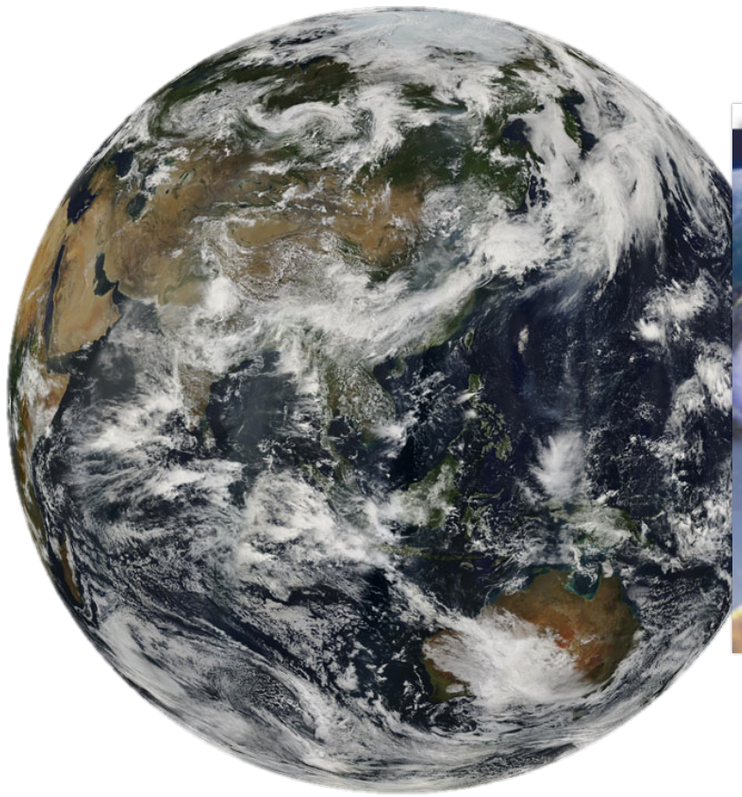
MODIS Atmosphere Team Webinar Series #1: Overview of Collection 6 Atmosphere Products and Level-1B Calibration

Steven Platnick and Xiaoxiong (Jack) Xiong

NASA Goddard Space Flight Center, Greenbelt, MD

25 June 2014



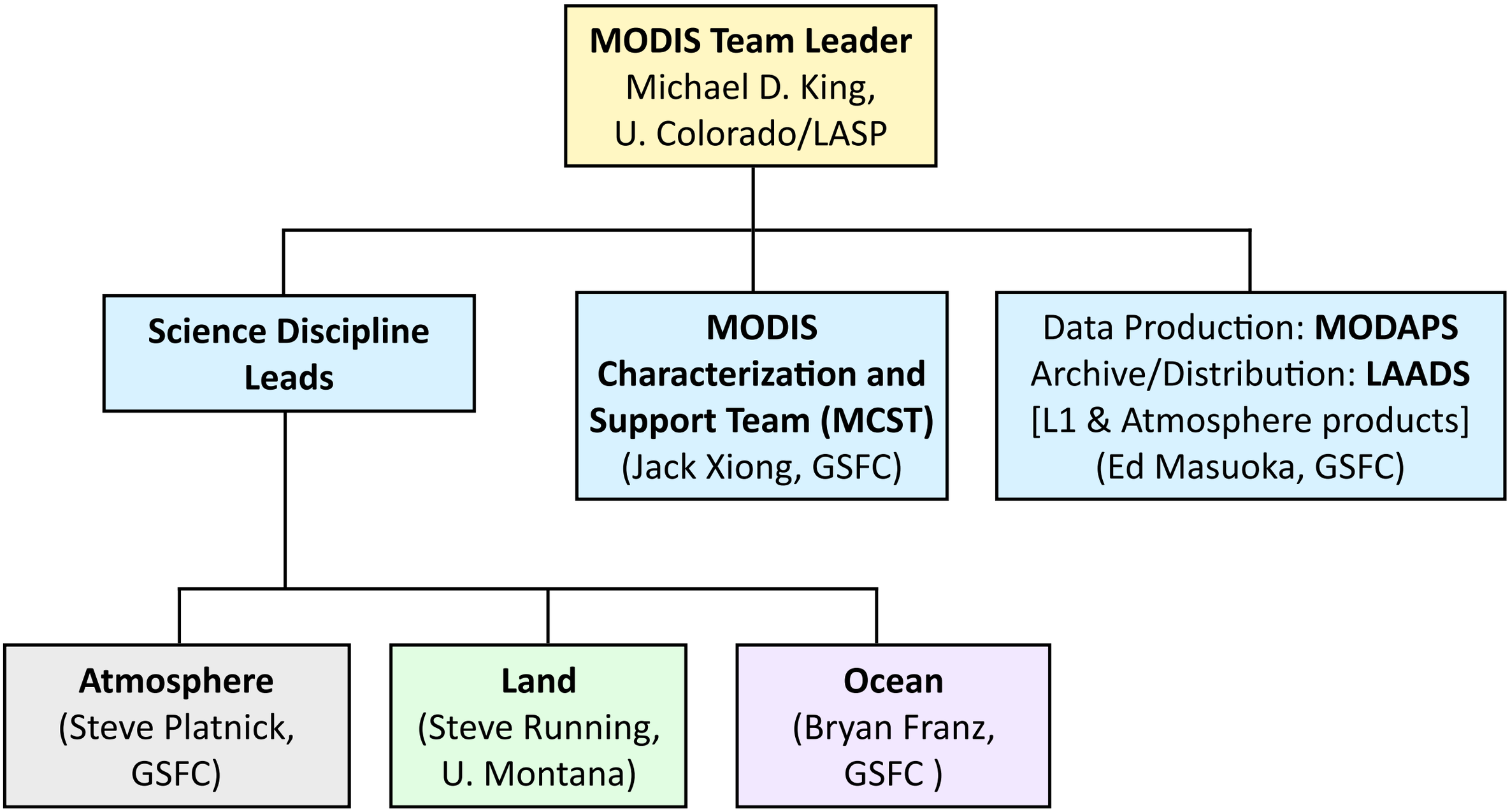
Atmosphere Team Webinar Schedule

http://aerocenter.gsfc.nasa.gov/ext/registration/

Topic	Presenter(s)	Date
Overview of Collect 6 update L1 Calibration Overview	Steve Platnick Jack Xiong	25-Jun-14
MODIS Dark Target Global 10 Km Product	Rob Levy	2-Jul-14
MODIS Aerosols Deep Blue	Andy Sayer	9-Jul-14
MODIS Aerosols Merged Dark Target: Deep Blue Product	Rob Levy / Andy Sayer	16-Jul-14
MODIS Dark Target 3 Km Product	Leigh Munchak	23-Jul-14
MOD035 Cloud Mask and Clear Sky Products atmosphere profile and clear sky radiance maps	Steve Ackerman	13-Aug-14
MOD06 Cloud Top Properties Product	Paul Menzel	20-Aug-14
MOD06 Cloud Optical Properties Product	Steve Platnick	27-Aug-14
MOD08 Level 3 Product	Steve Platnick / Bill Ridgway	3-Sep-14
Archives/Data Acquisition: LAADSWEB, MIRADOR, ECHO-Reverb	To Be Determined.	10-Sep-14
MODIS Atmosphere Educational Materials & Resources	Richard Kleidman	17-Sep-14
Giovanni - Aerosols Express	Jim Acker	24-Sep-14
MAIAC 1 Km Aerosol Product	Alexei Lyapustin	01-Oct-14

1. MODIS and Atmosphere Team Overview

MODIS Organization and People



Nomenclature and Acronyms

- Product "Level" designations
  - Level-0 (**L0**): raw instrument data (digital counts)
  - Level-1B (**L1B**): calibrated/geolocated instrument data
  - Level-2 (**L2**): derived geophysical retrieval data ("pixel" level)
  - Level-3 (**L3**): gridded data (spatial and/or temporal aggregation of geophysical products)
  - Level-4: combination of model and measured/retrieved data (not generated by atmosphere team)
- MODIS "Collection"
  - refers to a (re)processing production run with consistent algorithms (or nearly consistent)
  - **C5** production began began in summer 2006, reprocessing completed about a year later. C51 update in late 2008. Collection 6 (**C6**) Aqua L2 production began in Dec 2013.

MODIS Standardized Filenaming Convention

NASA Earth Science Data filenames for MODIS

Terra MODIS: **MOD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHHMMSS.hdf**

Aqua MODIS: **MYD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHHMMSS.hdf**

Definition of highlighted text:

MOD06 = Earth Science Data Type name

L2 = Denotes a Level-2 product (or L3 for Level-3, etc.)

A = indicates following date/time information is for the acquisition (observation)

YYYYDDD = acquisition year and day-of-year

HHMM = acquisition hour and minute start time

CCC = collection (e.g., '006' for Collection 6)

YYYYDDDHHMMSS = production data and time

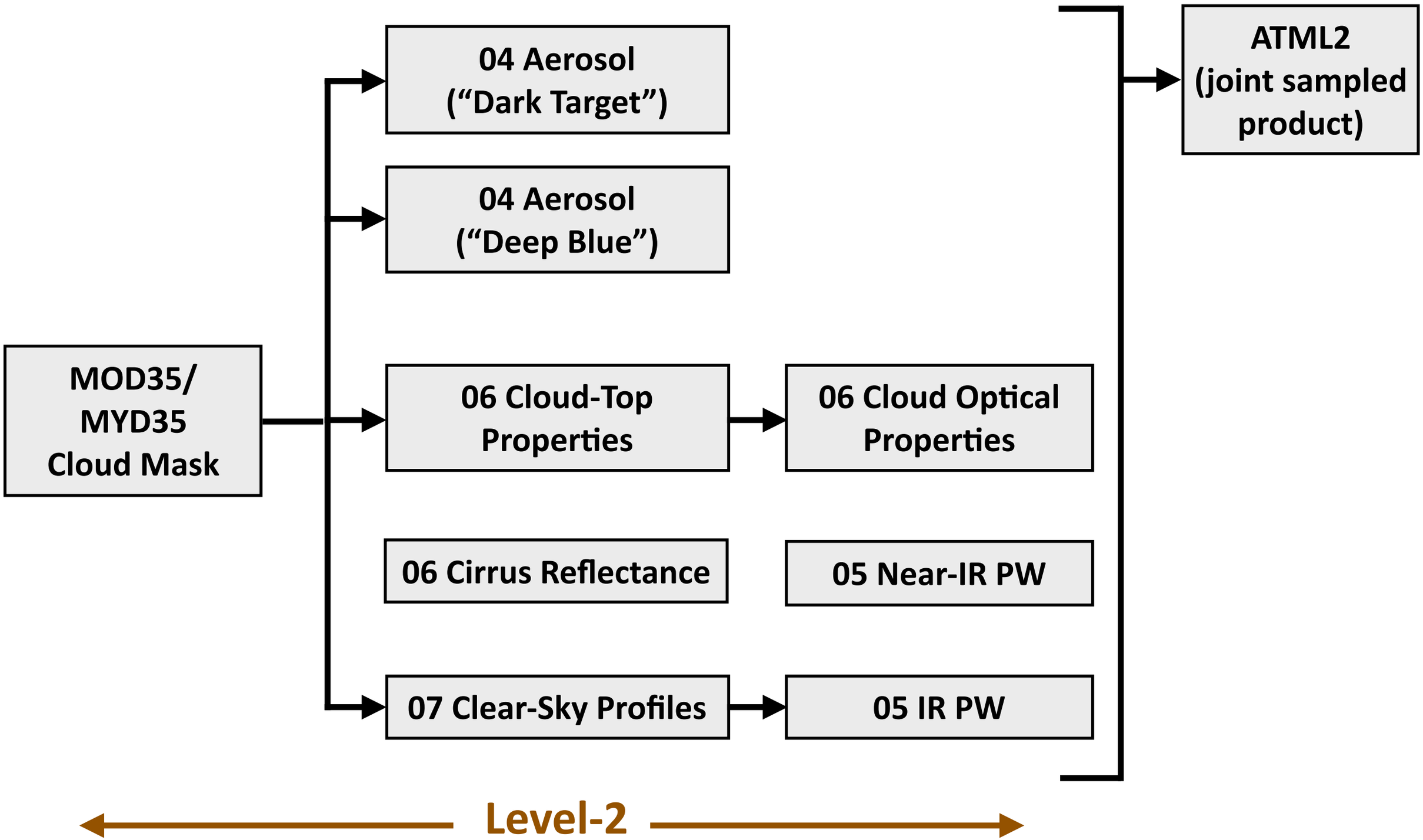
hdf = denotes HDF file format

MODIS Atmosphere Team Product Organization and People

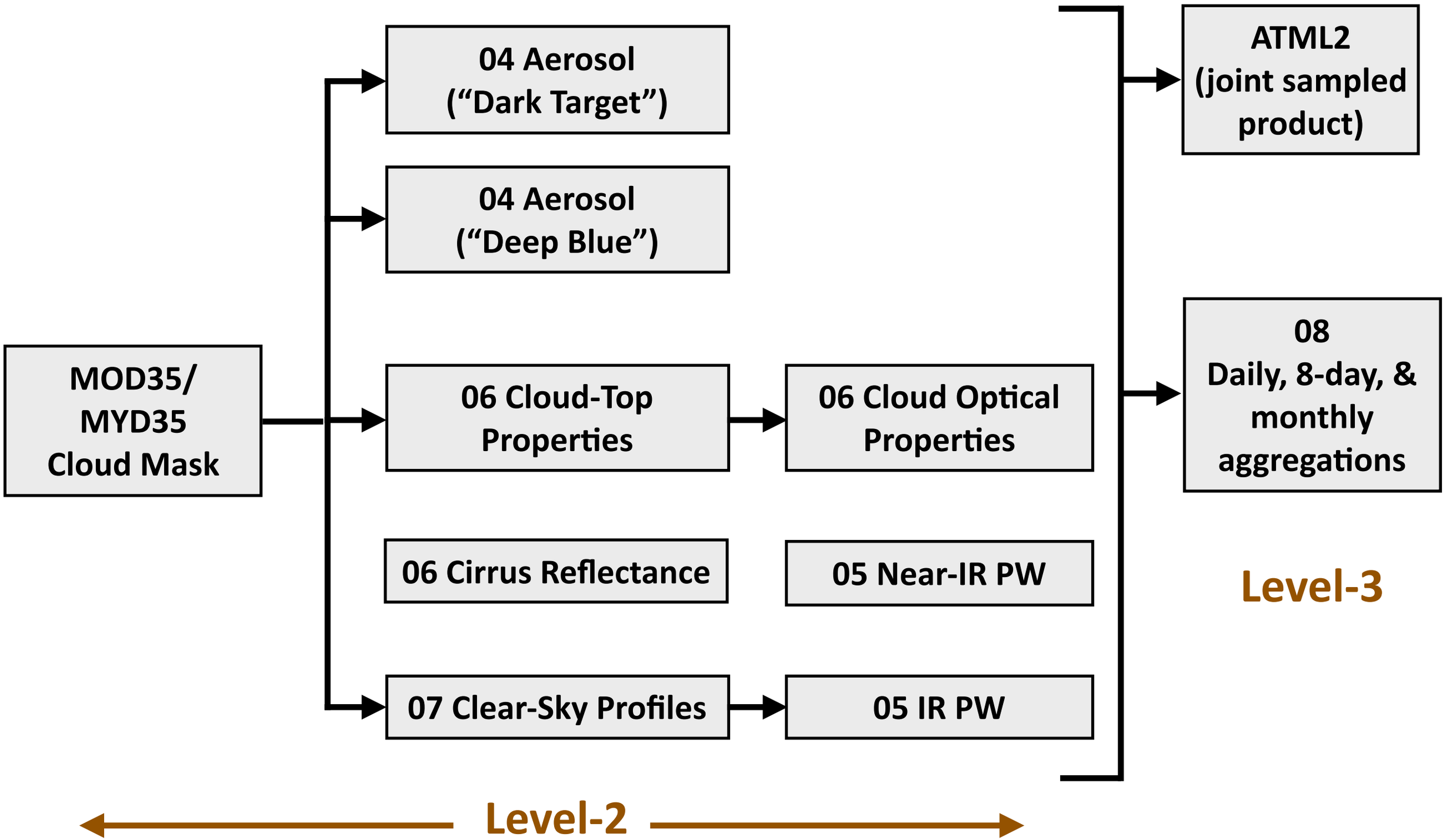
MOD35/ MYD35 Cloud Mask

Level-2

MODIS Atmosphere Team Product Organization and People



MODIS Atmosphere Team Product Organization and People



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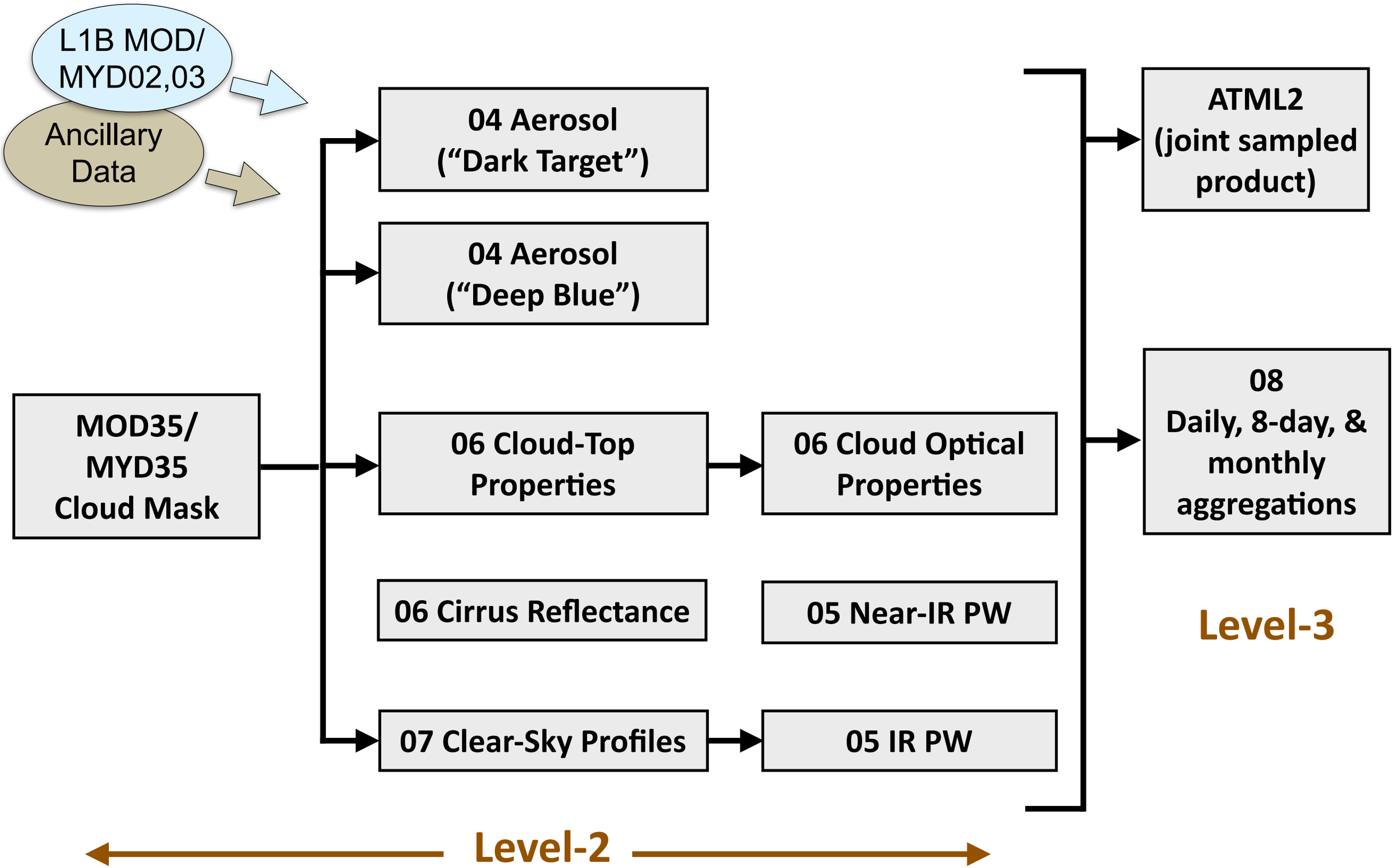

