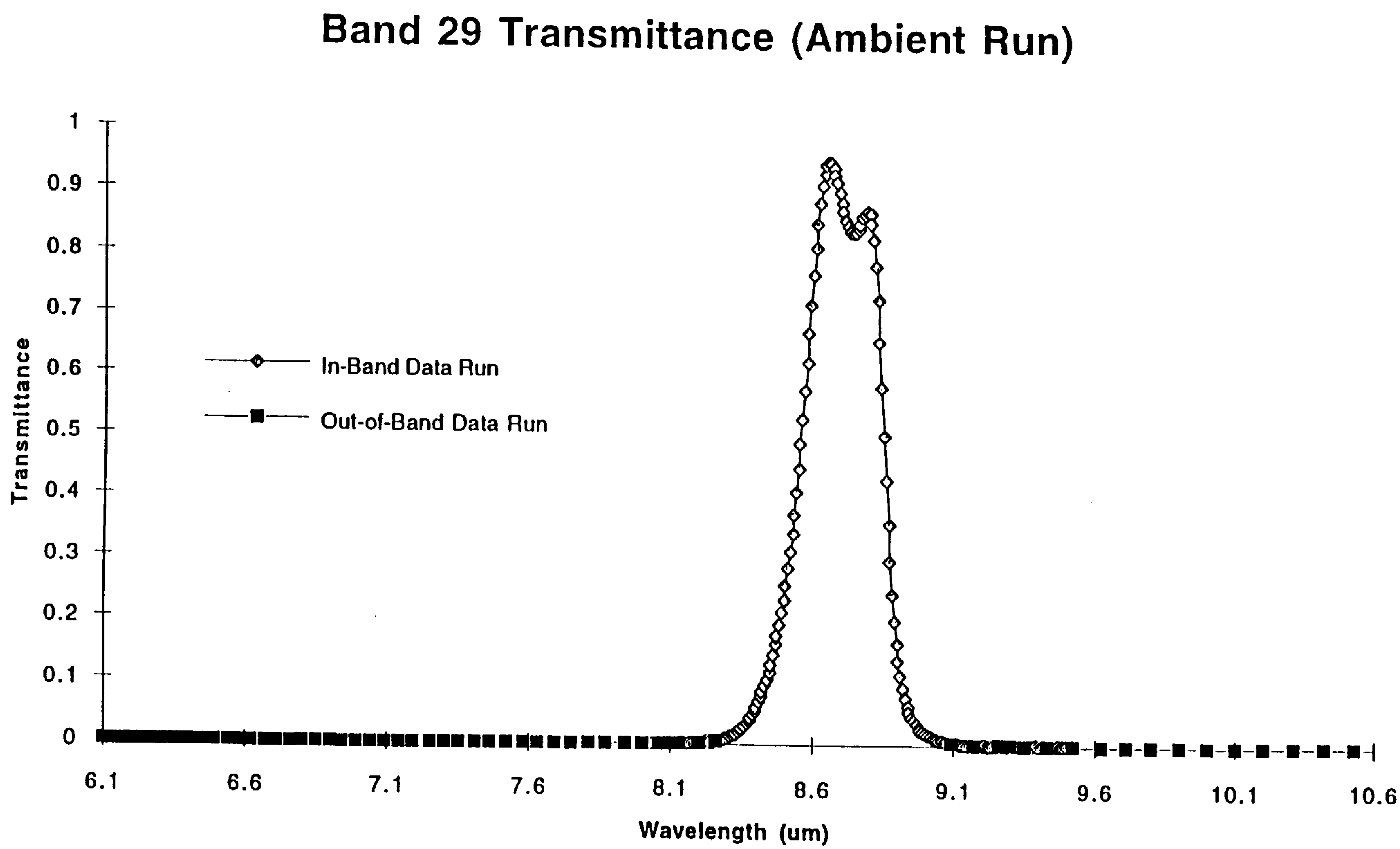
Compared to Ideal Filter
Examined Sensitivity to Spectral Shift
Examined Effects due to Out-of-Band Radiance

