



Instrument Calibration and Performance Status

Jack Xiong (NASA/GSFC), Bill Barnes (UMBC)

and

MCST



Presentation at MST Meeting (July 13-15, 2004)





Outline



- Introduction
 - Instrument Background (*backup slides*)
 - MCST Support and Contact
- MODIS On-orbit Calibration and Characterization
 - Calibration Methodology
 - Calibration Algorithms (*backup slides*)
- Instrument Status
 - On-orbit Performance
 - Instrument Operations (Configuration Changes)
 - L1B/LUTs Updates
- Challenging Issues
- Summary



MCST Support and Contact



- MODIS Characterization Support Team (MCST)
 - Jack Xiong, Bill Barnes, Vince Salomonson (Science Team Leader)
 - Contract Team: SAIC, SSAI, and STGI
- Responsibilities and Contacts
 - Maintain and support instrument (Terra and Aqua MODIS) operations
 - IOT (Bryan Breen)
 - Maintain and update L1B code and LUTs
 - L1B (James Kuyper)
 - Maintain, design, and improve algorithms; perform instrument calibration and data analysis; provide science support
 - MAT (Vincent Chiang and Junqiang Sun)
- MsWG (MODIS Sensor Working Group)
 - Science Group Representatives and Instrument Vendor
 - Moeller (Atmos), Vermote and Wan (Land), Esaias and Evans (Miami ocean group), McClain and Feldman (New ocean group), Biggar (CAL/VAL), Drake (SBRS)
- MTM and MCST Workshops



MCST Workshop



Wednesday, 14 July 2004, 7:00-9:00pm

1. Welcome and Introduction (5 min)
(Bill Barnes/Jack Xiong)
2. MODIS Calibration and Characterization Status (25 min)
(Jack Xiong)
3. Atmosphere Group Calibration Issues (20 min)
Chris Moeller
4. Land Group Calibration Issues (20 min)
Eric Vermote
5. Ocean Calibration Issues (30 min)
Bryan Franz / Kay Kilpatrick
6. Other CAL/VAL Related Topics (20 min)
Stuart Bigger / Jack Xiong



Useful Sites



MCST Web

<http://www.mcst.ssai.biz/>

Instrument Operations Team (Daily and Weekly Reports)

<http://www.mcst.ssai.biz/IOT/>

L1B Algorithm, Product Information, and Code/LUTs Change History

<http://www.mcst.ssai.biz/mcstweb/L1B/product.html>

MCST Contacts

<http://www.mcst.ssai.biz/mcstweb/info/mcststaff.html>

[New L1B ATBD](#)

MODIS PFM RSR

ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/PFM_L1B_LUT_4-30-99/L1B_RSR_LUT/

MODIS FM1 RSR

ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/FM1_RSR_LUT_07-10-01/

MCST - Solar Spectral Irradiance Data Sets

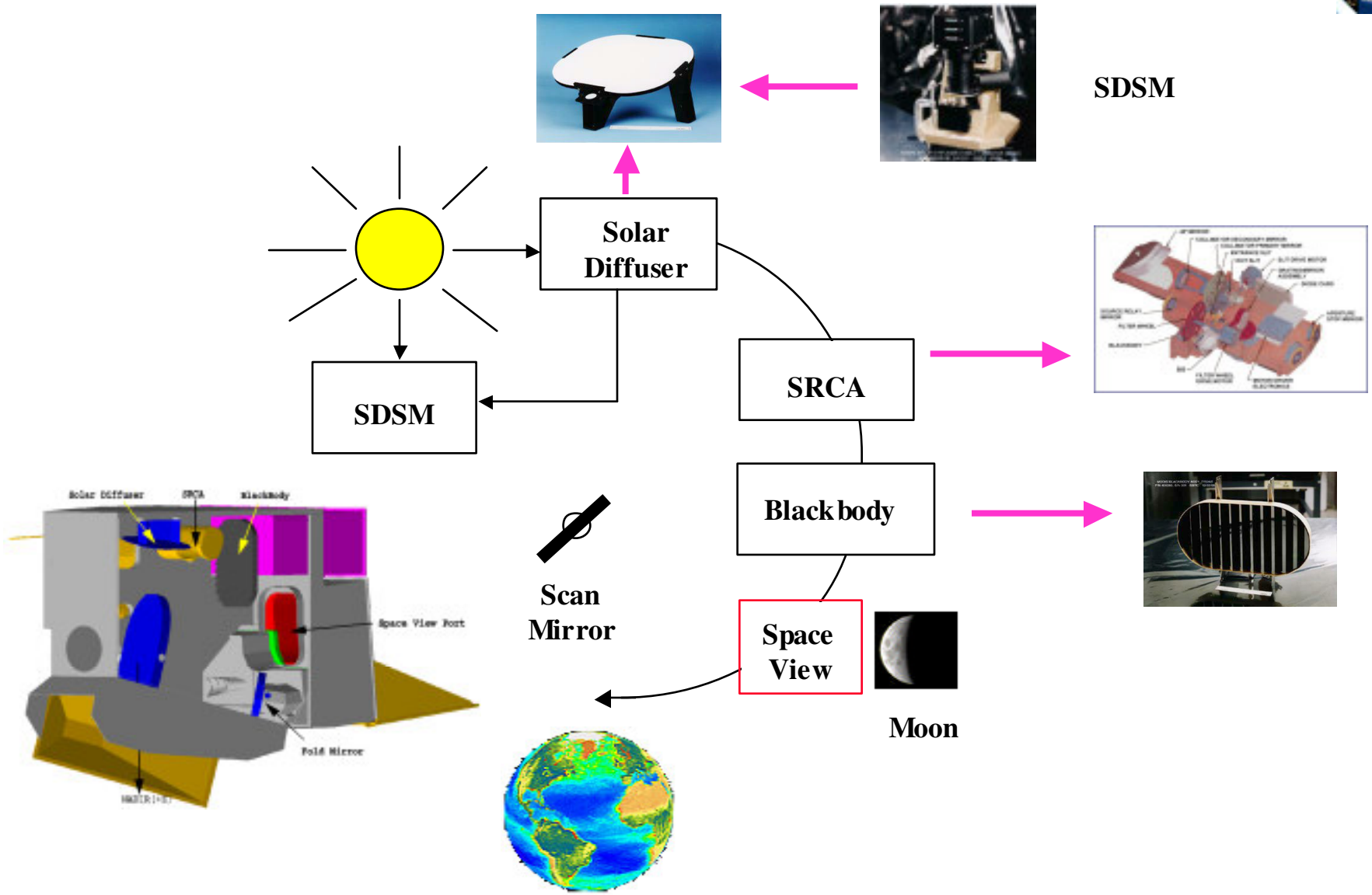
ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/Solar_Irradiance/

MCST Workshop Materials

<ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/WorkShop/>



MODIS On-orbit Calibration and Characterization



SDSM

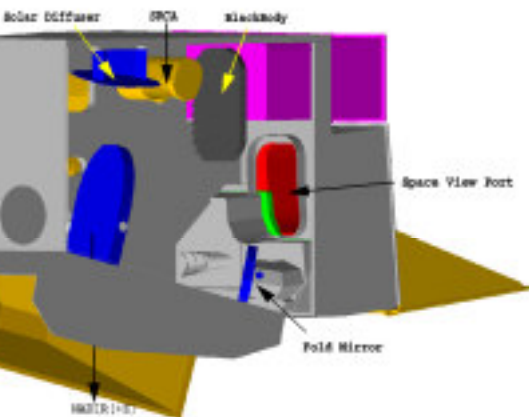
SRCA

Blackbody

Space View

Moon

Scan Mirror





On-orbit Calibration Activities



- Radiometric
 - Thermal emissive bands by BB ([warm-up/cool-down, quarterly](#))
 - Reflective solar bands by SD/SDSM ([weekly first year to bi-weekly](#))
 - Terra SD observations every orbit
- Spatial and Spectral
 - Spatial for RSB and TEB by SRCA ([bi-monthly](#))
 - Spectral for RSB by SRCA ([quarterly](#))
- Maneuvers (special request)
 - Lunar Observations (roll, [monthly](#))
 - SD BRF and SD screen characterization (yaw)
 - TEB RVS (pitch, Terra only)



Instrument Status



- On-orbit Performance
 - Radiometric
 - Response trending (*MCST workshop materials*)
 - Noise characterization
 - Spectral and Spatial
- Instrument Operations
 - Timeline of Configuration Changes & Spacecraft and Instrument Events
- L1B/LUTs Updates
 - Updating history



On-orbit Performance

- Thermal Emissive Bands (16 bands and 160 detectors)
 - Terra MODIS
 - Stable short-term and long-term response trending (excluding sensor configuration change and instrument reset events)
 - 20 (10 from pre-launch, B36) noise detectors and 0 inoperable detectors
 - Aqua MODIS (similar and better)
 - Better response trending than Terra MODIS
 - 1 (1 from pre-launch) noise detectors and 0 inoperable detectors
- Reflective Solar Bands (20 bands and 330 detectors)
 - Terra MODIS
 - Noticeable optics degradation (wavelength dependent, mirror side dependent)
 - 21 (20 from pre-launch, band 7) noise detectors and 0 inoperable detectors
 - Aqua MODIS (more stable)
 - Noticeable optics degradation (wavelength dependent)
 - 3 noise detectors (all in B6) and **15 (13 from pre-launch, 12 in B6 and 1 in B5) inoperable detectors**



On-orbit Performance

- Spectral (RSB only)
 - Terra MODIS
 - Center wavelength shifts of less 0.5nm for all bands
 - Aqua MODIS
 - Center wavelength shifts of less 0.5nm for all bands, except for B2
- Spatial (RSB and TEB)
 - Terra MODIS
 - BBR in specification in along scan direction
 - BBR in specification in along track direction, except 2 bands slightly out specification
 - Aqua MODIS
 - BBR in specification for bands within VIS/NIR and bands within SMIR/LWIR
 - About 450m shift in both along scan and along track directions for the SMIR/LWIR FPA (relative to NIR FPA)
- **Aqua MODIS performs better than Terra MODIS**



