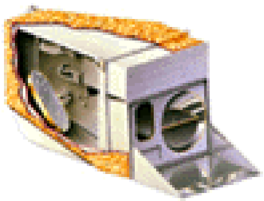
MODIS Instrument Operations Status



Terra Flight Operations

- Terra Spacecraft Status
  - 15+ years of successful operation
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – 32 supersets allocated: 1 lost since last STM
  - Battery – Anomaly on 10/13/09 resulted in loss of 1 cell (out of 54 total). No impact on operations or power availability.
  - Orbit Maneuvers: Drag Make-up #84-90, Inclination Adjustment #39-41

Aqua Flight Operations

- Aqua Spacecraft Status
  - 13 years of successful operations
  - No major flight operation anomaly or extensive data losses since last STM
  - Solid State Recorder – Full data allocation
  - Battery – Fully functional
  - Orbit Maneuvers: Drag Make-up #84-96, Inclination Adjustment #43-47

MODIS Instrument Operations (Terra)

- **Terra MODIS is healthy and operating nominally**

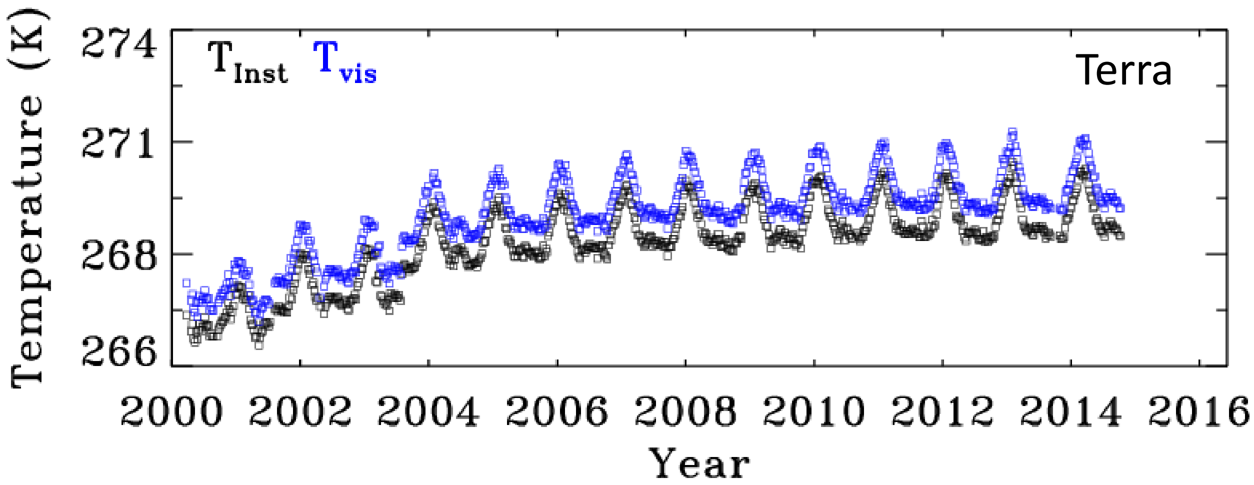
- **Operational Configuration (No change since last STM)**
  - A-side: launch to Oct 30, 2000
  - B-side: Oct 30, 2000 to June 15, 2001
  - A-side: July 02, 2001 to Sept 17, 2002
  - A-side electronics and B-side formatter: Sept 17, 2002 to present
  - BB temperatures set at 290K
  - Cold FPA (SMIR and LWIR) controlled at 83K
  - SD door fixed to "open" position since July, 2003
- **Events**
  - None
- **Concerns**
  - SSR allocation – further decrease could result in data loss

MODIS Instrument Operations (Aqua)

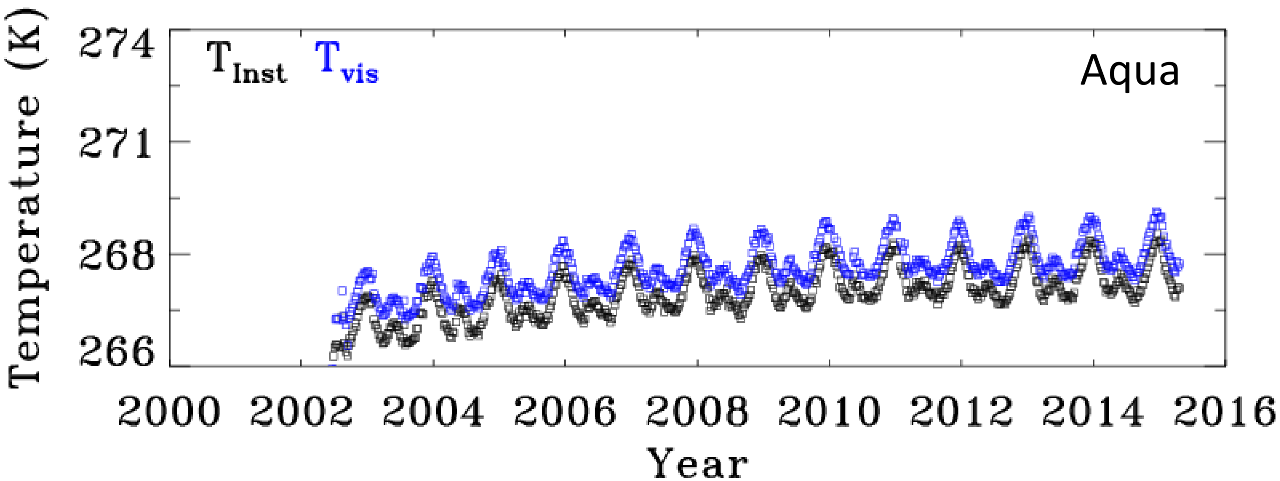
- **Aqua MODIS is healthy and operating nominally**

- **Operational Configuration (No change since last STM)**
  - Same B-side configuration since launch
  - BB temperatures set at 285K
  - Cold FPA (SMIR and LWIR) controlled at 83K
- **Events**
  - None
- **Concerns**
  - Loss of radiative cooler margin – Cold FPA not maintained at 83 K through entire orbit.