RESULTS

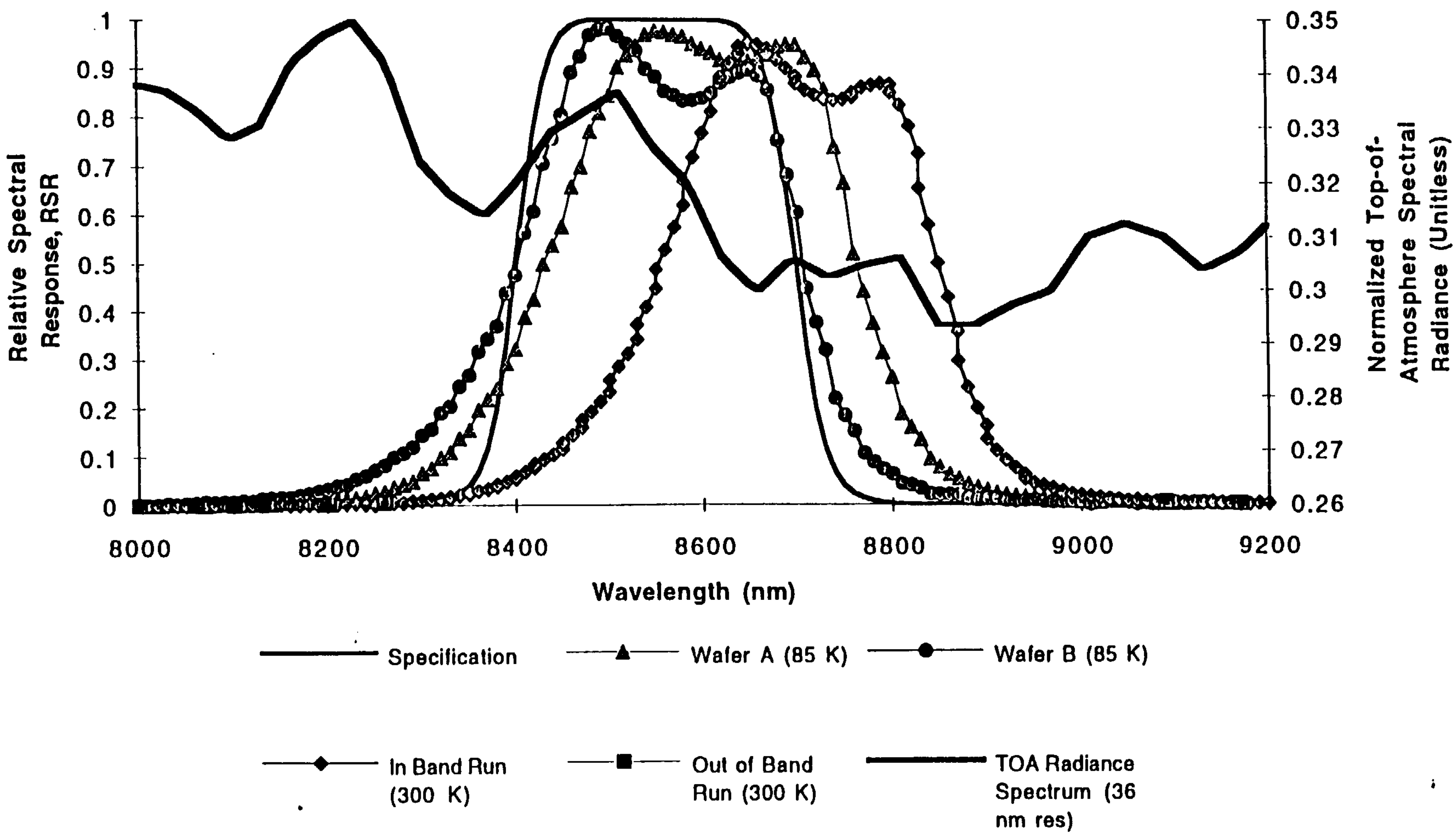
Wafer B land Wafer A show similar sensitivity to potential after-launch wavelength Shifts
Wafer B displayed shifts/radiances comparable to Ideal Filter
Out-of-Band Radiance contributions minimal