Terra MODIS TEB Noisy Detector History



Detectors in Product Order																		
Day/Year	Band	21		27		28				30			33	34				36
	Spec NEdT[K]	0.20		0.25		0.25				0.25			0.25	0.25				0.35
	Detector #	4	5	1	6	1	3	8	10	2	5	8	1	5	6	7	8	1-10
Pre-launch	-				0.10		0.05	0.04			0.09	0.09	0.14	0.20	0.20	0.21	0.20	0.45
055/2000	Nadir door open	0.17	0.17	0.09	0.09	0.05	0.06	0.06	0.05	0.10	0.11	0.11	0.28	0.23	0.26	0.27	0.29	0.43
232/2000	Back from FPA recycle	0.16	0.15	0.10	0.24	0.05	0.05	0.05	0.05	0.11	0.31	0.11	0.27	0.24	0.33	0.37	0.38	0.42
030/2001	-	0.15	0.16	0.10	0.27	0.05	0.06	0.05	0.05	0.12	0.29	0.30	0.25	0.24	0.33	0.37	0.37	0.43
087/2002	Back from save mode	0.18	0.25	0.11	0.24	0.06	0.32	0.05	0.04	0.10	0.26	0.64	0.25	0.24	0.29	0.32	0.33	0.43
022/2003	-	0.14	0.16	0.10	0.23	0.05	0.30	0.27	0.04	0.10	0.25	0.65	0.27	0.25	0.33	0.37	0.37	0.43
086/2003	After DSM ¹	0.16	0.15	0.11	0.23	0.05	0.29	0.08	0.05	0.10	0.47	0.65	0.26	0.24	0.33	0.36	0.36	0.44
118/2004	-	0.16	0.15	0.26	0.26	0.05	0.16	0.36	0.16	0.10	0.33	0.41	0.27	0.21	0.29	0.32	0.32	0.43
158/2004	-	0.18	0.17	0.28	0.25	0.05	0.16	0.37	0.21	0.10	0.31	0.40	0.27	0.22	0.28	0.31	0.31	0.43
162/2004	-	0.16	0.16	0.26	0.27	0.05	0.16	0.37	0.20	0.14	0.32	0.42	0.27	0.22	0.30	0.34	0.34	0.43
175/2004	-	0.15	0.15	0.28	0.26	0.12	0.17	0.35	0.17	0.17	0.30	0.41	0.27	0.21	0.28	0.32	0.32	0.43

¹Spacecraft Deep Space Maneuver

In Spec

Near the Spec

Out of Spec



Aqua MODIS TEB Noisy Detector History



Day/Year	Band	20		21	
	Spec NEdT [K]	0.05		0.20	
	Detector #	10	3	9	others
Pre-launch	-	0.05	0.16	0.28	
175/2002	Nadir door open	0.03	0.23	0.23	near 0.2
183/2002	Back from safe mode	0.03	0.20	0.25	near 0.2
218/2002	Back from safe mode	0.03	0.19	0.26	near 0.2
255/2002	Back from safe mode	0.03	0.23	0.20	near 0.2
102/2003	-	0.03	0.43	0.19	near 0.2
201/2003	-	0.03	0.18	0.18	near 0.2

¹Spacecraft Deep Space Maneuver

	In Spec		Near the Spec		Out of Spec



Terra MODIS RSB Noisy Detector History



Detectors in Product Order																	
Day/Year	Band	5										6			7		
	SNR Spec	74										275			110		
	Detector	2	4	6	11	13	16	17	18	19	20	3	7	8	1-10	11-13,15-20	14
055/2000	Nadir Dorr Open	0	0	60	80	0	30	0	0	80	0	0	0	100	100	110	0
160/2000	CFPA Lost Control	95	95	60	80	80	30	80	80	80	80	0	0	100	100	110	0
232/2000	Back from FPA recycle	75	95	50	0	80	50	80	0	70	0	0	0	100	100	110	0
304/2000	B Side	85	20	85	80	80	60	80	80	80	80	350	350	275	90	100	100
183/2001	A Side	95	10	90	90	90	90	90	90	90	90	380	380	380	100	110	110
259/2002	A Side B Formatter	100	10	100	100	100	100	100	100	100	100	380	380	380	100	110	110
			In Spec		Near Spec												

0 SNR: inoperable detectors (when certain Vdet/ltwk settings were used)



Aqua MODIS RSB Noisy Detector History



Detectors in Product Order												
Day/Year	Band	5	6									
	SNR Spec	74	275									
	Detector	20	2	4	5	6	7	9	10	12-16	17	18-20
175/2002	Nadir Dorr Open	0	0	0	0	0	470	470	0	0	100	0
189/2002	Back from Safe Mode	0	0	470	470	0	470	470	0	0	470	0
255/2002	Back from Safe Mode	0	0	0	0	0	470	470	0	0	470	0
266/2002	Back from Safe Mode	0	0	0	0	0	150	400	0	0	470	0
110/2003		0	0	0	0	0	260	470	0	0	320	0
160/2003		0	0	0	0	0	290	400	0	0	470	0
265/2003		0	0	150	0	0	290	400	0	0	275	0
360/2003		0	0	200	0	0	290	275	0	0	270	0
				In Spec				Nera Spec			Out Spec	

0 SNR: inoperable detectors (B6 problems)



Operational Configurations (Terra MODIS)



Date	Events	Description
Dec 18, 1999	Launch	Launched successfully
Feb 13, 2000	Science Mode	MODIS started science mode on A-side
Feb 24, 2000	Nadir Door Open	Terra MODIS First Light
June 2000	CFPA Lost Control	Ice began to cover radiative cooler surface
Aug 5, 2000	Formatter Anomaly	MODIS entered standby mode then safe mode
Aug 8, 2000	Outgas	Turned on outgas heater for two days (Back to science mode on Aug 19)
Oct 30, 2000	B-side Electronics	Transitioned to science mode on B-side
Jun 15, 2001	PS2 Anomaly	Powered supply 2 (B-side) off passing SAA
Jul 2, 2001	A-side Electronics	Returned to science mode on A-side with PS1
Mar 19, 2002	S/C Safe Hold	Anomaly during inclination maneuver (Back to science mode on Mar 23)
Sep 17, 2002	Formatter B	On A-side but cross-strapped to Formatter B
May 6, 2003	SD Door Failure	Set the SD open with screen down on July 2
Sep 24, 2003	S/C SSR Anomaly	Science recording shuts down and is re-enabled
Nov 30, 2003	S/C SFE Anomaly	SFE reports Sync errors
Dec 16, 2003	S/C ACE-B Anomaly	Anomaly due to Attitude Control Electronics (Back to science mode on Dec 22. Nadir door opened on Dec 24.
Jan 15, 2004	S/C SFE Recycled	SFE Side-A was recycled
Feb 18, 2004	S/C SFE Anomaly	SFE autonomously shuts down while passing through the SAA. Turned back on the same day



Operational Configurations (Aqua MODIS)



Same Configuration Thus Far

Date	Events	Description
May 4, 2002	Launch	Launched successfully
June 7, 2002	Science Mode	MODIS started science mode on B-side (SMIR Itwk/Vdet = 102/184)
June 24, 2002	Nadir Door Open	Aqua MODIS First Light
June 27, 2002	S/C Safe Hold	Aqua spacecraft Single Event Upset (SEU) SMIR Itwk/Vdet was left at 102/136 (Returned to 102/184 on July 8) MODIS returned to science mode on July 2
July 29, 2002	S/C Safe Hold	S/C ground pointing management anomaly MODIS science mode resumed on Aug 6
Aug 9-14, 2002	SD Door Open	SDSM calibration command dropped
Sep 12, 2002	S/C Safe Hold	Error in lower fidelity ephemeris S/C recovered to Fine Pointing Mode same day



Operational Configurations Impact on Data (Example)



2002 SUMMARY OF KEY AQUA MODIS OPERATIONAL CONFIGURATIONS

2002																															2002																														
JAN																															FEB																														
MAR																															APR																														
MAY																															JUN																														
JUL																															AUG																														
SEP																															OCT																														
NOV																															DEC																														

Legend	Science Data in Earth View Sector	Yes	No	Partial data lost
	SW/MWIR Focal Plane Bias (DN)	136	184	
	Temperature Control of Cold Focal Plane	Yes	Turned off	
	A-side /B-side Electronics	A-side (PS1; Formatter A)	B-side (PS2; Formatter B)	



L1B and LUTs Updates (Summary)



NUMBER OF MCST L1B TERRA AND AQUA CODE & LUT DELIVERIES						
Submission Period	<i>2000</i>	<i>2001</i>	<i>2002</i>	<i>2003</i>	<i>Jan-June 2004</i>	<i>TOTAL</i>
Mission	Terra	Terra	Terra+Aqua	Terra+Aqua	Terra+Aqua	

Recipient	Code, LUTs	Code, LUTs	Code, LUTs	Code, LUTs	Code, LUTs	Code, LUTs
GDAAC/SDST	5, 9	2, 11	3+2, 5+6	2+3, 23+27	0+0, 9+6	17 96
U. Miami	NA	NA	3+2, 5+6	6+3, 32+27	0+0, 1+0	14 71
SeaWiFS	0+0, 0+0	0+0, 0+0	0+0, 0+0	0+0, 0+0	1+1, 3+7	2 10
RRT	NA	NA	0+0, 2+3	0+0, 14+10	0+0, 0+0	0 29
MODAPS	NA	NA	NA	7+0, 10+0	0+1, 0+1	8 11
U.Wisc. Atmos.	0+0, 0+0	0+0, 0+0	0+0, 0+0	0+0, 0+0	0+0, 1+0	0 1
MCST	NA	NA	0+0, 0+15	0+0, 16+16	0+0, 22+0	0 69
Total	5, 9	2, 11	10, 42	21, 175	3, 50	41 287



L1B and LUTs Updates (Example)



Code Version	LUT versions	LUT Changes
V3.1.0_Aqua	0, 1, 2, 3	<ul style="list-style-type: none"> • Pre-launch LUTs inserted. • Several LUTs updated after more Pre-launch analysis • New RSB and TEB calibration coefficient LUTs • New BB temp. saturation limits • Detector quality flags changed • SWIR correction switch ON
V4.1.1_Aqua	0,1	<ul style="list-style-type: none"> • LUTs updated from V3.1.0.3 • New RSB calibration coefficient LUTs using SD degradation • Band 21 b1 table piece added • Detector quality flags changed
V4.1.3_Aqua	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	<ul style="list-style-type: none"> • LUTs updated from V4.1.1.1 • R* LUT deleted • Continuous Reflective Calibration Coefficient updates • Band 21, Detector 9 (product order) changed to “noisy” as of Version 3



Challenging Issues



- ✓ Resolved
 - No valid pre-launch RVS for Terra MODIS TEB
 - Terra MODIS PC optical leak
 - SDSM sun view signal ripples caused by a design error
 - B13H and B14H calibration
 - No SD vignetting function characterization

- ✓ Improved but still not perfect
 - SWIR crosstalk: uncertainty and striping
 - RSB response changes (mirror side, AOI, detector, temporal)

- Other identified challenging issues
 - Noisy detectors and out of family: uncertainty and striping
 - RSB RVS (challenges for ocean color)
 - Calibration uncertainty