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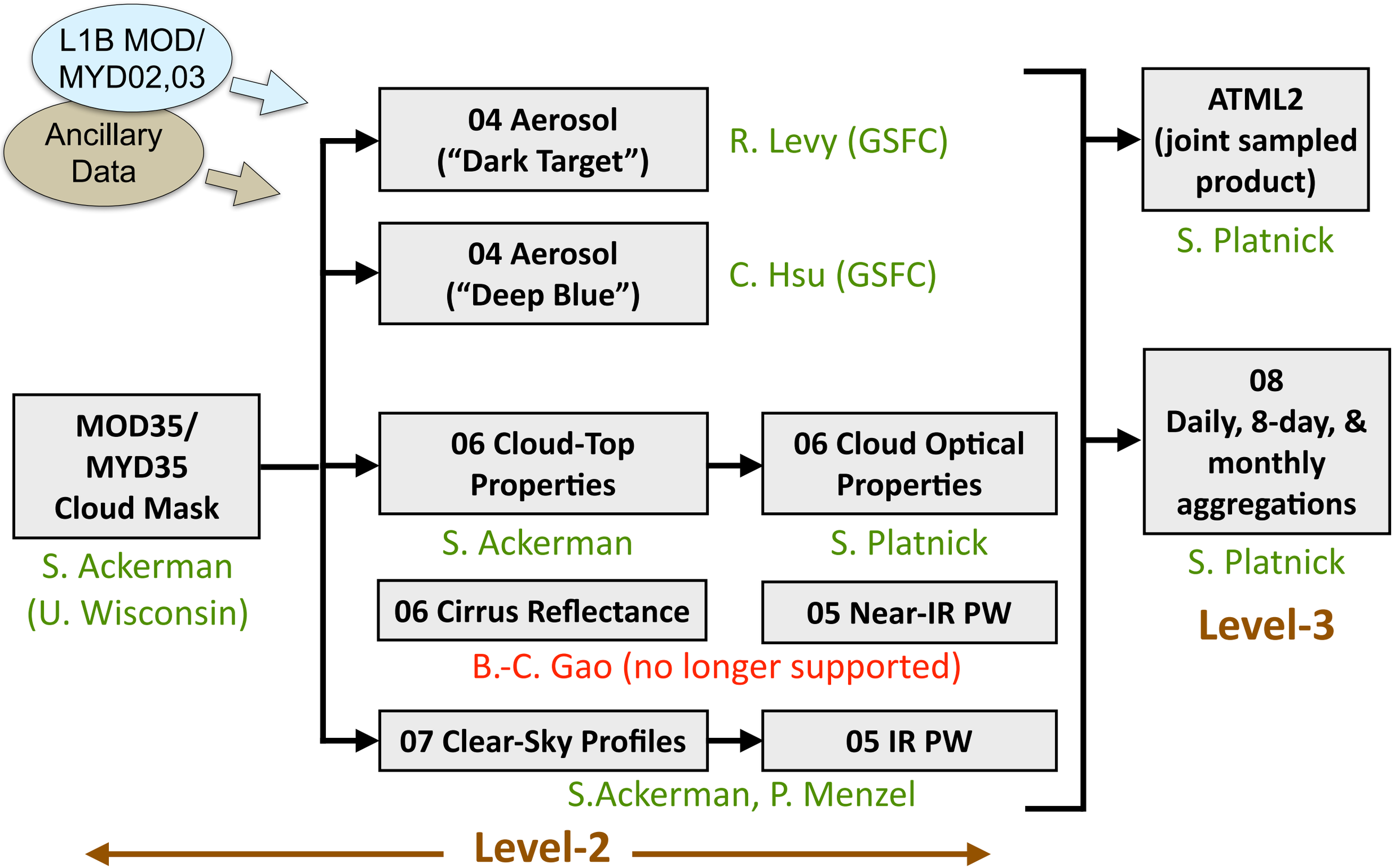


Status of MODIS C6 Production

- L1B (details in later slide)
- Atmosphere Products
  - Cloud Mask (MOD35) and Atmospheric Profile (MOD07) Terra/Aqua reprocessing started in 2012 and has completed
  - Reprocessing of other L2 products from Aqua MODIS started on 12-06-2013 and has completed
  - Aqua L3 expected to begin in late June
  - Terra reprocessing to start after completion of Aqua L3
- Land Products
  - Evaluation of C6 algorithm changes is in progress.
  - Reprocessing for the first tier of products expected to start in June 2014.
- Both C6 and C5 processing streams will continue for about a year

Useful Links

- Atmosphere Team Web Site
  - Home page, news, etc.: modis-atmos.gsfc.nasa.gov
  - L2 Global Browse imagery: http://modis-atmos.gsfc.nasa.gov/IMAGES/index.html. Selected products, resolution, longitude.
  - L3 Aqua MODIS Browse: TBD
  - C6 Algorithm and Product Documents: modis-atmos.gsfc.nasa.gov/products_C006update.html
  - Known problems page: modis-atmos.gsfc.nasa.gov/validation.html
- Product Distribution (LAADS)
  - Home page: ladsweb.nascom.nasa.gov/data/ (search, status, etc.)
  - ftp: ladsweb.nascom.nasa.gov/data/ftp_site.html

    e.g., allData/6/MYD04_L2/2014/001/<*filename*>

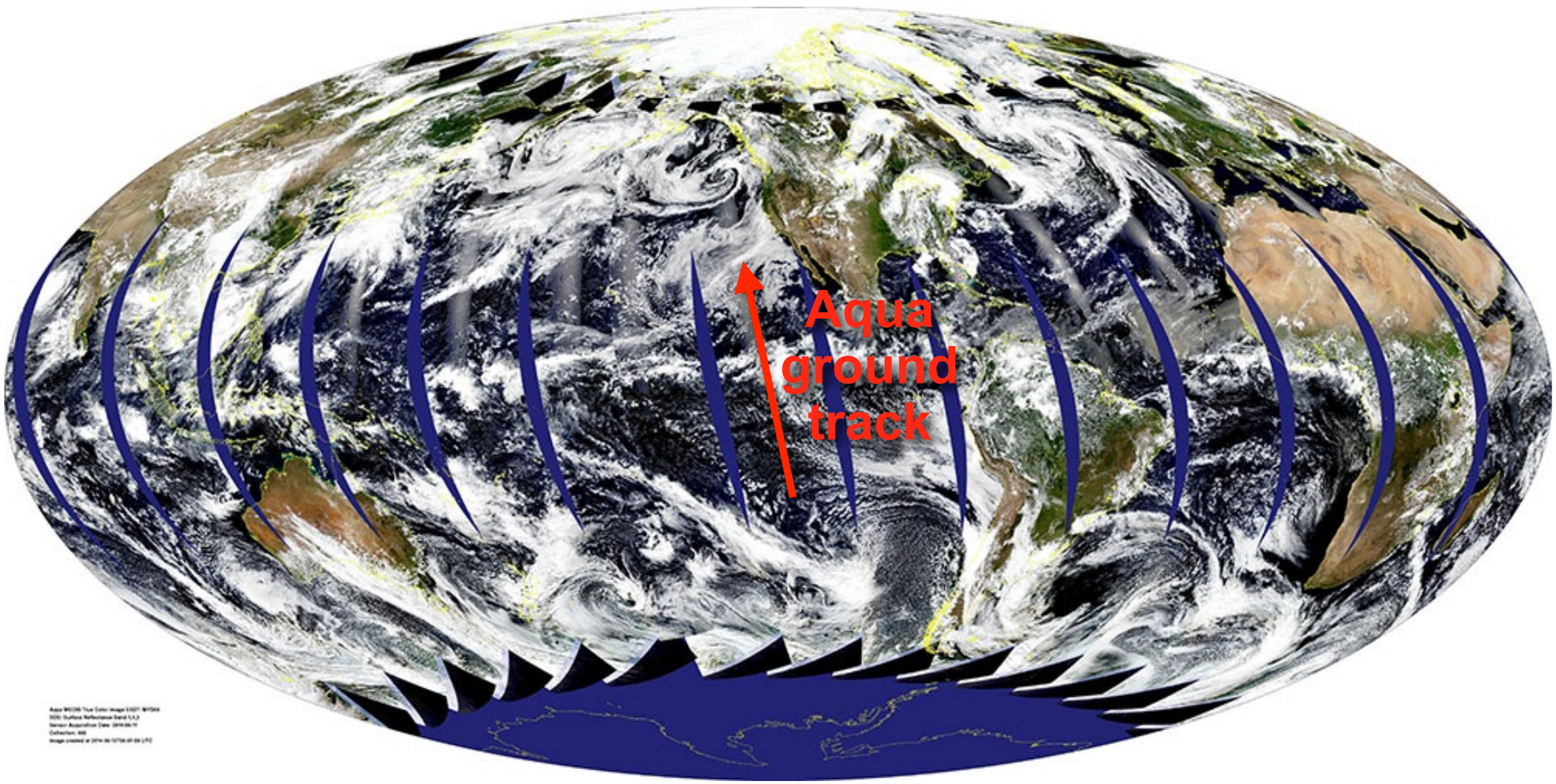
2. MODIS Characterization and Calibration

Instrument Overview

- 36 Spectral Bands, from visible through IR (0.41–14.2 μm)
- Moderate resolution with wide swath global coverage (~2330 km or 1354 1km pixels)
  - “whisk broom” scanner: two-sided paddle wheel scan mirror
  - changing angle of incidence on mirror across the swath
- Must meet a variety of science requirements (aerosol, clouds, land, ocean color)
- Radiometric uncertainty requirements, specified at typical signal level & within 45° of nadir scan angle:
  - Reflective Solar Bands (RSB) reflectance: 2%
  - Thermal Emissive Bands (TEB) radiance: 1% for most bands; 0.5% [b31, b32], 0.75% [b20], 10% [b21 (3.95 μm)]
  - additional 1% uncertainty applied for observations at other scan angles and signal levels (between 0.3 typical – 0.9 max spec).

Polar Sun-synchronous, 704 km, 16-day repeat

- Terra: 1030 LT equatorial crossing (descending)
- Aqua: 1330 LT equatorial crossing (ascending), in A-Train constellation

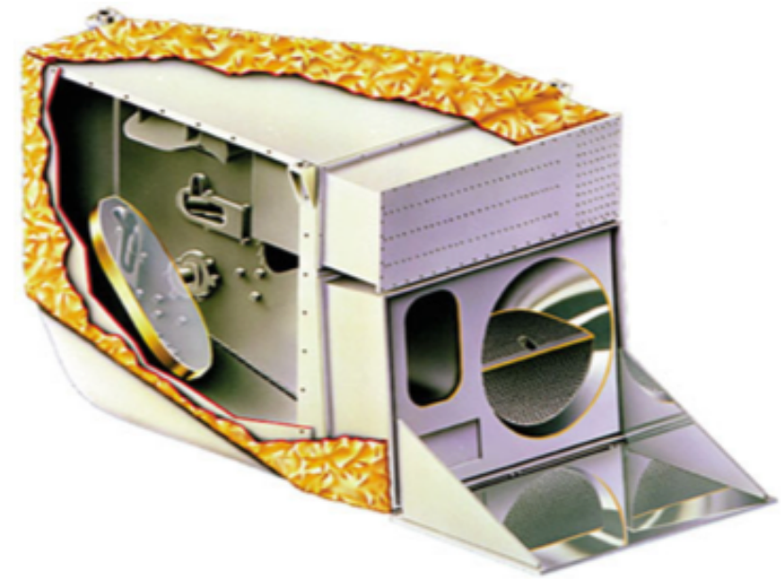


Aqua true color composite: 13 June 2014
(modis-atmos.gsfc.nasa.gov/IMAGES/index.html)

MODIS Spectral Bands (Channels)

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

20 Reflective Solar Bands



Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
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	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

[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)
[3] SNR = Signal-to-noise ratio
[4] NE(delta)T = Noise-equivalent temperature difference

Note: Performance goal is 30-40% better than required

16 Thermal Emissive Bands (TEB)

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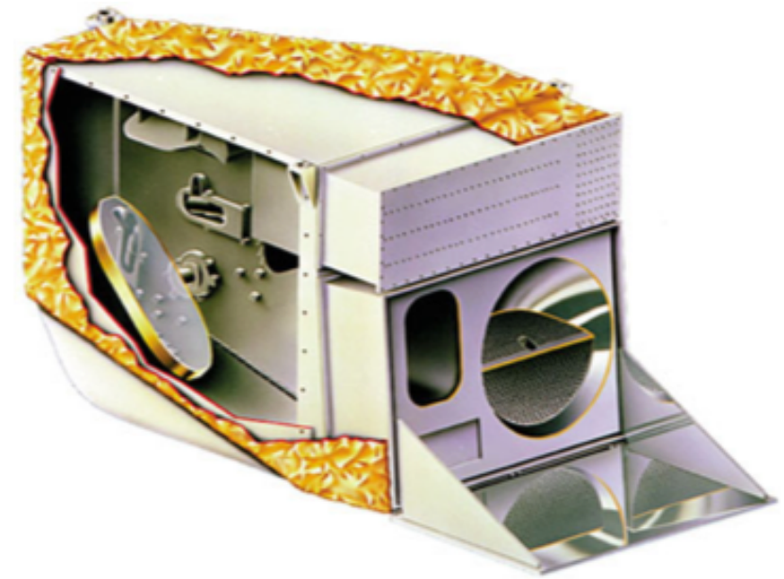

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16 Thermal Emissive Bands (TEB)

Spatial Resolution at Nadir

- 250 m: bands 1-2 (**MOD02QKM**)
- 500 m: bands 3-7 (**MOD02HKM** incl. 250 m bands)
- 1000 m: all others (**MOD021KM** incl. 250 & 500 m bands)

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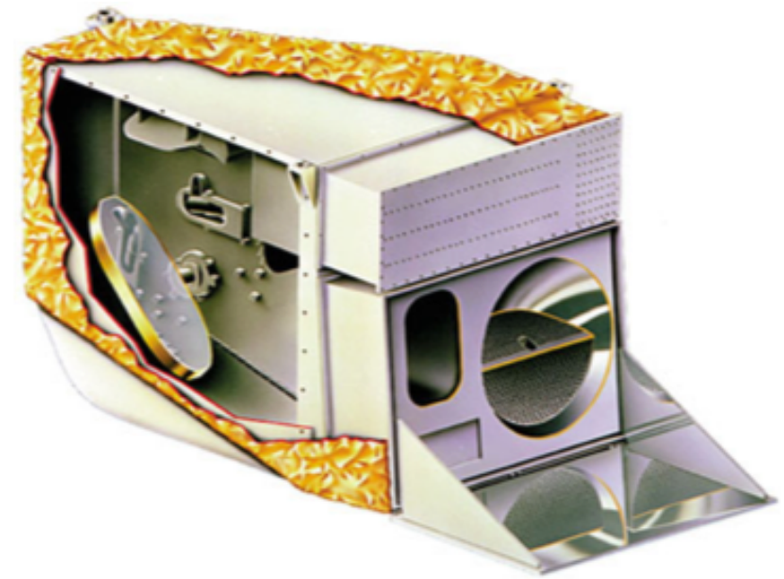

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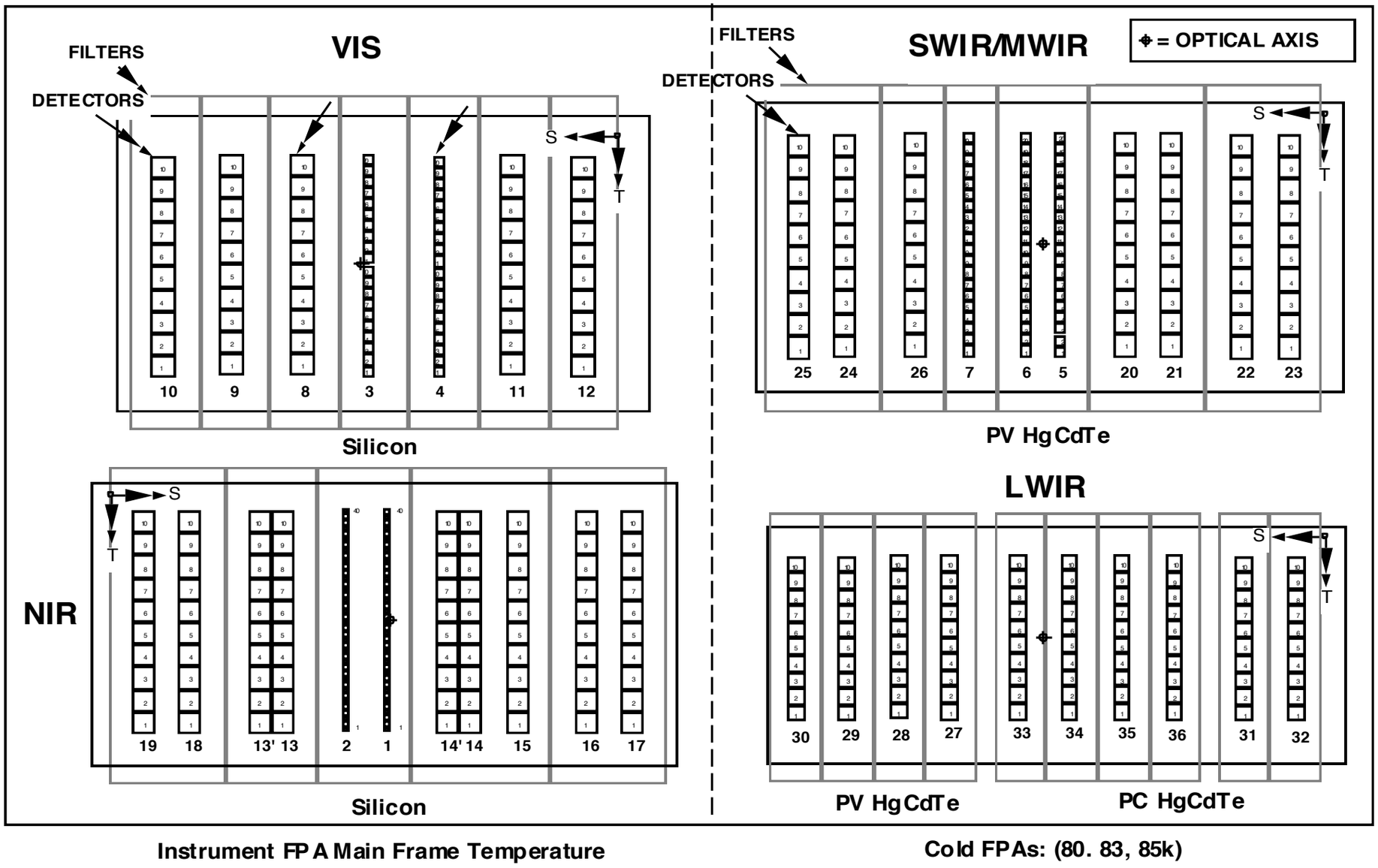
Note: Aqua-MODIS b6 (1.6 µm) has 13 inoperable detectors ['noisy' detector list in backup slides]

Four Detector Focal Planes

each mirror side sweeps out a 10km along-track image



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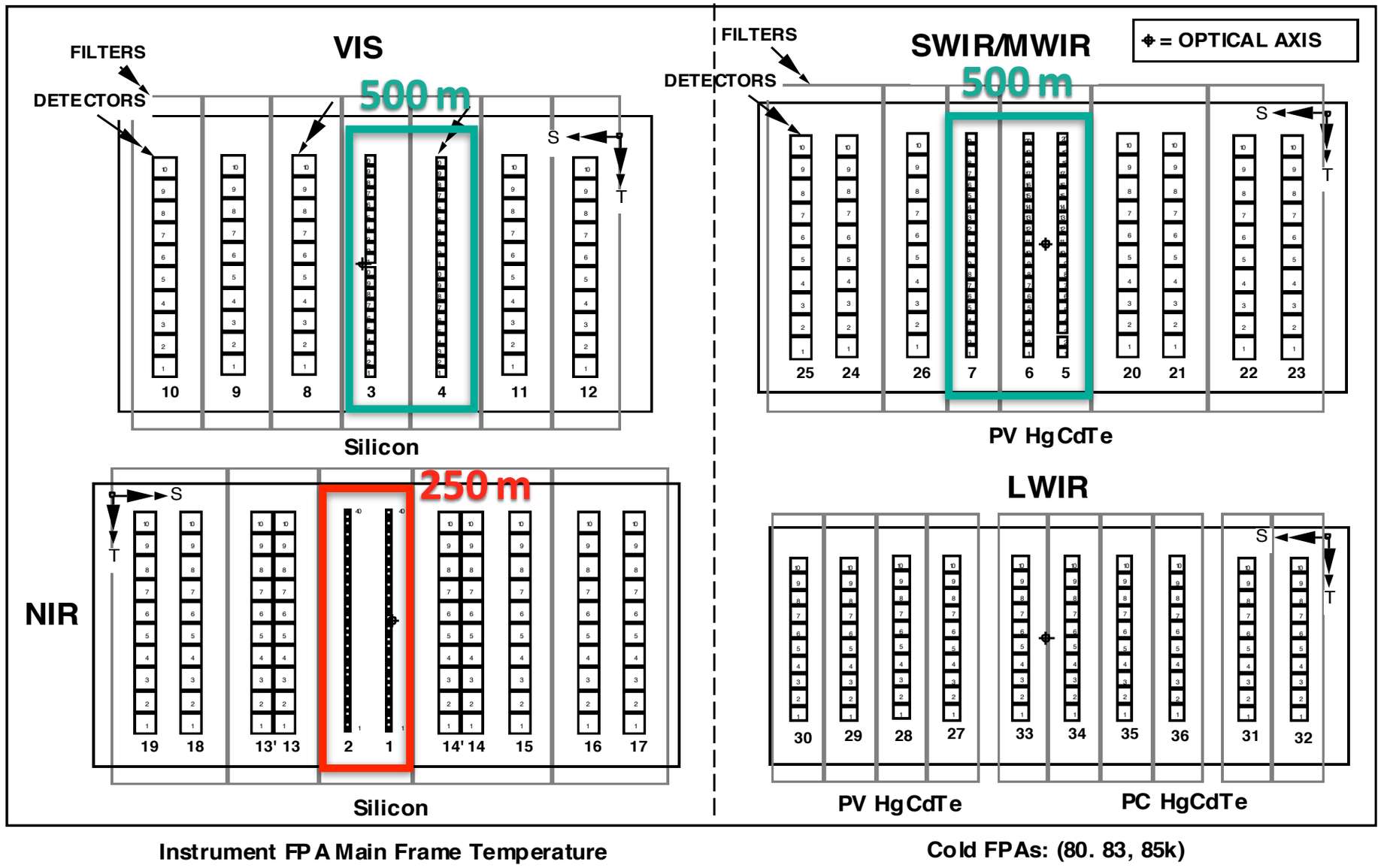