Instrument Temperature Trends

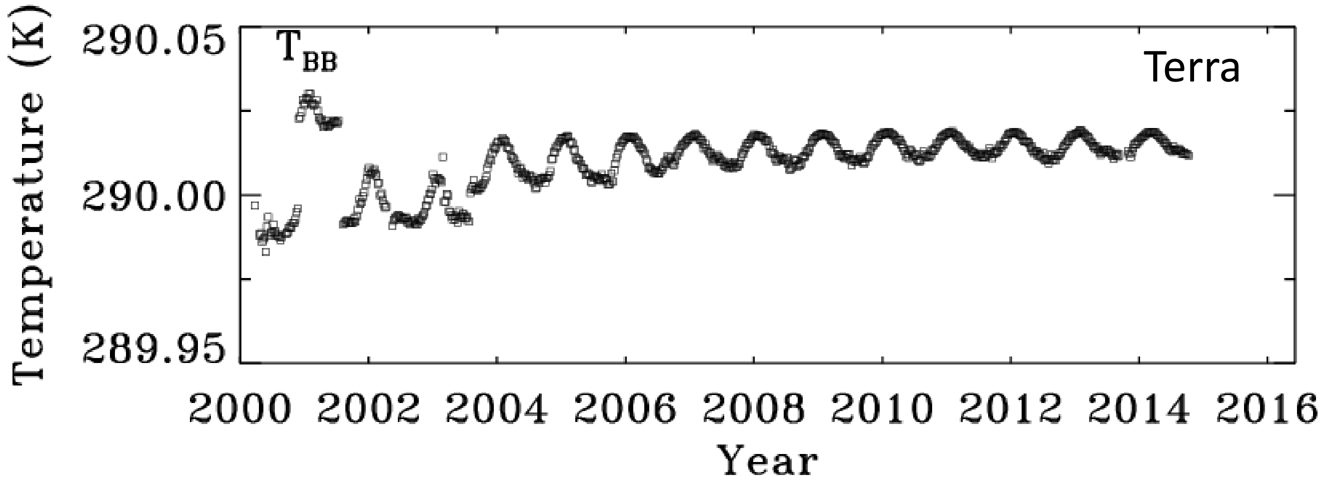


3.5K increase over 15 years

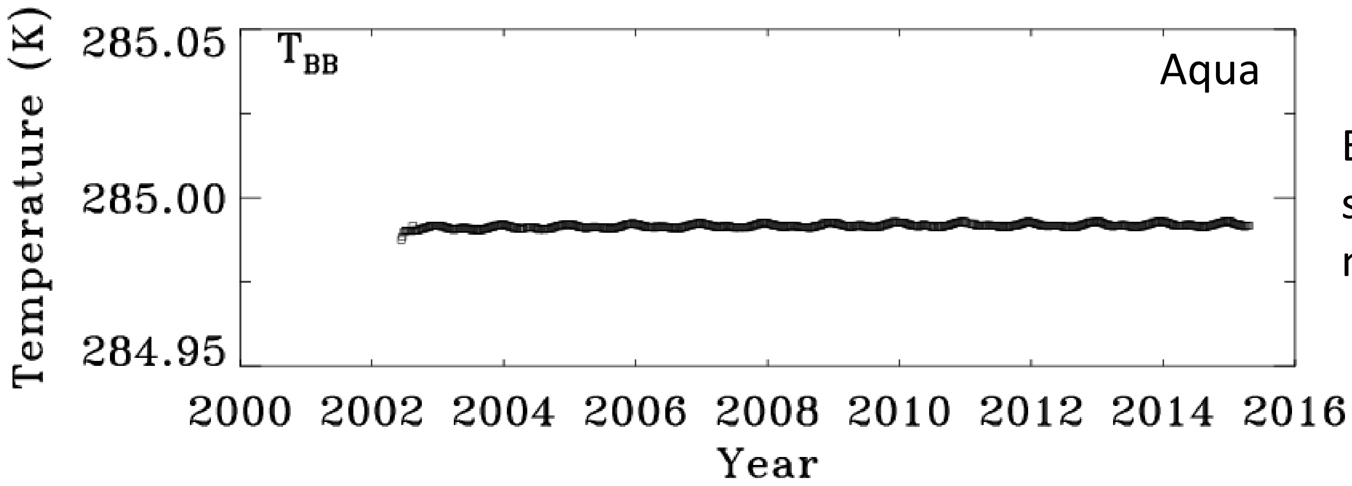


< 2K increase over 13 years

BB Temperature Trends

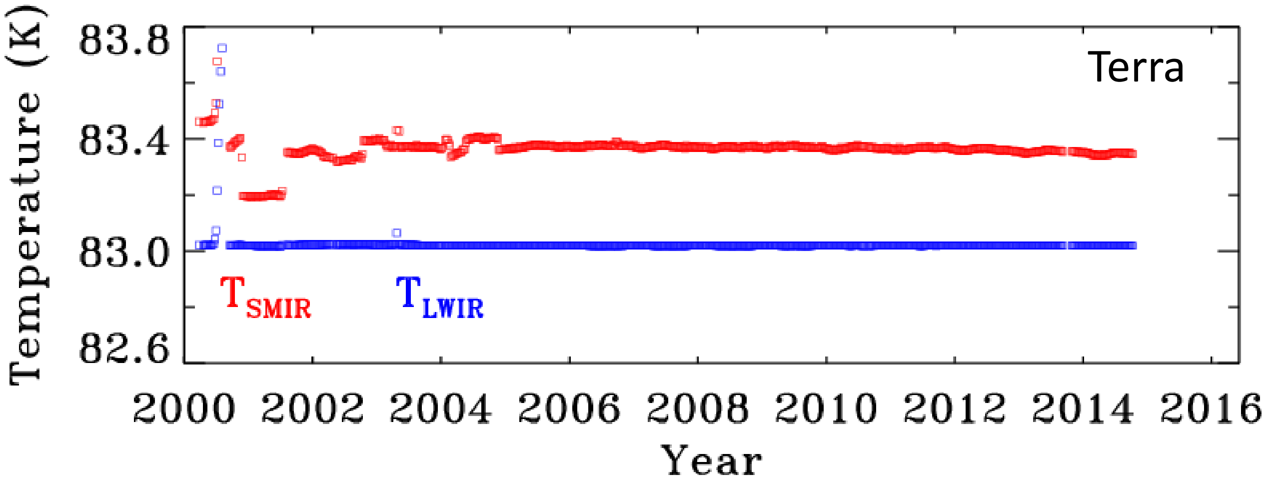


< 30 mK increase over 15 years

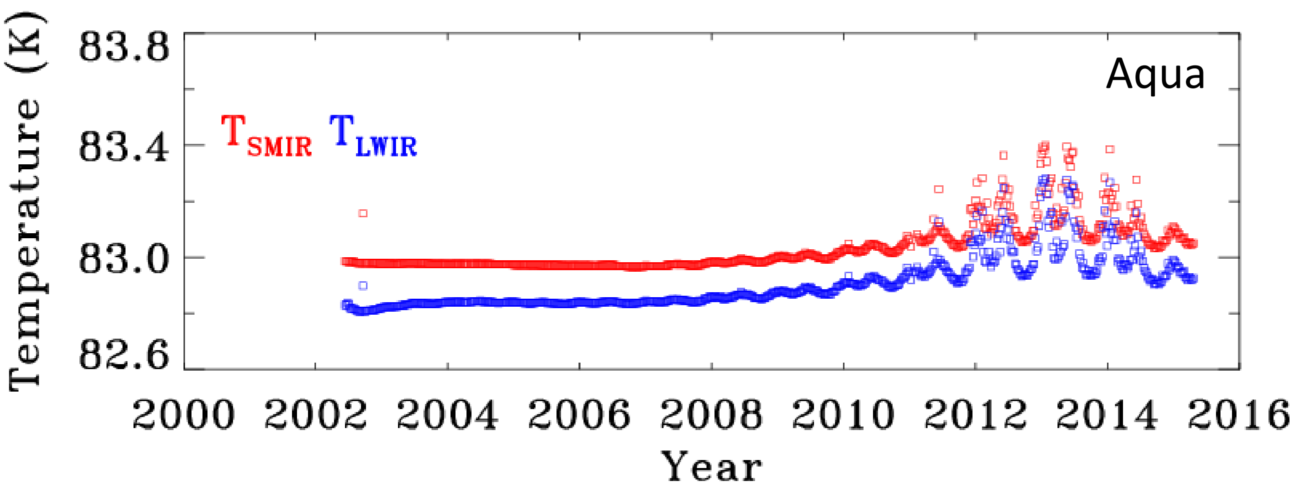


Excellent stability over mission lifetime

CFPA Temperature Trends



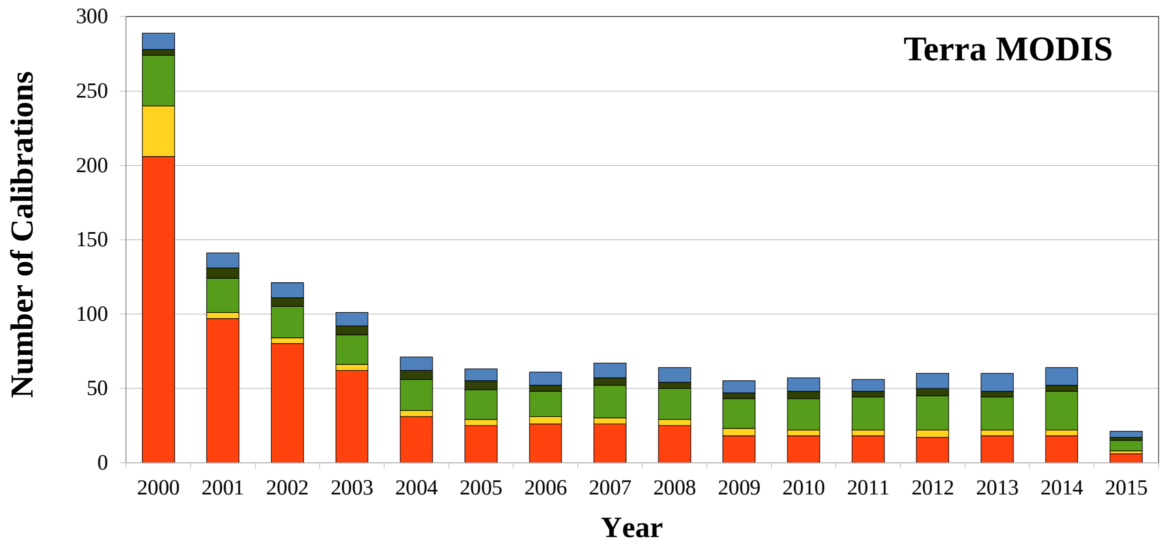
Very stable over lifetime



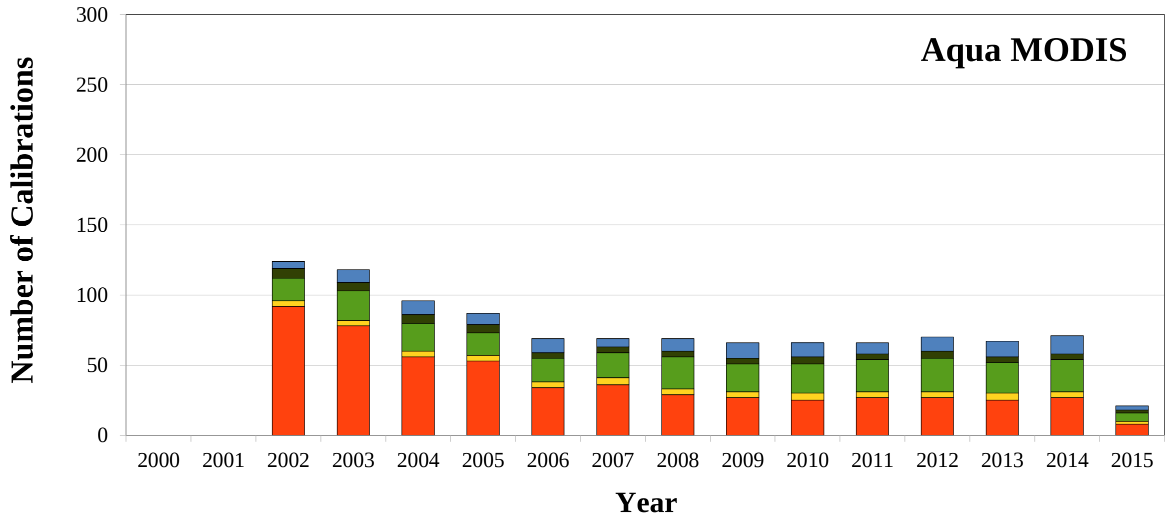
Increase in recent years

MODIS Calibration Operations

Terra



Aqua



Lunar Roll

PV Ecal

SRCA

BB

SD/SDSM

Terra/Aqua MODIS OBC Operations

TERRA

Activity	PL to 05/14	05/14 – present	Total
SD/SDSM#	674	17	691
BB WUCD	90	5	95
SRCA*	318	22	340
Electronic Cal	71	5	76
Lunar Roll	138	12	150

AQUA

Activity	PL to 05/14	05/14 - present	Total
SD/SDSM#	517	27	544
BB WUCD	53	4	57
SRCA*	248	22	270
Electronic Cal	61	4	65
Lunar Roll	111	12	123

Open & Screened Activities counted independently
* Includes Spatial, Spectral and Radiometric
05/01 = last Science Team Meeting

SRCA Calibrations

- Terra – 340 SRCA Calibrations
- Aqua – 270 SRCA Calibrations
- Please note there was a minor reconciliation of the usage numbers
- Lamps well within lifetime usage margins
- No lamp failures since 2006

Lamp Power		10W				1W	
Lamp #		1	2	3	4	1	2
Terra	Usage (hr)	351.8	172.1	190.3	127.3	586.0	298.1
	Life (hr)	500	500	500	500	4000	4000
	percent	70.4%	Failed on 11-20-2004	Failed on 2-18-2006	25.5%	14.7%	7.5%
Aqua	Usage (hr)	343.5	188.0	205.7	128.4	526.8	287.9
	Life (hr)	500	500	500	500	5000	5000
	percent	68.7%	Failed on 4-14-2003	Failed on 6-28-2005	25.7%	10.5%	5.8%

Future Operational Considerations

- Aqua MODIS CFPA temperature control
  - Currently set at 83K
  - Minimal impact on science data
  - No need for mitigation at this time

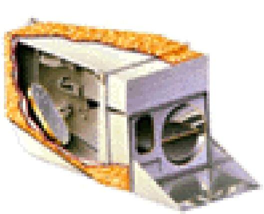
- Aqua SD/SDSM door movements
  - Passed projected lifetime limit on movements
  - No change in current frequency of SD calibration activities planned at this time
  - No expectation of Aqua SD Door failure

	PL to 05/14	05/14 to present	Total	Design Lifetime	% Used
Terra*	2146	0	2146	3022	71.01
Aqua+	3146	72	3218	3022	106.49

* As of 07/02/2003, SD Door in fixed 'open' position with screen in place

+ Aqua reached designed lifetime of door movement on DOY 2012/191 (July 2012).

MODIS Level 1B Code and LUT Status



MCST Workshop at MST Meeting (May 18, 2015)

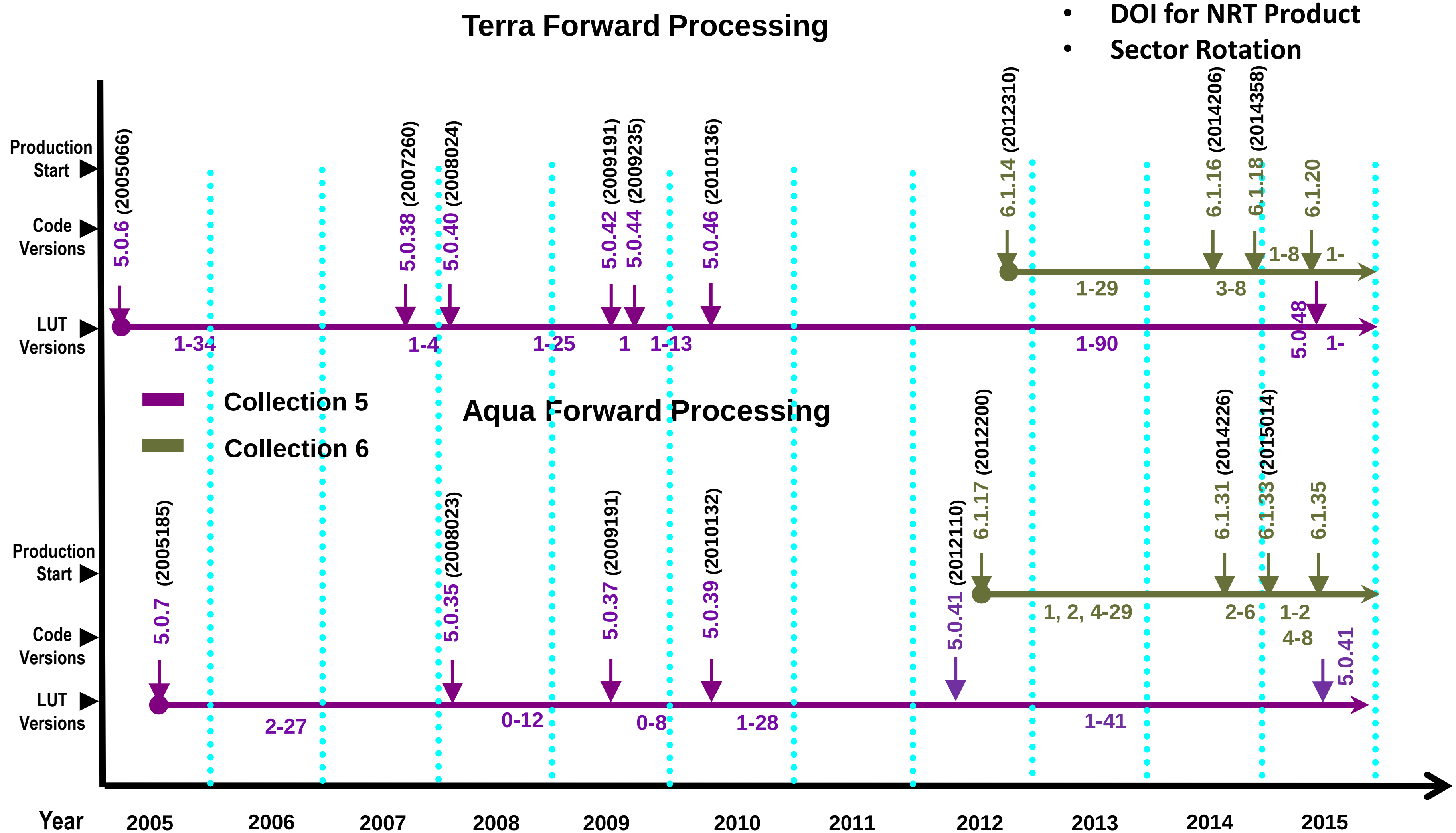
C5/C6 L1B Code and LUT Updates

- **Two separated sets of code and LUT (look-up-table)**
  - One for Terra MODIS and one for Aqua MODIS
- **Two versions**
  - C5 (2005 – present): Terra V5.0.48; Aqua: V5.0.43
  - C6 (2012 – present): Terra V6.1.20; Aqua: V6.1.35
- **L1B code updates (since the last STM (4/29/2014))**
  - C5: Terra 1; Aqua: 1
  - C6: Terra 3; Aqua: 3
- **L1B LUT updates (since the last STM)**
  - Terra MODIS C5: 19; C6: 19; Aqua MODIS C5: 17; C6: 16
  - Most LUT updates were driven by response changes of VIS bands

MODIS MOD_PR02 L1B Code/LUTs

Major Production Changes Timeline (C5 & C6)

- SDP Toolkit Update
- DOI for NRT Product
- Sector Rotation



C5/C6 L1B LUT Updates

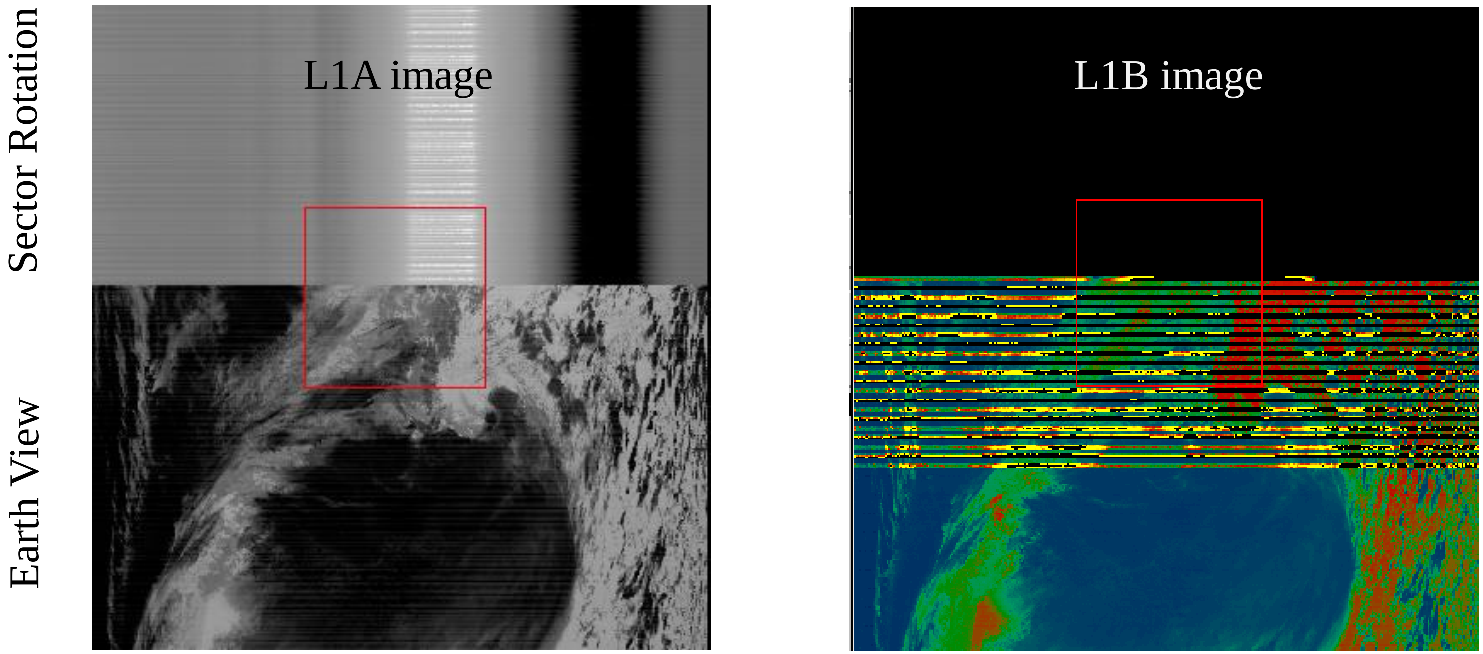
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Terra C5	10	14	14	17	19	18	18	21	15	17	8
Terra C6	0	0	0	0	0	0	0	5	14	17	8
Aqua C5	6	9	11	9	9	13	15	13	11	14	7
Aqua C6	0	0	0	0	0	0	0	7	11	15	7
Total	16	23	25	26	28	31	33	46	51	63	30

- Phase out of C5 timeline considerations
  - Atmosphere Products
    - C6 released in April 2015; continuing C5 until May 1, 2016
  - Land Products
    - C6 reprocessing underway
  - Ocean Products
    - No C5 needed

Anomaly Pre- and Post- Lunar Roll Issue

- Reported from fire product: a multi-scan swath wide ‘fire’ – for the period right after the 2014345 lunar activity

2014345.0635 Terra Band 22



- A scan of sector rotated data was considered ‘valid’ which contaminates the calibration of the 20 subsequent scans (TEB use a 40 scan average for the b1 calibration)

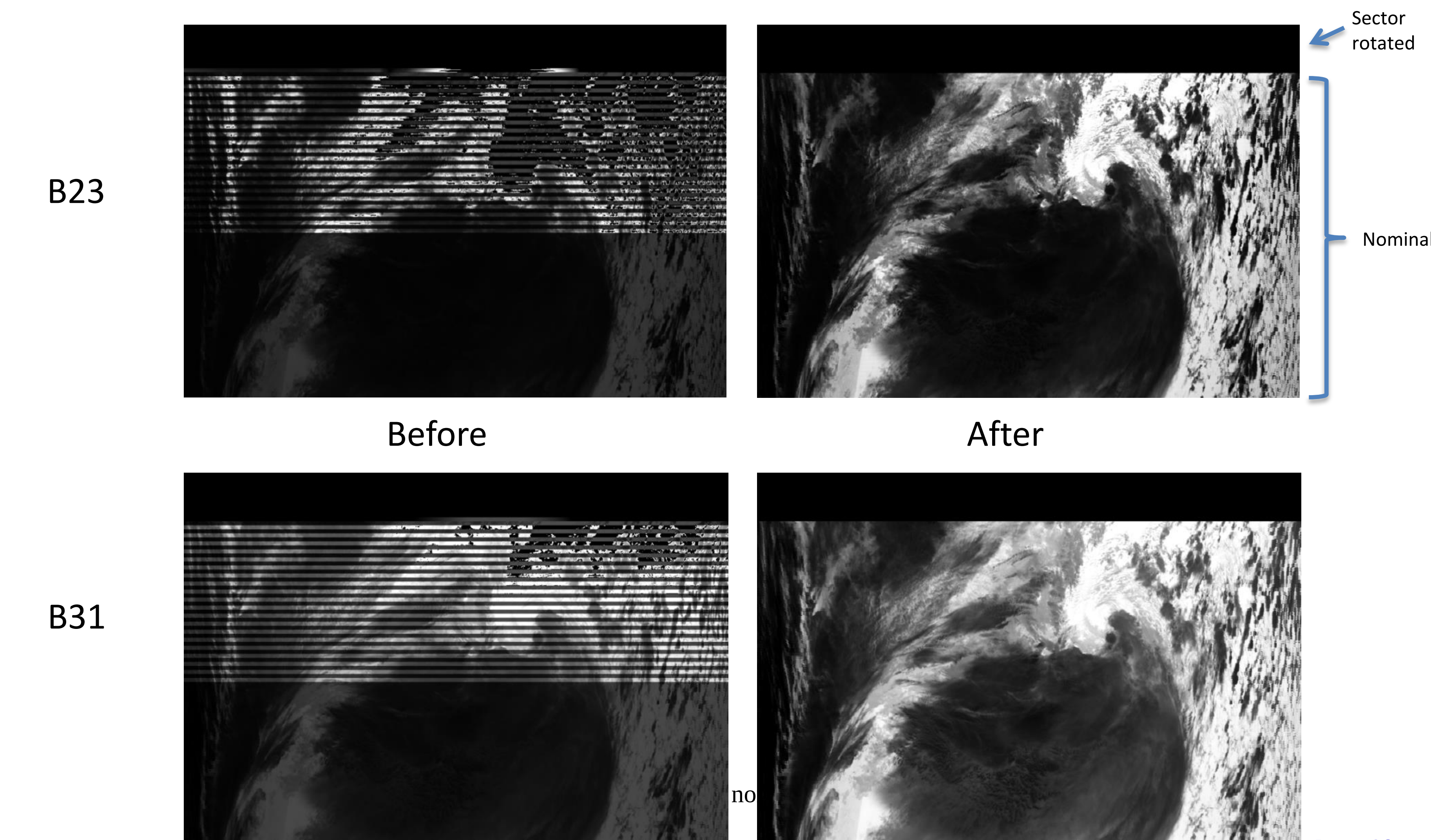
Anomaly Pre- and Post- Lunar Roll Investigation