Summary



- Instruments performed well according to design specifications
 - Terra (+4.5 years) and Aqua (+2.0 years); Aqua better than Terra in a number of areas
- Constant efforts made to maintain and improve instrument calibration and characterization
 - MCST working closely with science groups (representatives) and instrument vendor (SBRS)
- Lessons learned for future sensors
 - Terra MODIS lessons benefited Aqua MODIS development
 - MODIS experience helps NPOESS and NPP VIIRS and other sensors' design and development
- What's next?
 - Collection 5



Collection 5



- Science Group Representatives
 - Chris Moeller (Atmos), Eric Vermote (Land), Bob Barnes (Ocean)
- Code Changes (Science Input)
 - B21 b1 with mirror side difference?
 - SWIR crosstalk improvement?
 - Noise detectors and de-stripping
- LUTs Updates
 - DSM TEB RVS
 - Consistent RSB RVS and SD degradation
 - Smoothly fitted calibration coefficients
 - Predicted coefficients for forward data processing
 - Improved QA (timeline)

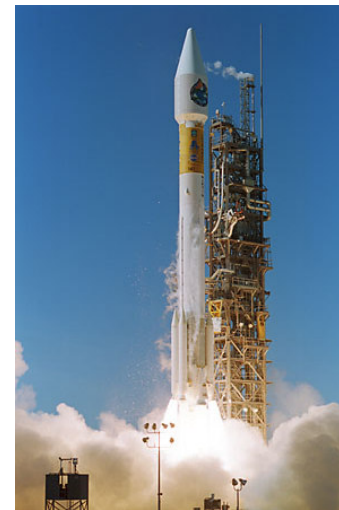
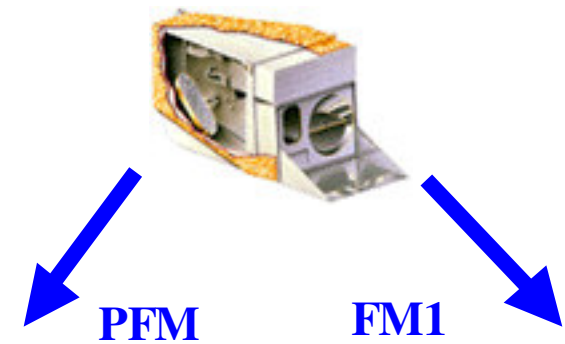
Backup Charts



Instrument Background

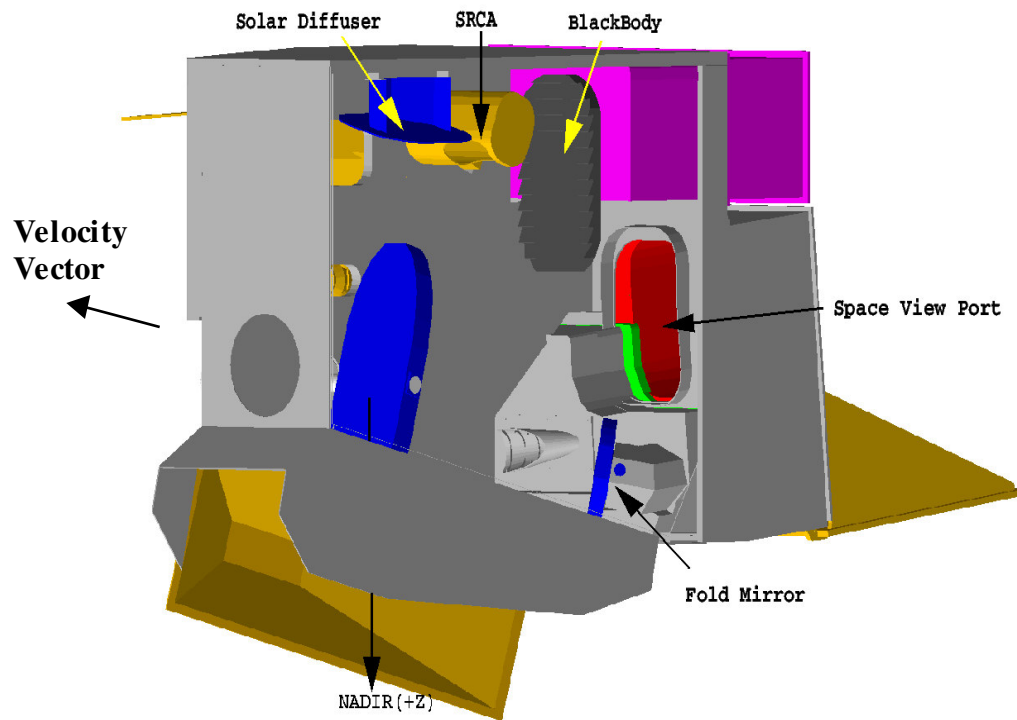


- MODIS is on both Terra and Aqua spacecraft. Terra (EOS-AM) launched on 12/18/99 (first light 02/24/00); Aqua (EOS-PM) launched on 05/04/02 (first light 06/24/02)
 - <http://terra.nasa.gov/>
 - <http://eos-pm.gsfc.nasa.gov/>
- Improved sensor (over heritage sensors)
 - Spectral, spatial, temporal resolutions
 - Applications (land, oceans, atmosphere)
 - Frequent global coverage
 - Morning & afternoon observations
- Extensive Calibration
 - Pre-launch
 - On-orbit calibration





Instrument Background



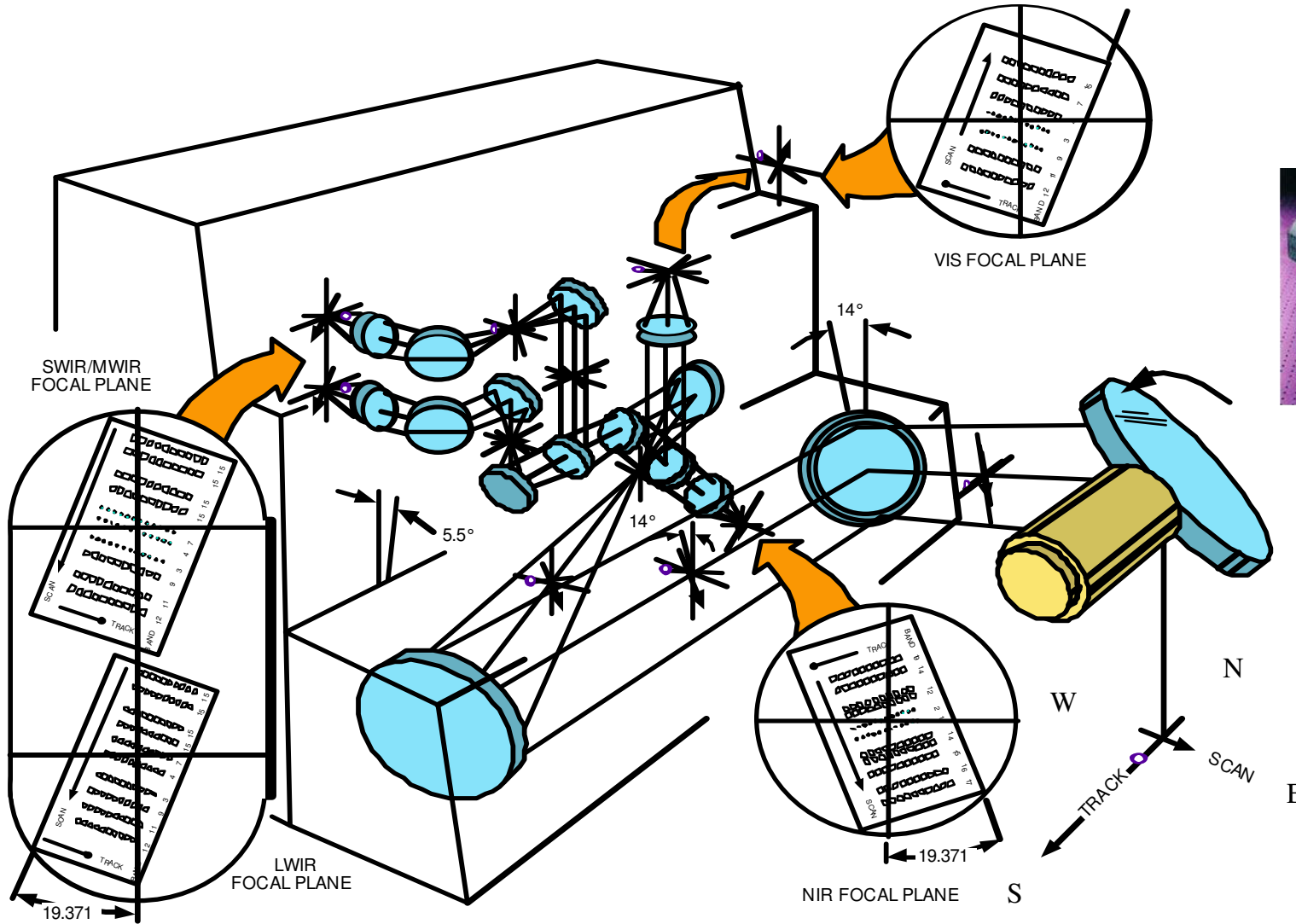
- **2-sided Paddle Wheel Scan Mirror**
 - (10km by 2330 km swath per 1.478 sec)
 - Day data rate = 10.6 Mbps, night data rate = 3.3 Mbps (100% duty cycle, 50% day and 50% night)

- **36 spectral bands (4 FPAs)**
 - Reflective solar bands (1-19, and 26)
 - Thermal emissive bands (20-25, 27-36)
- **3 nadir spatial resolutions**
 - 250m (1-2), 500m (3-7), and 1km (8-36)
- **On-Board Calibrators (OBC):**
 - Solar diffuser (SD)
 - SD stability monitor (SDSM)
 - Blackbody (BB)
 - Spectroradiometric calibration assembly (SRCA)
 - Space View (SV)

[More details in backup charts](#)