CONCLUSION

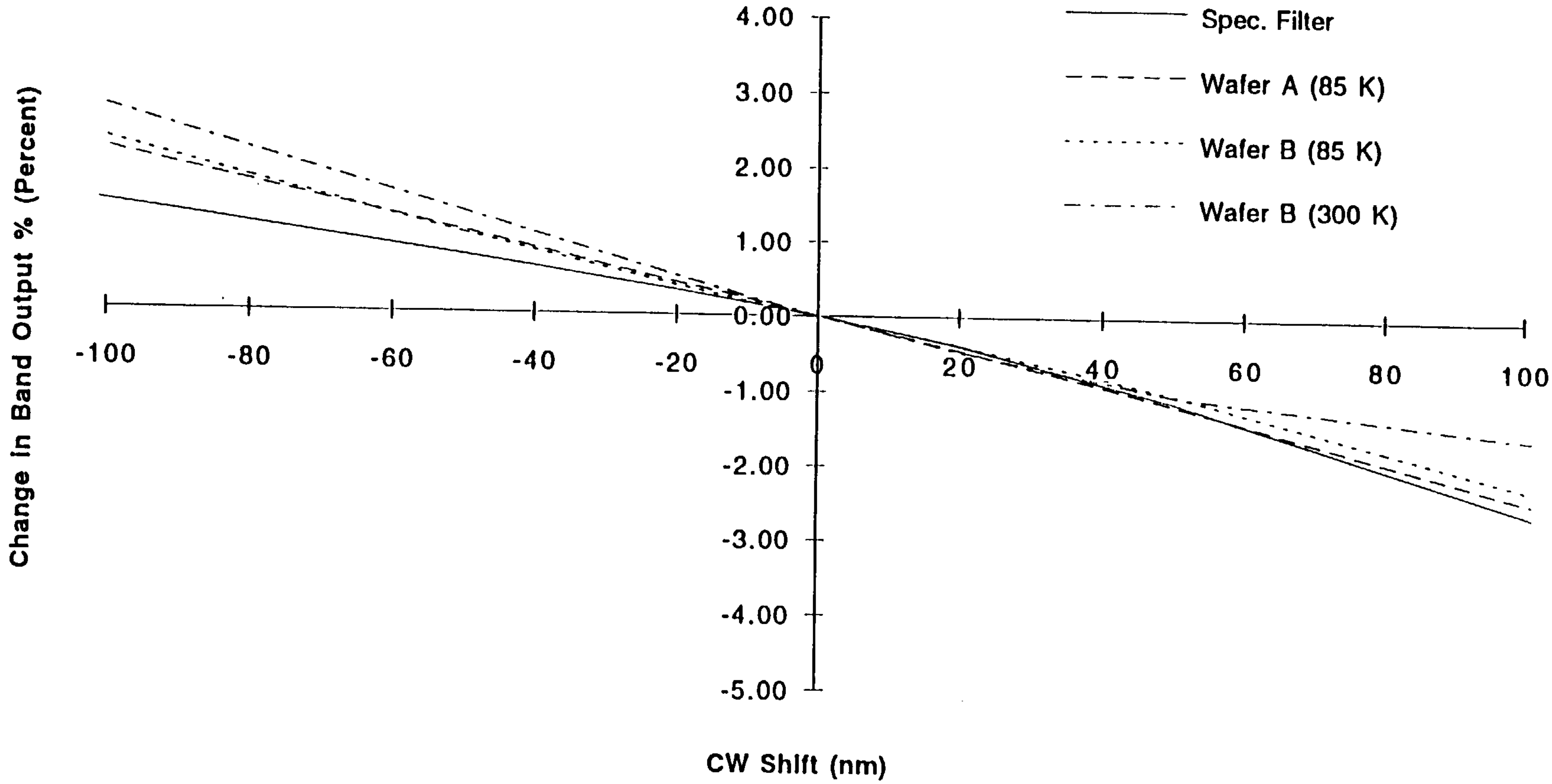
Wafer B deemed acceptable


Band 29 Transmittance (Ambient Run)
Transmittance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
In-Band Data Run
Out-of-Band Data Run
6.1
6.6
7.1
7.6
8.1
8.6
9.1
9.6
10.1
10.6
Wavelength (um)