- L1B was originally designed to use a telemetry 'CS_FR_ENC_DELTA'
  - ➢ Anomaly pre-lunar roll (reported and fixed in 2009)
    - 'CS_FR_ENC_DELTA': updated every 8 seconds
    - MODIS scan: 1.477 s
  - ➢ Anomaly post-lunar roll
    - 'CS_FR_ENC_DELTA' readout one scan early than the command implementation complete (~ 20%)

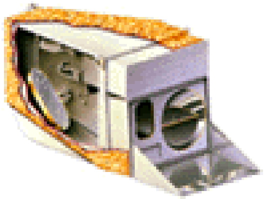
- 'SET_FR_ENC_DELTA' telemetry correlates with the sector rotation encoder position, and is updated for each scan

- L1B code change
  'CS_FR_ENC_DELTA' → 'SET_FR_ENC_DELTA'
  Fix anomaly pre- and post-lunar roll activities
  Applied in the forward processing (C5/C6, Aqua/Terra)

Anomaly Pre- and Post- Lunar Roll Test Result



MODIS RSB Calibration and Performance

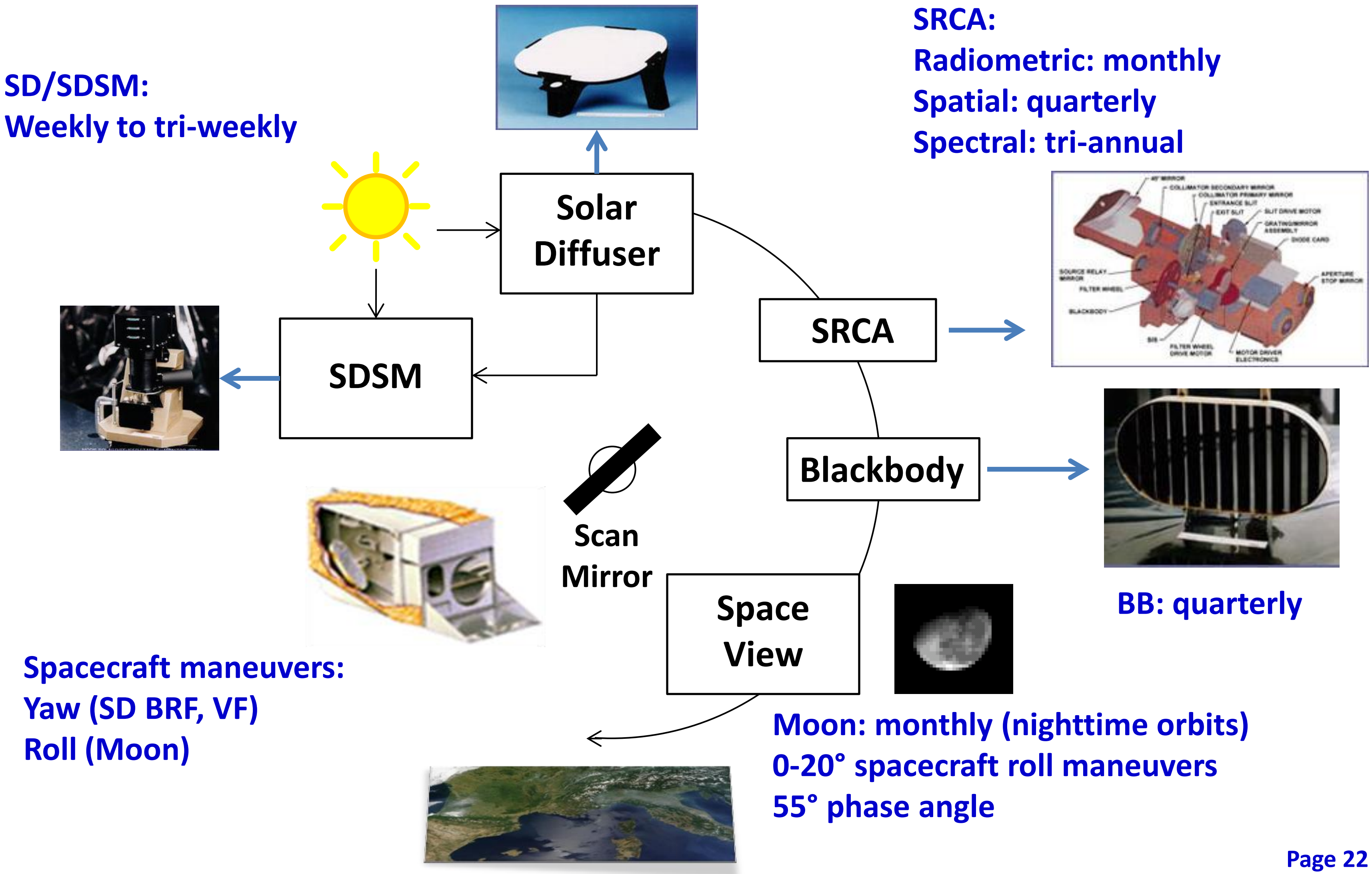


MCST Workshop at MST Meeting (May 18, 2015)

Outline

- Introduction
- RSB calibration using SD/SDSM
  - SD degradation
  - RSB gain performance
- Lunar calibration
  - RSB gain from lunar measurements
- EV response trending
- Current Algorithm and Updates
  - Terra Band 5
  - Terra Band 10
- RSB SNR
- Summary of RSB performance

On-orbit Calibration Activities



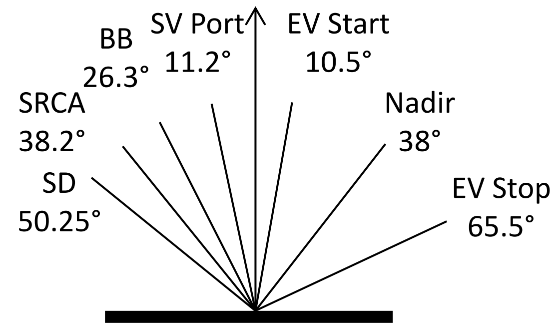
RSB Calibration

- EV Reflectance

$$\rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS}$$

- Look-Up-Tables (LUTs) updated regularly for RSB
  - m_1: Inversely proportion to gain at the AOI of SD
  - RVS : Sensor Response versus Scan angle (normalized to SD AOI)
  - Uncertainty tables

- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - SRCA and EV mirror side (MS) ratios
  - Response trending from EV targets



Angle of Incidence (AOI)

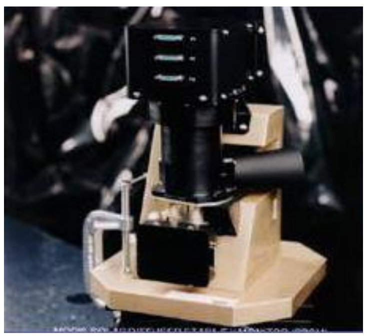
RSB SD Calibration

Sun

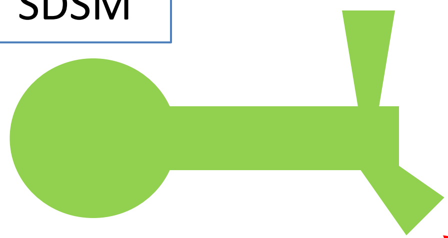
1.44 % screen

Optional 7.8 % screen (SD)

Terra: SD screen in permanent down position since July 2, 2003



SDSM



SD degradation

$$\Delta_{SD} = \frac{dc_{SD}^{i}/dc_{SD}^{9}}{dc_{Sun}^{i}/dc_{Sun}^{9}}$$

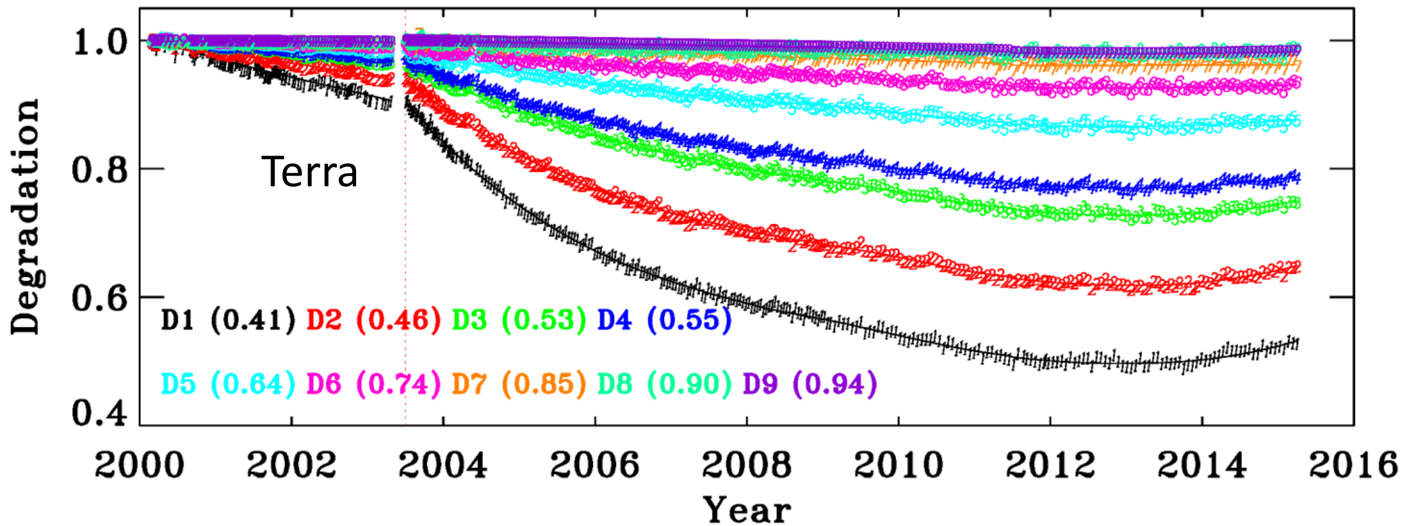
Scan mirror

SD

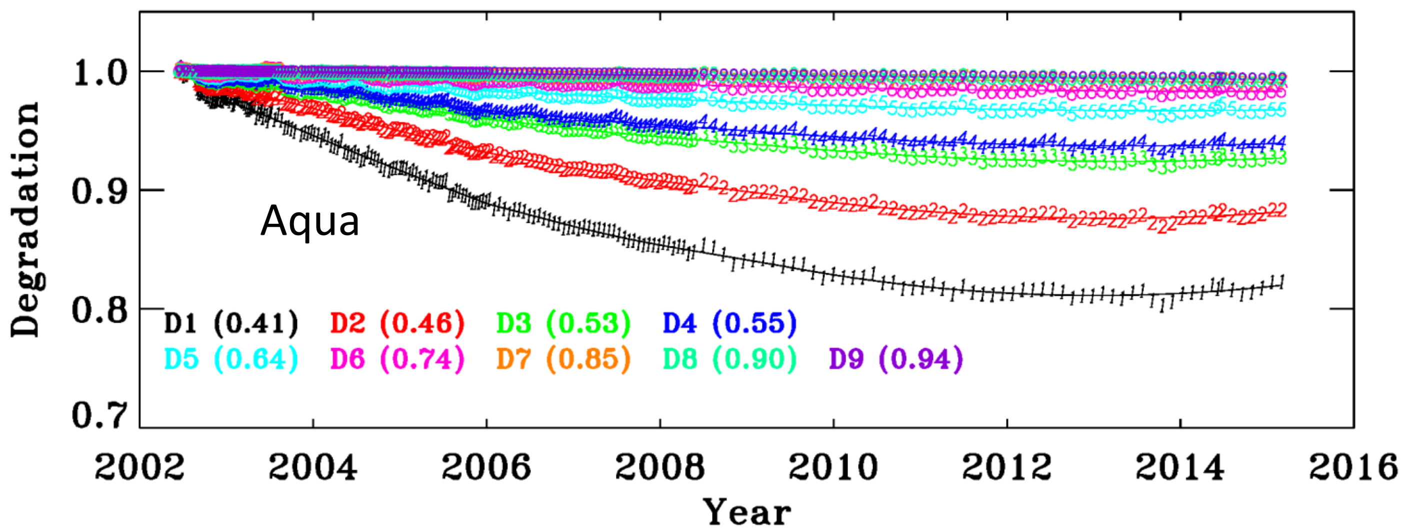
$$m_1 = \frac{\rho_{SD} \cdot cos(\theta_{SD})}{dn_{SD}^{*} \cdot d_{Earth\_Sun}^{2}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}$$

$\rho_{SD} \cdot cos(\theta_{SD})$ = BRF, dn_{SD}^{*} = Signal from SD (temperature and background corrected),
Δ_{SD} = SD degradation, Γ_{SDS} = screen attenuation