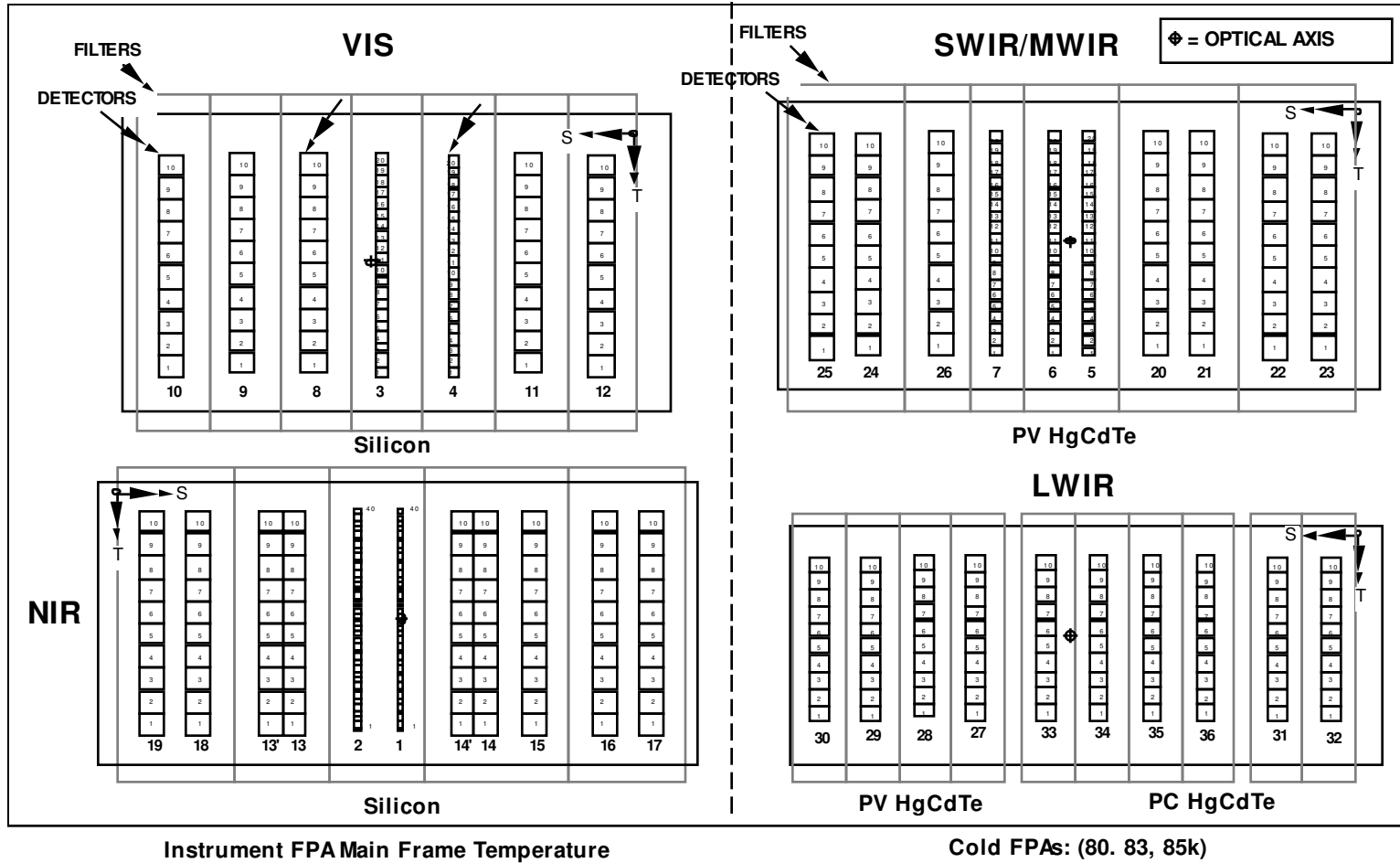


MODIS Optics System





MODIS Focal Plane Assemblies (FPA)



S: scan direction; T: track direction

B13 and B14 have 2 columns of detectors for TDI high and low gain output



MODIS Key Specifications



Primary Use	Band	Band width ¹	Spectral Radiance ²	Required SNR ³	Primary Use	Band	Band width ¹	Spectral Radiance ²	Required NEΔT(K) ⁴	
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128	Surface/Cloud Temperature	20	3.660 - 3.840	0.45 (300K)	0.05	
	2	841 - 876	24.7	201		21	3.929 - 3.989	2.38 (335K)	0.2	
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243		22	3.929 - 3.989	0.67 (300K)	0.07	
	4	545 - 565	29	228	23	4.020 - 4.080	0.79 (300K)	0.07		
	5	1230 - 1250	5.4	74	Atmospheric Temperature		24	4.433 - 4.498	0.17 (250K)	0.25
	6	1628 - 1652	7.3	275	25	4.482 - 4.549	0.59 (275K)	0.25		
	7	2105 - 2155	1	110	Cirrus Clouds Water Vapor		26	1.360 - 1.390	6	150 ³
Ocean Color/Phytoplankton/Bio geo chemistry	8	405 - 420	44.9	880	27	6.535 - 6.895	1.16 (240K)	0.25		
	9	438 - 448	41.9	838	28	7.175 - 7.475	2.18 (250K)	0.25		
	10	483 - 493	32.1	802	Cloud Properties		29	8.400 - 8.700	9.58 (300K)	0.05
	11	526 - 536	27.9	754	Ozone		30	9.580 - 9.880	3.69 (250K)	0.25
	12	546 - 556	21	750	Surface/Cloud Temperature		31	10.780 - 11.280	9.55 (300K)	0.05
	13	662 - 672	9.5	910	32	11.770 - 12.270	8.94 (300K)	0.05		
	14	673 - 683	8.7	1087	Cloud Top Altitude		33	13.185 - 13.485	4.52 (260K)	0.25
	15	743 - 753	10.2	586	34	13.485 - 13.785	3.76 (250K)	0.25		
Atmospheric Water Vapor	16	862 - 877	6.2	516	35	13.785 - 14.085	3.11 (240K)	0.25		
	17	890 - 920	10	167	36	14.085 - 14.385	2.08 (220K)	0.35		
	18	931 - 941	3.6	57	¹ Bands 1 to 19 are in nm; Bands 20 to 36 are in μm ² Spectral Radiance values are (W/m ² -μm-sr) ⁴ NEΔT = Noise-equivalent temperature difference					
	19	915 - 965	15	250						

³ SNR = Signal-to-noise ratio



Pre-launch Calibration Activities



- Radiometric (gain/response, non-linearity, SNR/NE Δ T, reference transfer, ...)
- Spectral (RSR, CW, OOB, reference transfer, ...)
- Spatial (alignment, FPA co-registration, BBR, MTF, reference transfer, ...)
- Polarization (RSB only)
- Response Versus Scan-angle (RVS)
- Others (ECAL, ADC, thermal, vibration, opto-mechanic, radiation, ...)

Evaluate Instrument Performance

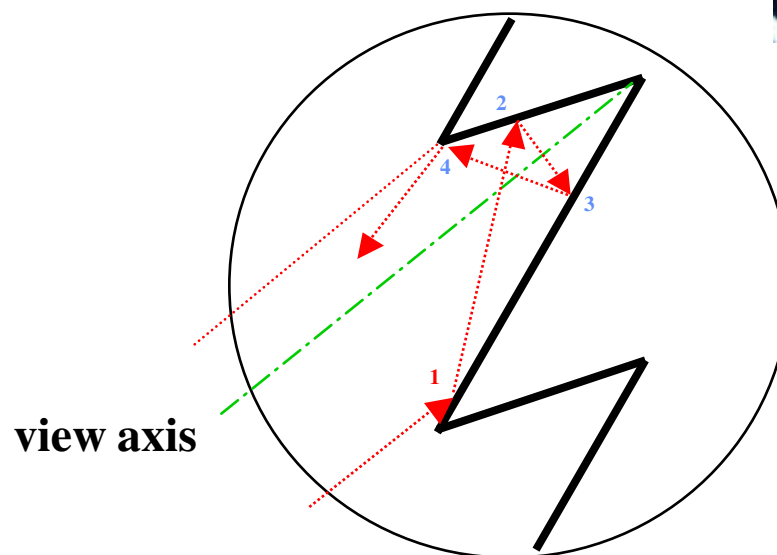
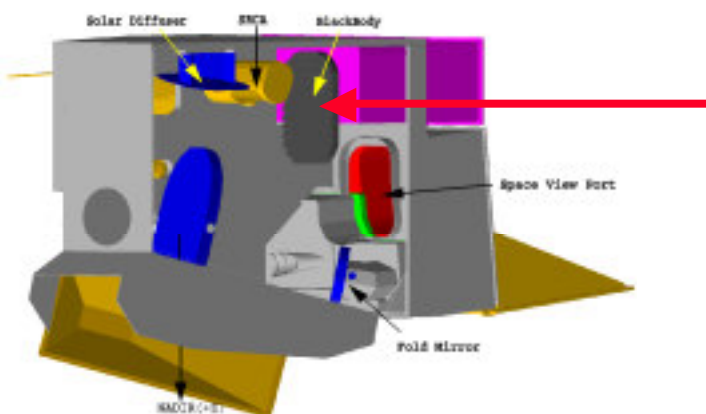
Verify Calibration Algorithm

Derive Calibration Parameters

Conduct Pre-launch (ground) to On-orbit (on-board) Calibration Reference Transfer



MODIS TEB Calibration Using Blackbody



Calibration coefficient, b_1 , from BB

$$RVS_{BB} \cdot \epsilon_{BB} \cdot L_{BB} + (RVS_{SV} - RVS_{BB}) \cdot L_{SM} + RVS_{BB} \cdot (1 - \epsilon_{BB}) \cdot \epsilon_{cav} \cdot L_{cav} = a_0 + b_1 \cdot dn_{BB} + a_2 \cdot dn_{BB}^2$$

→ b_1

Radiance (TOA), L_{EV}

$$RVS_{EV} \cdot L_{EV} + (RVS_{SV} - RVS_{EV}) \cdot L_{SM} = a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2$$

RVS: Response Versus Scan-angle
 ϵ : Emissivity
L: Spectral band averaged radiance
dn: Digital count with background corrected