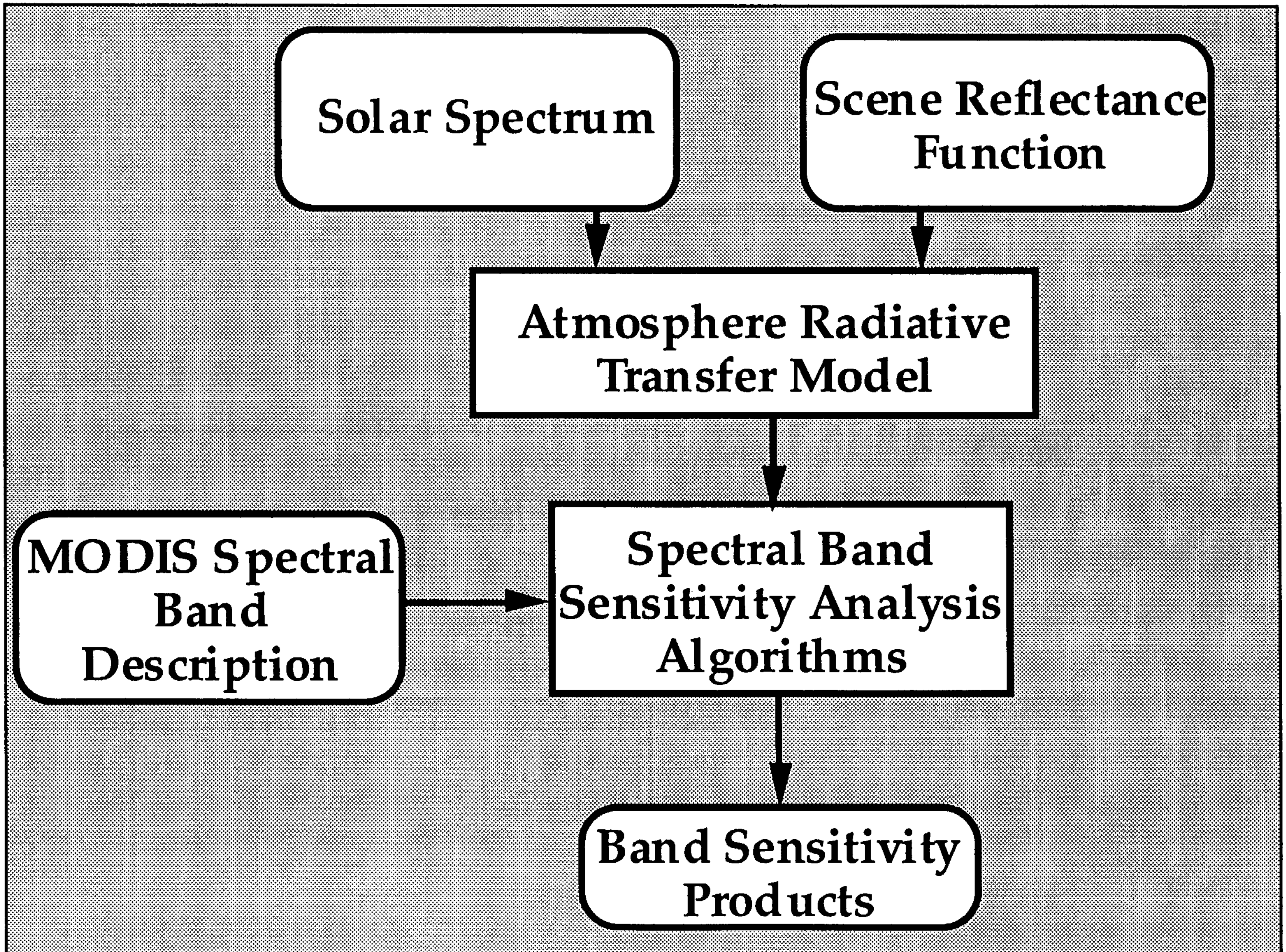
Band 29 with TOA Radiance Spectrum



Change In MODIS Band-29 Output due to Shift in Center Wavelength
(Spec. CW = 8550 nm, CW Tolerance = 43 nm)