MODIS SD Degradation

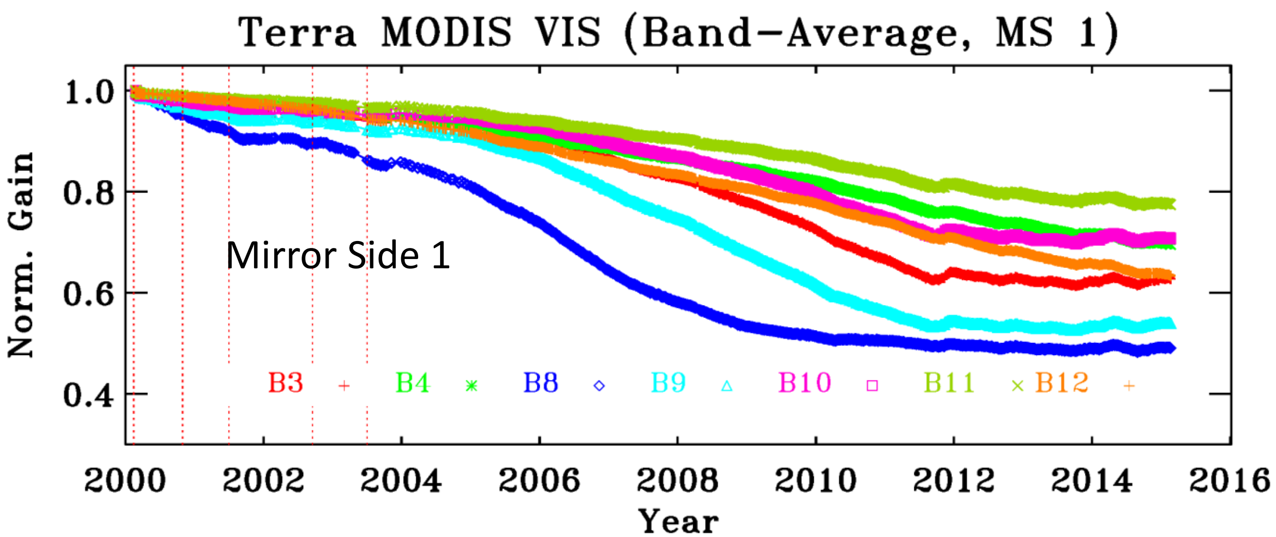


Increased degradation after SD door anomaly on July 2, 2003

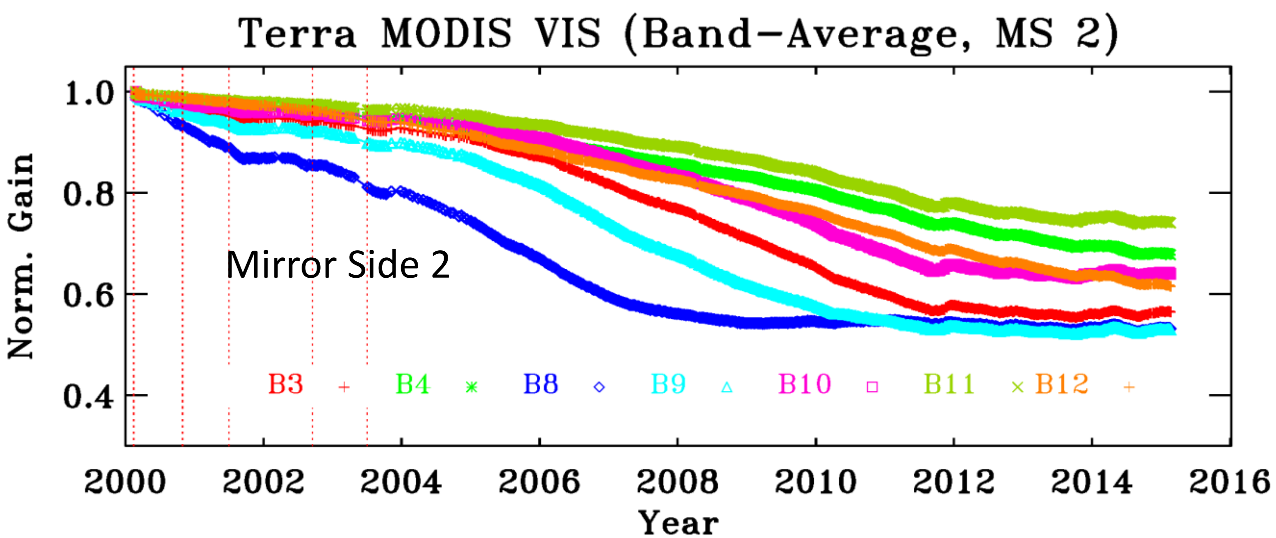


Larger SD degradation at shorter wavelengths for both instruments

SD Gain Trending: Terra

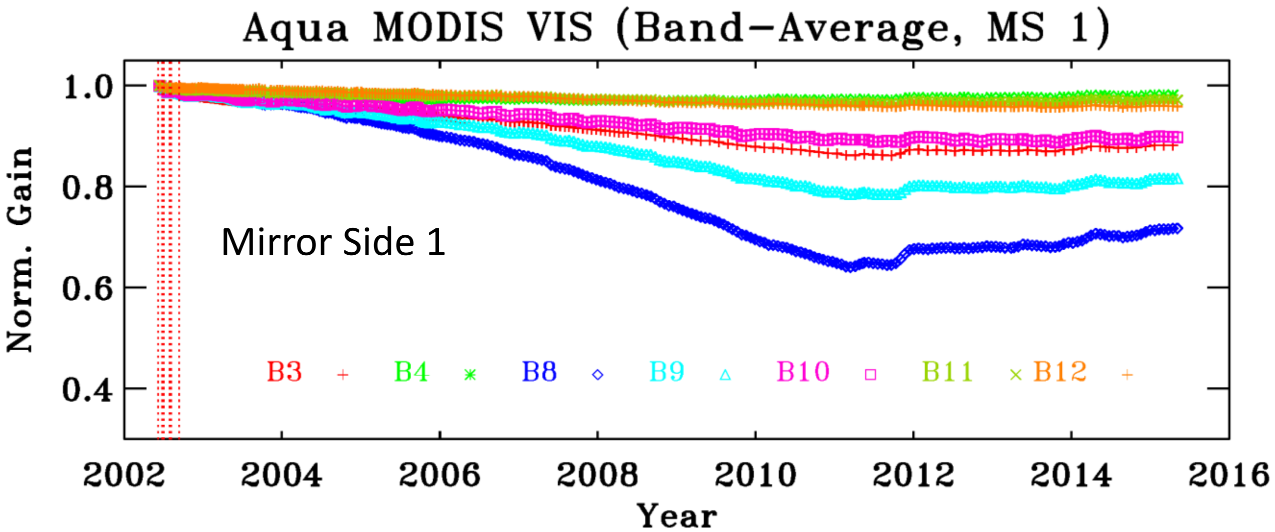


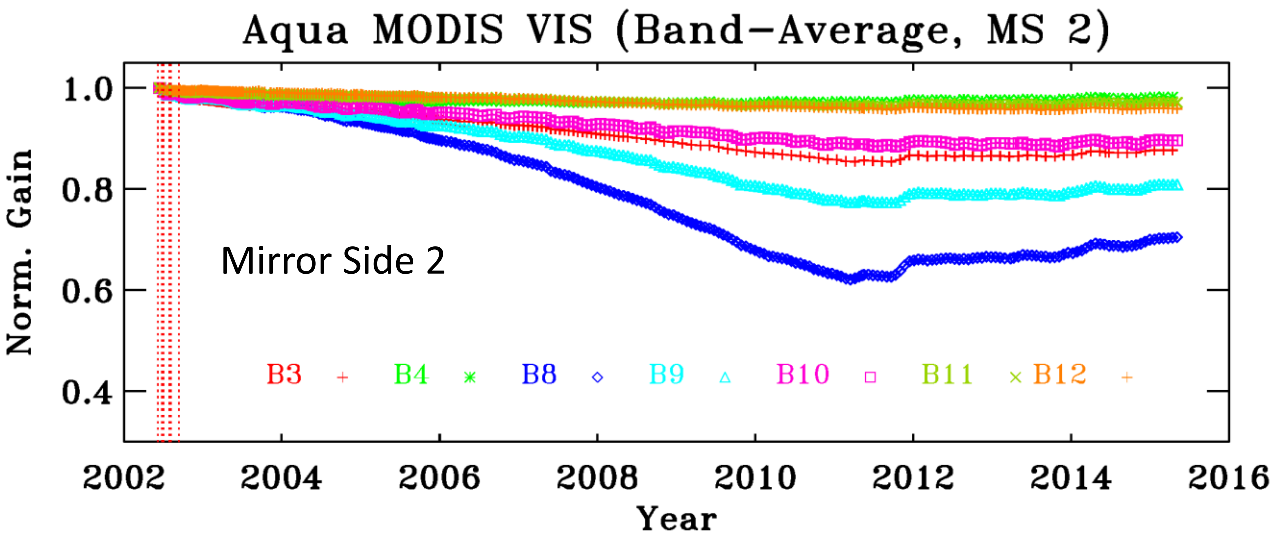
- Most change observed for short-wavelength bands
- Band 8 (.412 µm) changes by over 50%



Terra VIS bands have a maximum mirror-side difference of about 11% at the SD AOI (Band 3 - .469 µm)

SD Gain Trending: Aqua



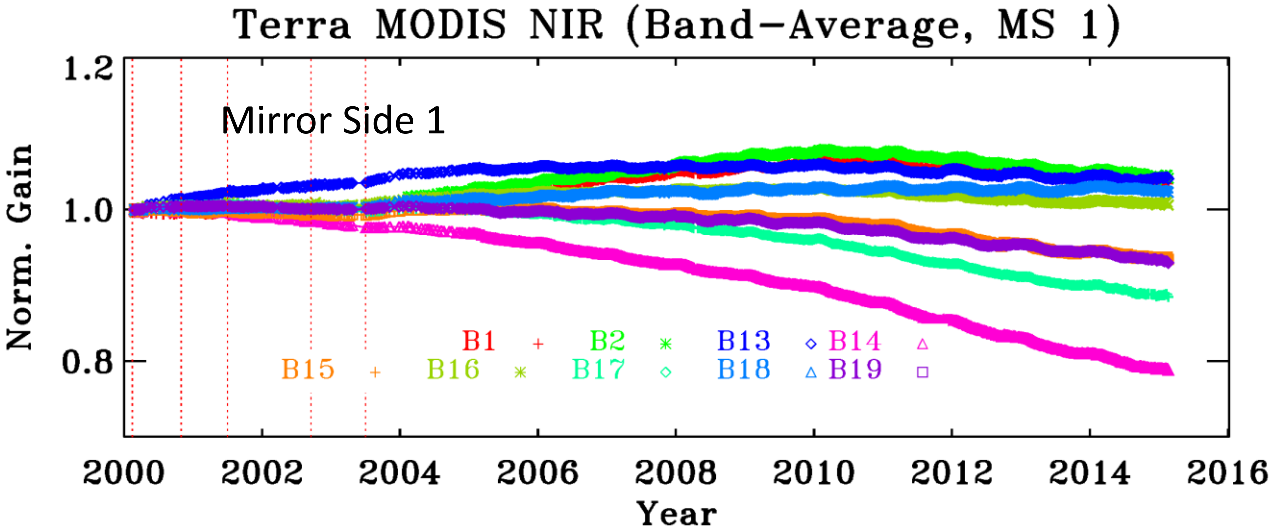


Most change observed for short-wavelength bands

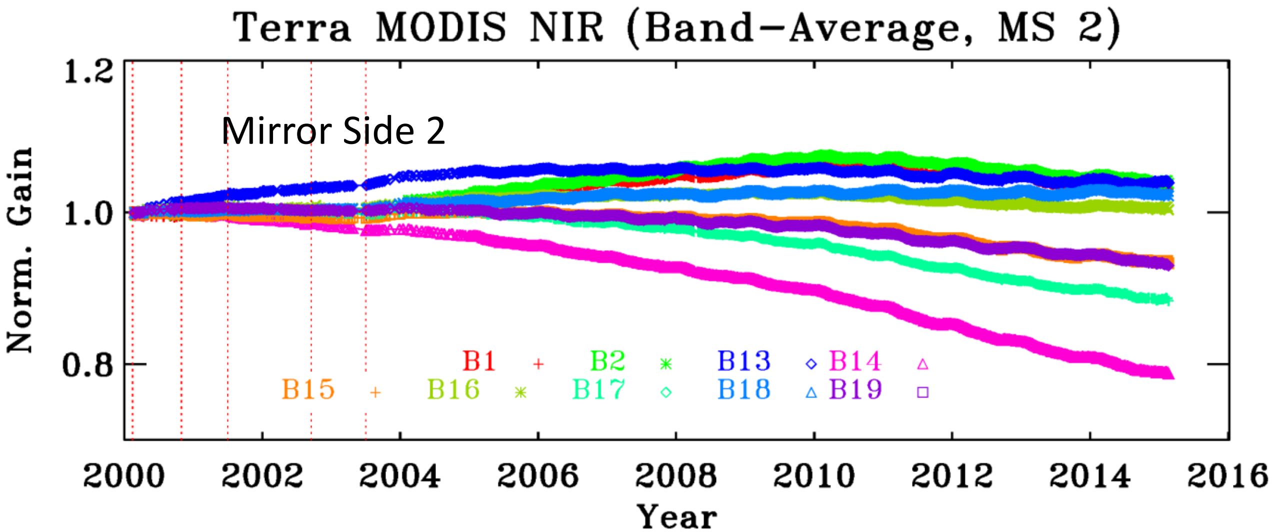
Band 8 (.412 µm) maximum change is ~40%

Aqua VIS bands have a maximum mirror-side difference of about 3% at the SD AOI (Band 8)