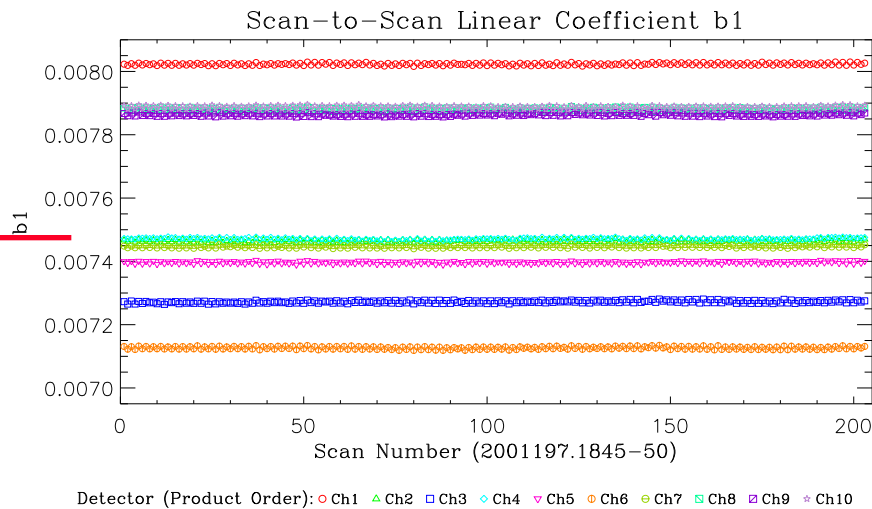
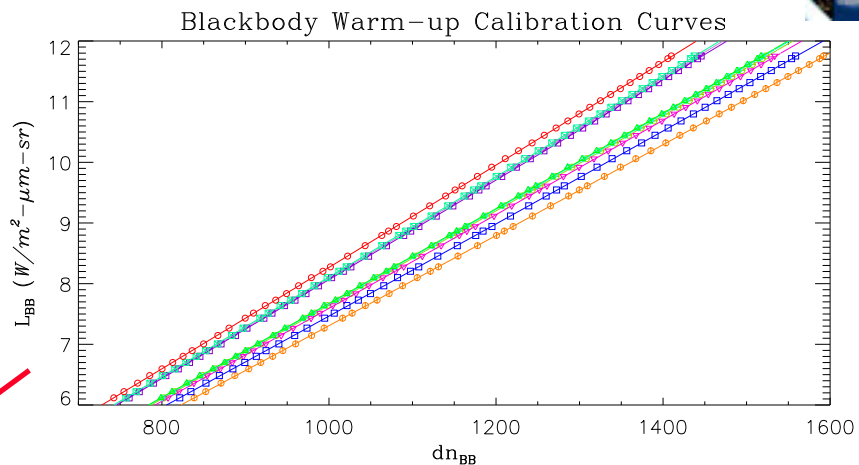


MODIS TEB Calibration Using Blackbody



BB from 270-317K provides a0 and a2

BB at T_BB provides b1 on a scan by scan basis



Other Calibration Issues:

B21 (Terra/Aqua)

PC Xtalk (Terra)

B33,35,36 (Aqua) at high T_BB

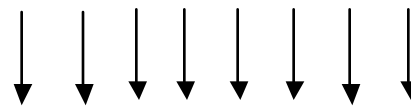


MODIS RSB Calibration Using SD/SDSM

Reflectance

$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn_{EV}^* \cdot d_{Earth-Sun}^2$$

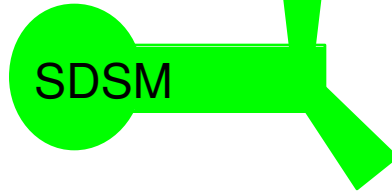
Sun



1.44% Screen

Optional 7.8% Screen

$$\Delta_{SD} = \frac{dc_{SD}}{dc_{Sun}}$$



$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{\langle dn_{SD}^* \rangle \cdot d_{Earth-Sun}^2} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$



Scan Mirror (MODIS)



SD

- Δ_{SD} : SD degradation factor;
- Γ_{SD} : SD screen vignetting function
- d : Earth-Sun distance
- dn^* : Corrected digital number; dc : Digital count of SDSM



MODIS RSB Calibration Using SD/SDSM



EV Radiance:

$$L_{EV} = \frac{E_{Sun} \cdot \rho_{EV} \cdot \cos(\theta_{EV})}{\pi \cdot d_{Earth_Sun(EV)}^2}$$

Solar Irradiance E_{SUN} :

0.4-0.8 μm Thuillier et al., 1998;

0.8-1.1 μm Neckel and Labs, 1984;

Above 1.1 μm Smith and Gottlieb, 1974

Others:

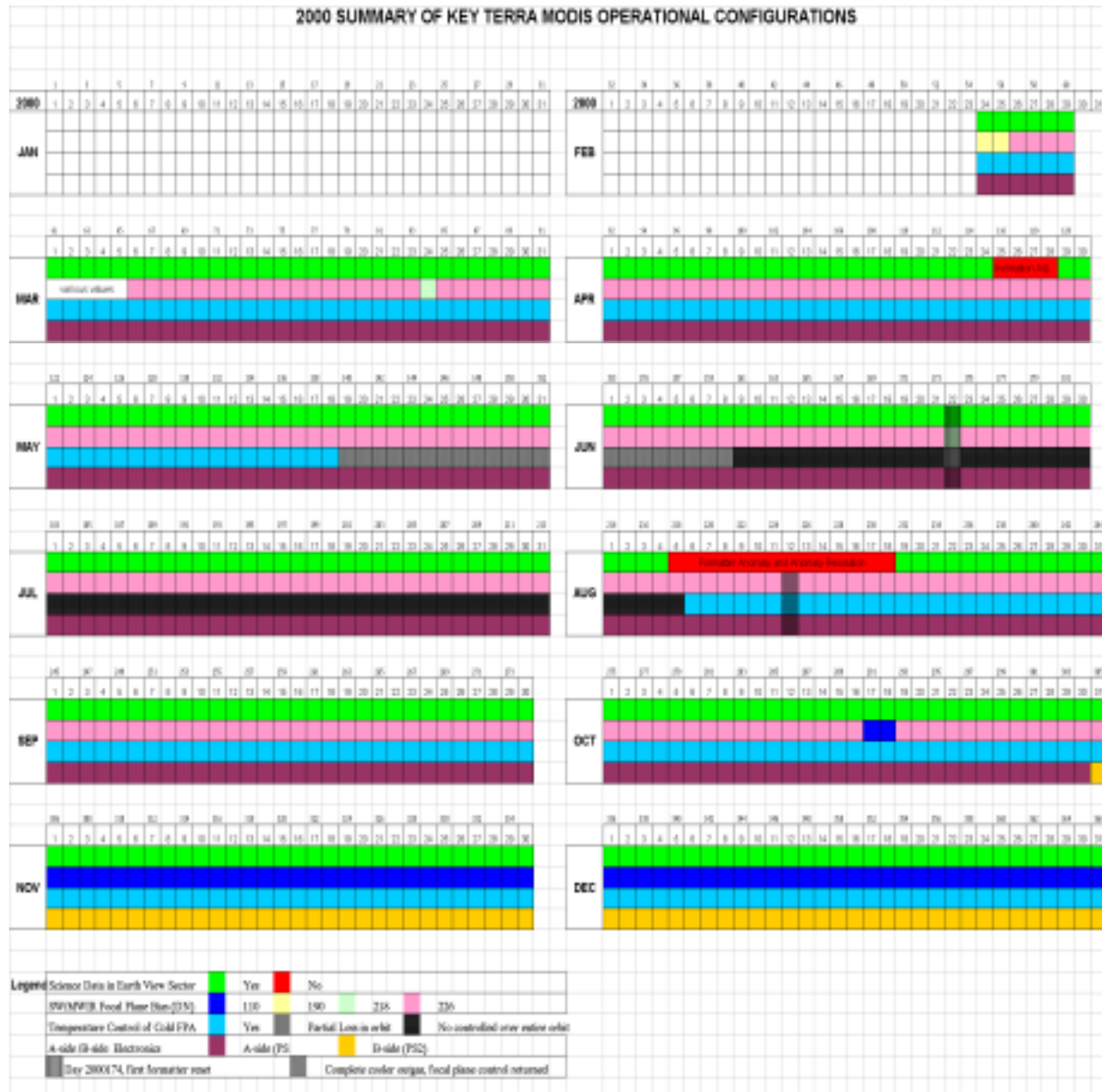
Thermal leak applied for SWIR bands (B5-7, B26)

Leak coefficients determined from EV night time data

B26 de-stripping algorithm added (from C. Moeller of Wisconsin)