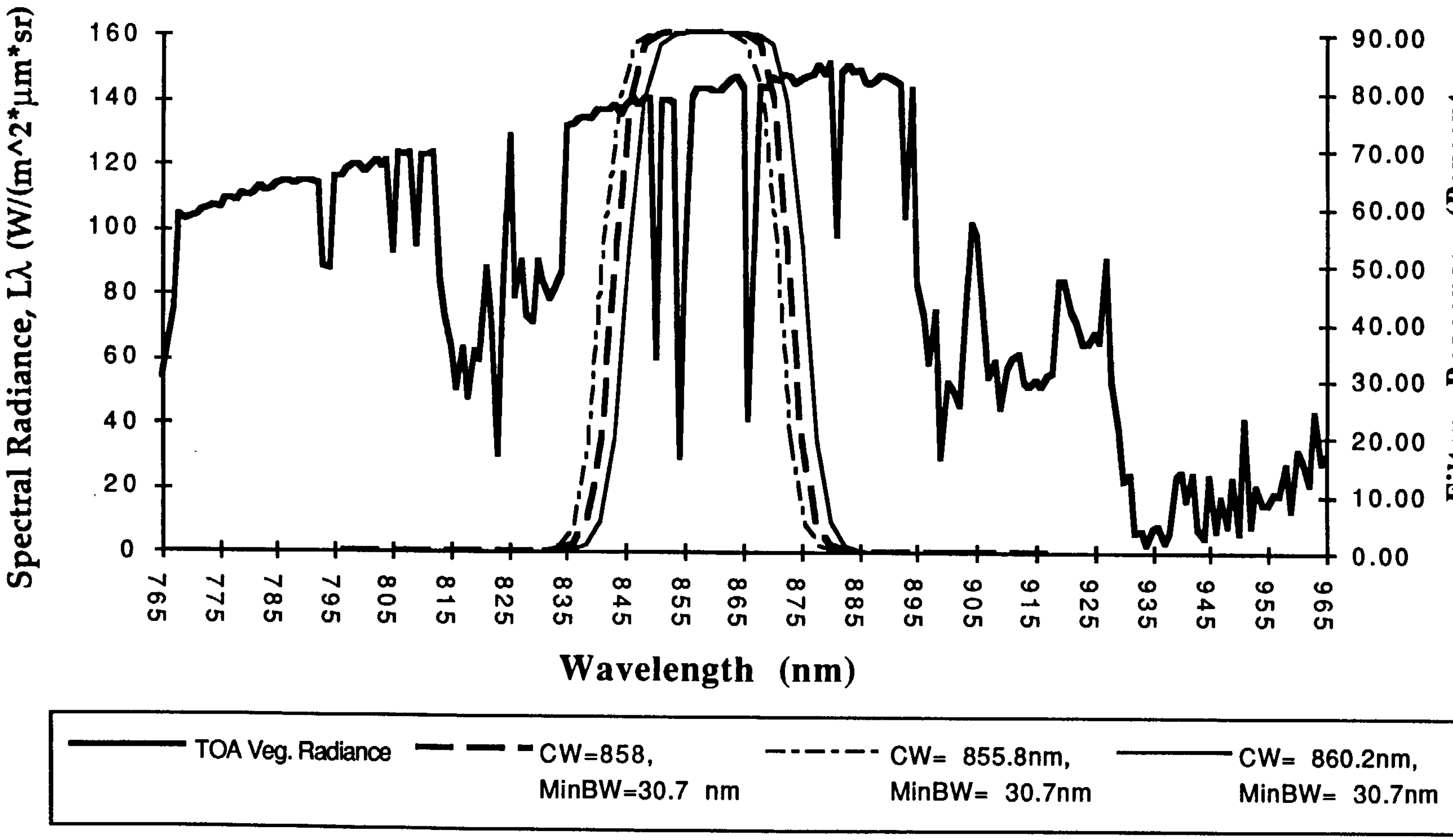


Sensitivity Analysis System Modules



DK0011

Simulated MODIS Band-2 Filter Response Functions and Vegetation Spectral Radiance Spectra (TOA)



DK0014

MODIS Center Wavelength (CW) Spectral Sensitivity Study

Change in MODIS Band Output Radiance without Solar Diffuser Calibration

TOA Spectral Radiance Input (Kurucz solar spectrum, 1 cm water vapor, nominal vegetation reflectance)