SD Gain Trending: Terra

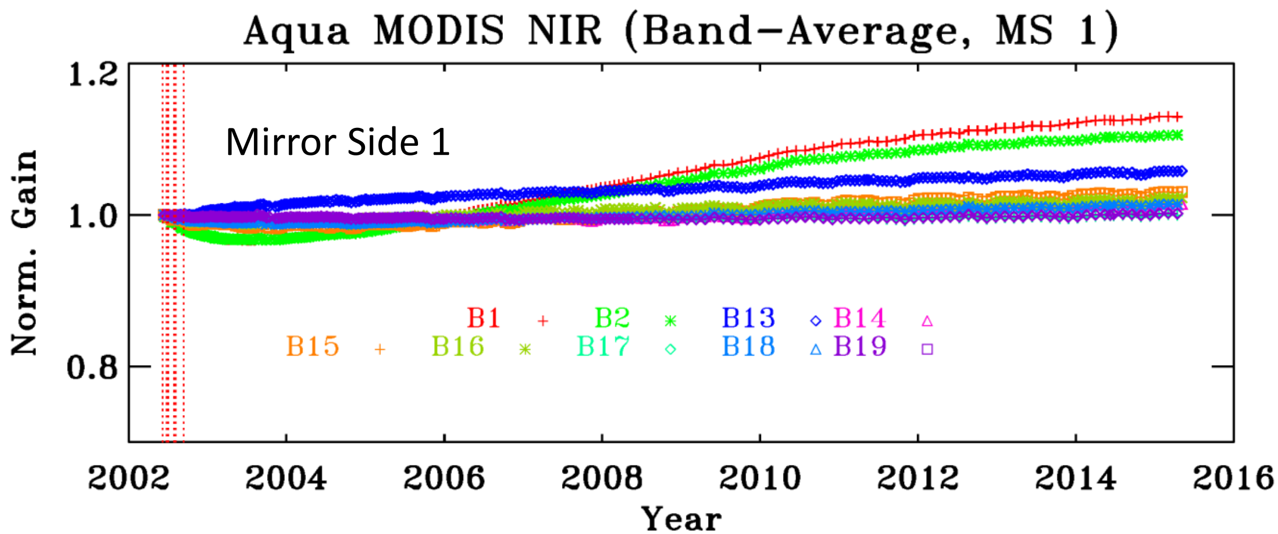


Changes for most NIR bands are within 10%

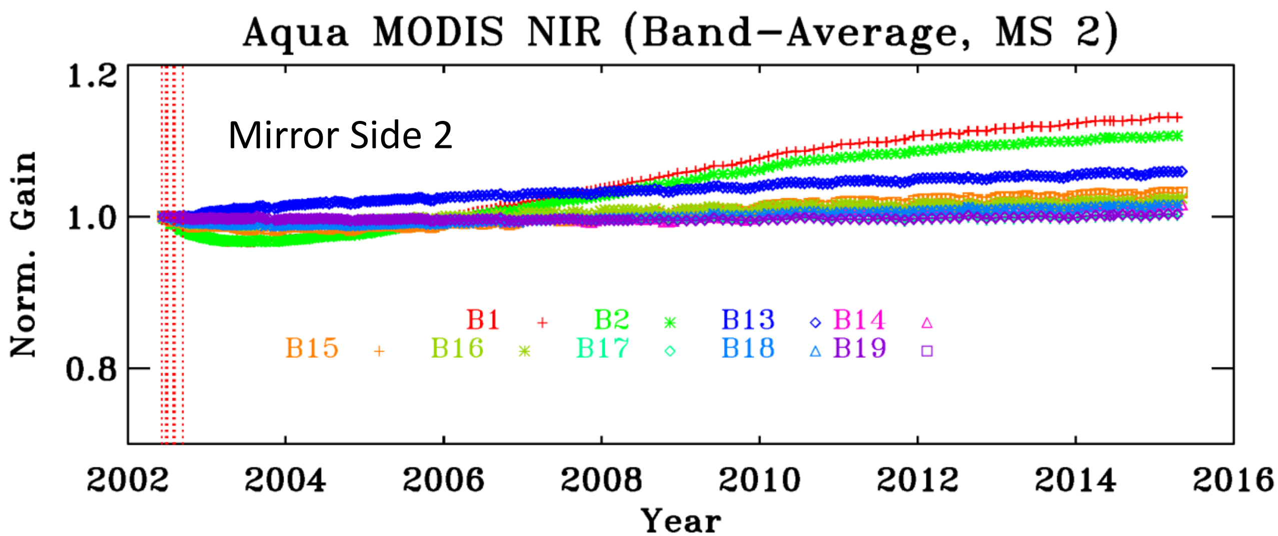


Mirror-side differences are <1%

SD Gain Trending: Aqua

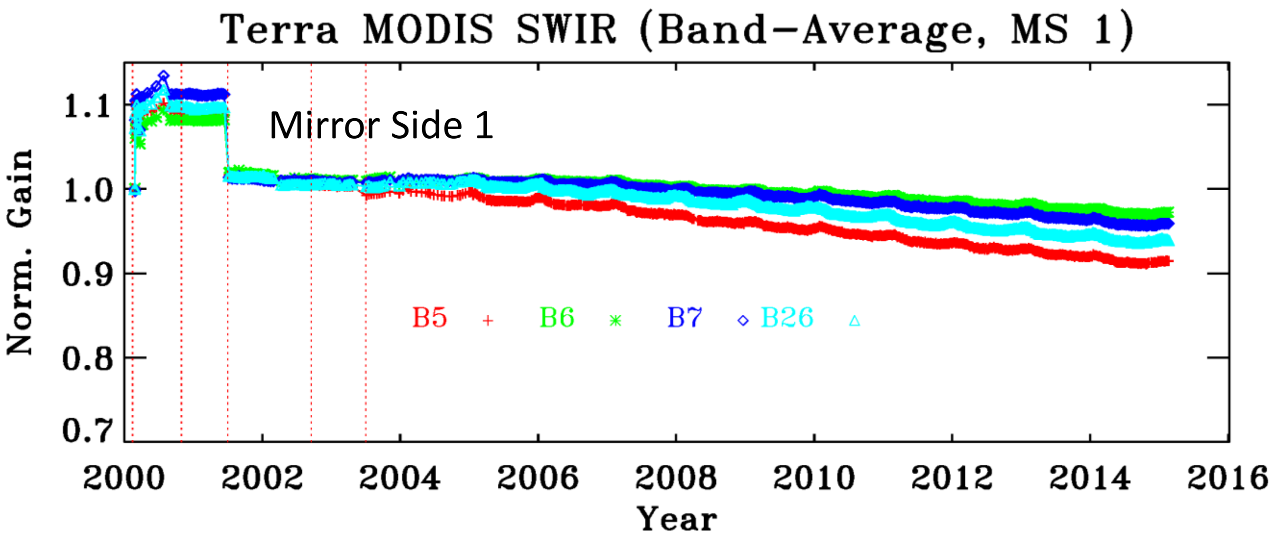


Changes for most NIR bands are within 6%

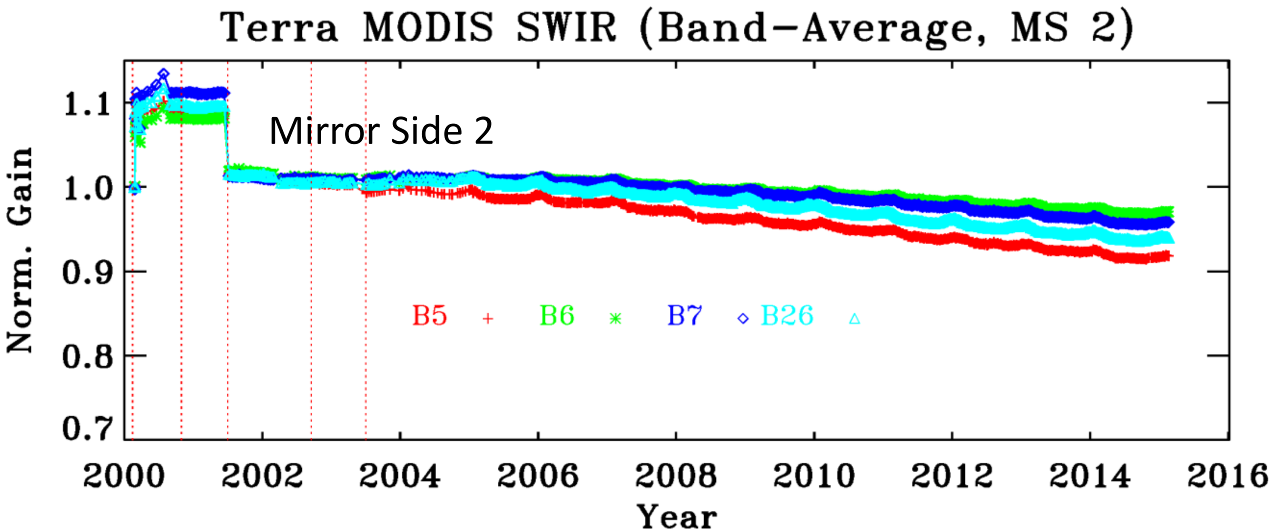


Mirror-side differences are <1%

SD Gain Trending: Terra



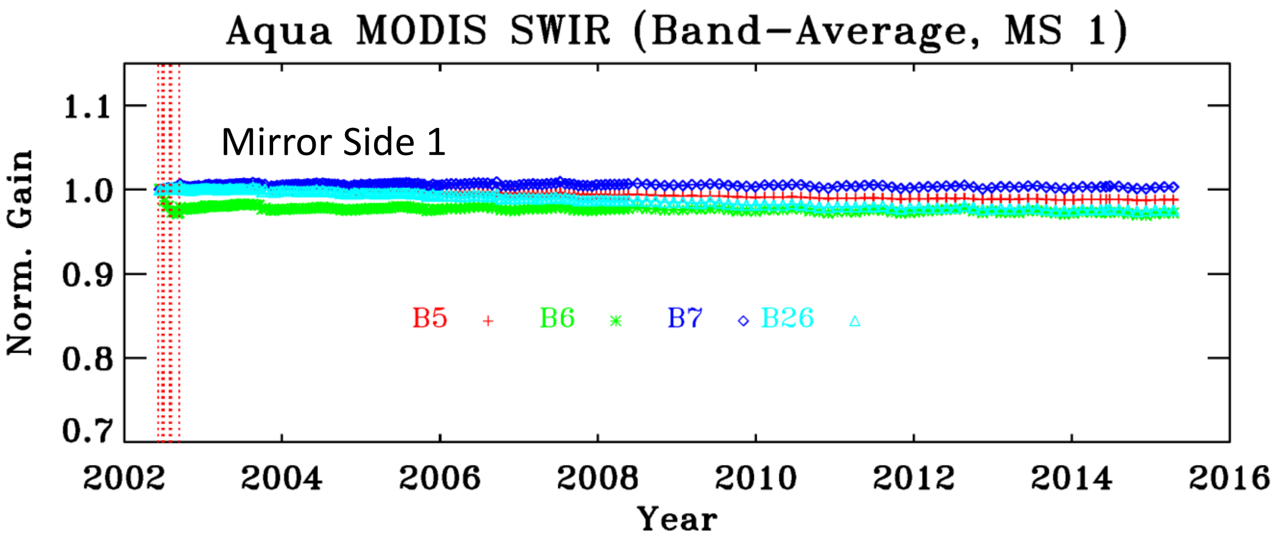
All SWIR bands change by < 10%



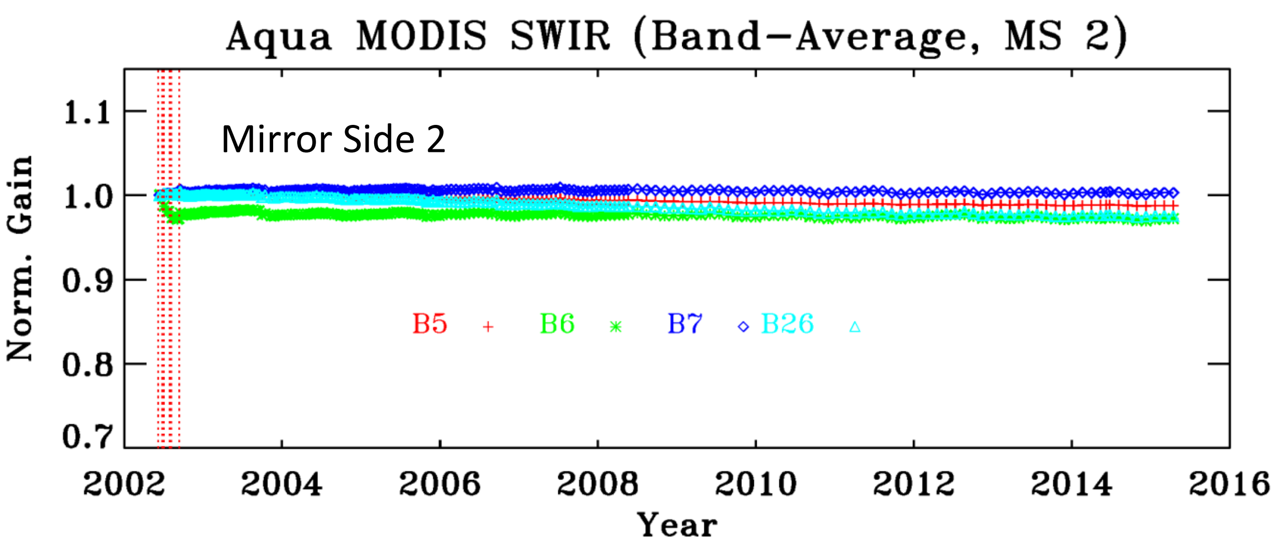
Mirror-side differences are <1%

* Noisy and inoperable detectors excluded

SD Gain Trending: Aqua



All SWIR bands change by < 3%

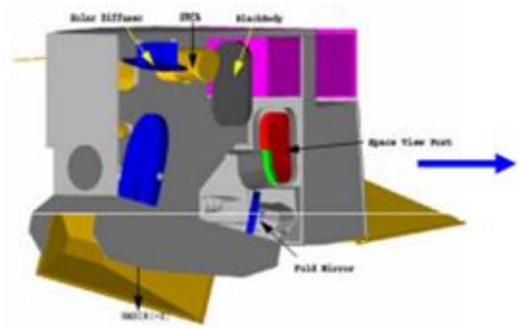


Mirror-side differences are <1%

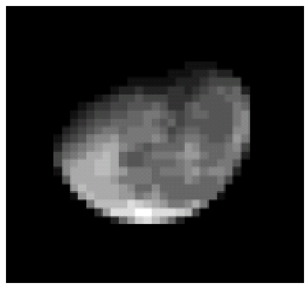
* Noisy and inoperable detectors excluded

RSB Lunar Calibration

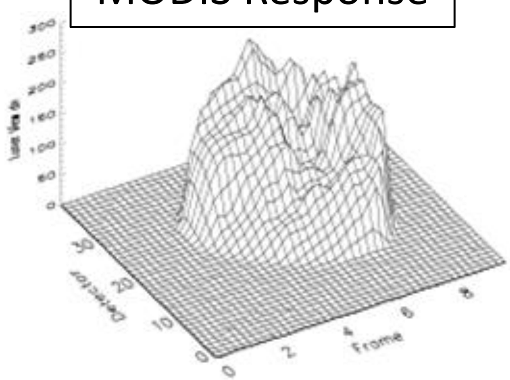
MODIS



Moon



MODIS Response



Near-monthly calibration
Phase angles between 55°- 56°

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

$$m_1^{moon} = \frac{f_{vg}}{< dn_{moon}^{*} >}$$

Bands 13-16 (saturated)

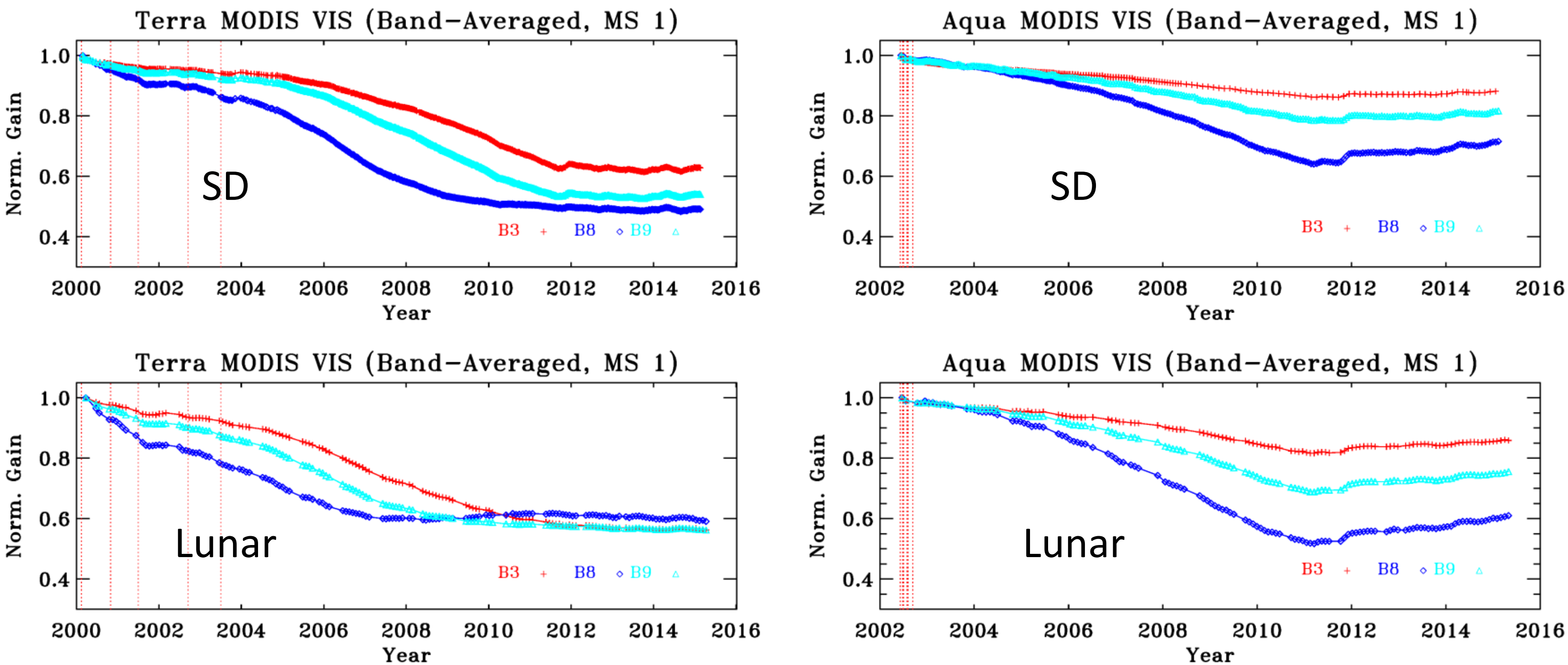
$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn_{Moon,B18}^{*} >}{< dn_{Moon}^{*} >}$$

View geometry correction

$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d_{Sun-Moon}^2 \cdot d_{Moon-MODIS}^2}$$