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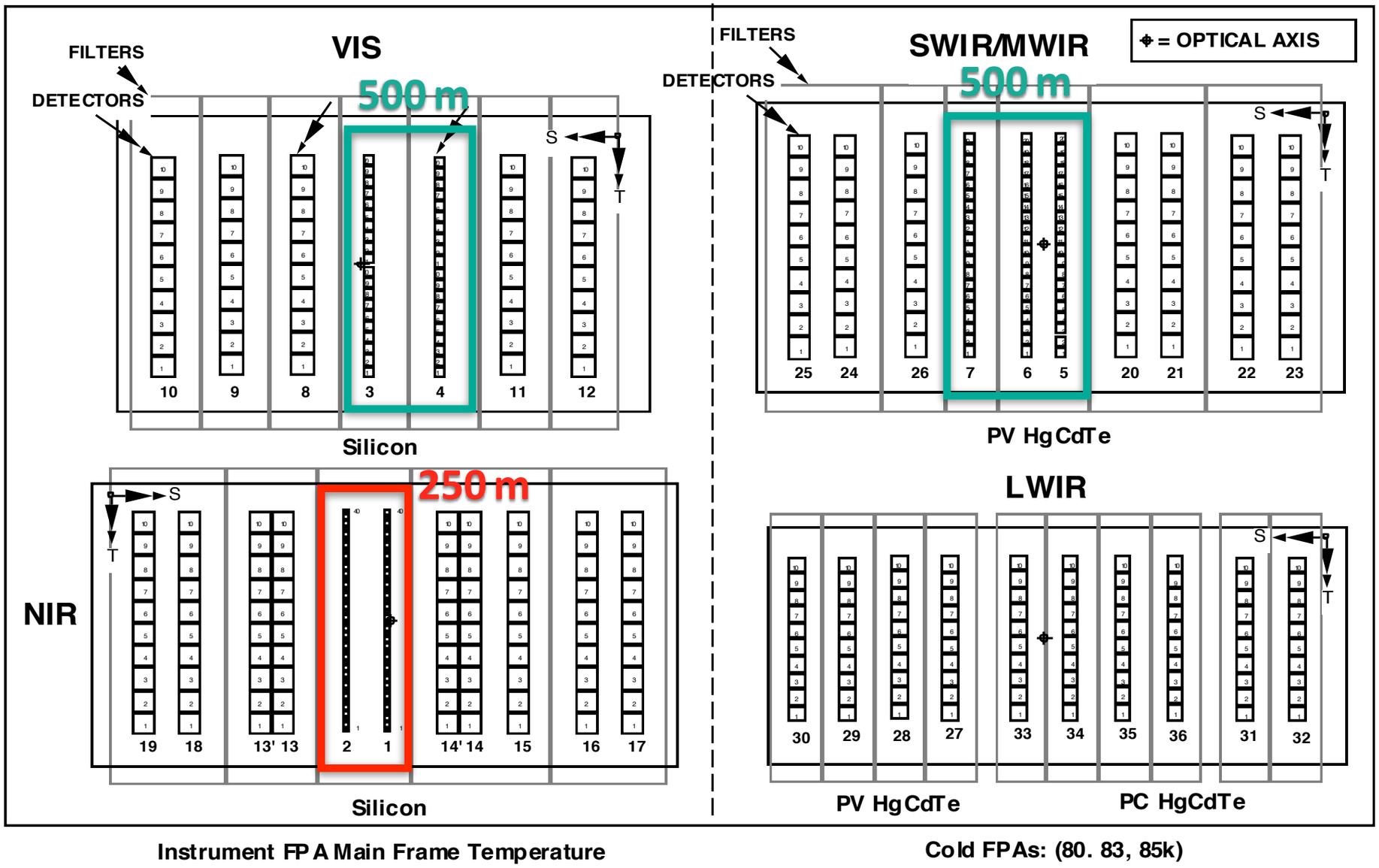
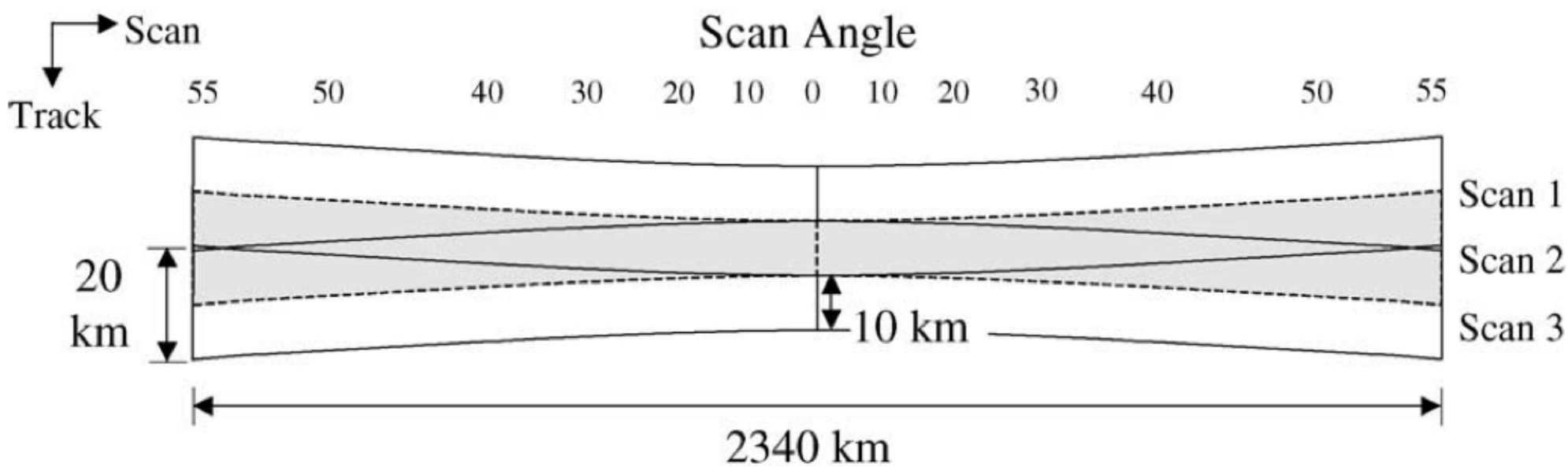


Calibration challenges: (1) Lots of detectors: Band 1 ➠ 40 detectors (w/4 time subsamples), 2 mirror sides, changing mirror angle of incidence along the swath (1354 pixels)! (2) Focal plane alignment: to allow for retrievals that use bands from multiple focal planes.

Along Track Characteristic: The Bow-Tie Effect

overlapping swaths away from the nadir view



From R. Wolfe et al., *Rem. Sens. Env.*, 2002

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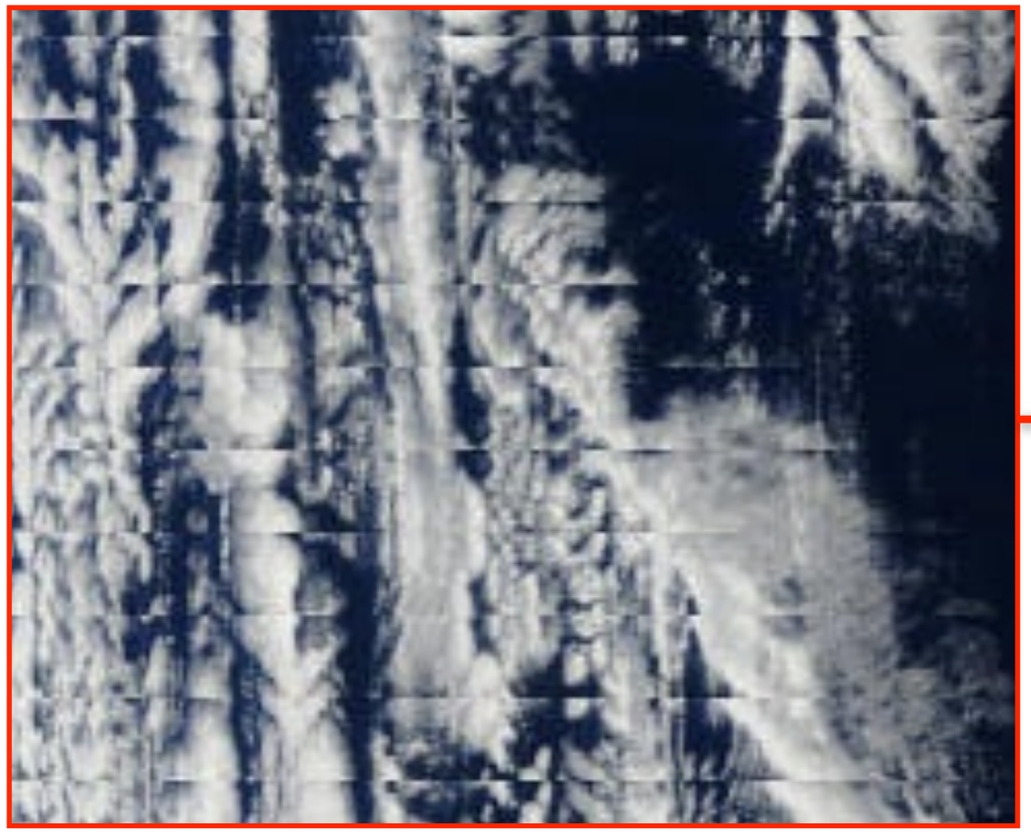
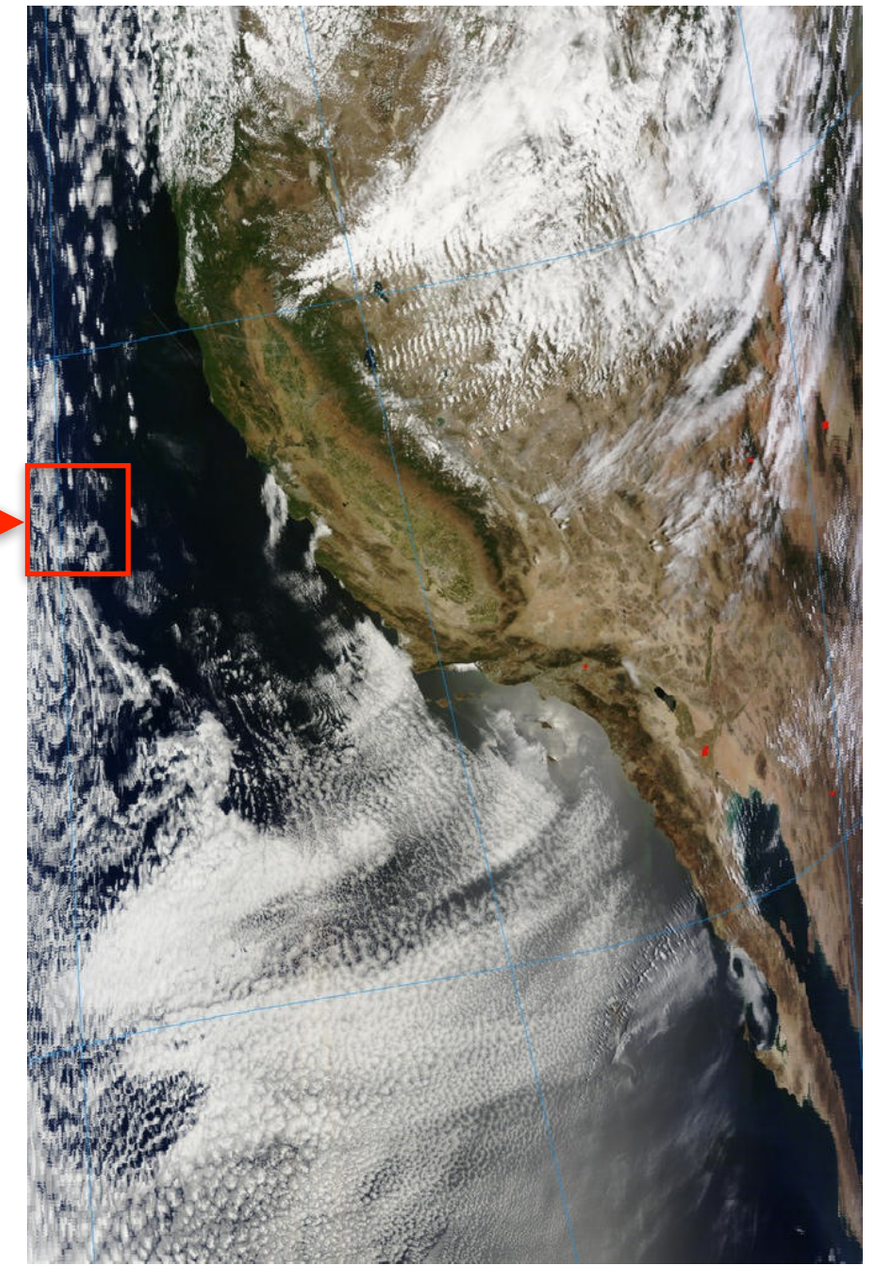


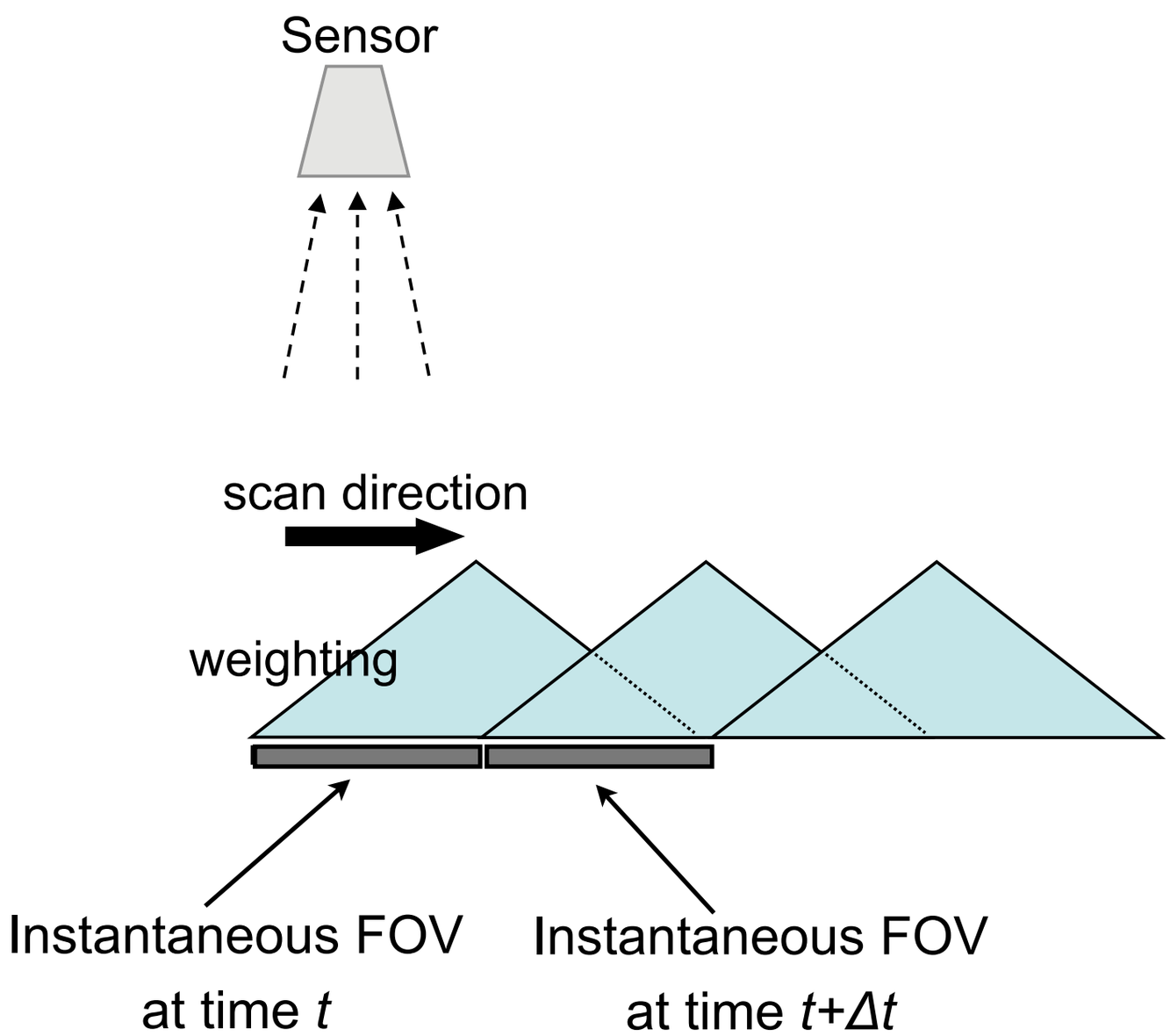


lance-modis.eosdis.nasa.gov/cgi-bin/imagery/realtime.cgi

Terra MODIS, 16 June 2014 1850 UTC

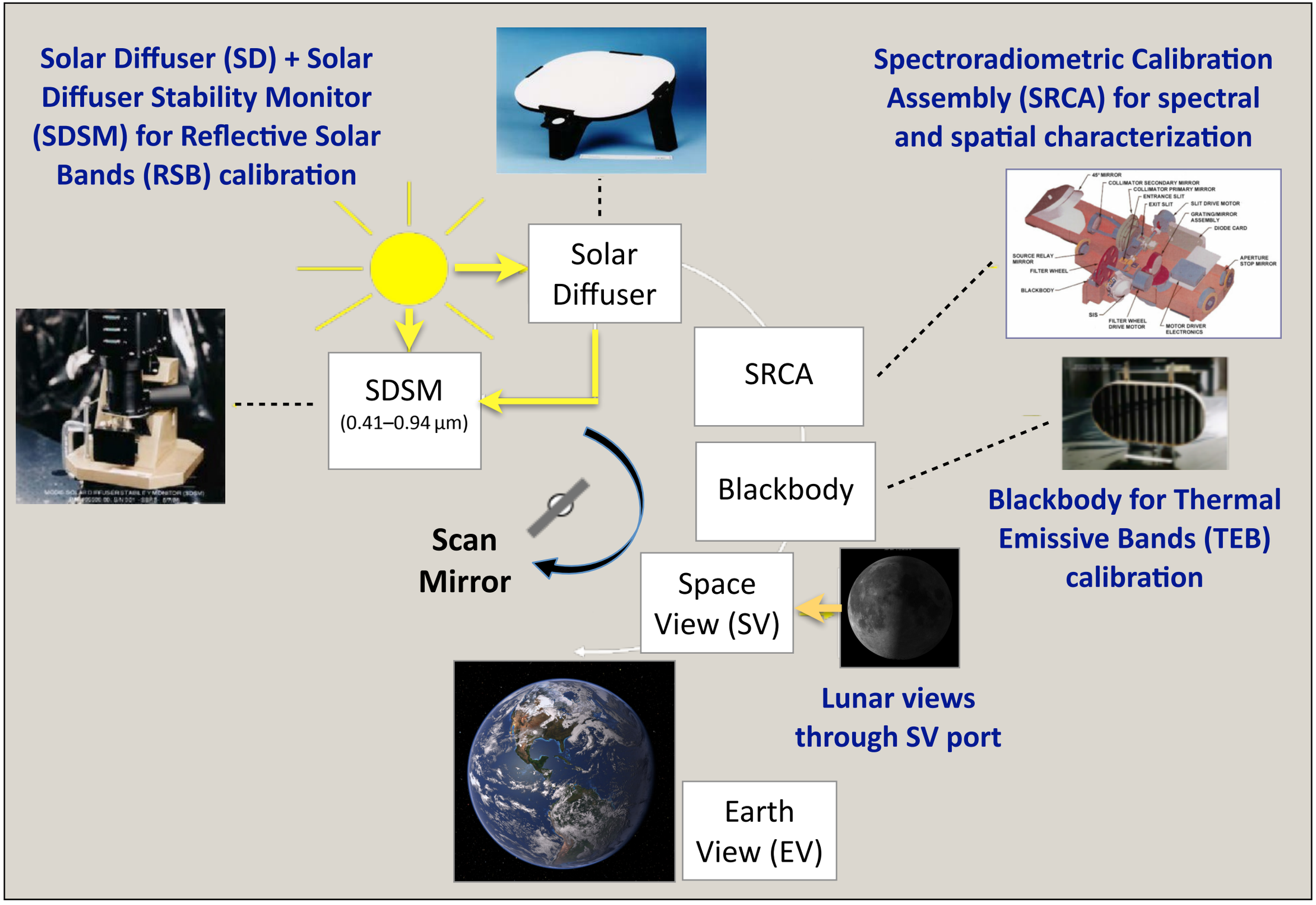
Cross-Track Characteristic: Time Integration Effect

What Do We Mean by a “Pixel”?