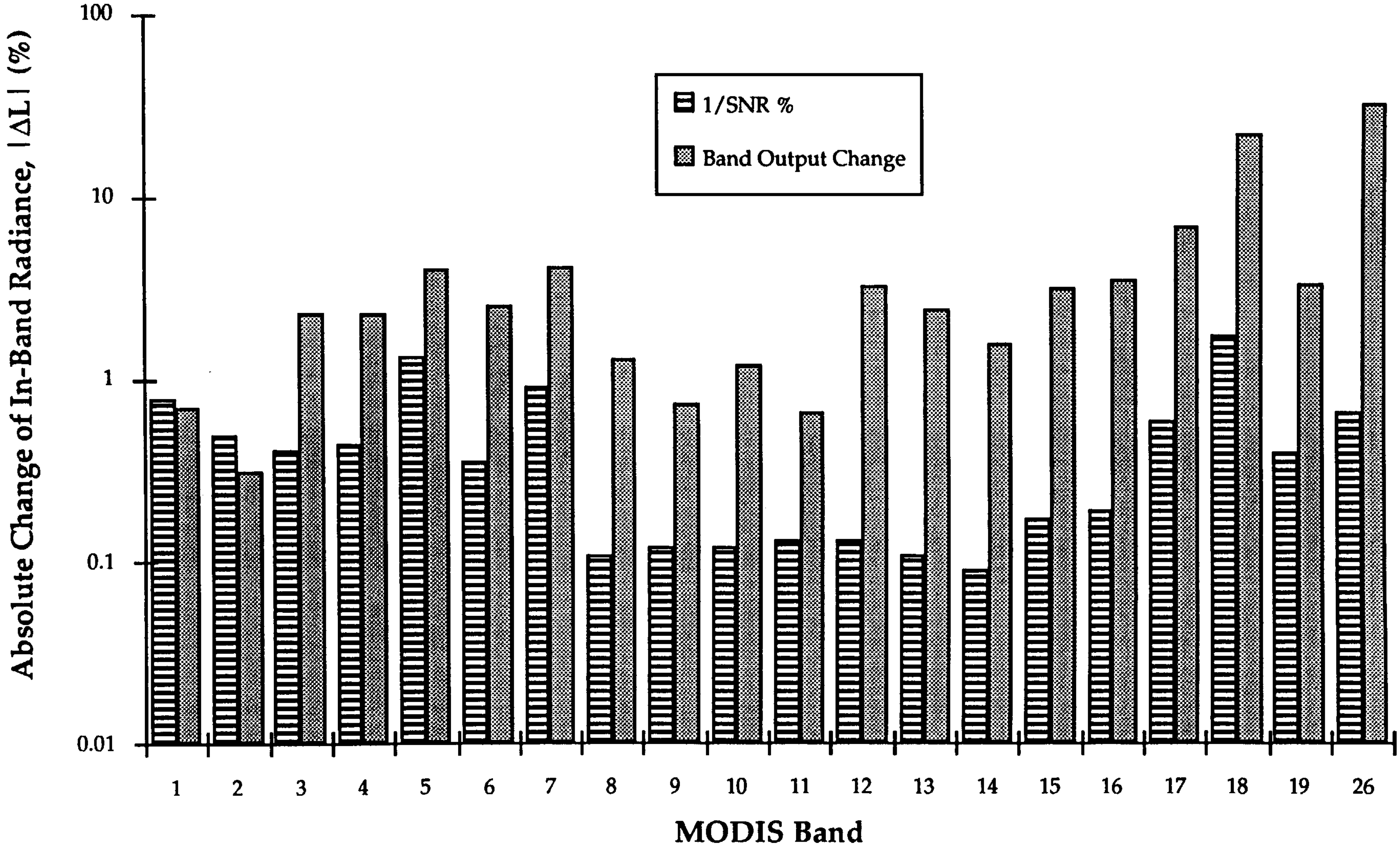
MODIS Band	Change of In-Band Radiance (%)								
	CW Shift -10nm	CW Shift -5nm	CW Shift -2nm	CW Shift -1nm	CW Shift 0	CW Shift +1nm	CW Shift +2nm	CW Shift +5nm	CW Shift +10nm
1	2.5	0.9	0.3	0.1	0.0	-0.1	0.0	0.2	1.7
2	-2.3	-0.6	-0.3	-0.2	0.0	0.2	0.2	1.3	2.0
3	6.7	2.9	1.2	0.5	0.0	-0.5	-0.5	-2.9	-6.8
4	5.2	2.5	1.1	0.5	0.0	-0.6	-0.6	-3.1	-6.1
5	5.9	3.4	1.5	0.7	0.0	-0.8	-1.6	-4.1	-7.9
6	1.5	1.2	0.6	0.3	0.0	-0.3	-0.7	-1.8	-3.8
7	1.8	1.1	0.5	0.3	0.0	-0.3	-0.3	-2.0	-5.8
8	no data	no data	1.3	0.6	0.0	-0.5	-0.8	-2.3	-7.3
9	-7.7	-2.5	-0.7	-0.5	0.0	0.8	0.9	3.2	2.7
10	12.0	5.9	2.1	1.0	0.0	-0.7	-0.2	-0.4	-3.3
11	1.2	1.5	0.6	0.2	0.0	-0.3	-0.3	-2.8	-5.6
12	4.1	2.3	1.1	0.6	0.0	-1.1	-1.1	-3.3	-6.2
13	-11.0	-6.2	-2.4	-1.3	0.0	1.4	1.5	8.2	17.0
14	-15.0	-7.5	-3.0	-1.4	0.0	1.3	1.1	2.6	-2.4
15	-17.0	-9.0	-3.3	-1.5	0.0	1.0	0.6	0.3	22.0
16	-6.2	-2.2	-0.6	-0.3	0.0	0.5	0.7	3.6	6.1
17	38.0	18.0	6.9	3.4	0.0	-3.2	-2.9	-14.0	-26.0
18	304.0	110.0	22.0	7.8	0.0	-2.8	-2.8	5.7	11.0
19	22.0	8.0	2.7	1.3	0.0	-1.0	-1.9	-3.1	-3.7
26	84.0	17.0	3.5	1.4	0.0	-1.0	-0.8	-5.2	-22.0