Oversampling effect also needs to be corrected if multiple scans are used

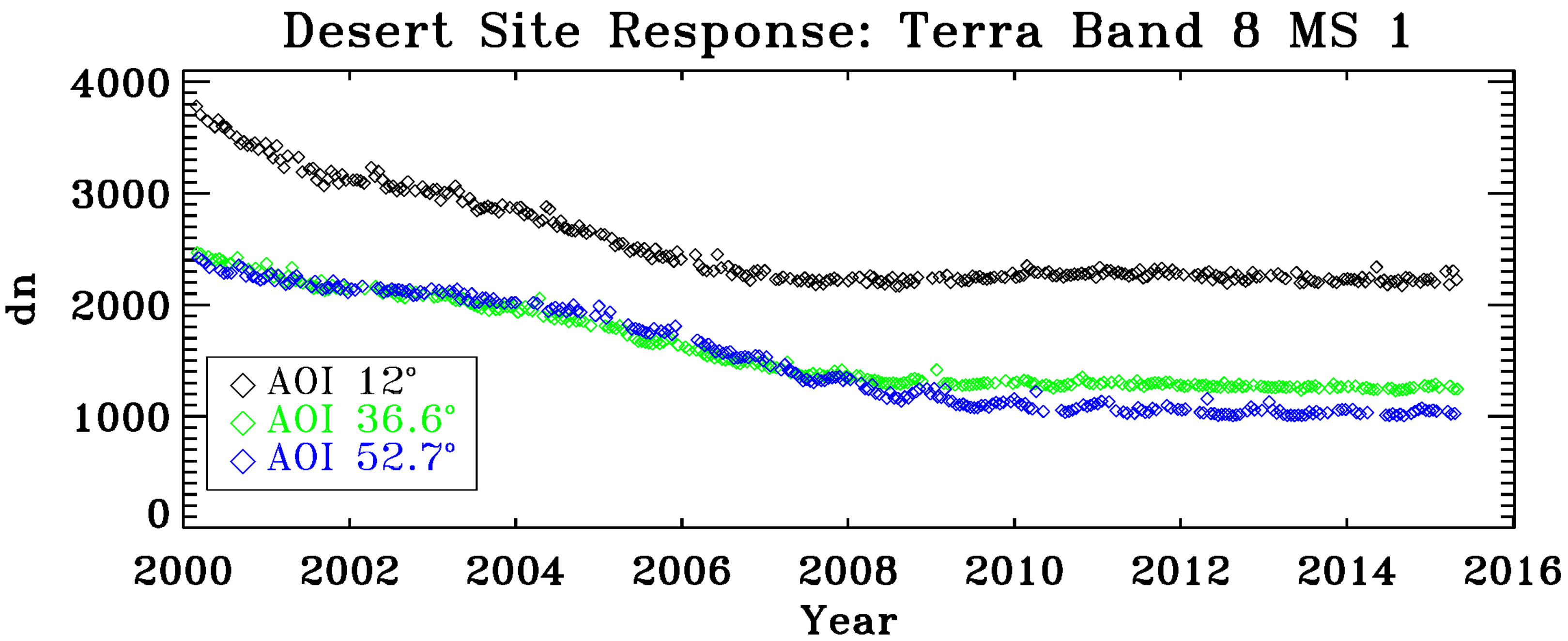
SD & Lunar Gain Trending



SD & Lunar measurements used to derive the on-orbit RVS change

SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

EV-based RVS - Terra

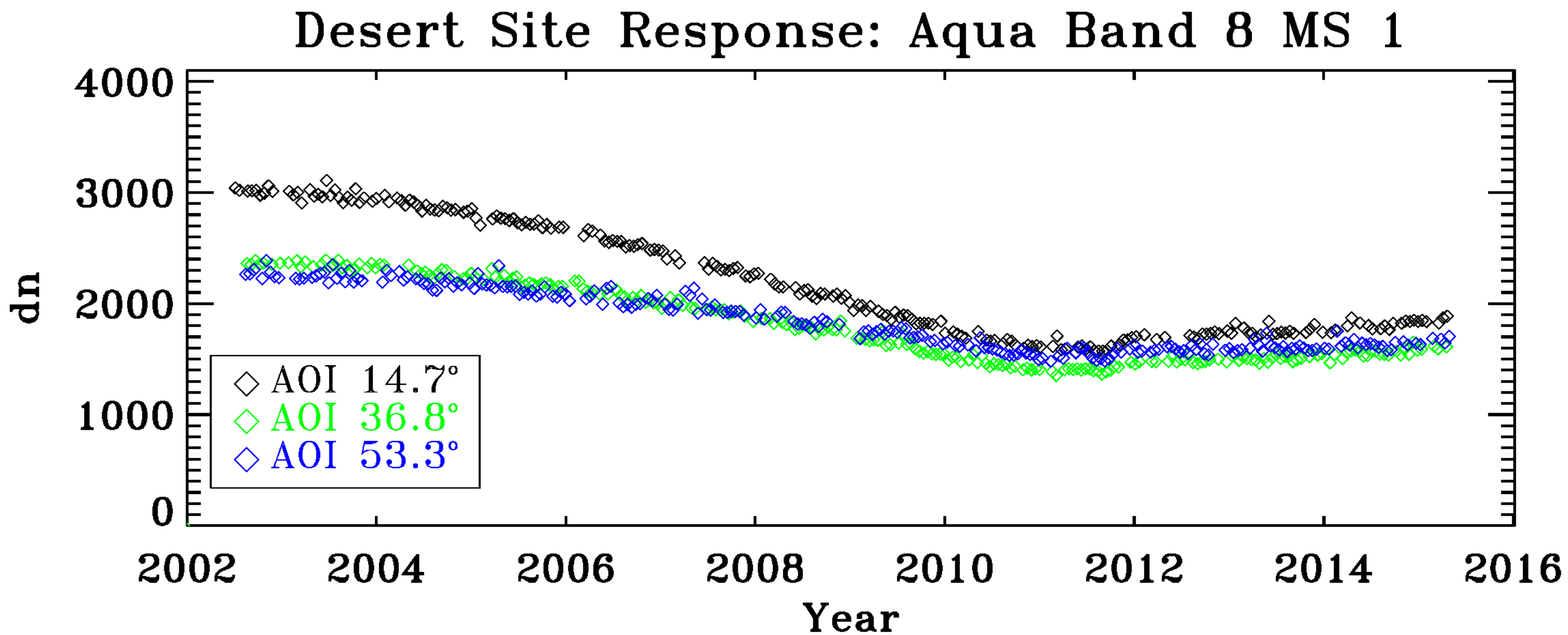


Response trending at multiple AOIs from pseudo-invariant desert sites

AOI 12° uses the Libya 2 desert site (25.05°, 20.48°)

AOI 36.6° and AOI 52.7 ° use the Libya 4 desert site (28.55°, 23.39°)

EV-based RVS – Aqua



Response trending at multiple AOIs from pseudo-invariant desert sites

AOI 14.7° and AOI 36.8° use the Libya 2 desert site (25.05°, 20.48°)
AOI 52.7° uses the Libya 4 desert site (28.55°, 23.39°)

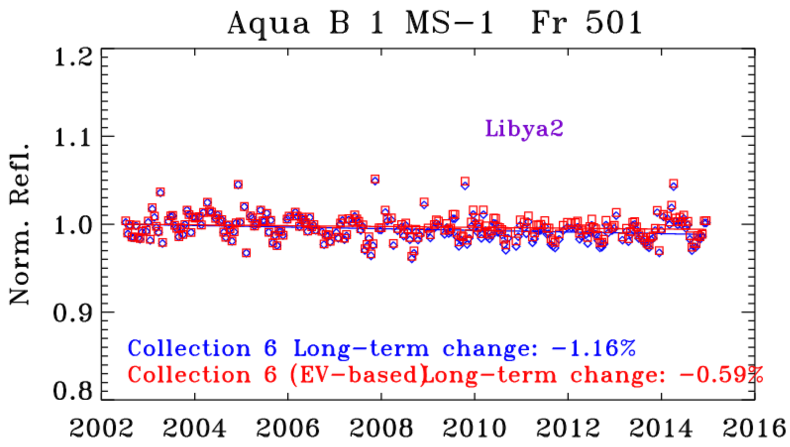
RSB Algorithm Updates

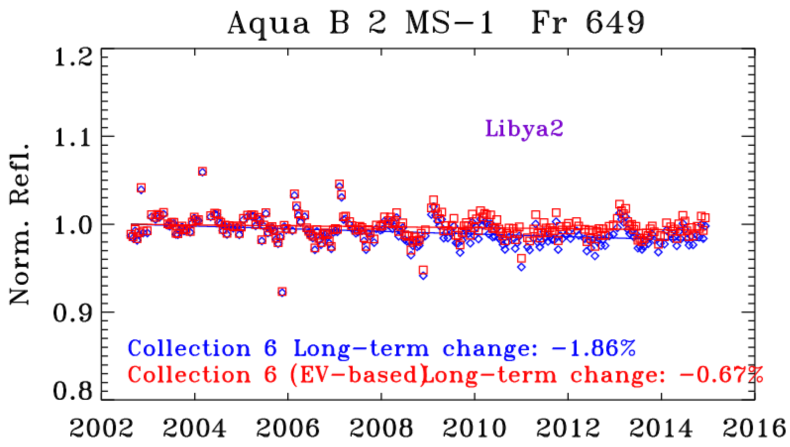
Terra Band 10 EV-based RVS

- Collection 6 includes EV-based RVS for Terra bands 1-4, 8-9 and Aqua bands 8-9
- Timeline
  - April 17, 2013 (MODIS Science Team Meeting 2013): MCST presented Terra band 10 RVS algorithm that included EV-based RVS after recommendation from OBPG
  - June 14, 2013: MCST delivered a test LUT to OBPG
  - January 08, 2014: OBPG provided test results for the Terra Band 10 ocean-color products using the special LUT delivered by MCST. The new LUT showed good agreement with the OBPG corrections.
  - March 2014: The gradual incorporation to the forward C6 LUT update began.
  - September 2014: It was fully implemented and continues to be used in forward updates.
- MCST also continues to provide support to the OBPG with a special LUT

Aqua Bands 1-4 EV-based RVS

- Current trending of earth-scene reflectance over pseudo-invariant sites shows long-term drift for Aqua Bands 1-4
- We are evaluating applying EV-based RVS for these bands, starting with Bands 1 and 2
  - Drift at nadir > 1.0%
- MCST has delivered a LUT and it is waiting for science team approval.
- More details to follow in MCST special topics section



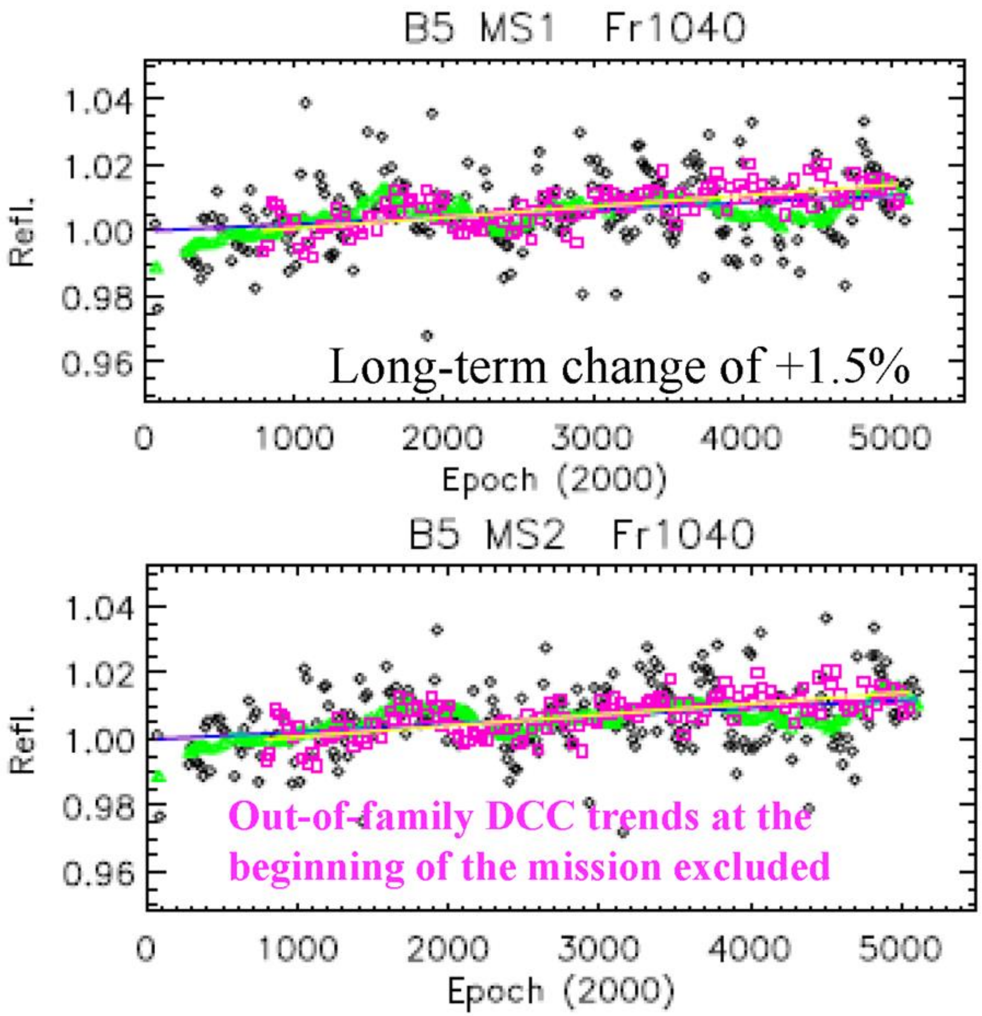


Terra Band 5 Long-term Trend

- The MODIS RSB calibration is performed using a SD with its degradation monitored using the SDSM (wavelength range from .412-.936 µm).
- Consequently, no correction for SD degradation is applied beyond the SDSM wavelength range.
- The gain for Band 5 (1.24 µm) and other SWIR bands is computed without factoring in the possible degradation of the SD.
- Terra SDSM d9 (936 nm) change over ~15 years on-orbit is measured to be 2%. Aqua SDSM d9 change is 0.7%.
- Pseudo-invariant desert targets are already in use to track the long-term stability of VIS/NIR bands. Similar desert response at the SD AOI can be tracked to evaluate the long-term change in Terra Band 5.

- Update and future plans
  - LUTs incorporating the correction to Terra Band 5 were delivered in August 2014.
  - We are investigating the impact to the remaining Terra SWIR bands as well as the Aqua SWIR bands.