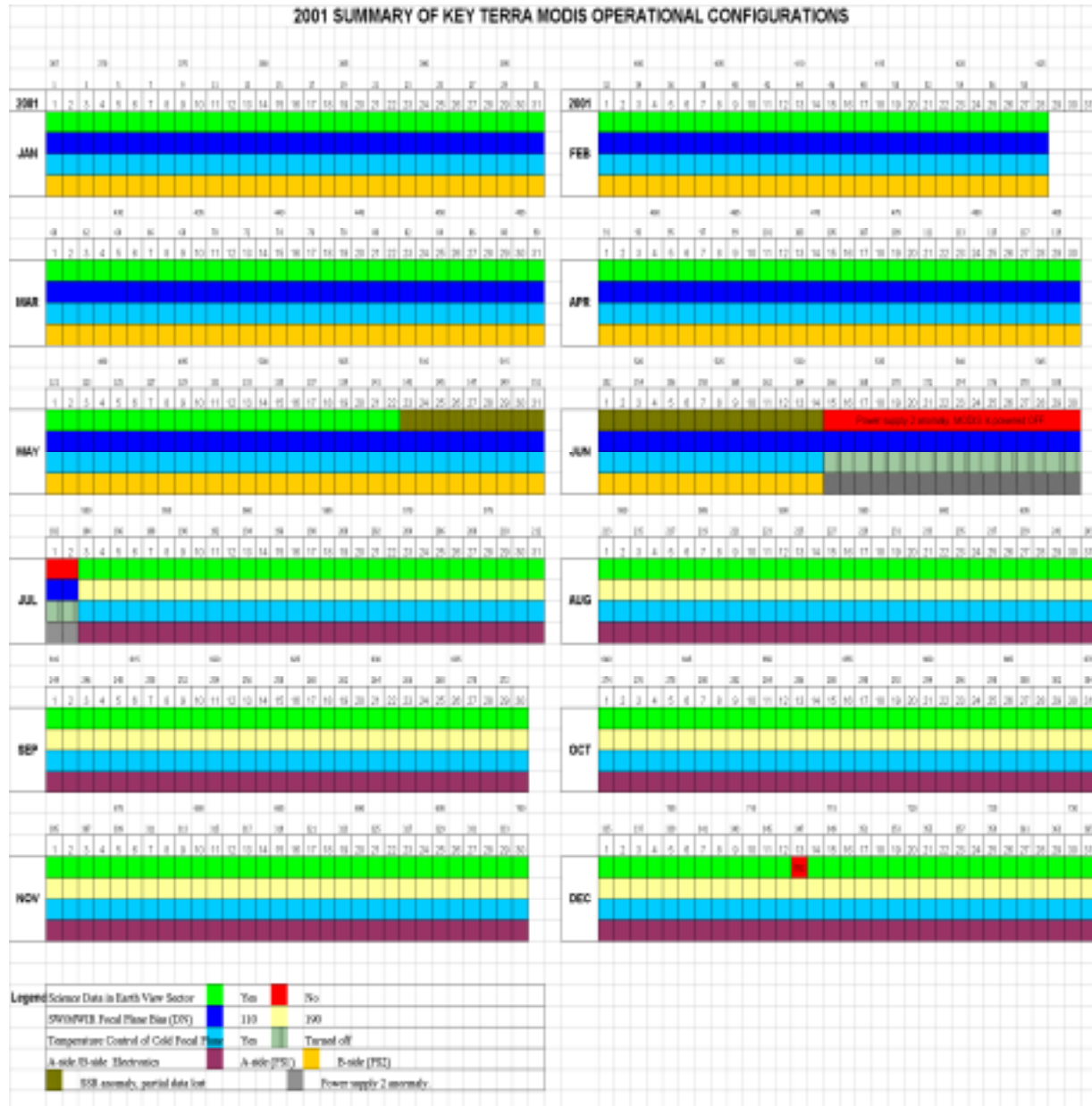


Terra Operational Configuration – 2000



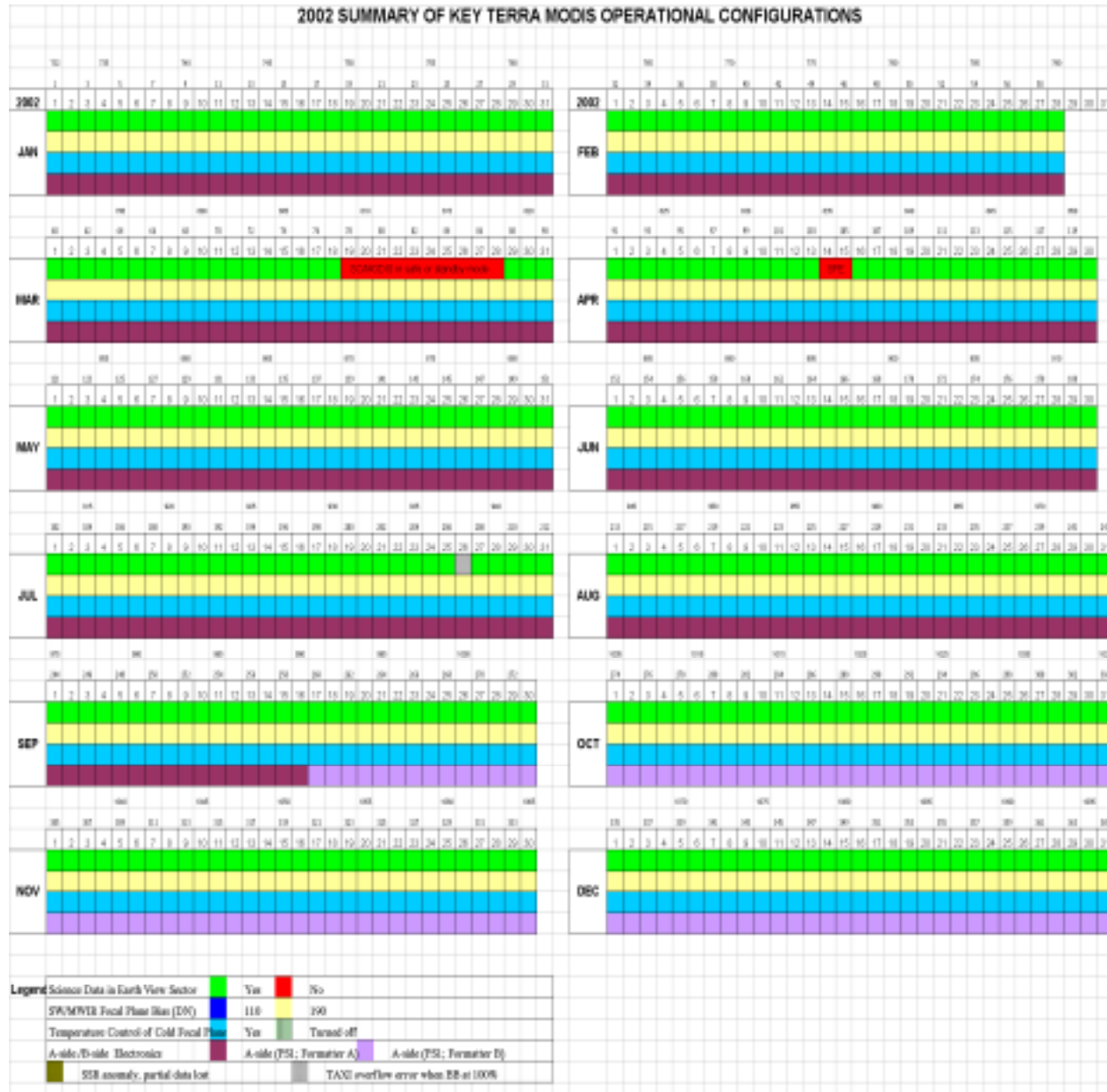


Terra Operational Configuration – 2001



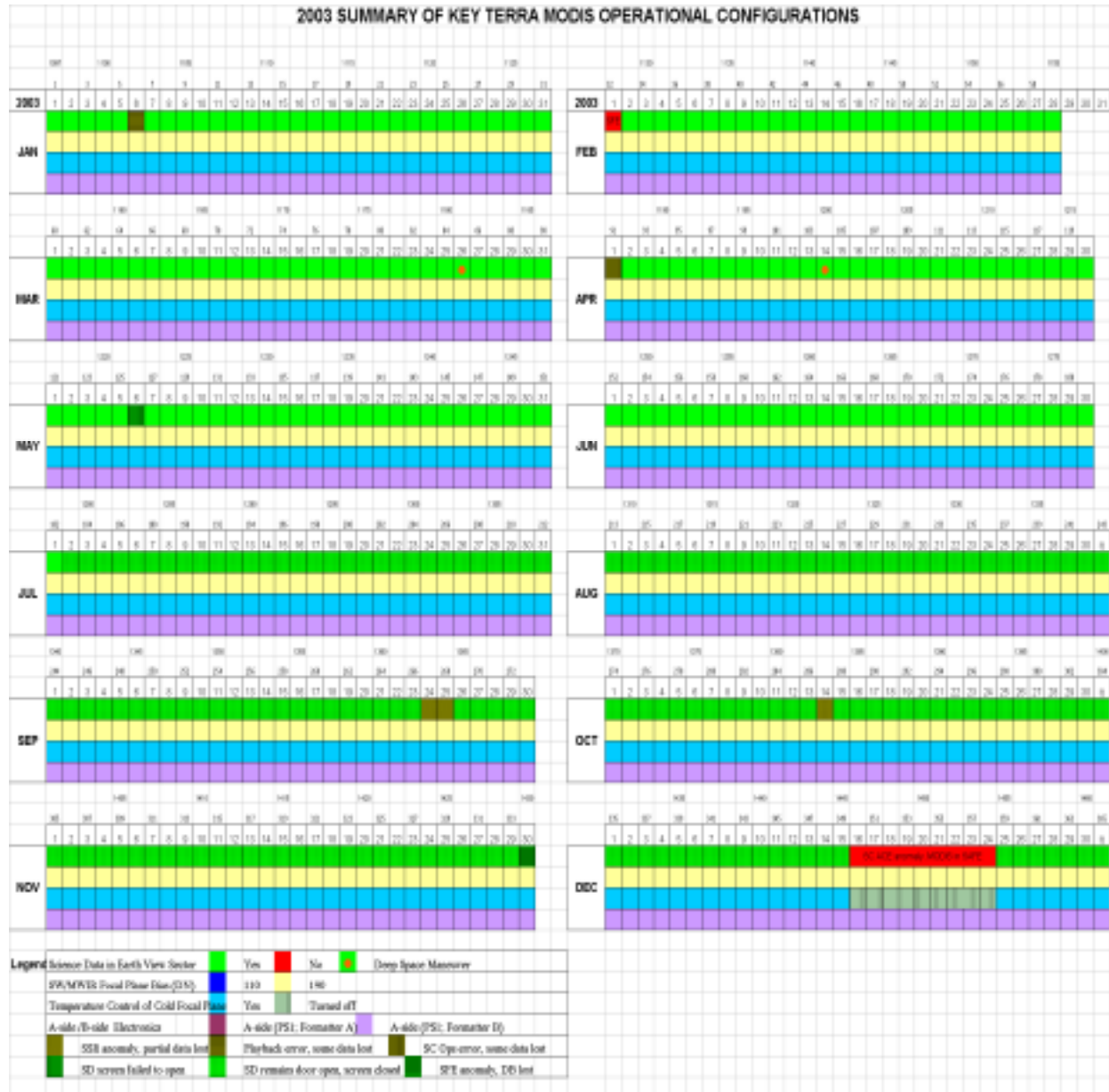


Terra Operational Configuration – 2002





Terra Operational Configuration – 2003



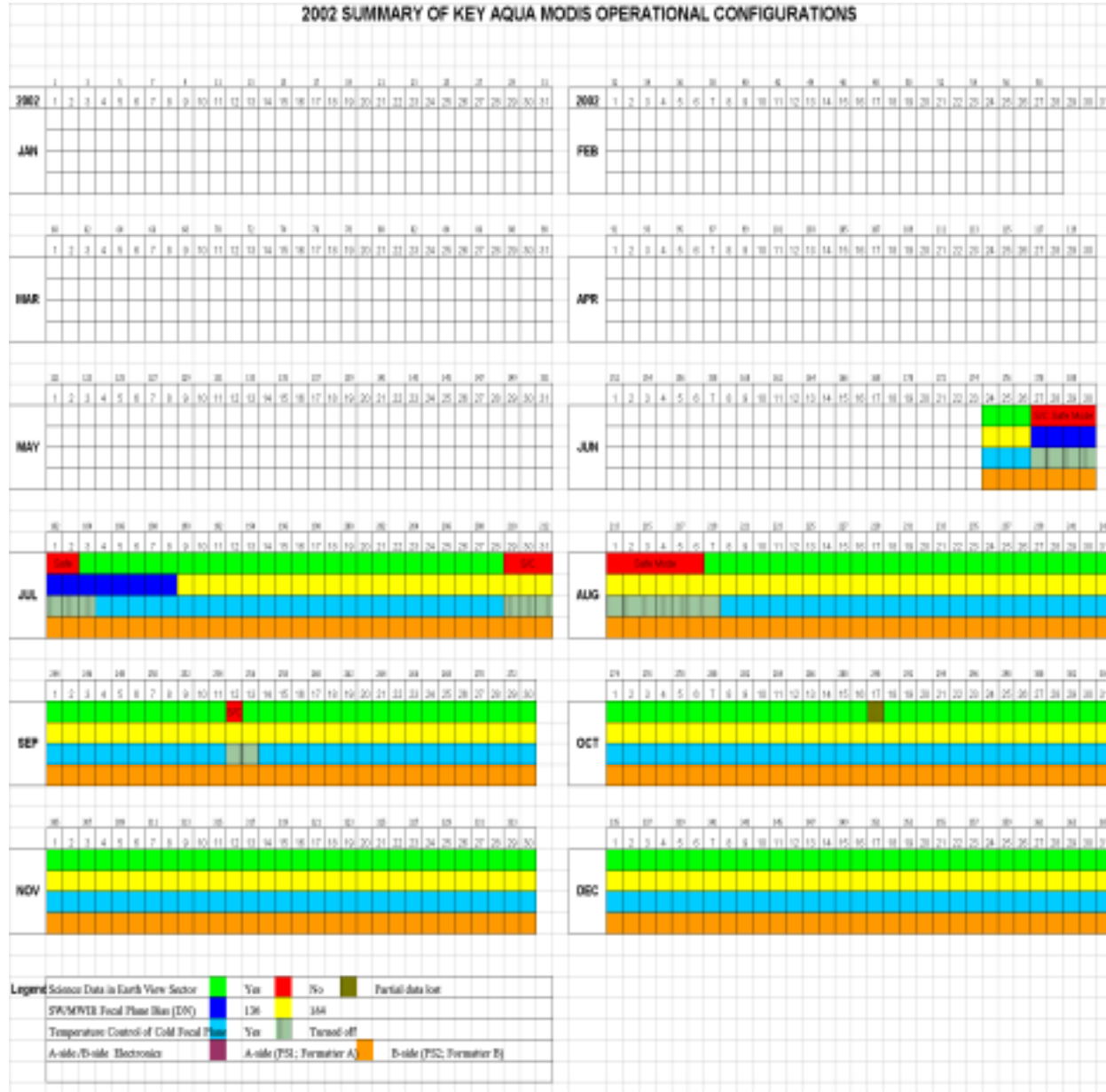


Terra Operational Configuration – 2004



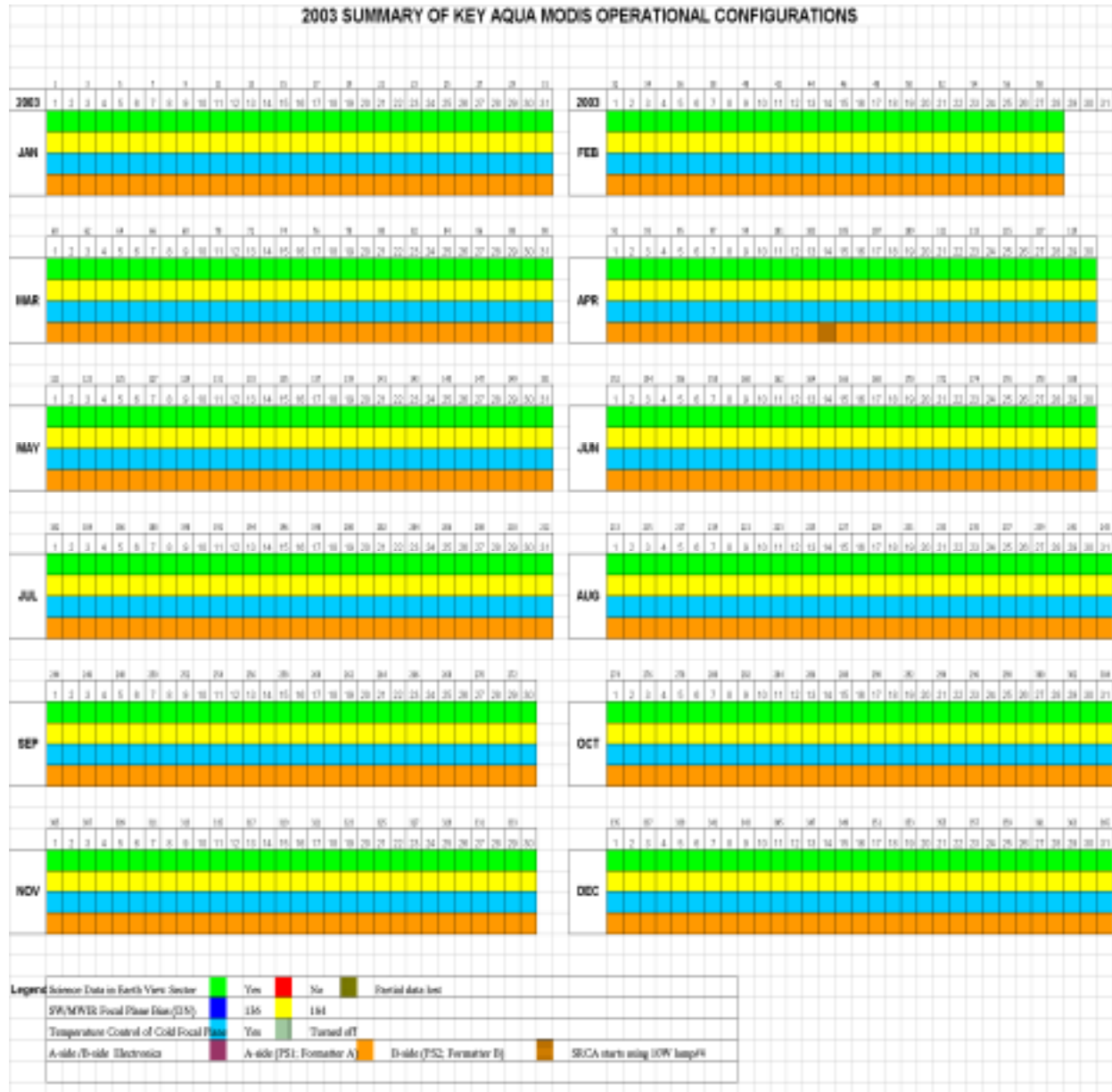


Aqua Operational Configuration – 2002



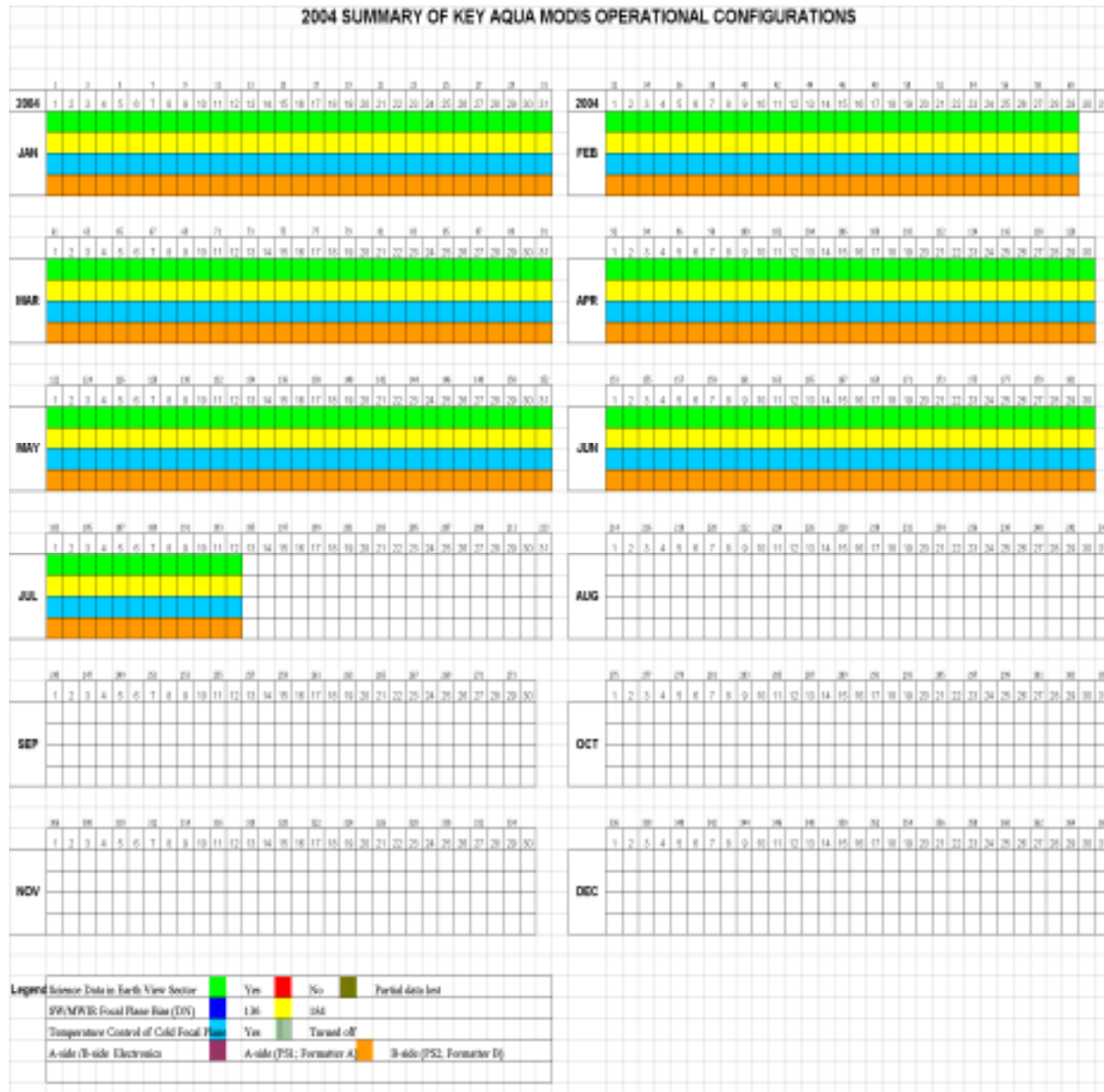


Aqua Operational Configuration – 2003





Aqua Operational Configuration – 2004





Production Changes to MOD_PR02 TERRA L1B Code



Version	Production Begin	Code Changes
V2.3.2_Terra	3/17/2000 (077 2000) 00:00	<ul style="list-style-type: none"> • Pre-Launch calibration (SMWIR Itwk/Vdet = 79/190).
V2.4.2_Terra	6/19/2000 (171 2000) 00:00	<ul style="list-style-type: none"> • Corrected indexing bug affecting emissive bands (this appeared in the product as if something was wrong with RVS). • Corrected bug for determining when the moon is in the SVP (sign error) • Maximum number of scans raised to 208 (consistent with L1A code)
V2.4.3_Terra	8/18/2000 (231 2000) 14:00	<ul style="list-style-type: none"> • Corrected bug in emissive bands preprocessing for PC bands X-talk. • Interpolation of scaled integers for non-functional (dead) detectors. • Time-dependent LUTs architecture.
V2.4.4_Terra	10/13/2000 (287 2000) 19:55	<ul style="list-style-type: none"> • New emissive band algorithm to compute <DNsv> with moon in SVP. • Corrected bug in emissive bands preprocessing for the 40 scans preceding or following a sector rotation or Ecal. • Corrected indexing bug in SWIR OOB correction (switch remained OFF). • Several other bug fixes affecting metadata.
V2.5.4_Terra	11/23/2000 (328 2000) 15:55	<ul style="list-style-type: none"> • Aqua compatible code and metadata • Removed obsolete metadata • New SWIR OOB algorithm & LUTs (for B-side only)
V2.5.5_Terra	02/13/2001 (044 2001) 13:55	<ul style="list-style-type: none"> • Misregistration of aggregated images corrected. • Detector average of Esun used for computation of band-dependent radiance_scales.