“Pixels” (individual observations) overlap substantially in the across-track direction

On-Board Calibration/Characterization



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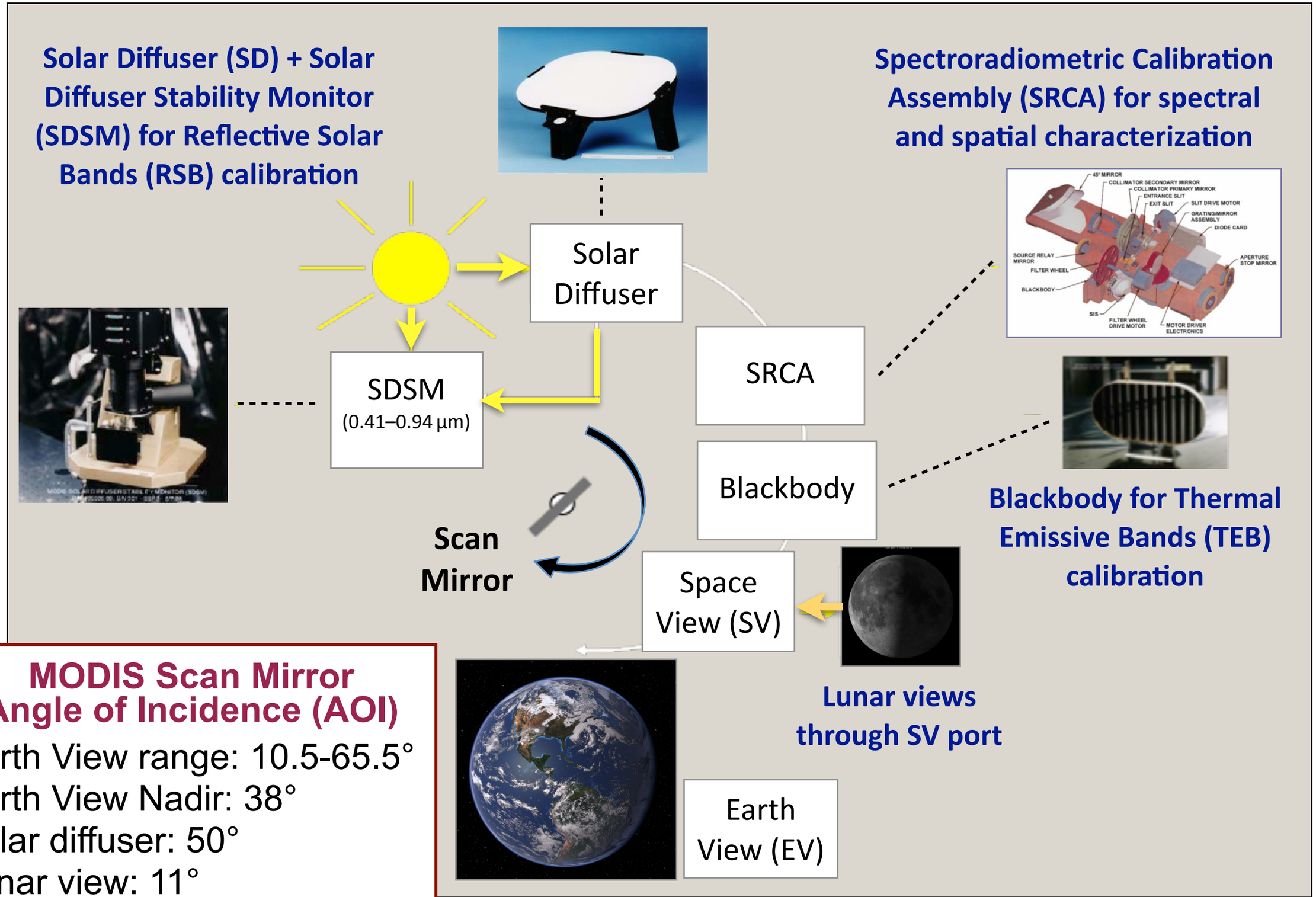
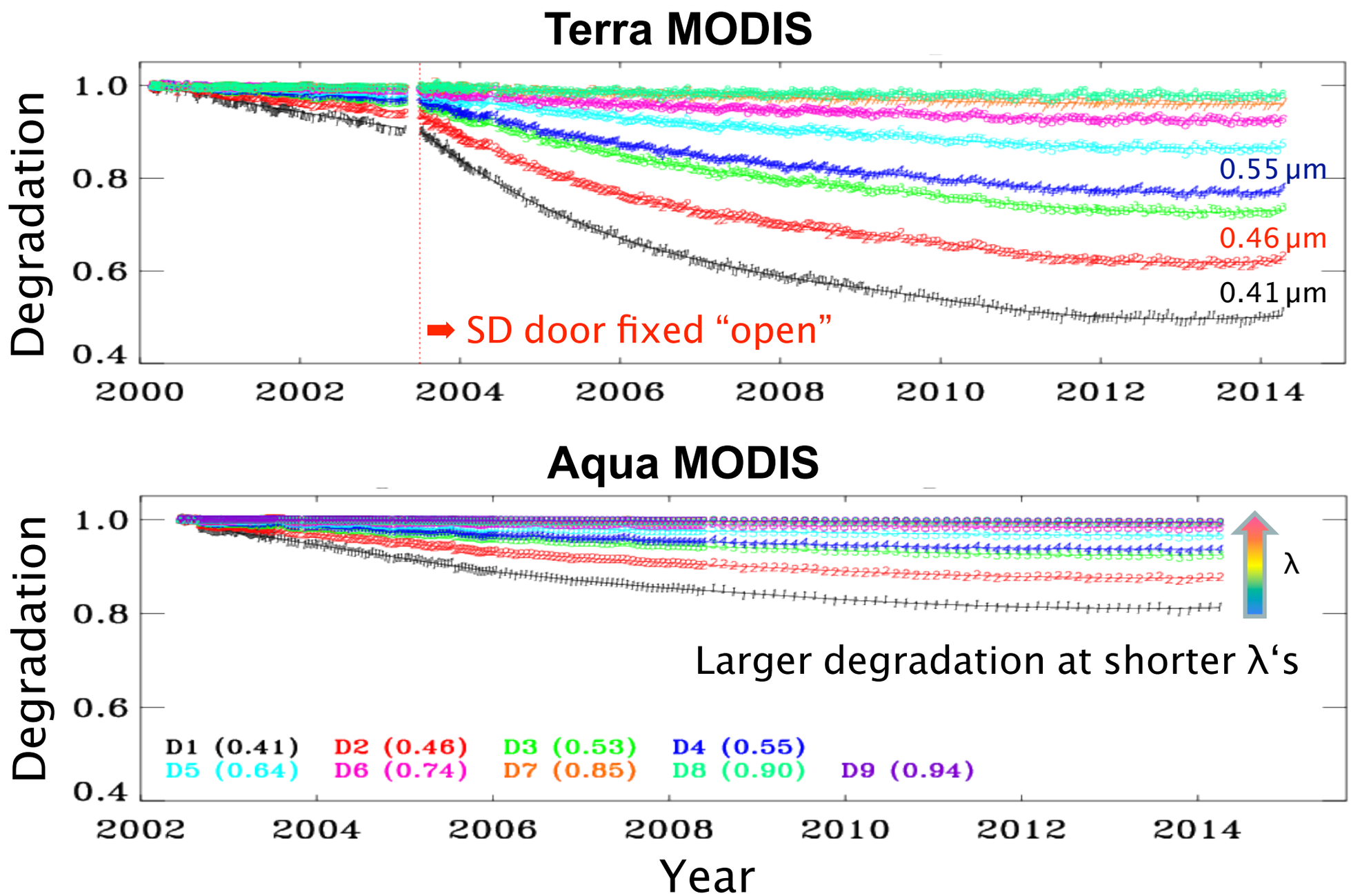


MODIS Scan Mirror Angle of Incidence (AOI)

Earth View range: 10.5-65.5°
Earth View Nadir: 38°
Solar diffuser: 50°
Lunar view: 11°

Solar Diffuser Degradation



SD/SDSM calibration frequency decreased in recent years. Currently:

Aqua: SD+SDSM every 3 weeks w/screen, every 6 weeks w/out screen

Terra: SD every orbit, SDSM every 3 weeks (SDSM uses different motor than the one for SD door)

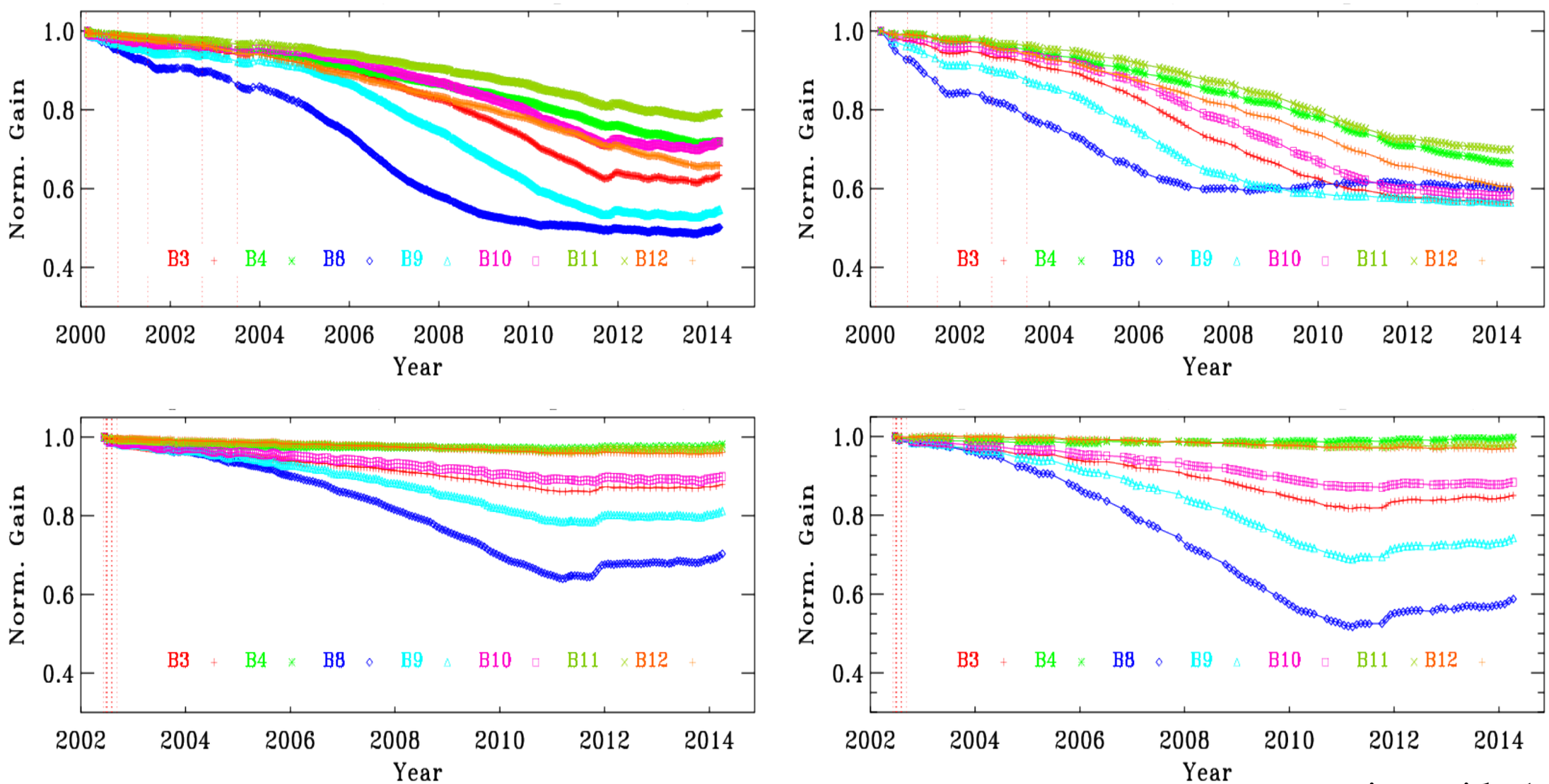
Spectral Degradation: Diffuser vs. Moon for Visible Bands

Is linear interpolation across AOI sufficient?

Solar Diffuser (AOI=50°) | **Lunar Observations (AOI=11°)**

Terra

Aqua

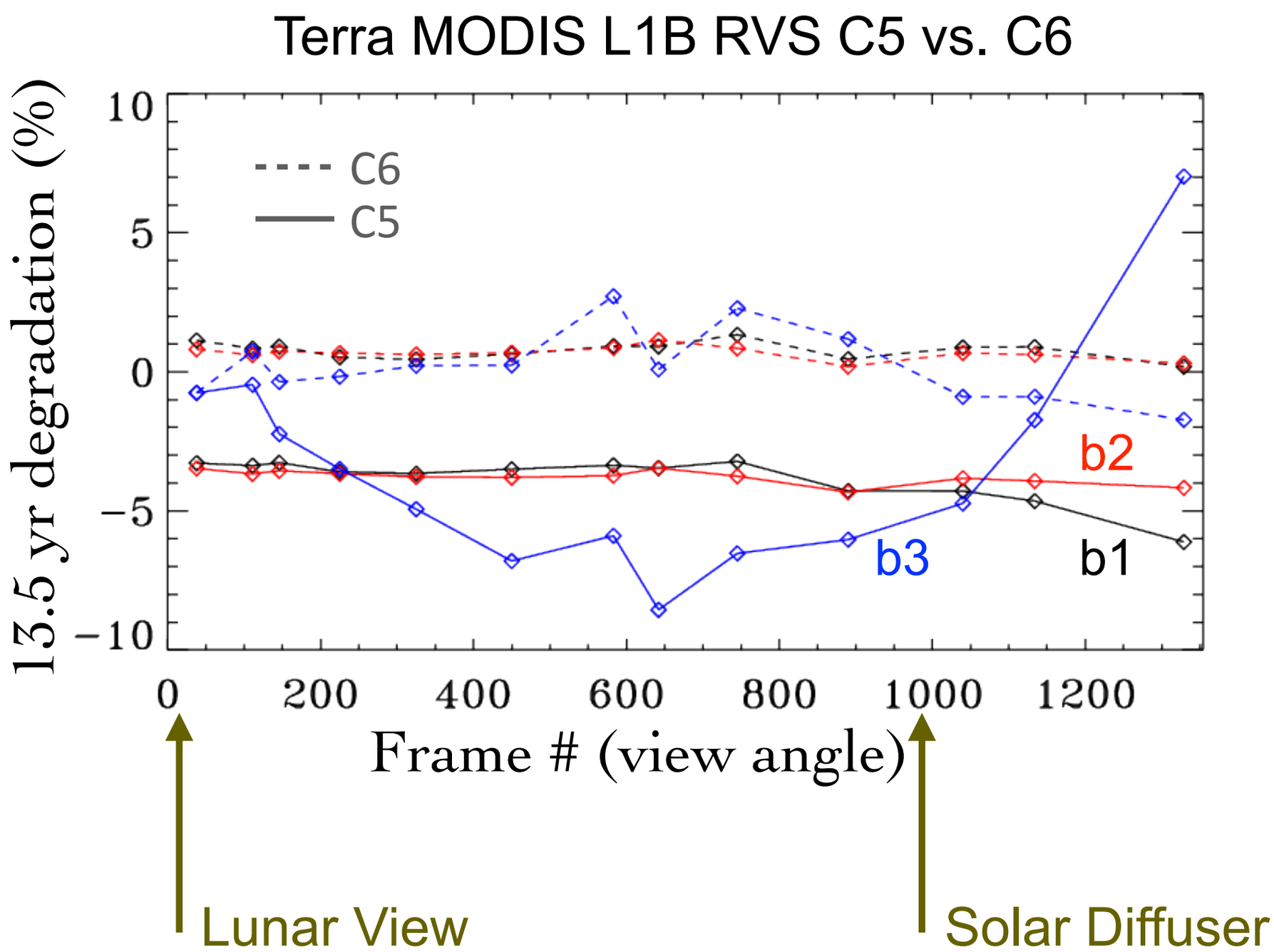


mirror side 1

Reminder: Earth View AOI between 10.5 – 65.5°

Use of CEOS Desert Targets for AOI Correction

Accounting for a non-linear Response vs. Scan Angle (RVS)

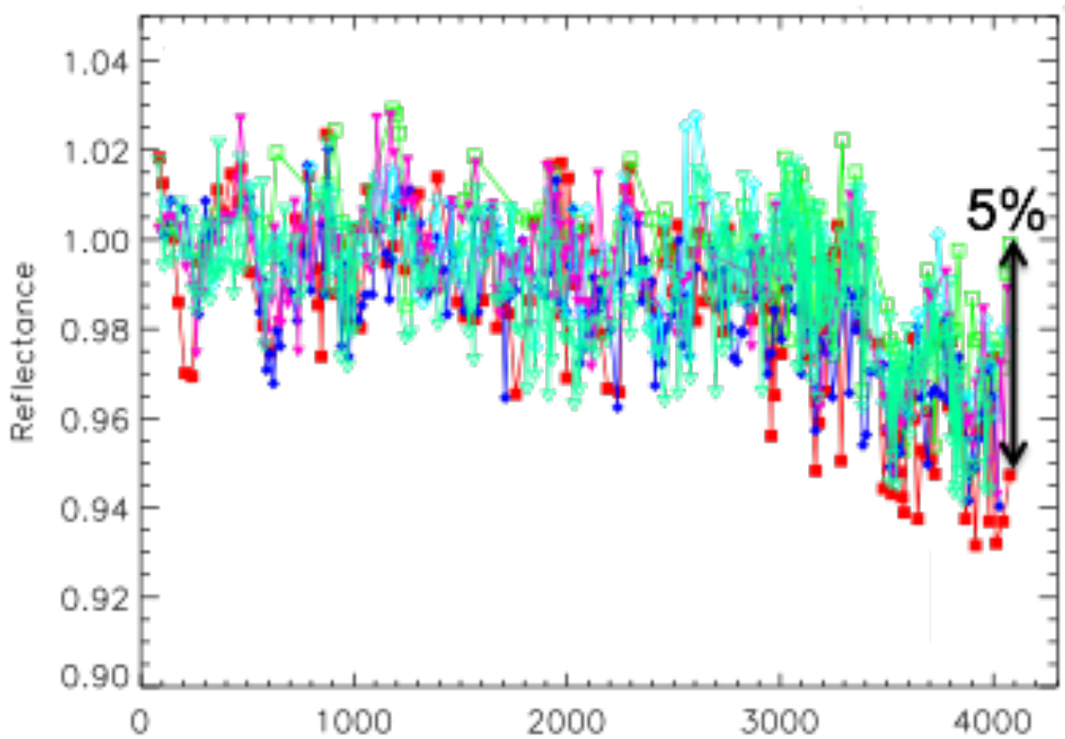


Use of CEOS Desert Targets for AOI Correction

Accounting for a non-linear Response vs. Scan Angle (RVS)