EV-based Evaluation of Band 5 Stability



TOA EV reflectance from Libya 4 (BRDF correction applied)

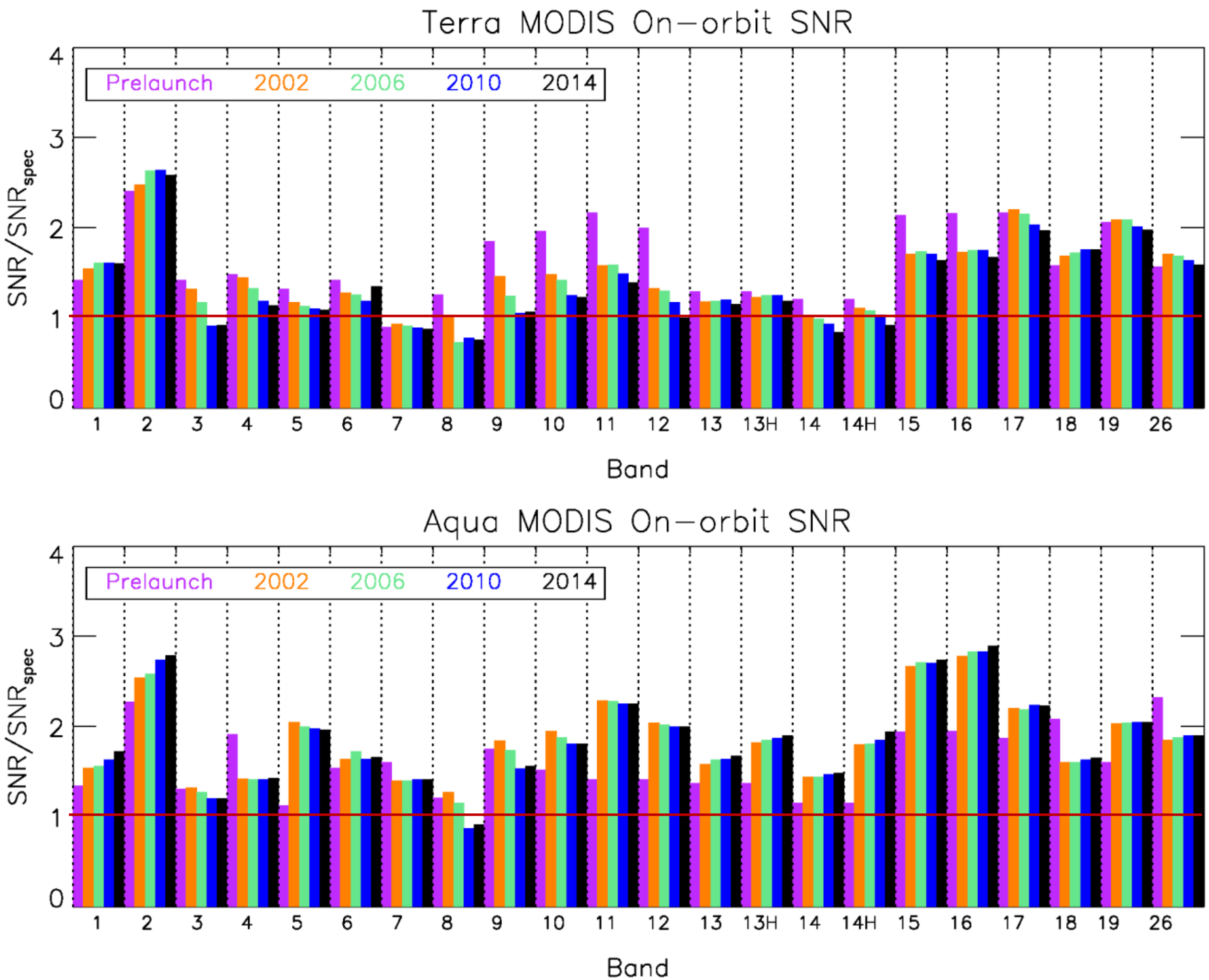
Moving window yearly average of the TOA reflectance trends

DCC trends

DCC data provided by D. Doelling and R. Bhatt

Measurements normalized to the first point of the fitted curve

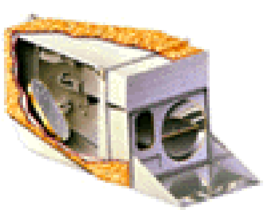
MODIS RSB SNR



No Quality Flag Changes in RSB since 2012

Summary

- SD/SDSM and lunar observations are used to track RSB on-orbit gain change
  - Additional information from EV response from desert sites are used for select RSB (Terra 1-4, 8-9 and Aqua 8-9)
    - Recently applied to Terra Band 10, starting in July 2014 (with history unchanged)
- Shorter wavelength VIS Bands show larger degradation (strong wavelength, mirror-side, and scan-angle dependence)
  - Gain change over 50% seen in Terra Band 8 (.412 μm) at the AOI of SD (50.25°)
- NIR bands gain change generally within 10%
- SWIR bands gain change within 10%
  - Terra Band 5 correction using EV desert site trending to account for long-term drift in reflectance
- Challenges:
  - Degradation of the solar diffusers
  - Changes in the RVS
  - Impacts of polarization

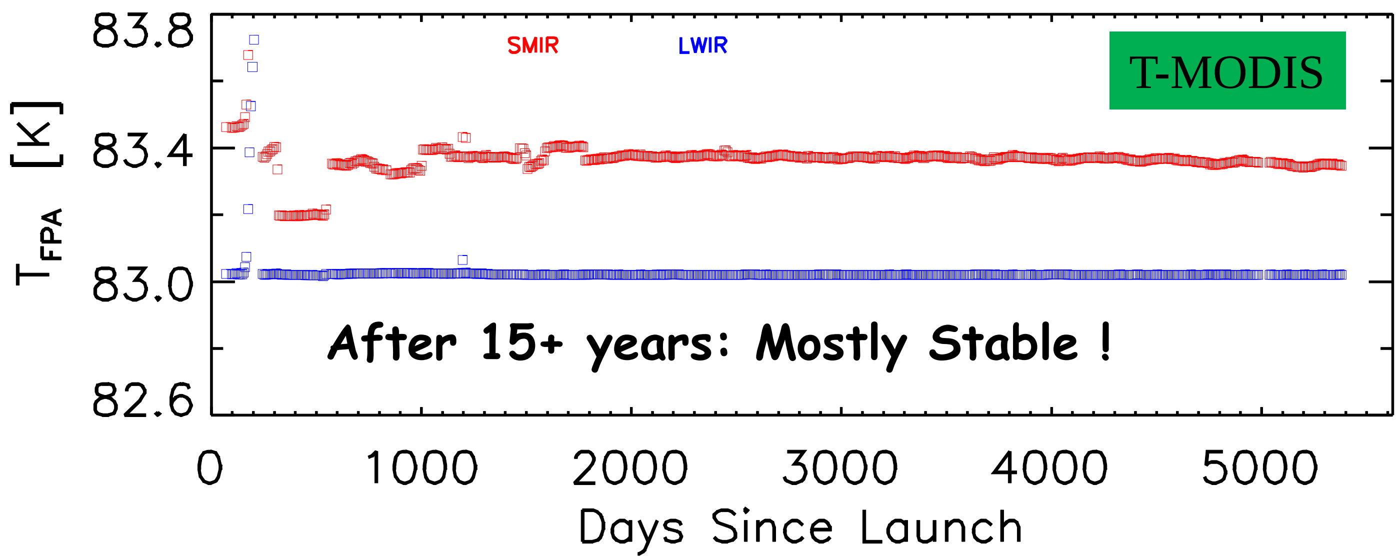


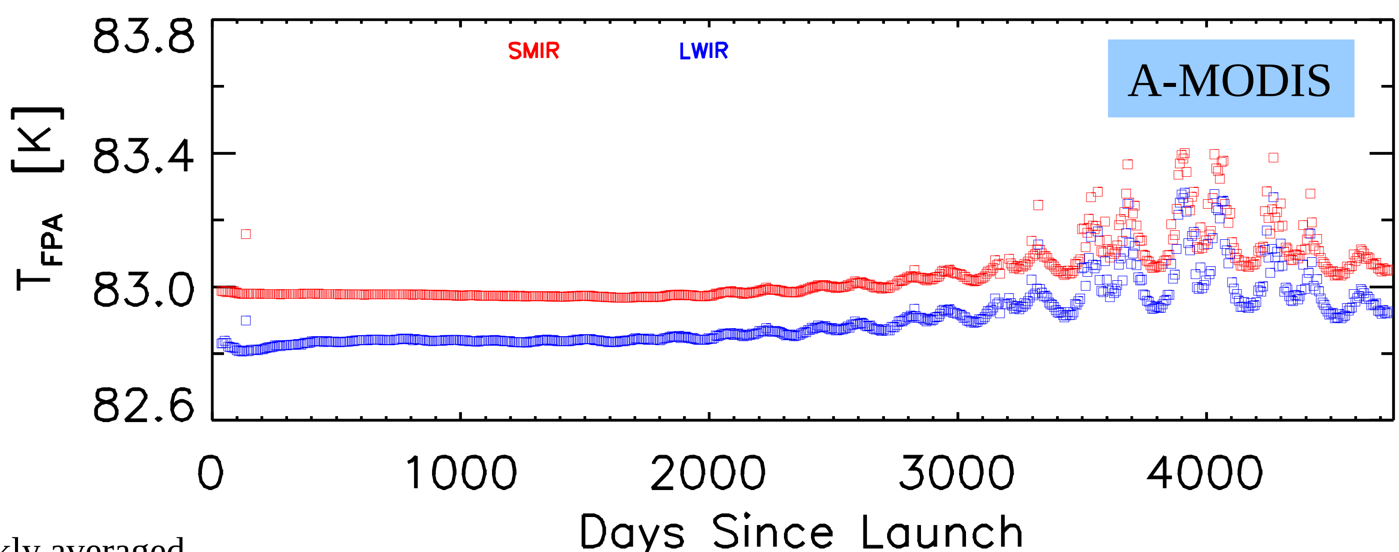
MODIS TEB Performance

TEB Calibration Performance

- Instrument Performance
  - Telemetry trending (Cold focal plane, Blackbody)
- TEB Calibration Requirement & Algorithm
- Terra (T) and Aqua (A) TEB On-orbit Performance
  - Detector response & NEdT trending
  - Noisy detector history