DK-0006

MODIS Spectral Band Output Change due to Shift in Center Wavelength

(Plotted Value is Max. Abs. Change in the Center Wavelength Tolerance Range)

(J. Barker, 6 Aug., 1993)

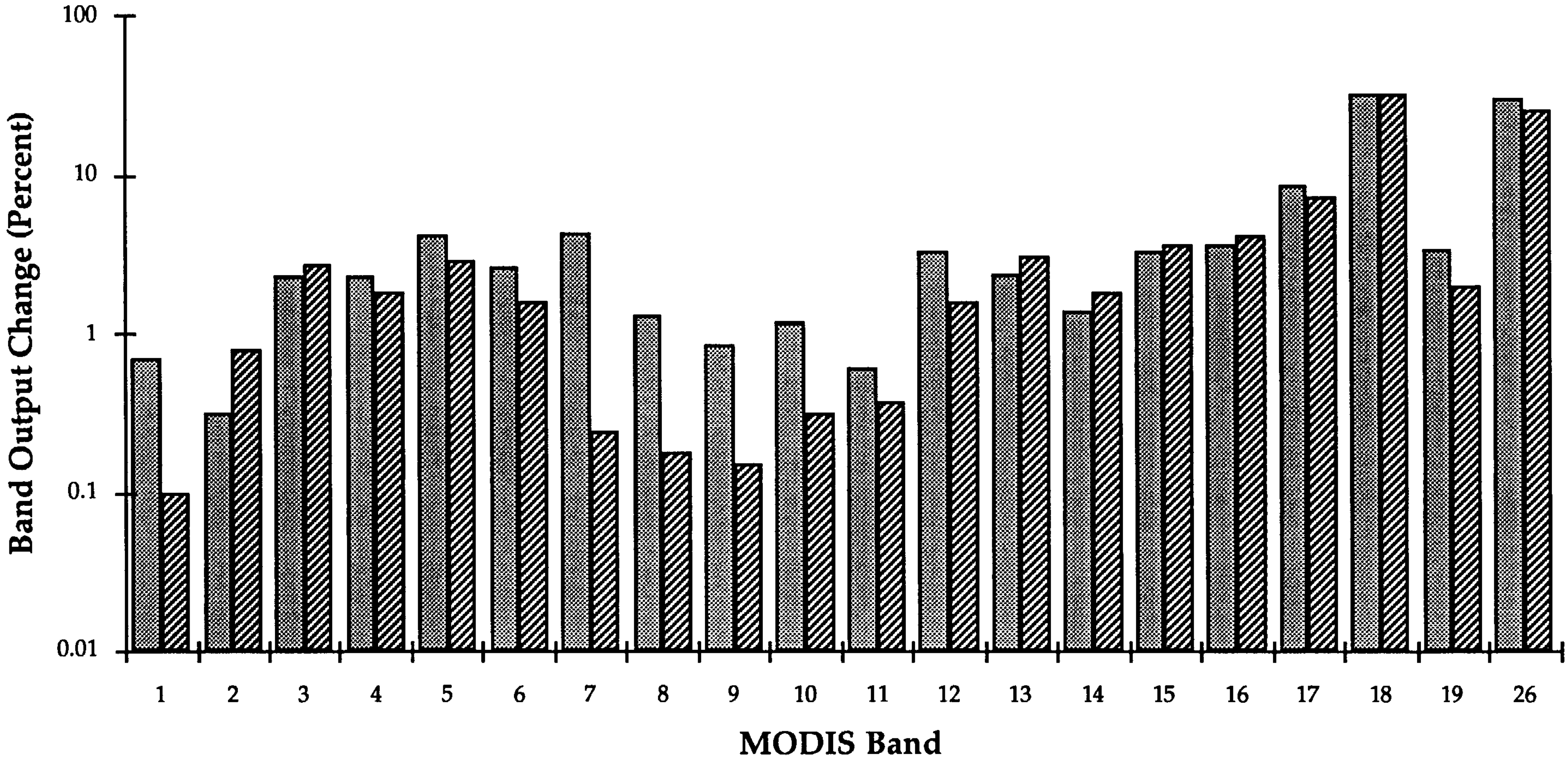


DK-0009

Effect of Solar Irradiance Normalization
MODIS Spectral Band Output Radiance Change
due to Center Wavelength Change