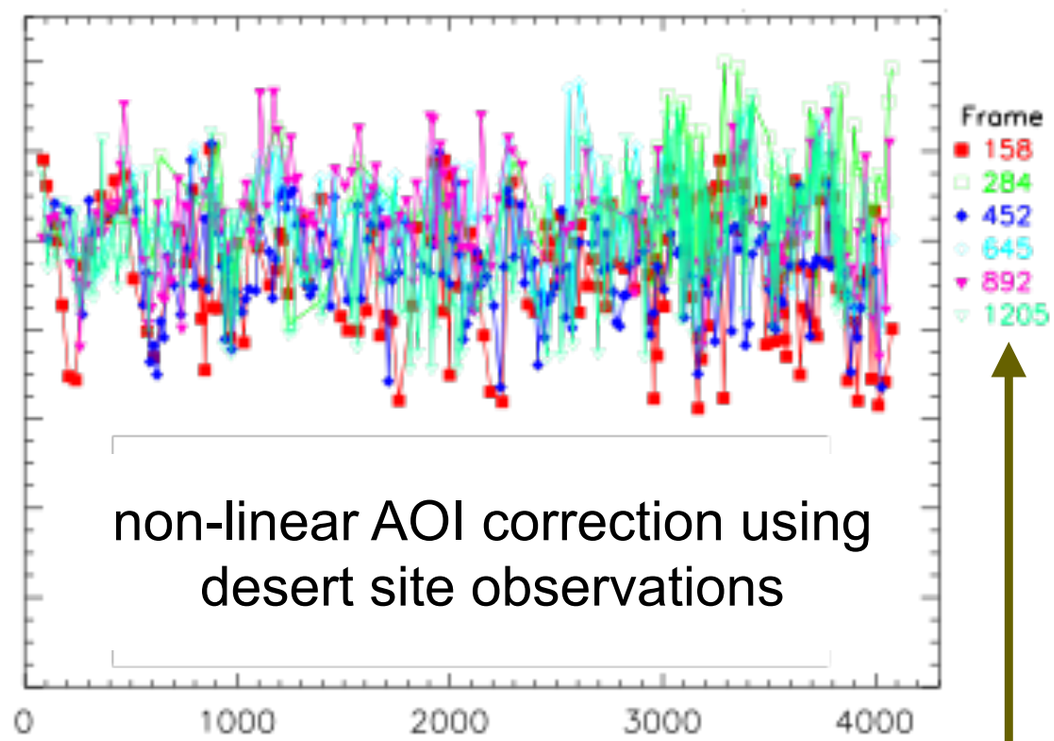
Terra MODIS band 2 (0.86 µm) 11-yr Time Record

Collection 5



days since Jan 2000

Collection 6



non-linear AOI correction using desert site observations

days since Jan 2002

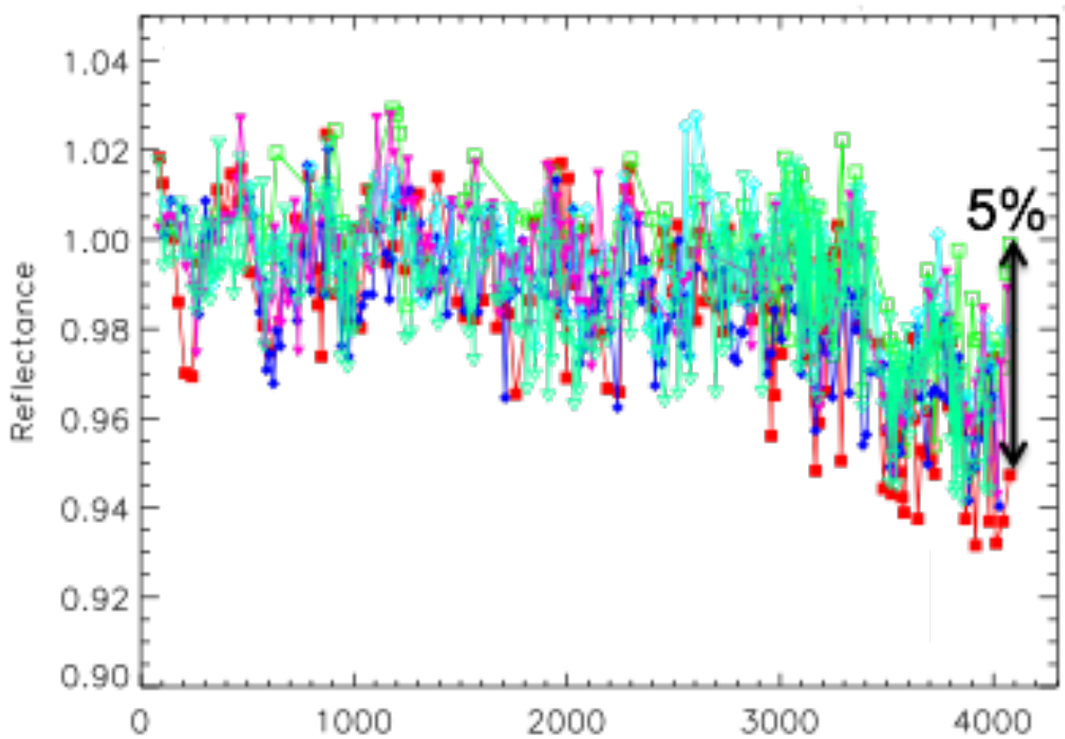
different AOI (sensor view angles)

Use of CEOS Desert Targets for AOI Correction

Accounting for a non-linear Response vs. Scan Angle (RVS)

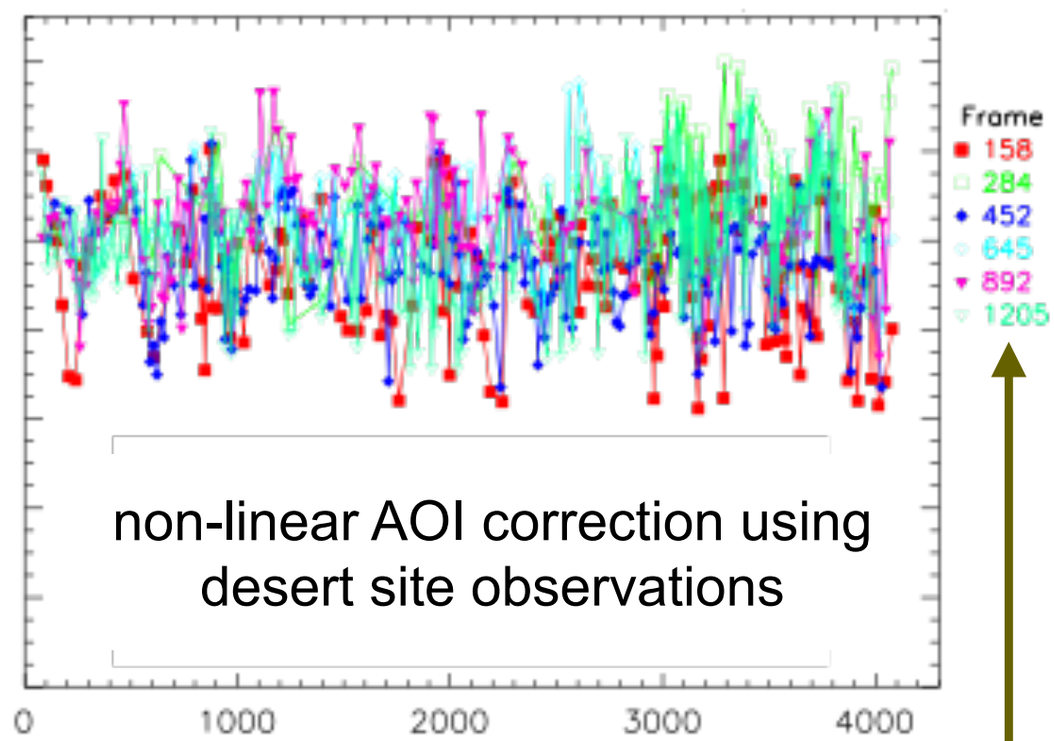
Terra MODIS band 2 (0.86 µm) 11-yr Time Record

Collection 5



days since Jan 2000

Collection 6



non-linear AOI correction using desert site observations

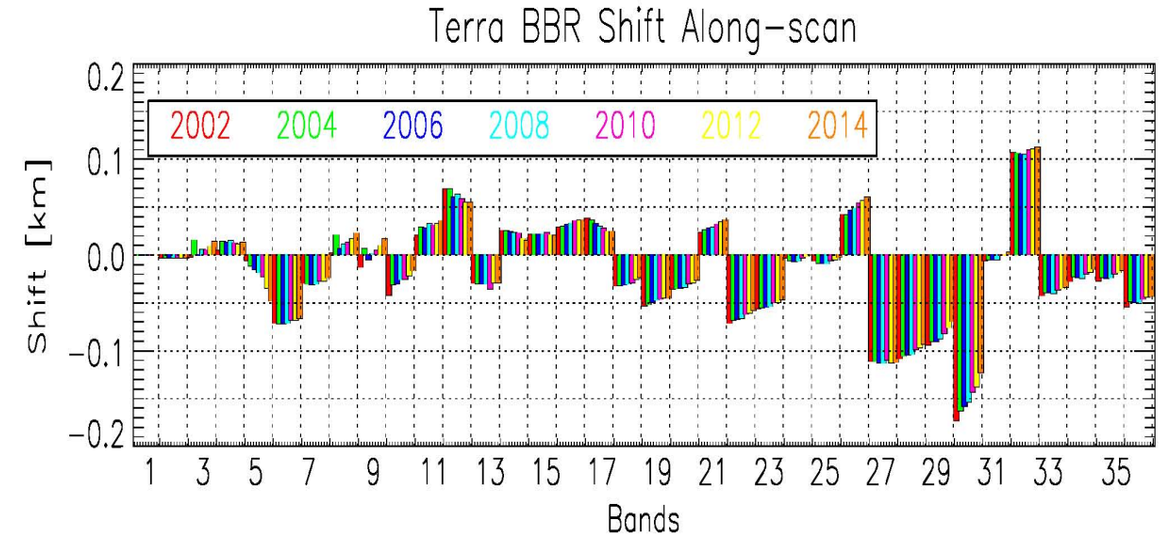
days since Jan 2002

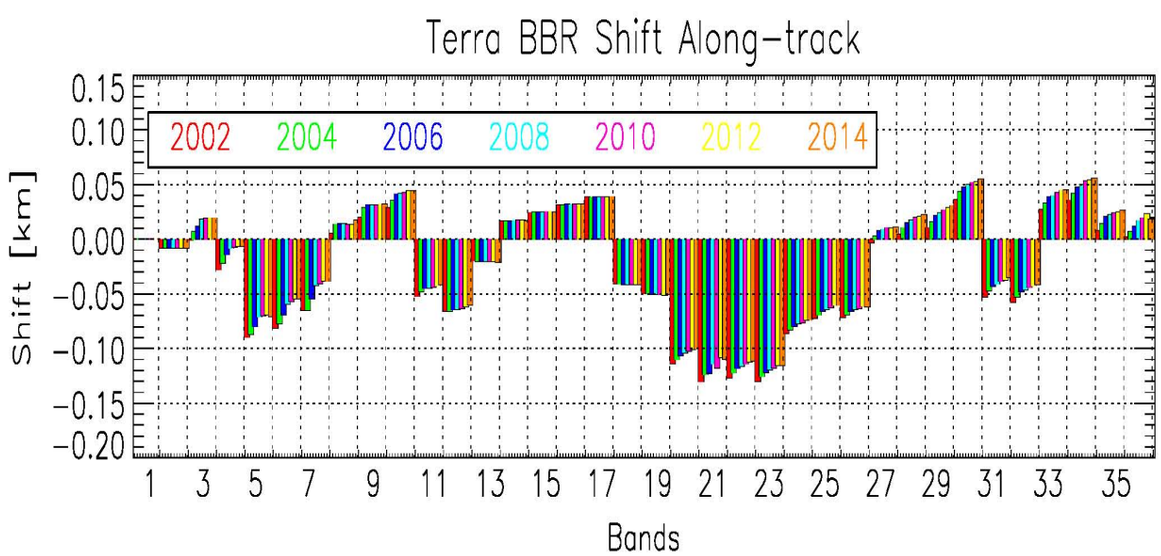
different AOI (sensor view angles)

Terra C5 trend artifacts show up in bands 1-4 and some ocean bands. Affects Aerosol Optical Depth (MOD04) over land and Cloud Optical Thickness (MOD06) over land and ocean.

Band-to-Band and Focal Plane Spatial Registration
(from SRCA)

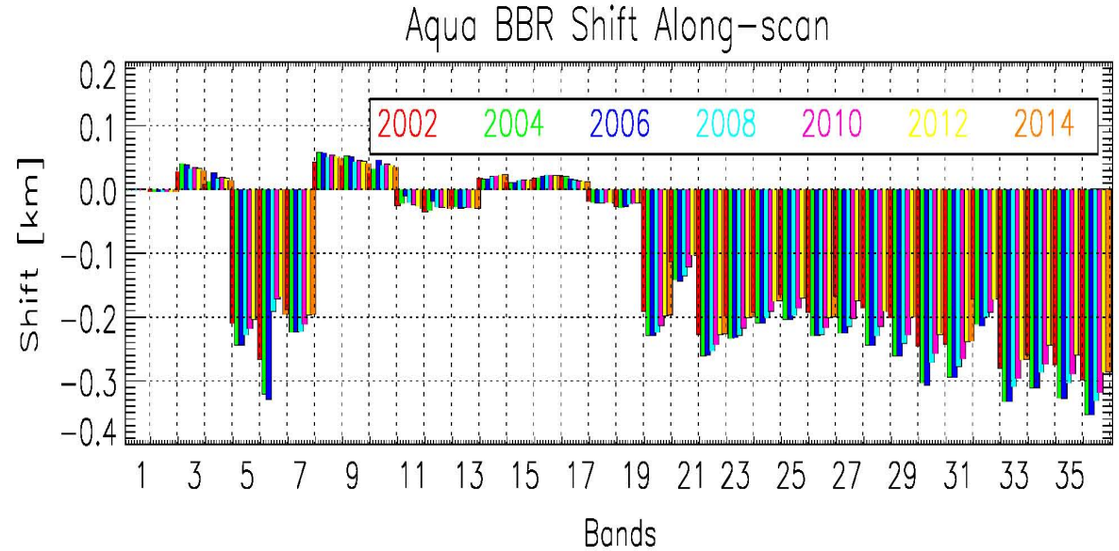
Terra

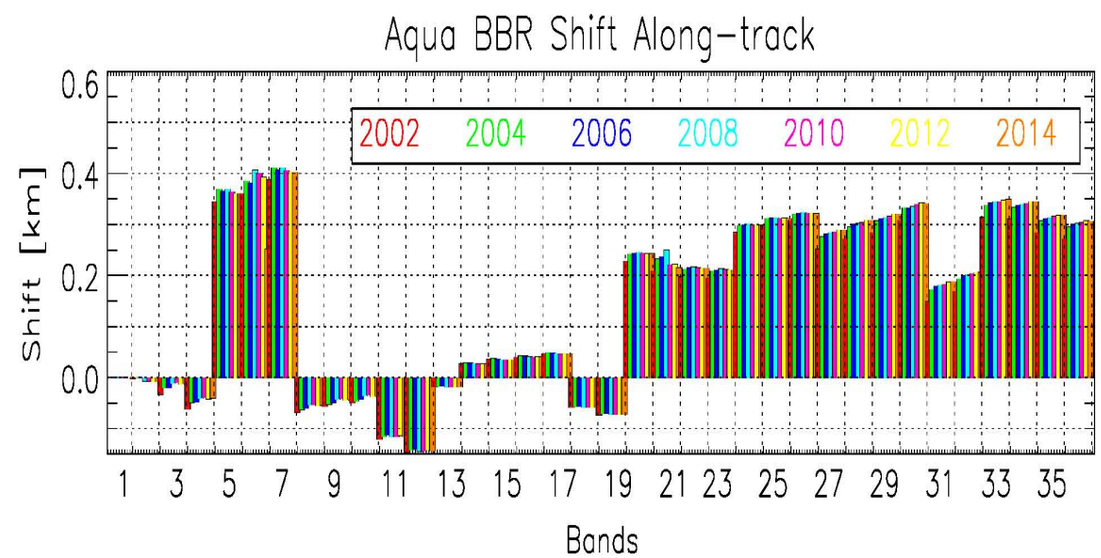




Terra within spec (±100 m) for all band pairs (except for along-scan b30 & b32)

Aqua

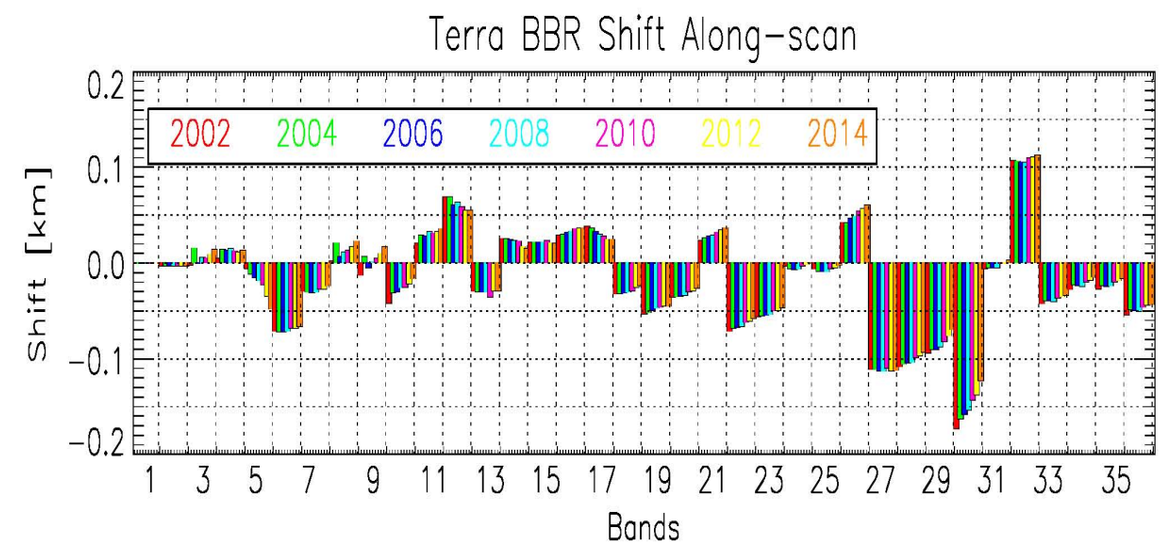


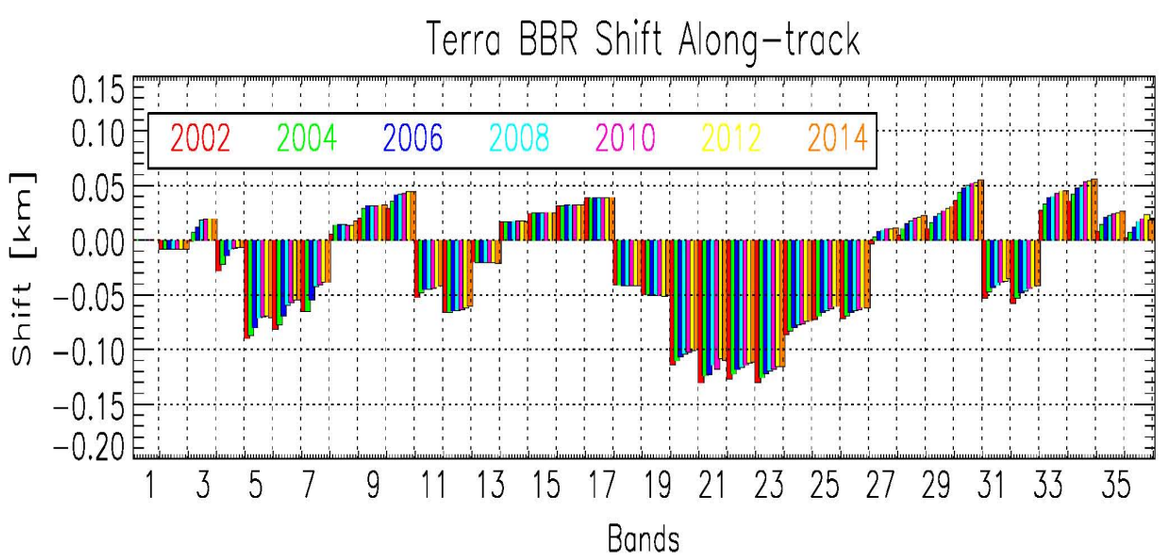


Aqua mis-registration issue known since pre-launch

Band-to-Band and Focal Plane Spatial Registration
(from SRCA)