Production Changes to MOD_PR02 TERRA L1B Code (continued)



Version	Production Begin	Code Changes
V3.0.0_Terra	05/24/2001 (144 2001) 00:00	<ul style="list-style-type: none"> • Piecewise linear LUT capability added. • Reflective solar bands (RSBs) now check Space View subtracted values for saturation against lookup table. • For SWIR bands, when the moon is in the Space view port, method of computing average background DN same as that used for emissive bands.
V3.0.1_Terra	2/25/2002 (056 2002) 00:00	<ul style="list-style-type: none"> • Production of 250m and 500m resolution night data may be turned off. • Various code upgrades/bug fixes.
V4.1.2_Terra	01/30/2003 (030 2003) 01:55	<ul style="list-style-type: none"> • Band 26 Correction using aggregated Band 5 radiances inserted; turned ON • RVS correction changed to piecewise linear. • New flag TEB_B1_NOT_CALCULATED added. • Various code upgrades/bug fixes. • Metadata field "ProcessingEnvironment" is filled in from a call to "uname" from within the L1B code • R* LUT deleted • New OBC MCF files • RSB cal. coefficients reworked in LUTs
V4.2.0_Terra	08/22/2003 (234 2003) 02:00	<ul style="list-style-type: none"> • SWIR out-of-band correction "sending" band changed to value determined by LUT • Earth-Sun distance calculation corrected • NAD open/closed determination changed • Nominal platform height corrected • ANSI-C compliance
V4.3.0_Terra	12/22/2003 (356 2003) 22:35	<ul style="list-style-type: none"> • Maneuver flag changed to key on spacecraft attitude



Production Changes to MOD_PR02 TERRA L1B LUTs



Code Version	LUT versions	LUT Changes
V2.3.2_Terra	3	<ul style="list-style-type: none"> Emissive bands calibration and uncertainty LUTs Reflective bands calibration and uncertainty LUTs Uncertainty index scaling factors Detector quality flag “St. Patrick’s Day Update” LUTs derived from on-orbit data. SMWIR Itwk/Vdet = 110/226.
V2.4.2_Terra	0	<ul style="list-style-type: none"> Scientifically same as LUTs v2.3.2.3
V2.4.3_Terra	1	<ul style="list-style-type: none"> PC bands X-talk LUTs (from day 084 moon observation) Emissive bands calibration LUTs (from day 102 BB cool-down observation) RVS (for mirror side 2 only, from day 118 observation of NAD closed) L_max for bands 31 and 32 increased Reflective bands calibration LUTs (from day 171 solar diffuser observation) SWIR OOB leak correction turned OFF Detector quality flag – some detectors flagged as dead



Production Changes to MOD_PR02 TERRA L1B LUTs (continued)



Code Version	LUT versions	LUT Changes
V2.4.4_Terra	0, 1, 2	<ul style="list-style-type: none"> • Switch to B-side. Final values for SMWIR Itwk/Vdet = 79/110 • First implementation of time-dependent LUTs (A-side/B-side) • A-side calibration LUTs remained the same as before. • B-side emissive bands calibration LUTs (from day 305/306 BB observations) • Some B-side emissive bands uncertainty coefficient LUTs • L_max for several bands increased (both A and B side) • B-side reflective bands calibration LUTs (from day 305 solar diffuser observation) • B-side reflective bands uncertainty coefficient LUTs • Detector quality flag – all B-side detectors are functional. • B-side only: SWIR OOB correction switch turned ON and new SWIR LUTs (aimed at improving the first sub-sample of 500m bands)
V2.5.4_Terra	0	<ul style="list-style-type: none"> • New SWIR OOB LUTs (for B-side only)
V2.5.5_Terra	1, 2	<ul style="list-style-type: none"> • Added Reflective LUT "E_sun_over_pi"; deleted Emissive LUT "Number of overlap scans for temperatures" (No science content affected). • 2 detectors marked as non-functioning as of day 2001/019. • Time dependent LUT table pieces added to cover day 2000/063.



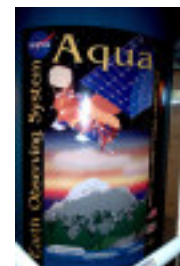
Production Changes to MOD_PR02 TERRA L1B LUTs (continued)



Code Version	LUT versions	LUT Changes
V3.0.0_Terra	2, 3, 4, 5, 6, 7	<ul style="list-style-type: none"> • RSB LUT update for Band 5 gain change (day 212/2001): • Time stamped table pieces added to RSB calibration tables. • Update for SWIR OOB correction on "A" side (after day 183/2001): • SWIR OOB correction switch turned ON. • New SWIR OOB correction table piece added. • RSB calibration table pieces reworked for SWIR OOB correction. • Update to Detector Quality Flags after return to "A" side electronics: • Detector quality flags QA table: Out-of-family gain flag set for 2 detectors; noisy detector flag set for one detector as of day 183 2001.
V3.0.1_Terra	0, 1	<ul style="list-style-type: none"> • Slope of fit for Band 3 calibration coefficients adjusted.
V4.1.2_Terra	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	<ul style="list-style-type: none"> • New RSB LUT calibration coefficients • Pre-launch SWIR corr. switch "OFF" • R* LUT deleted • RSB cal. coefficients reworked in LUTs • Detector quality flags QA table: noisy detector flag set for one detector as of day 183 2001 and for another detector as of day 086 2003. • Continuous Reflective Calibration Coefficient updates



Production Changes to MOD_PR02 TERRA L1B LUTs (continued)



Code Version	LUT versions	LUT Changes
V4.2.0_Terra	3, 4, 5, 6, 7, 8, 9	<ul style="list-style-type: none"> • SWIR out-of-band correction “sending” band changed to value determined by LUT • Name change for the three LUTs related to the Band 5 to Band 26 correction • Continuous Reflective Calibration Coefficient updates •
V4.3.0_Terra	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12	<ul style="list-style-type: none"> • LUTs updated from V4.2.0.8 • Attitude limit LUTs added for maneuver flagging as of Version 1 • Updates on coefficient for RVS computation • Updates on the coefficients for calculating a0 and a2, and on the value of b1 for each Band 21 detectors, derived using the BB warm-up data set from days 007- 008, 2004. • Detector quality flags QA table: Out-of-family gain” / “Noisy Detector” flag set for two detectors of Band 28. • Updated the SWIR bands correction coefficient. • Continuous Reflective Calibration Coefficient updates



Production Changes to MOD_PR02 AQUA L1B Code



Version	Production Begin	Code Changes
V3.1.0_Aqua	06/07/2002 (158 2002) 18:10	<ul style="list-style-type: none"> • Blackbody warmup saturation corr. • Aqua temp. conversion coefficients. • New flag TEB_B1_NOT_CALCULATED added.
V4.1.1_Aqua	10/31/2002 (304 2002) 00:15	<ul style="list-style-type: none"> • RVS corr. changed to piece-wise linear. • Various code upgrades/bug fixes.
V4.1.3_Aqua	01/22/2003 (022 2003) 09:55	<p>No Science Changes to the Code</p> <ul style="list-style-type: none"> • R* LUT deleted • New OBC MCF files
V4.2.1_Aqua	08/21/2003 (233 2003) 12:00	<ul style="list-style-type: none"> • SWIR out-of-band correction "sending" band changed to value determined by LUT • Destriping of Band 26 using aggregated Band 5 data added • Earth-Sun distance calc. corrected • NAD open/closed determination changed • Platform height corrected • ANSI-C compliance
V4.3.1_Aqua	06/02/2002 (183 2002) 15:25 (Reprocessing)	<ul style="list-style-type: none"> • Used for first reprocessing effort, Collection 4 • Maneuver flag changed to key on spacecraft attitude



Production Changes to MOD_PR02 AQUA L1B LUTs



Code Version	LUT versions	LUT Changes
V3.1.0_Aqua	0, 1, 2, 3	<ul style="list-style-type: none"> • Pre-launch LUTs inserted. • Several LUTs updated after more Pre-launch analysis • New RSB and TEB calibration coefficient LUTs • New BB temp. saturation limits • Detector quality flags changed • SWIR correction switch ON
V4.1.1_Aqua	0,1	<ul style="list-style-type: none"> • LUTs updated from V3.1.0.3 • New RSB calibration coefficient LUTs using SD degradation • Band 21 b1 table piece added • Detector quality flags changed
V4.1.3_Aqua	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	<ul style="list-style-type: none"> • LUTs updated from V4.1.1.1 • R* LUT deleted • Continuous Reflective Calibration Coefficient updates • Band 21, Detector 9 (product order) changed to “noisy” as of Version 3



Production Changes to MOD_PR02 AQUA L1B LUTs (continued)



Code Version	LUT versions	LUT Changes
V4.2.1_Aqua	4, 5, 6, 7, 8	<ul style="list-style-type: none"> • LUTs updated from V4.2.1.3, which is parallel to V4.1.3.10 • SWIR correction sending band changed to Band 28 before 2003104, Band 25 after as of Version 4 • Continuous Reflective Calibration Coefficient updates • LUTs added for Band 26 destriping using aggregated Band 5 data as of V. 4
V4.3.1_Aqua	1, 2, 3, 4, 5, 6, 7, 8	<ul style="list-style-type: none"> • LUTs updated from V4.2.1.8 • Reflective Calibration Coefficients reworked for reprocessing as of Version 1 <ul style="list-style-type: none"> • Improved SD sun angles used • BRF and vignetting as a function of SD zenith and azimuth used • Temperature using Kinst used • Non-SWIR bands fitted with smooth function • SWIR bands <ul style="list-style-type: none"> • Step functions before 2002255, Linear functions thereafter • SWIR correction sending band changed to Band 25 for entire mission • Attitude limit LUTs added for maneuver flagging as of Version 1 • Updates on coefficient for RVS computation and value of EV pixel dn to treat as saturated