(Plotted value is Max. Abs. Change in the CW tolerance range)

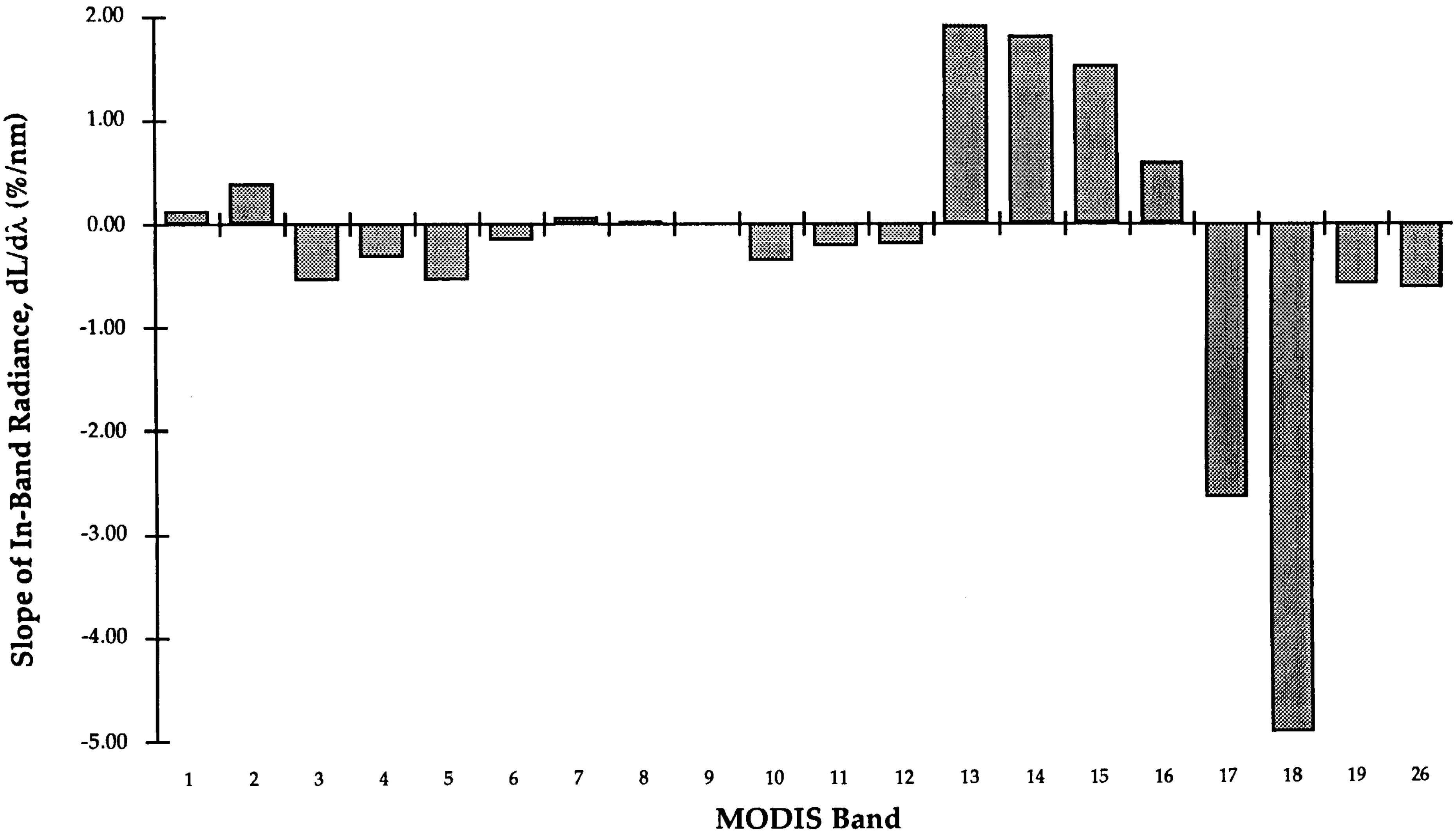
(J. Barker, 6 Aug., 1993)



DK0013

Sensitivity of MODIS Reflective Band Output to Shift in Center Wavelength

(J. Barker, 6 Aug., 1993)



DK-0007

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