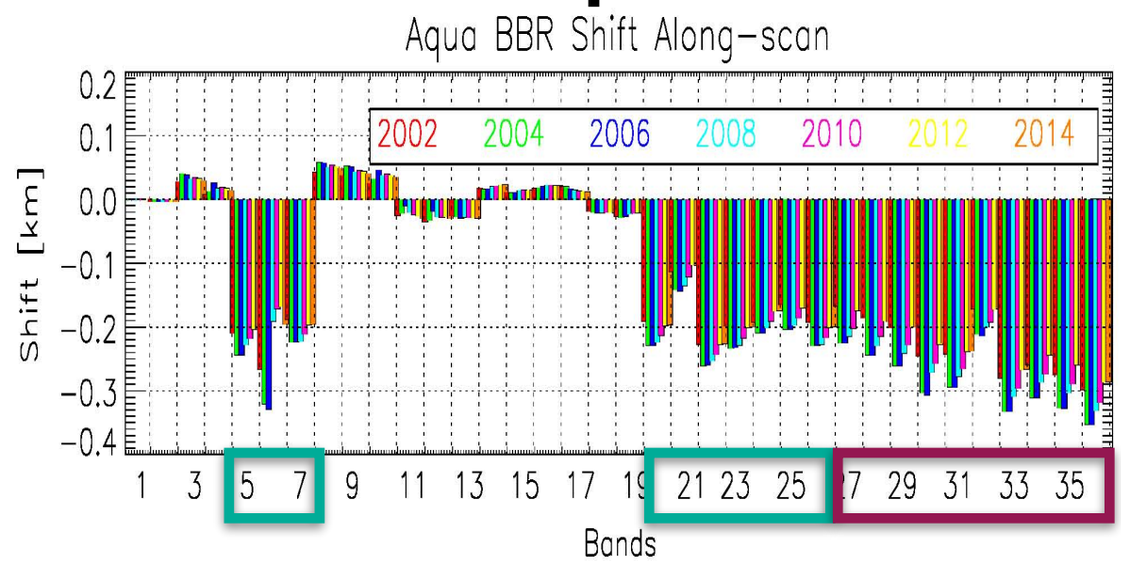
Terra

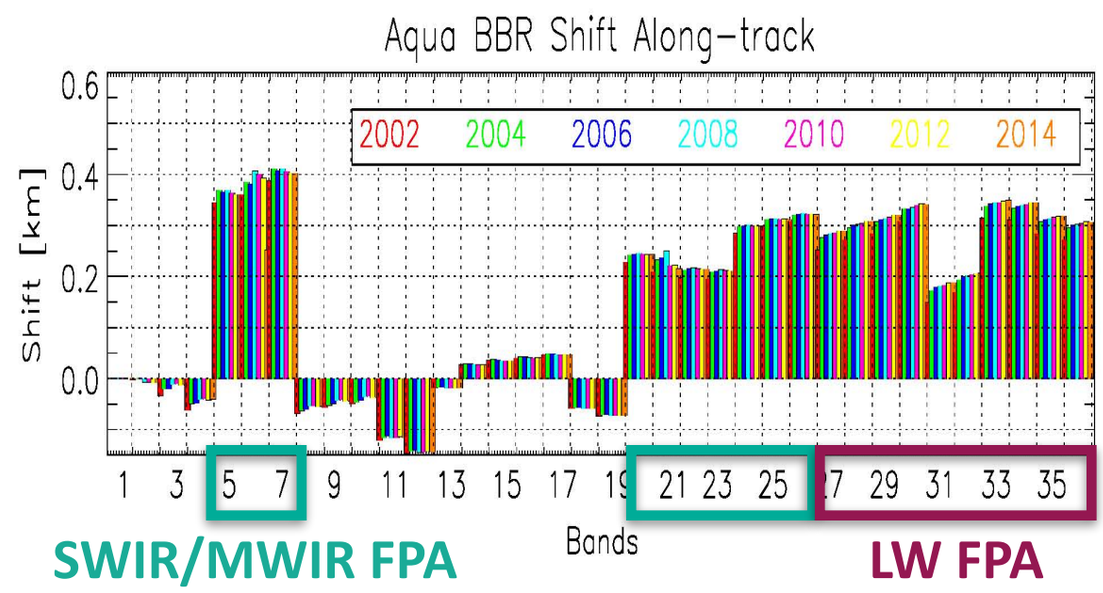




Terra within spec (±100 m) for all band pairs (except for along-scan b30 & b32)

Aqua

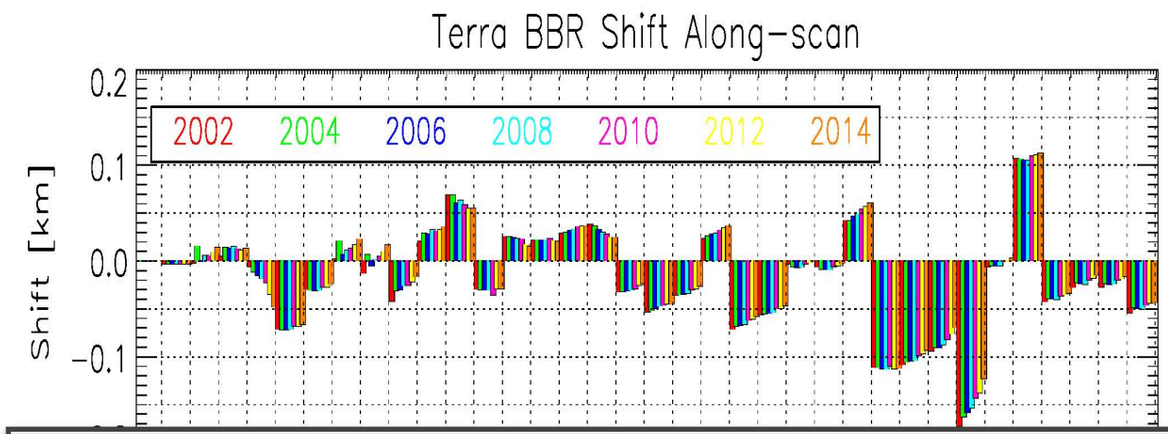




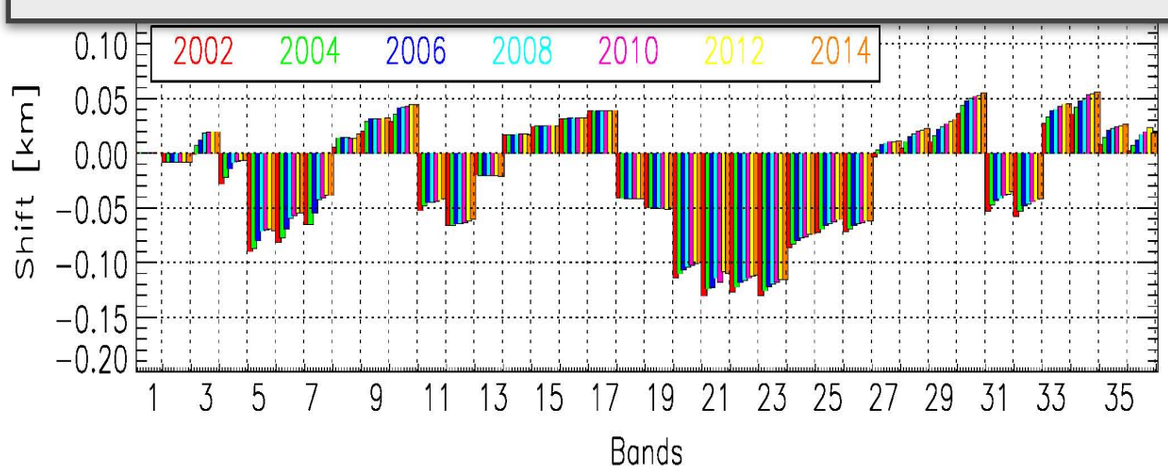
Aqua mis-registration issue known since pre-launch

Band-to-Band and Focal Plane Spatial Registration
(from SRCA)

Terra

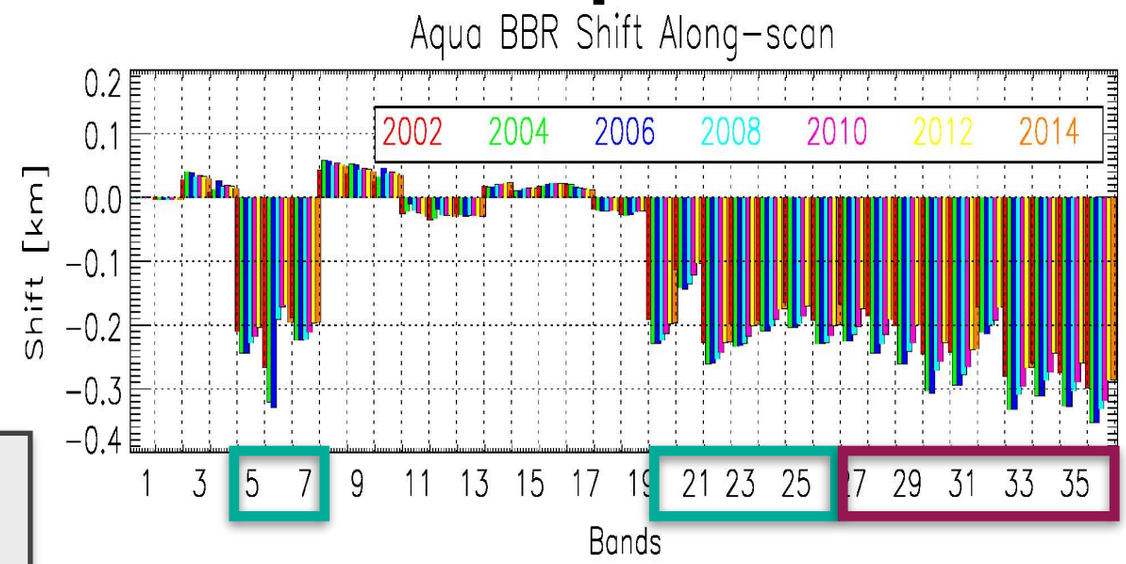


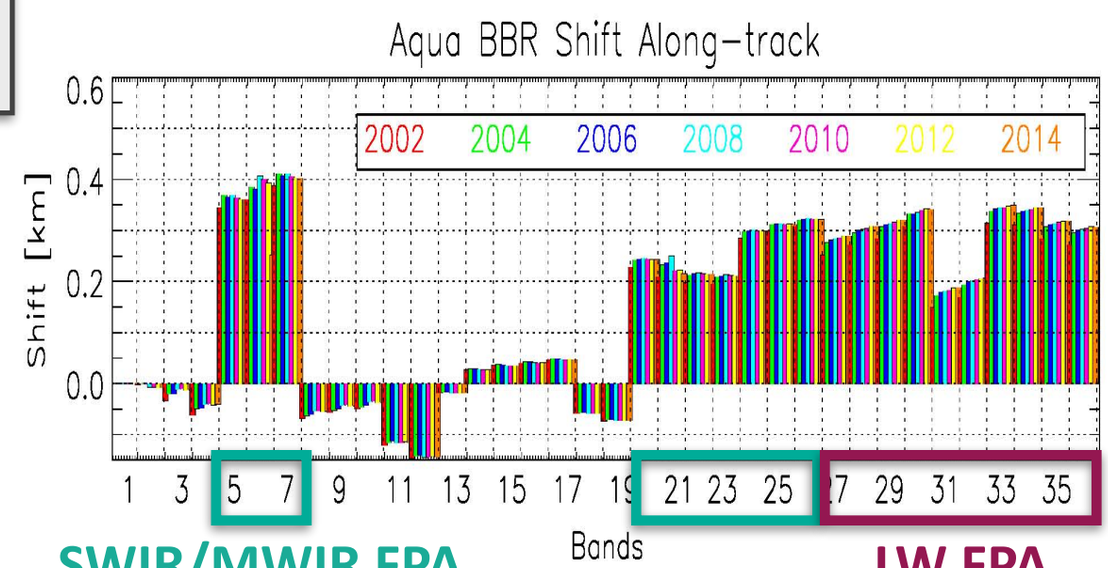
Atmosphere Team C6 re-aggregation: shift 250m band (b1, b2) relative positions before aggregating up to MOD021KM



Terra within spec (±100 m) for all band pairs (except for along-scan b30 & b32)

Aqua





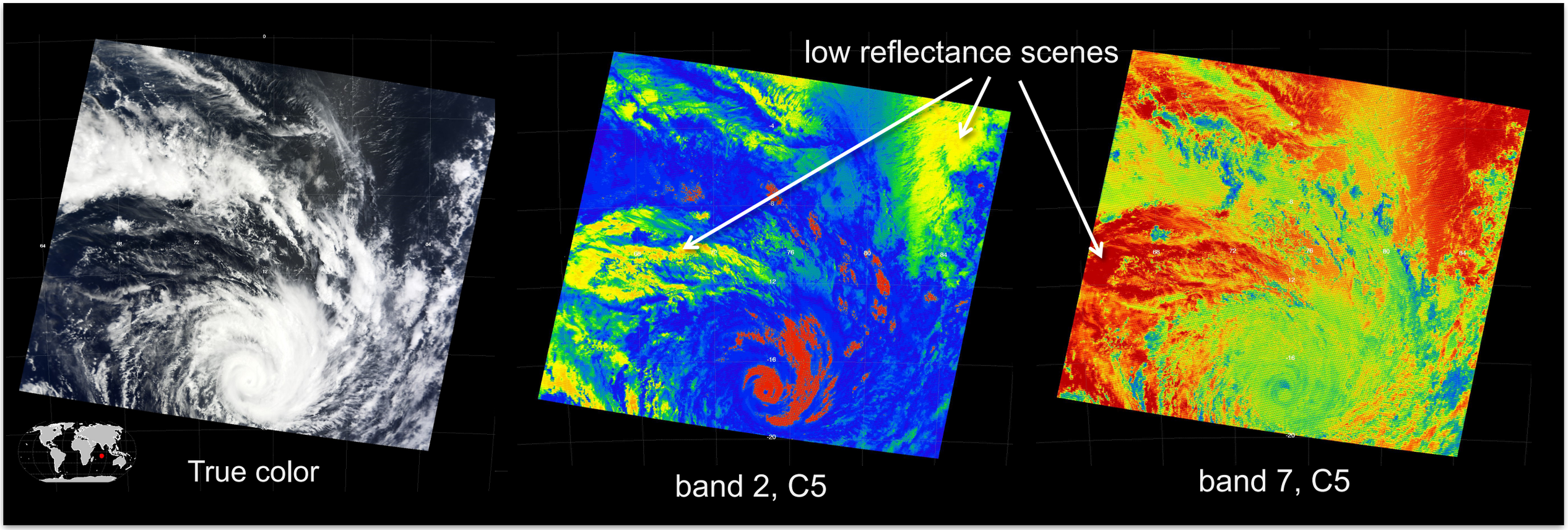
SWIR/MWIR FPA **LW FPA**

Aqua mis-registration issue known since pre-launch

L1B Uncertainty Index (0-15): C5 Example Data Granule

Terra MODIS, Tropical Cyclone Edzani, Indian Ocean, Jan. 2010

$$\text{uncertainty } (\%) = specified_uncertainty \times \exp\left(\frac{UI}{scale_factor}\right)$$



uncertainty (%)

0 7.5 15

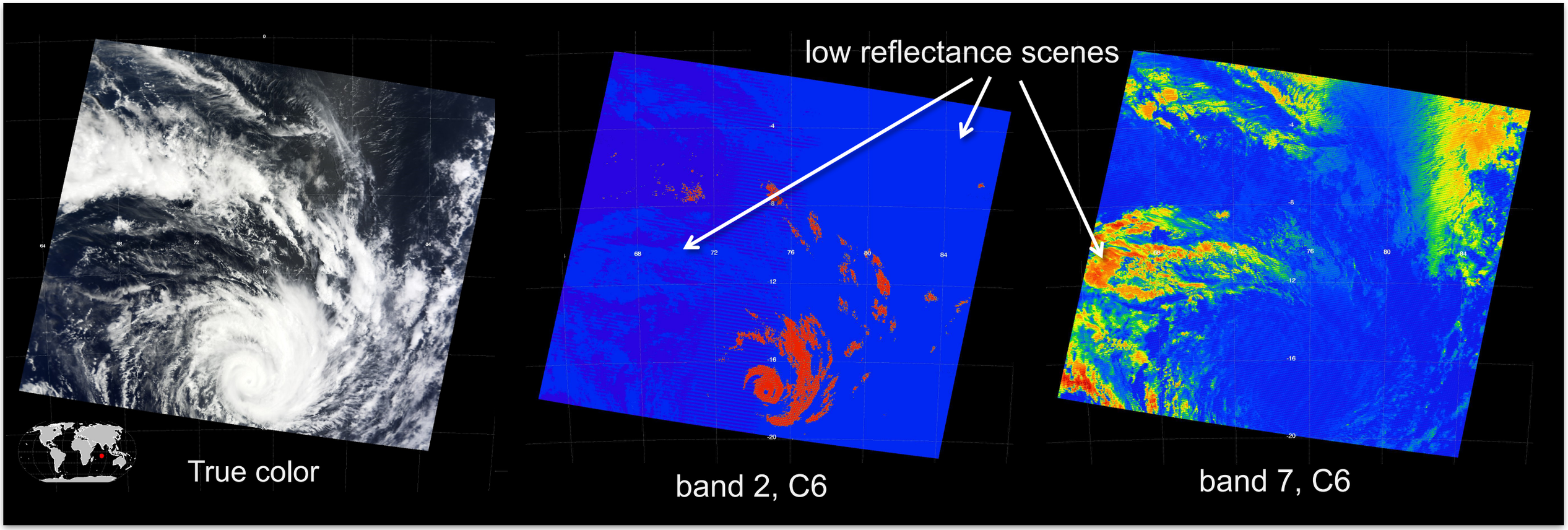
uncertainty (%)

0 10 30

L1B Uncertainty Index (0-15): C6 Example Data Granule

Terra MODIS, Tropical Cyclone Edzani, Indian Ocean, Jan. 2010

$$\text{uncertainty } (\%) = specified_uncertainty \times \exp\left(\frac{UI}{scale_factor}\right)$$



uncertainty (%)

0 7.5 15

uncertainty (%)

0 10 30

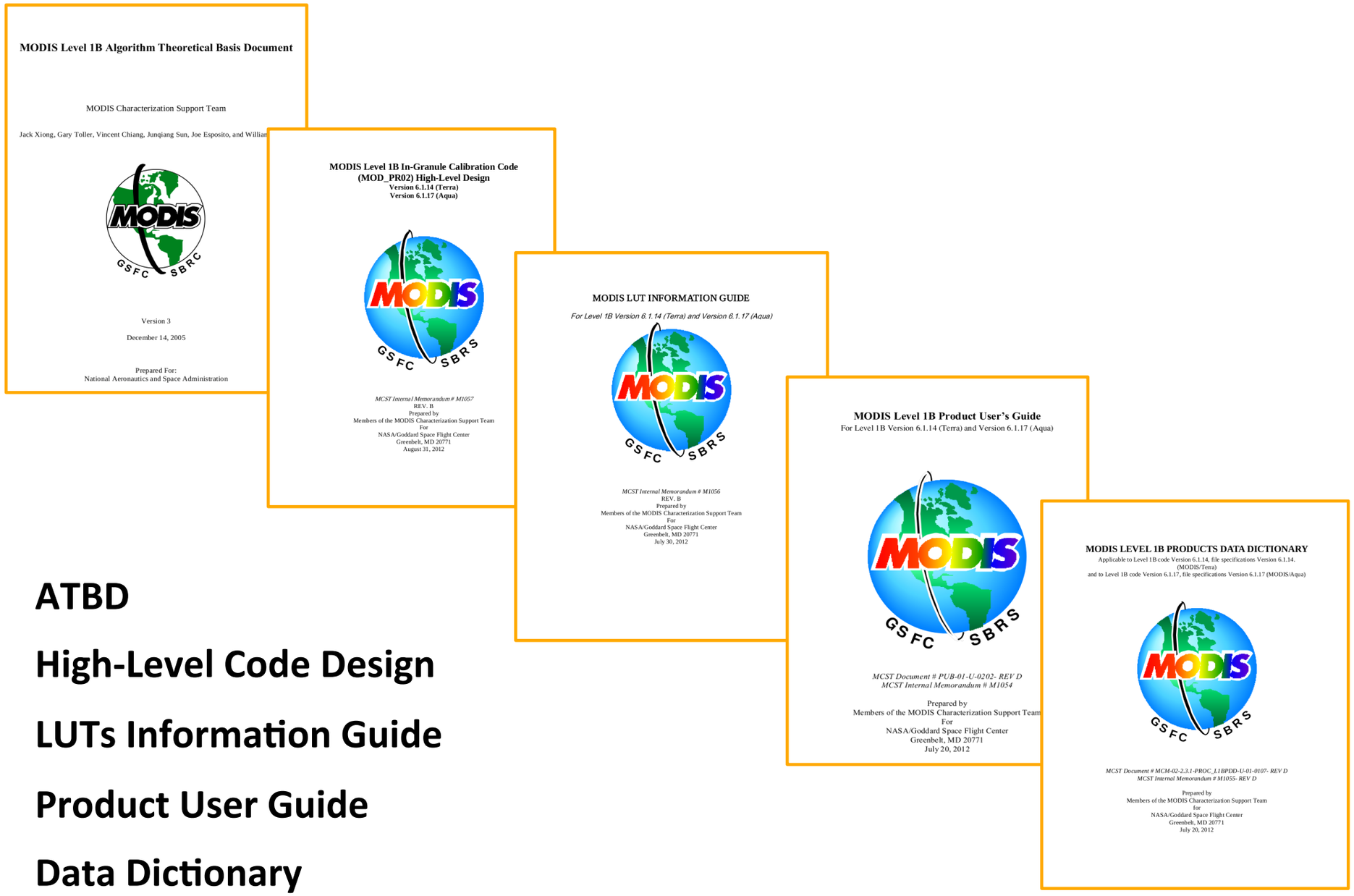
Continuing MODIS Calibration Challenges

- VIS/NIR response vs. scan angle (**RVS**)
  - Band (detector) and mirror side dependent
- Large solar diffuser (SD) **degradation** at short wavelengths (esp. Terra)
  - Impact on radiometric uncertainty estimates
  - SWIR SD degradation not tracked by SDSM
- **Polarization** sensitivity changes found in Terra MODIS
  - Band (detector), RVS, and mirror side dependent
  - No noticeable change seen in Aqua to date
- **Aging** instruments
  - Undesirable features, unpredictable changes
  - Gradual increase of Aqua MODIS cold focal plane assembly (CFPA) temperature
  - Impact from potential satellite mean local time drift

L1/Geolocation/L1B C6 Production Status

- Reprocessing of Aqua and Terra completed in 2012
- Forward processing of Terra and Aqua started in 2012 and is currently at leading edge.
- Products available to public since late 2012 on LAADS
- Update expected for Terra L1B to address trending in Band 5
- Forward processing of both C6 and C5 will continue for a year after completion of C6 land and atmosphere reprocessing
- MCST continues to derive/deliver forward Lookup Table (LUT) updates for both processing streams as needed

Key L1B Documents



ATBD

High-Level Code Design

LUTs Information Guide

Product User Guide

Data Dictionary

http://mcst.gsfc.nasa.gov/content/l1b-documents

Backup Slides

Summary of C6 L1B Changes [1]

- Reflective Solar Bands (RSB)
  - SD degradation at 936 nm included (previous degradation normalized at 936 nm)
  - Time dependent RVS for all VIS/NIR bands, including bands 13-16
  - Detector bias corrections (derived from EV data) and detector dependent RVS applied to Terra bands 3, 8-12 and Aqua bands 8-12
  - Earth View (EV) response trending used to correct calibration drifts noticeable in recent years at different AOIs (including SD AOI) for Terra bands 1-4, 8, 9, 10 (proposed) and Aqua 8-9
    - SD to provide radiometric calibration reference
    - Lunar trending to track on-orbit radiometric change
    - EV trending at different AOIs to track on-orbit changes in RVS

Summary of C6 L1B Changes [2]

- Thermal Emissive Bands (TEB)
  - Use BB cool-down data to compute TEB nonlinear calibration coefficients
  - Use a0=0 for Terra PV bands mirror side 1 (mirror side 2 a0 is adjusted to minimize the mirror side difference) and a0=0 for Terra/ Aqua b31-32
  - Aqua pre-launch a2 (used in L1B) are adjusted to capture on-orbit changes using on-board BB calibration, while keeping the small initial difference
  - Add FPA temperature dependence to the “fixed” b1 for Aqua bands 33, 35, and 36 when the BB is operated above their saturation temperatures

Summary of C6 L1B Changes [3]

- Other
  - Improved implementation of pixel-level “uncertainty index“ calibration algorithm reported in the file (based on actual on-orbit calibration/retrieval with time, AOI, and scene dependence) [*see previous slide example*]
  - Fill-value for inoperable detectors and QA flag for inoperable or noisy detectors at sub-frame level
  - L1B code fix for sector rotation data anomaly (during lunar roll)

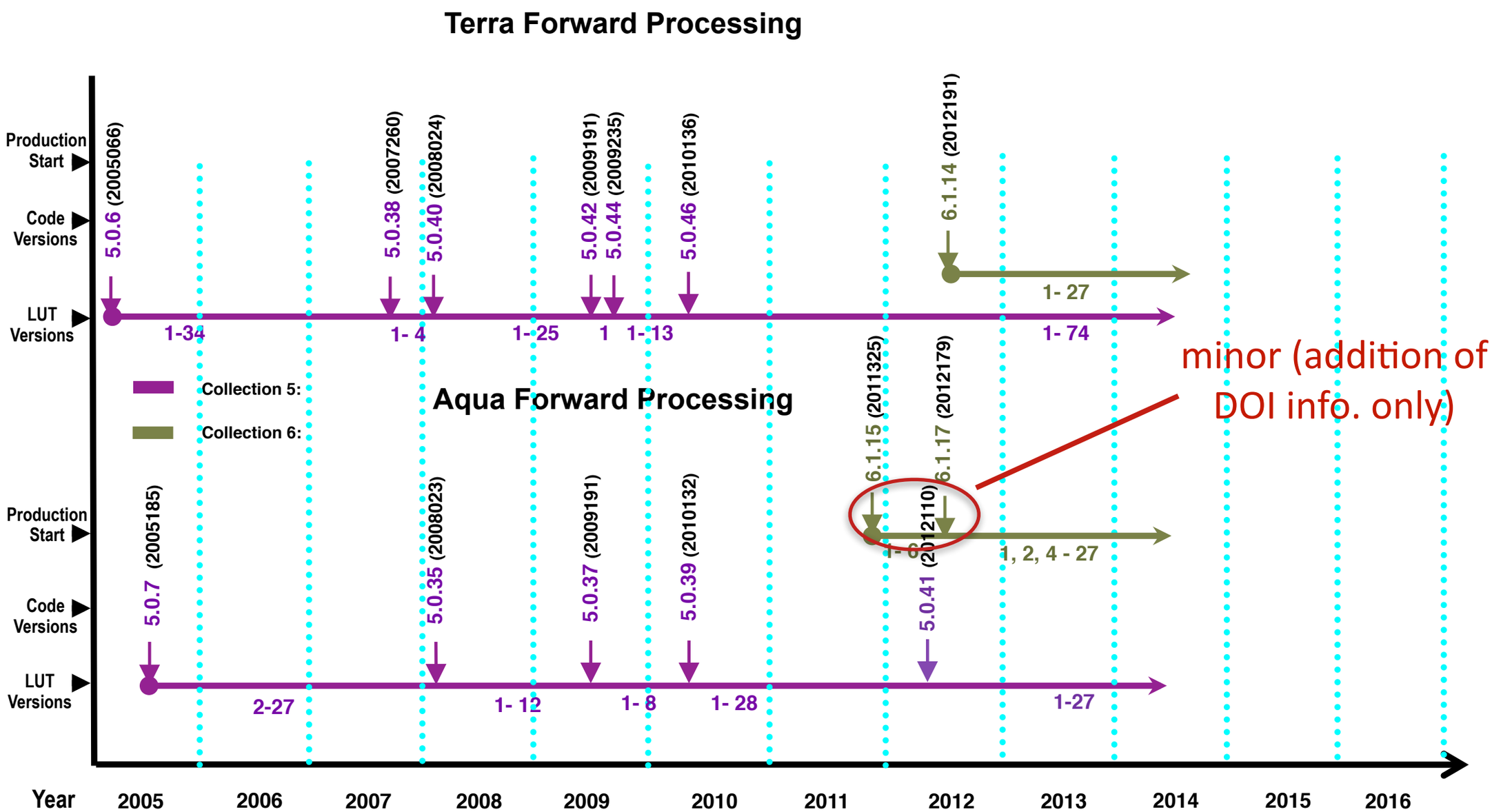
L1B Code Versions

Terra					Aqua			
Version	Production Time	Used	Delivered	Total	Production Time	Used	Delivered	Total
C2	03/2000-05/2001	6	6	19				
C3	05/2001-01/2003	2	2	2	06/2002-11/2002	1	1	1
C4	01/2003-early 2007	3	6	11	11/2002- early 2007	4	5	8
C5	03/2005-present	6	8	9	07/2005-present	5	7	9
C6	08/2012-present	1	2	7	02/2012-present	2	2	10
Total		18	24	48		12	15	28

Used: Used in official data production.
Delivered: Delivered to SDST by MCST for testing and data production
Total: All the code changes (major and minor) developed by MCST

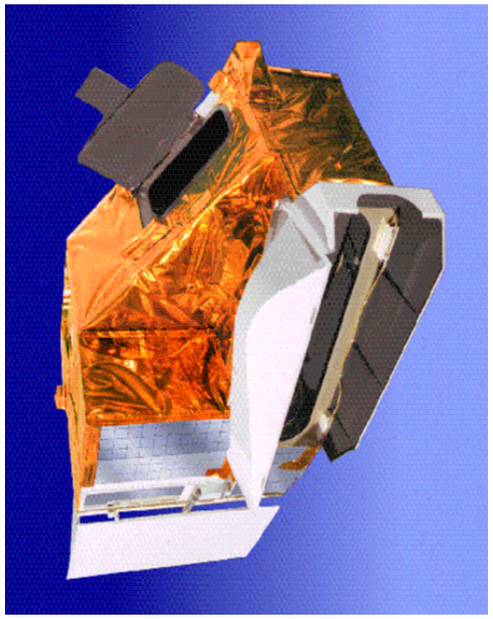
3

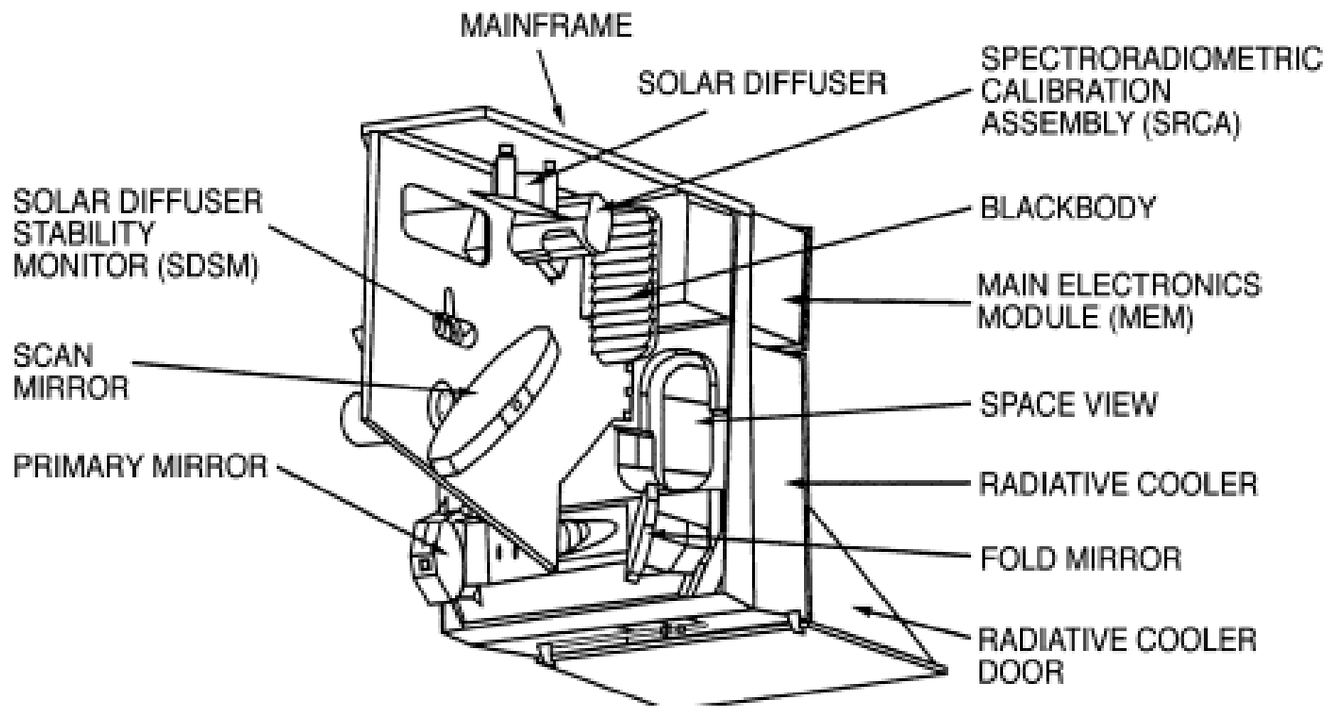
Timeline of MODIS L1B C5 and C6 Updates (code and LUTs)

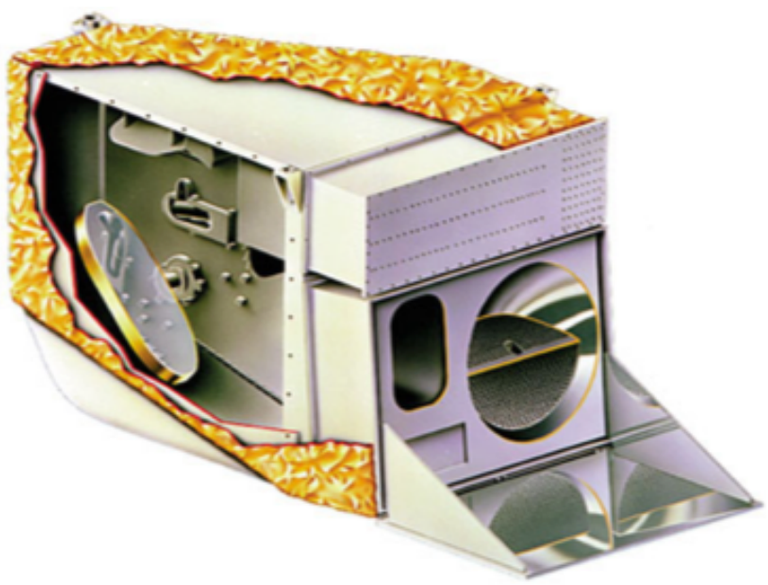


Further details at: mcst.gsfc.nasa.gov/l1b/l1b-lut-history

MODIS Instrument Schematic

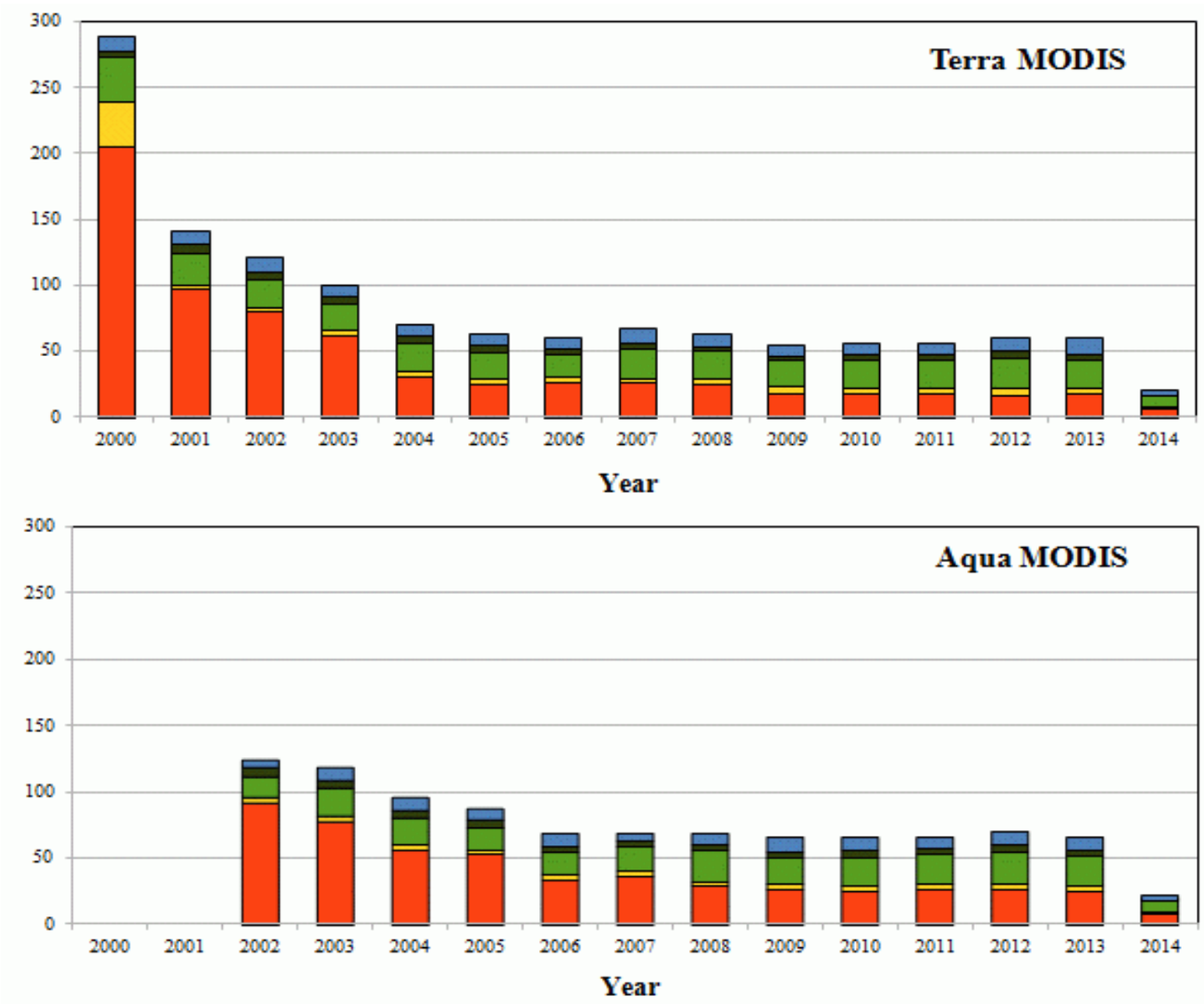






Calibration and Characterization Activities

Numbers of Calibration Events



	Terra	Aqua
Lunar Roll	136	116
PV Ecal	84	64
SRCA	396	271
BB	89	52
SD/SDSM	674	520

BB WUCD: 270 - 315K
SRCA: 3 modes

Others:
Maneuvers
Ground Targets
Inter-comparisons
Nighttime day mode ops

Details of Instrument Operation and Calibration: http://mcst.gsfc.nasa.gov/

Instrument Operations and Calibration Activities

Terra MODIS

- Launch: Dec 18, 1999
- First light: Feb 24, 2000
- A-side: launch - Oct 30, 2000
- B-side: Oct 30, 2000 - June 15, 2001
- A-side: July 02, 2001 - Sept 17, 2002
- A-side electronics & B-side formatter: since Sept 17, 2002

- BB nominally set at 290 K
- SD door fixed at "open" since July 02, 2003
- SRCA operated with 2 10-W lamps since 2006
- CFPA controlled at 83 K (briefly at 85 K: 3-5 Aug 2000)

Aqua MODIS

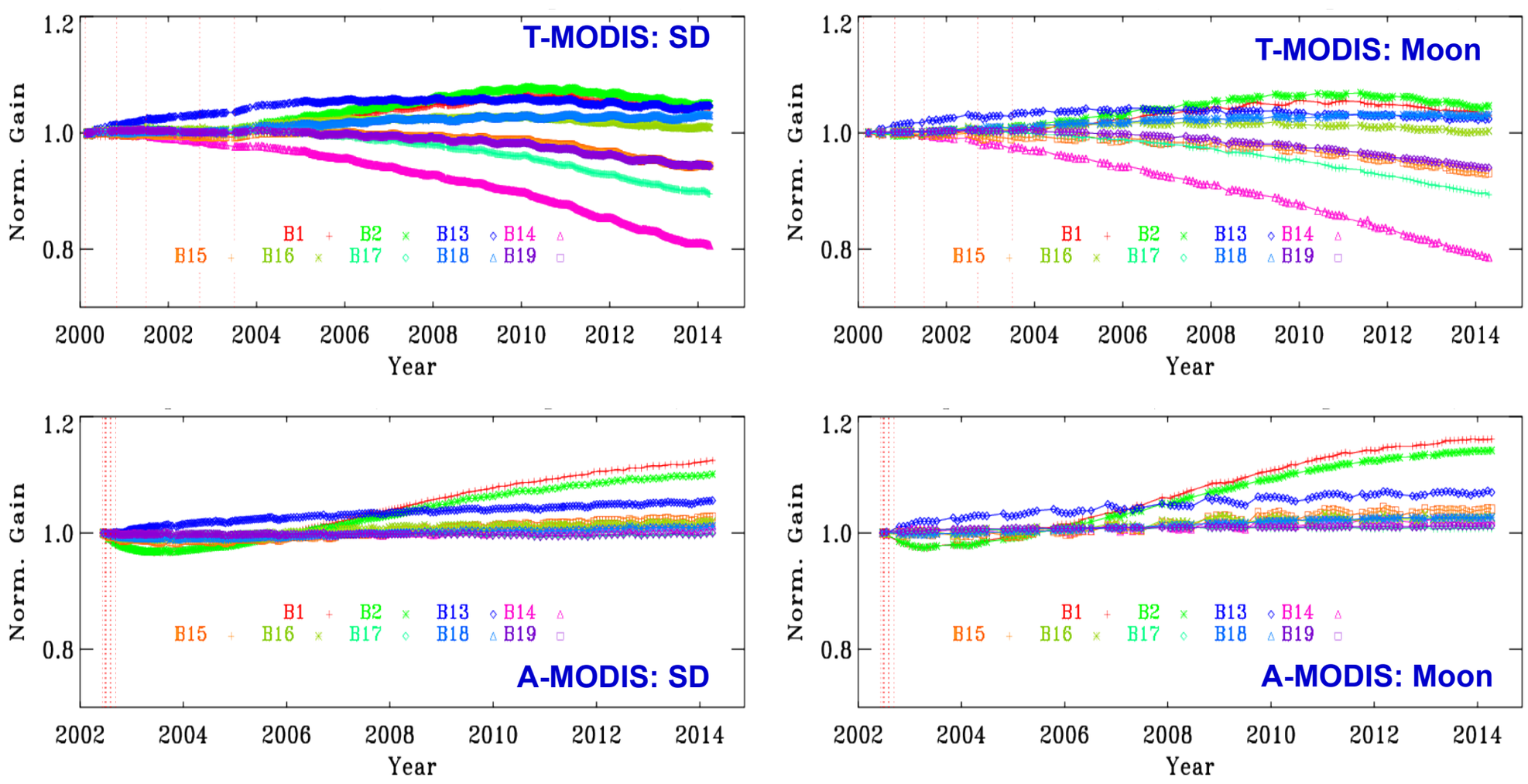
- Launch: May 04, 2002
- First light: June 24, 2002
- B-side: launch - present

- BB nominally operated at 285 K
- SD calibration: gradually reduced frequency
- SRCA operated with 2 10-W lamps since 2005
- CFPA controlled at 83 K (small increase of CFPA temperatures since 2007)

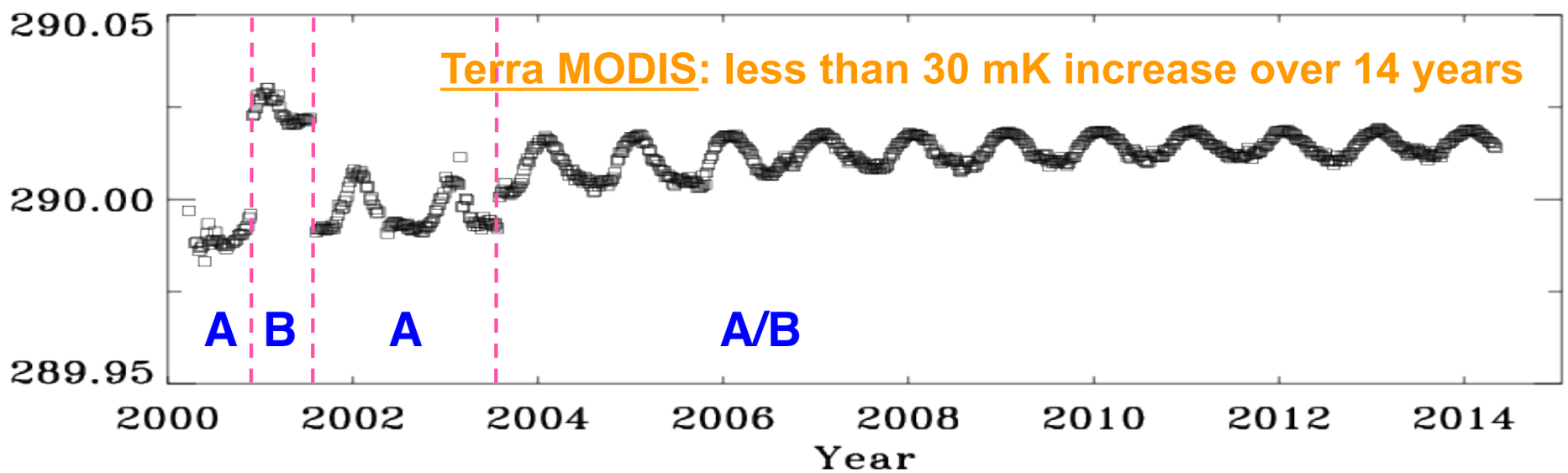
No Changes to Instrument Operation Configurations

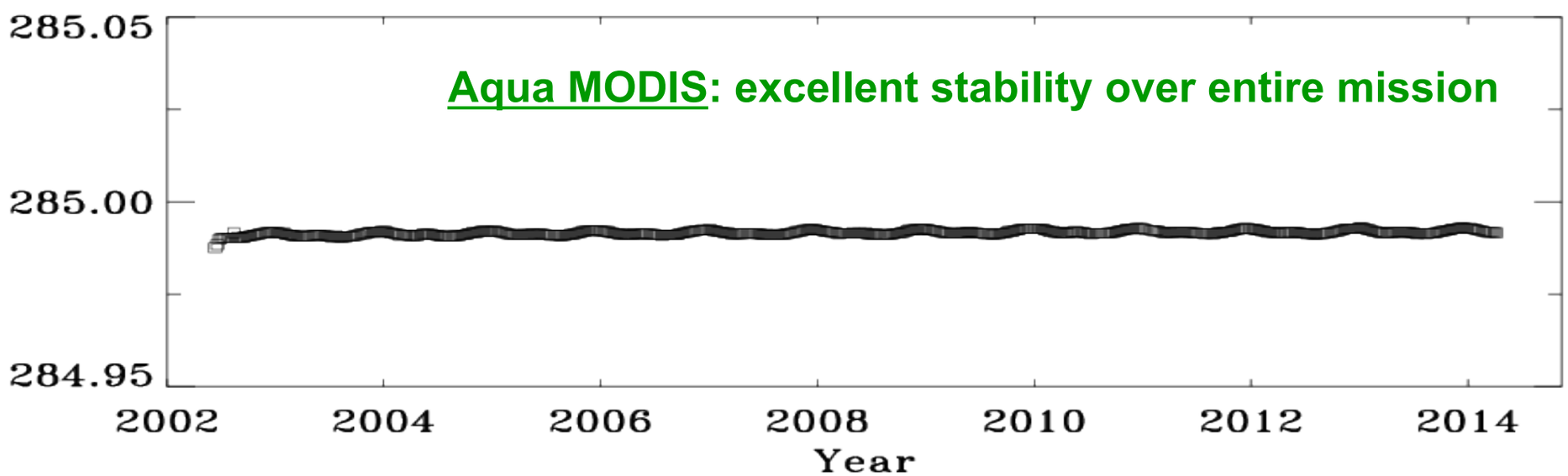
Spectral Band Responses (NIR)

Band Averaged, Mirror Side 1

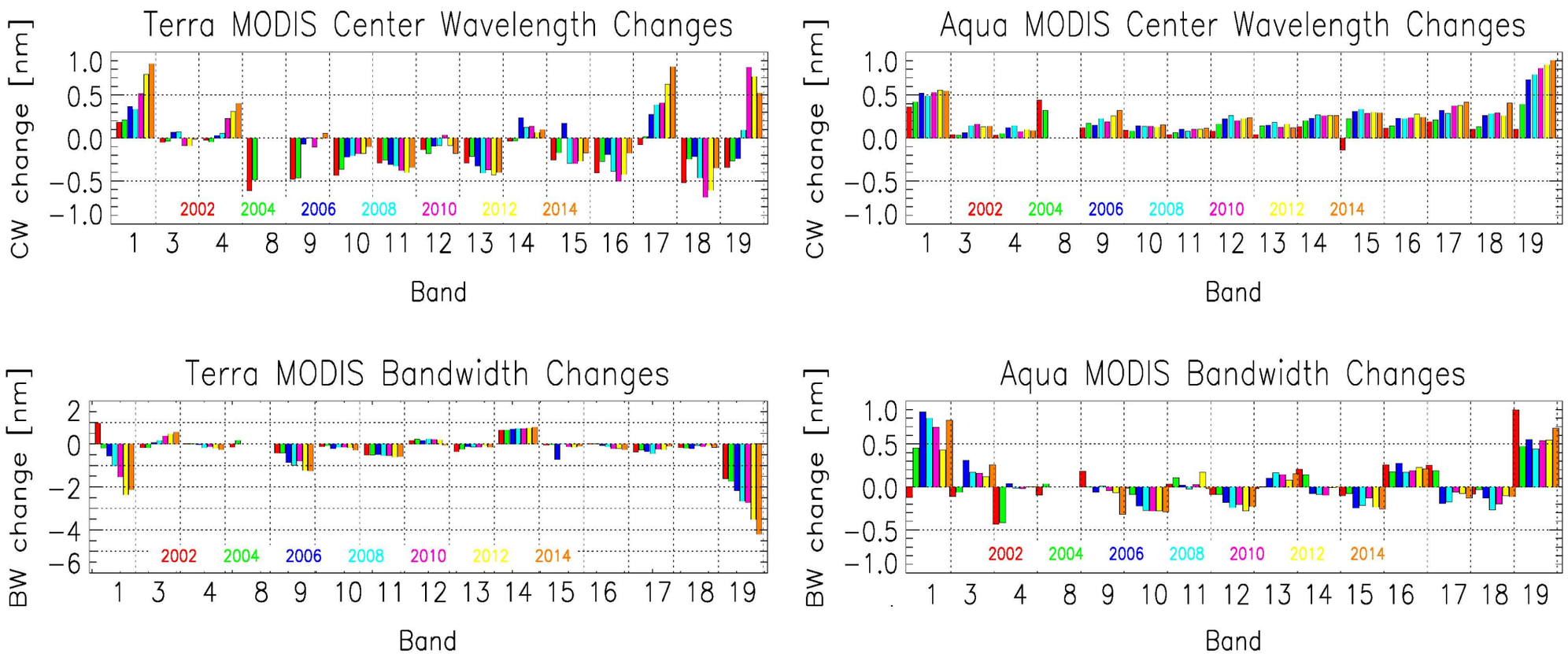


Blackbody Temperatures (nominal operation; long-term)





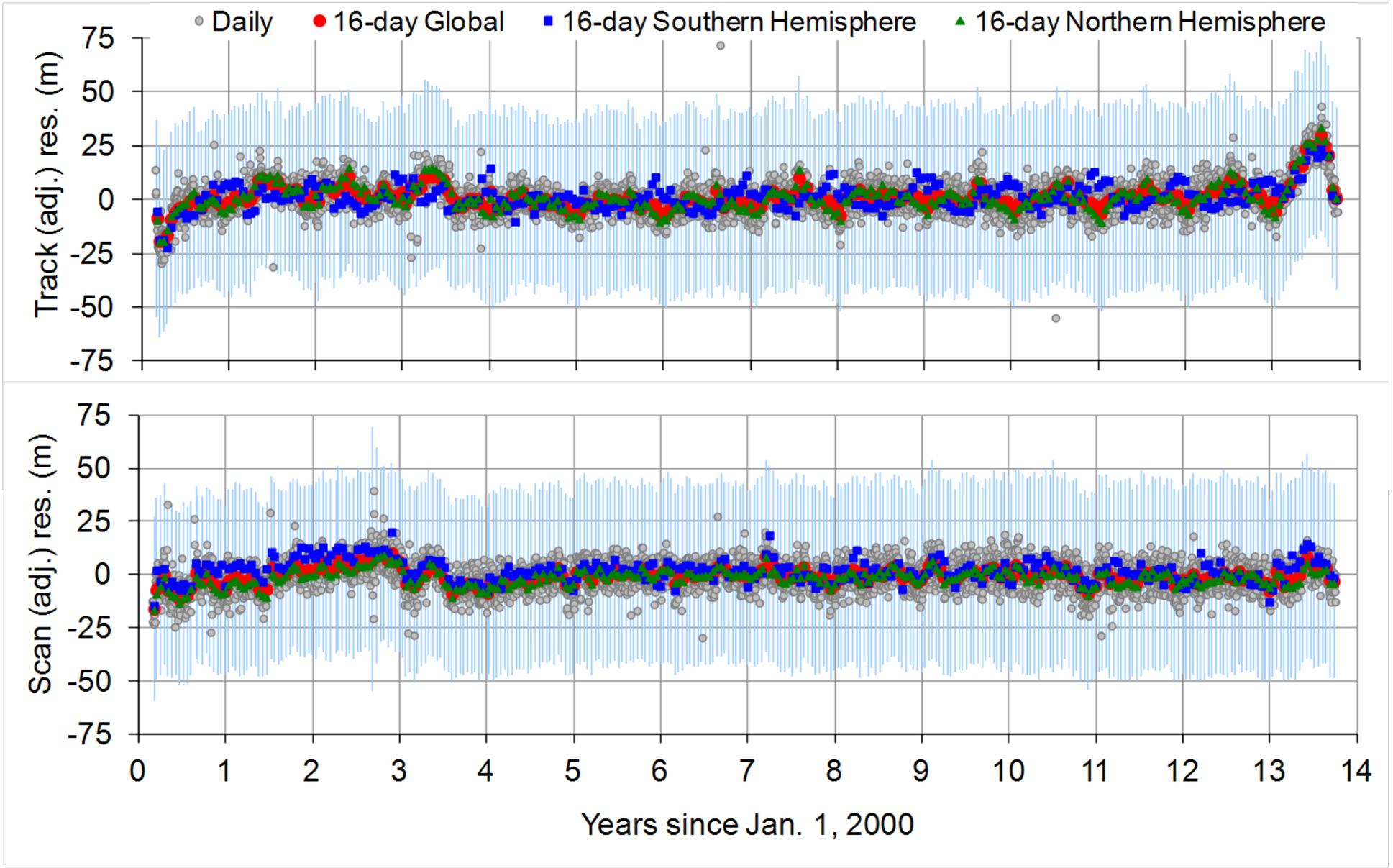
Spectral Characterization Performance



CW and BW changes are within 0.5 nm and 1.0 nm, respectively, for most VIS/NIR bands

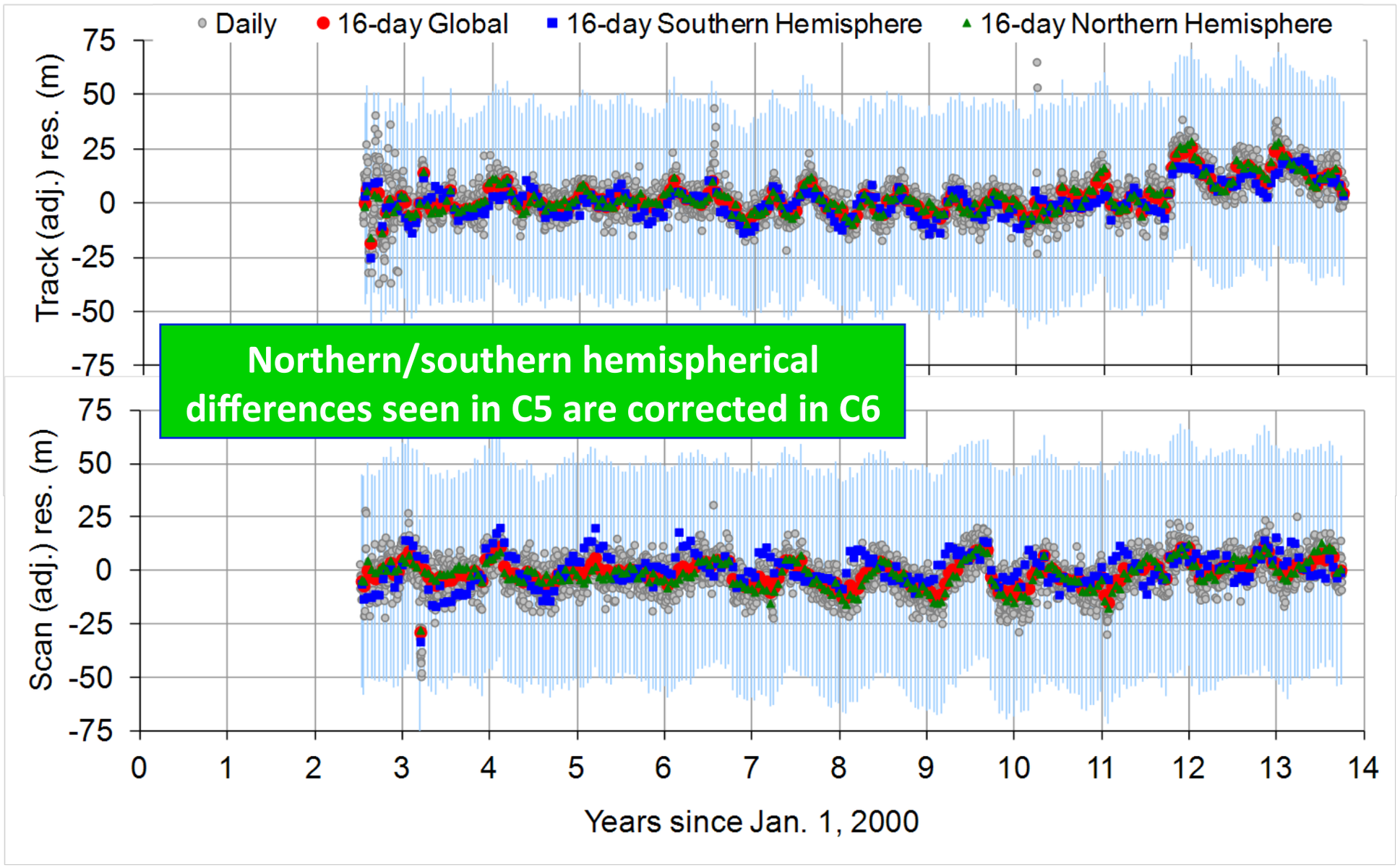
Relatively large changes are observed for bands with broad bandwidths (bands 1, 18, 19)

Terra MODIS Geolocation Results (C6)



Robert Wolfe et al. RMSE Track: 43 m Scan: 44 m

Aqua MODIS Geolocation Results (C6)



Robert Wolfe et al. RMSE Track: 46 m Scan: 53 m

Detector Noise Characterization

- **36 Spectral Bands with 490 individual detectors**
  - 3 new noisy detectors since 2009 (Aqua B29 D6, Terra B30 D7 and D4)
- **Terra: 47 noisy detectors (30 from pre-launch : 35 at launch) and no inoperable detectors**
  - B30 D4 became noisy recently (2014)
  - B29 D6 set to inoperable (2016)
- **Aqua: 7 noisy detectors (2 from pre-launch: 3 at launch) and 15 inoperable detectors (13 in Band 6)**

Time	Event	Noisy Band (Detector)
Pre-launch		B7(all), B36(all)
2000055.1527	Nadir Door Open	B5(4,16), B7(all), B33(1), B34(7,8), B36(all)
2000160.0000	CFPA Lost Control	B5(4,16), B7(all), B30(5) B33(1), B34(7,8), B36(all)
2000218.2210	Formatter Anomaly	B5(4,16), B7(all), B27(6), B30(5), B33(1), B34(6,7,8), B36(all)
2000304.1420	Switch to B-Side	B5(4,16), B7(all), B27(6), B30(5), B33(1), B34(6,7,8), B36(all)
2001019.1415	N/A	B5(4,16), B7(all), B27(6), B30(5, 8), B33(1), B34(6,7,8), B36(all)
2001183.2245	Switch to A-Side	B5(4), B7(all), B27(6), B30(5, 8), B33(1), B34(6,7,8), B36(all)
2002078.1615	Safe Mode	B5(4), B7(all), B27(6), B28(3), B30(5,8), B33(1), B34(5,6,7,8), B36(all)
2003350.1305	Safe Mode	B5(4), B7(all), B27(1,6), B28(8), B30(5,8), B33(1), B34(6,7,8), B36(all)
2005130.1345	SAA (Day)	B5(4), B7(all), B27(1,6), B28(1,8), B29(6), B30(5,8), B33(1), B34(6,7,8), B36(all)
2005309.1510	N/A	B5(4), B7(all), B27(1,6), B28(8,9), B29(6), B30(5,8), B33(1), B34(6,7,8), B36(all)
2006155.0210	SAA (Night)	B5(4), B7(all), B27(1,6), B28(8), B29(6), B30(3,5,8), B33(1), B34(6,7,8), B36(all)
2007193.1155	SAA (Day)	B5(4), B7(all), B27(1,6), B28(8), B29(6), B30(3,5,8), B33(1), B34(6,7,8), B36(all)
2008308.0900	SAA (Night)	B5(4), B7(all), B27(1,2,6), B28(8), B29(6), B30(1,3,5,8), B33(1), B34(6,7,8), B36(all)
2013125.1740	SAA (Night)	B5(4), B7(all), B27(1,2,6), B28(8), B29(6), B30(1,3,5,7,8), B33(1), B34(6,7,8), B36(all)

Time	Event	Noisy Band (Detector)	Inoperable Band (Detector)
Pre-launch		B6(17), B20(10)	B5(20), B6(2,12-14,16,18-20), B36(5)
2002175.2324	Nadir Door Open	B6(7,9,17)	B5(20), B6(2,4-6,10,12-16,18-20), B36(5)
2005010.1715	(Day)	B6(7,9,17), B27(3)	B5(20), B6(2,4-6,10,12-16,18-20), B36(5)
2007359.1020	N/A	B6(7,9,17), B27(3), B29(8)	B5(20), B6(2,4-6,10,12-16,18-20), B36(5)
2008038.1750	(Day)	B6(7,9,17), B27(3), B29(2,8)	B5(20), B6(2,4-6,10,12-16,18-20), B36(5)
2012022.1510	SAA (Day)	B6(7,9,17), B27(3), B29(2,6, 8)	B5(20), B6(2,4-6,10,12-16,18-20), B36(5)