Cold Focal Plane Temperature Performance

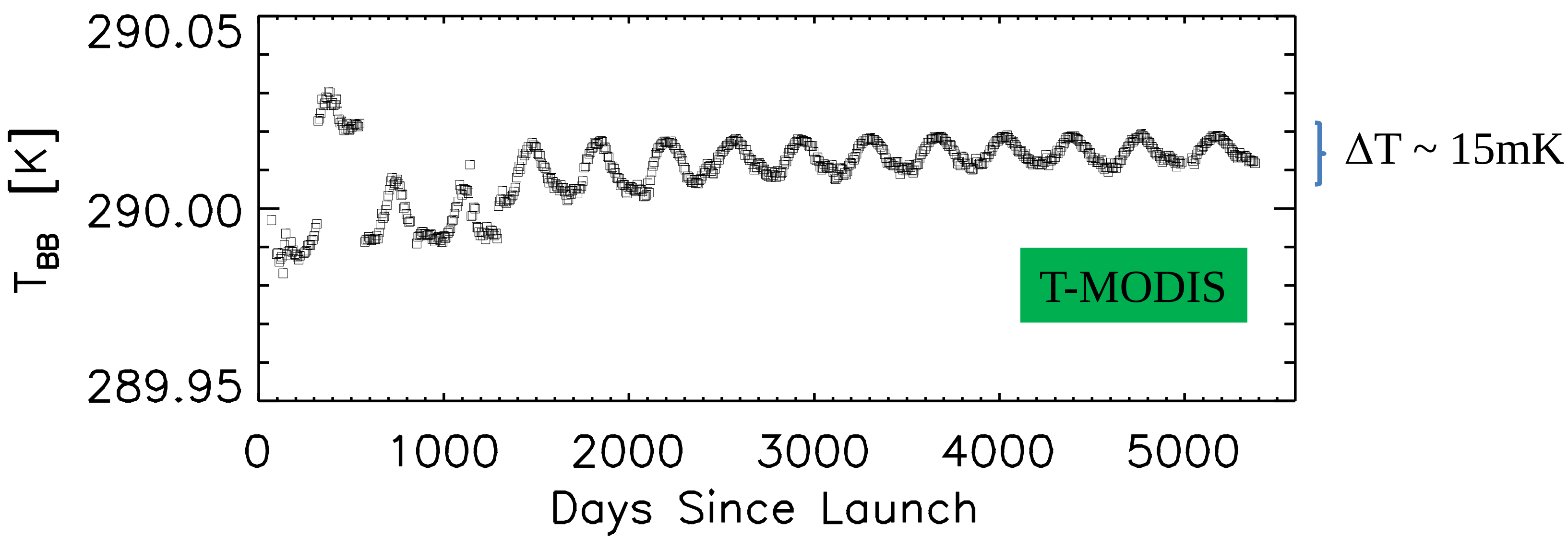


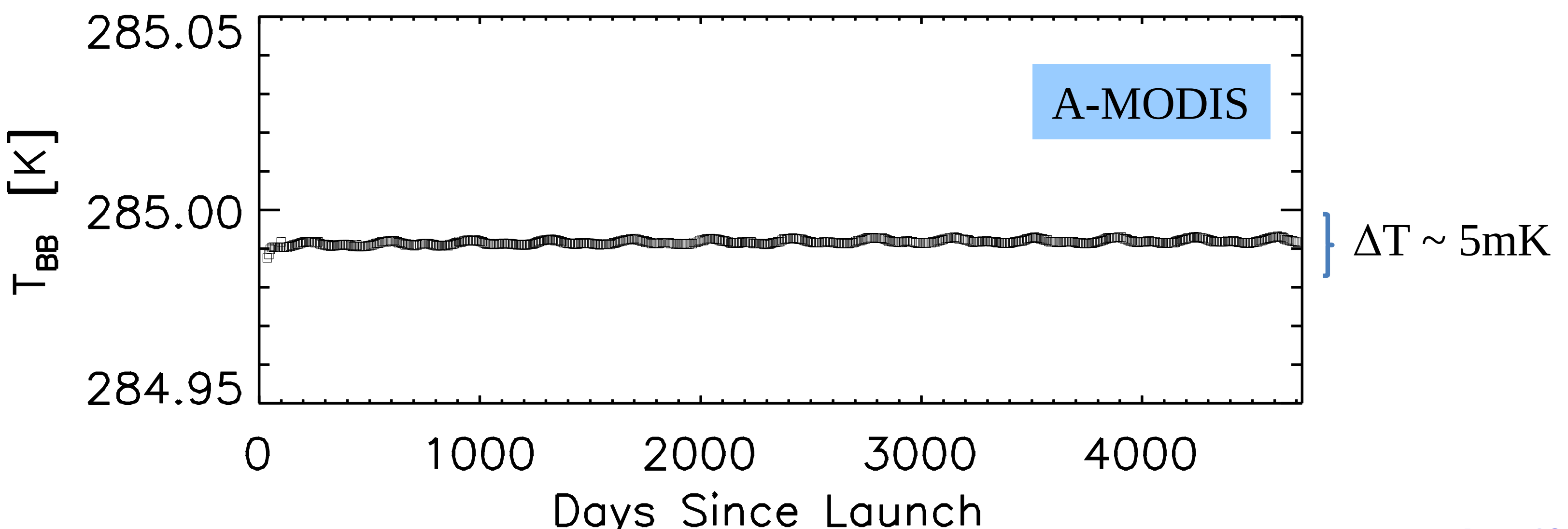


Max change 0.4 K
Since Last STM FP temperature oscillations have reduced

Weekly averaged

Long-term BB Performance





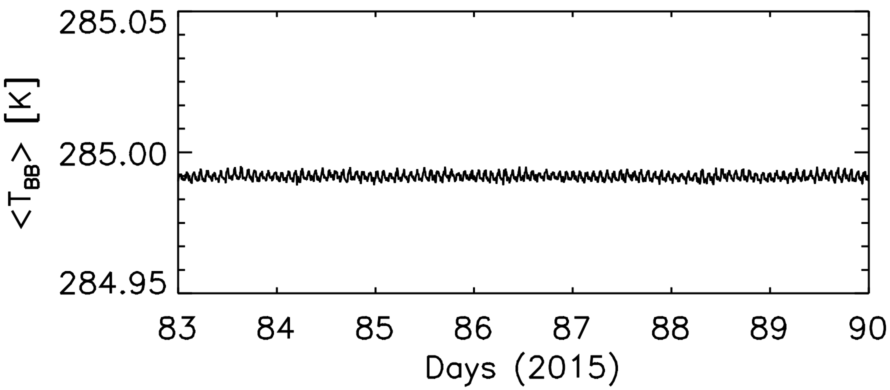
Weekly averaged

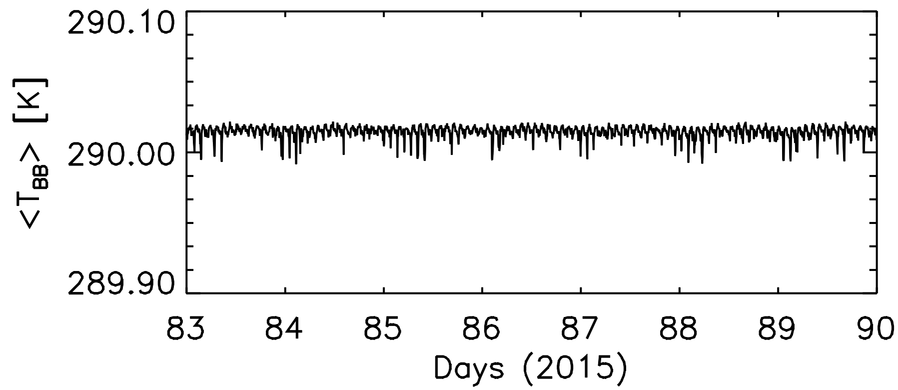
Short-term BB Performance

A-MODIS

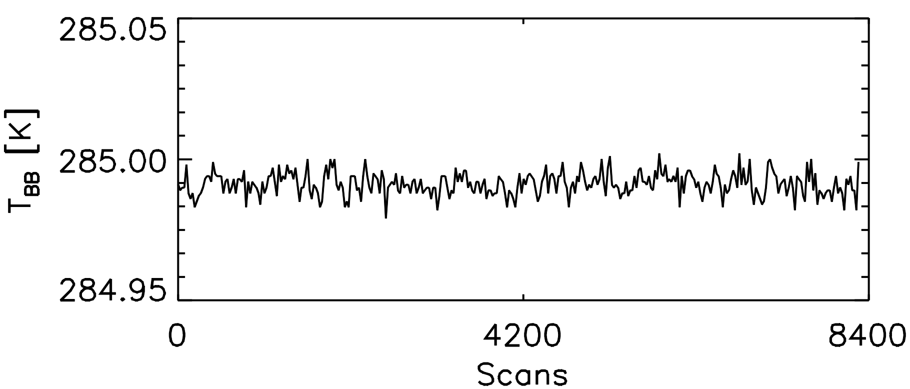
T-MODIS

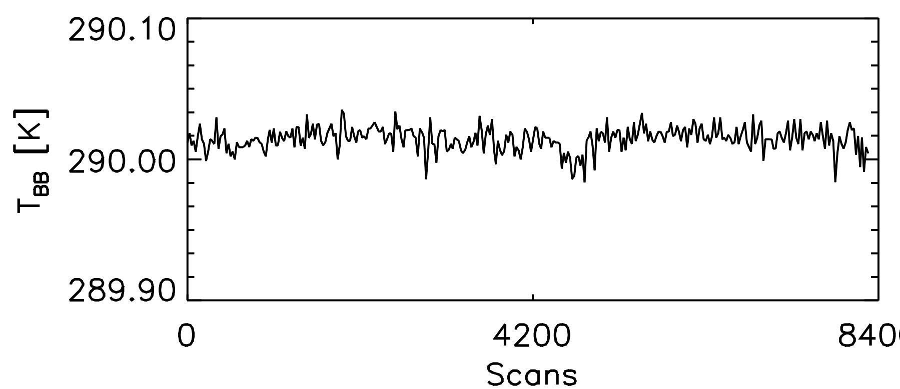
Weekly





2-orbits





TEB Calibration Requirements

Band	CW	Ttyp	NEdT	UC (%)	UC (K)
20	3.75	300	0.05	0.75	0.18
21	3.96	335	0.20	1	0.31
22	3.96	300	0.07	1	0.25
23	4.05	300	0.07	1	0.25
24	4.47	250	0.25	1	0.19
25	4.52	275	0.25	1	0.24
27	6.72	240	0.25	1	0.27
28	7.33	250	0.25	1	0.32
29	8.55	300	0.05	1	0.53
30	9.73	250	0.25	1	0.42
31	11.03	300	0.05	0.5	0.34
32	12.02	300	0.05	0.5	0.37
33	13.34	260	0.25	1	0.62
34	13.64	250	0.25	1	0.59
35	13.94	240	0.25	1	0.55
36	14.24	220	0.35	1	0.47

CW: center wavelength in μm;
Ttyp: typical scene temperature in K;
NEdT: noise equivalent temperature difference in K;
UC: uncertainty in percentage and in K

On-orbit Calibration Methodologies and Performance

- <u>Quadratic Algorithm</u>
  - Linear calibration coefficients computed on a scan-by-scan basis; 40-scan running average used in the L1B
  - Fixed coefficients used for B21 (a simple linear algorithm)
  - Fixed coefficients used till April 10 2012 for B33, 35, and 36 when T_bb are above T_sat (AQUA ONLY !!!)
    - **<u>Algorithm for default b1</u>** that tracks change scan by scan as a function of the focal plane temperature is introduced in both **<u>C5 & C6</u>**
- Period BB Warm-up and Cool-down (WUCD) Activities
  - Derive fixed linear coefficients
  - Compute nonlinear coefficients (update if necessary)
- Performance
  - Dedicated short- and long-term monitoring effort (offline)

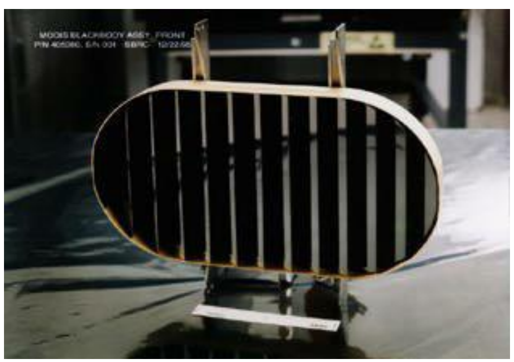
TEB Radiometric Calibration

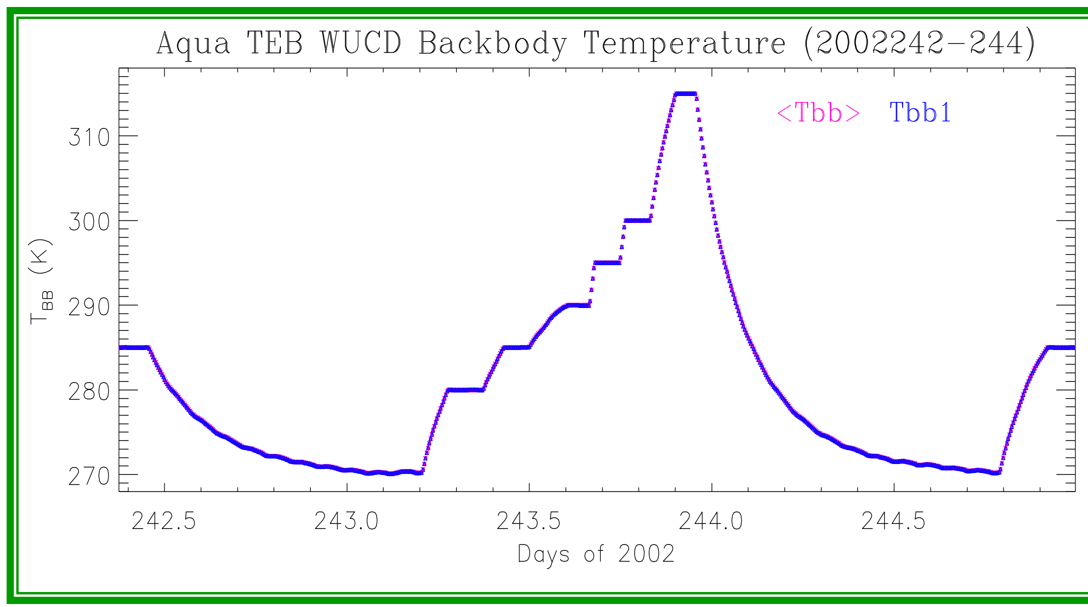
EV Radiance:

$$L_{EV}=\frac{1}{RVS_{EV}}\left(a_0+b_1\cdot dn_{EV}+a_2\cdot dn_{EV}^2-\left(RVS_{SV}-RVS_{EV}\right)\cdot L_{SM}\right)$$

Calibration Coefficients:

$$b_1=\left(RVS_{BB}\cdot\varepsilon_{BB}\cdot L_{BB}+\left(RVS_{SV}-RVS_{BB}\right)\cdot L_{SM}+RVS_{BB}\cdot\left(1-\varepsilon_{BB}\right)\cdot\varepsilon_{cav}\cdot L_{cav}-a_0-a_2\cdot dn_{BB}^2\right)/\,dn_{BB}$$





RVS: Response Versus Scan-angle

e: Emissivity

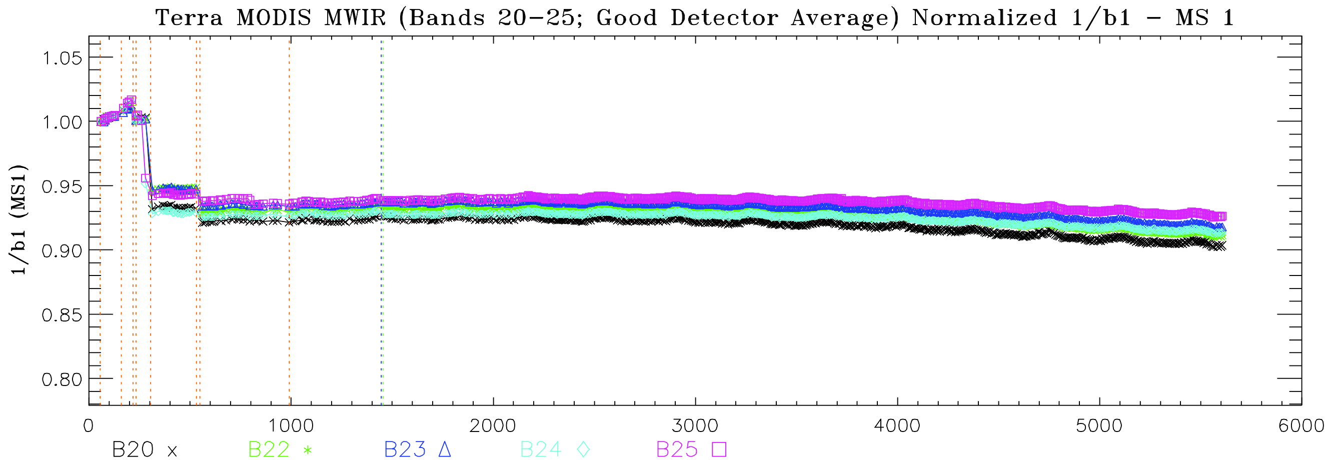
L: Spectral band averaged radiance

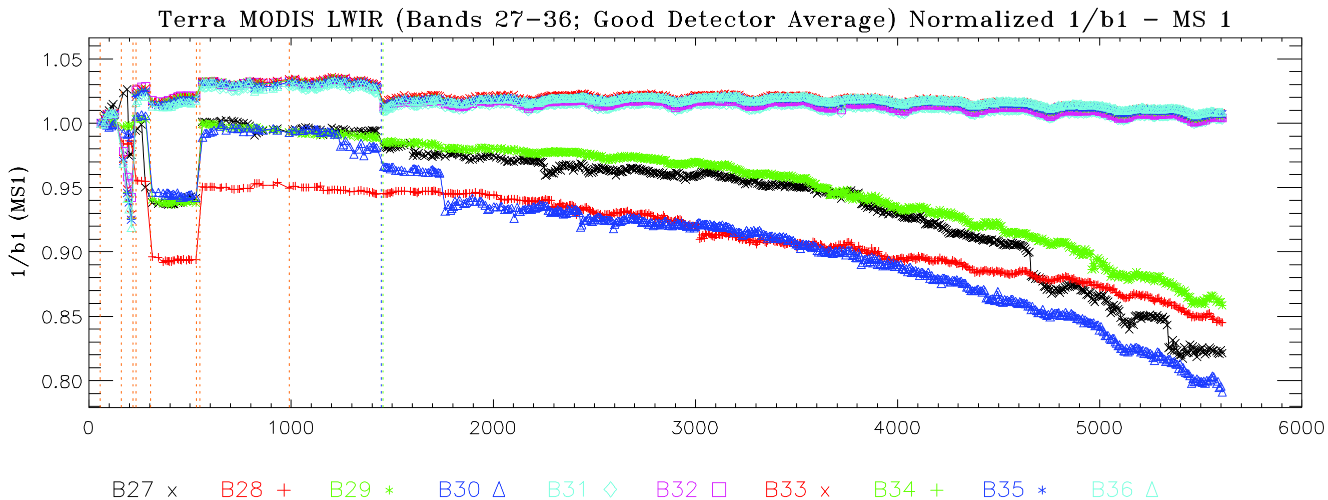
dn: Digital count with background corrected

RSR: Relative Spectral Response

WUCD T_{BB}: 270 to 315K

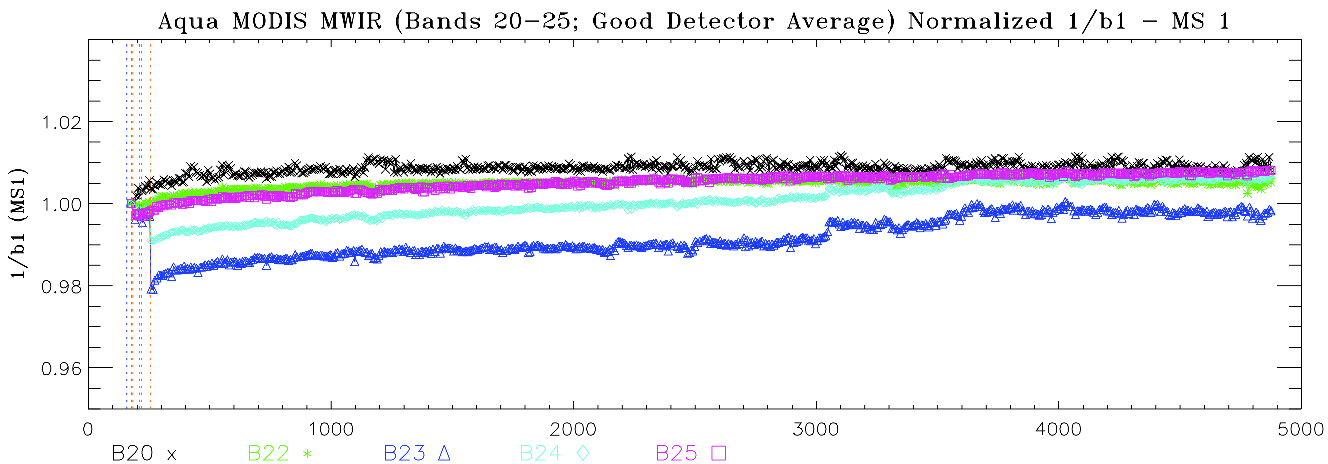
T-MODIS TEB Response Trend

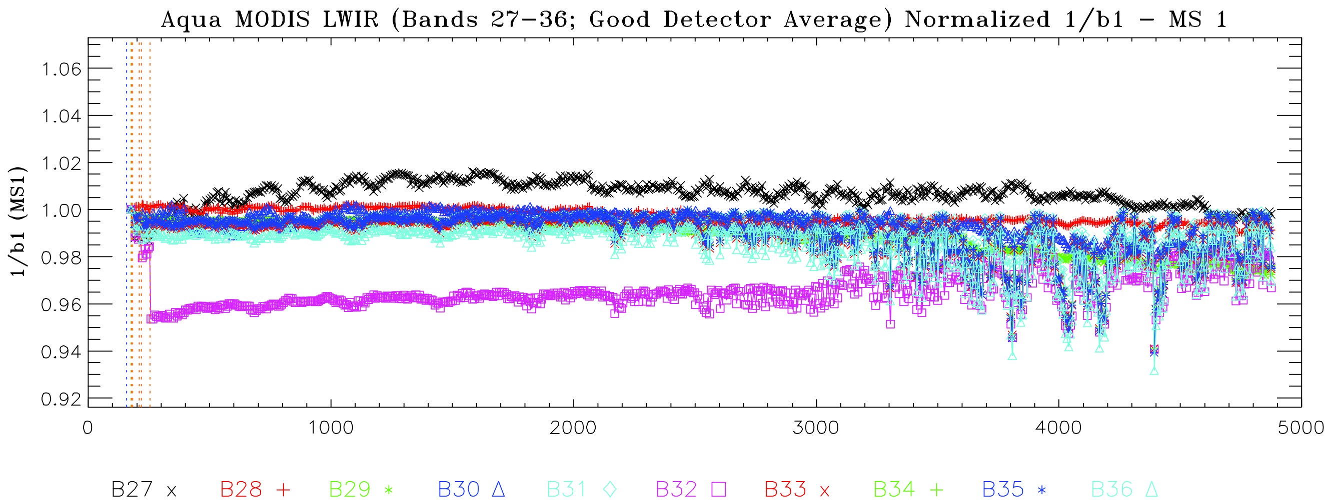




Band	Percent Change
20	-2.42
22	-2.43
23	-2.26
24	-1.66
25	-1.46
27	-15.65
28	-10.29
29	-12.39
30	-15.23
31	-1.01
32	-1.10
33	-1.17
34	-1.06
35	-0.89
36	-0.67

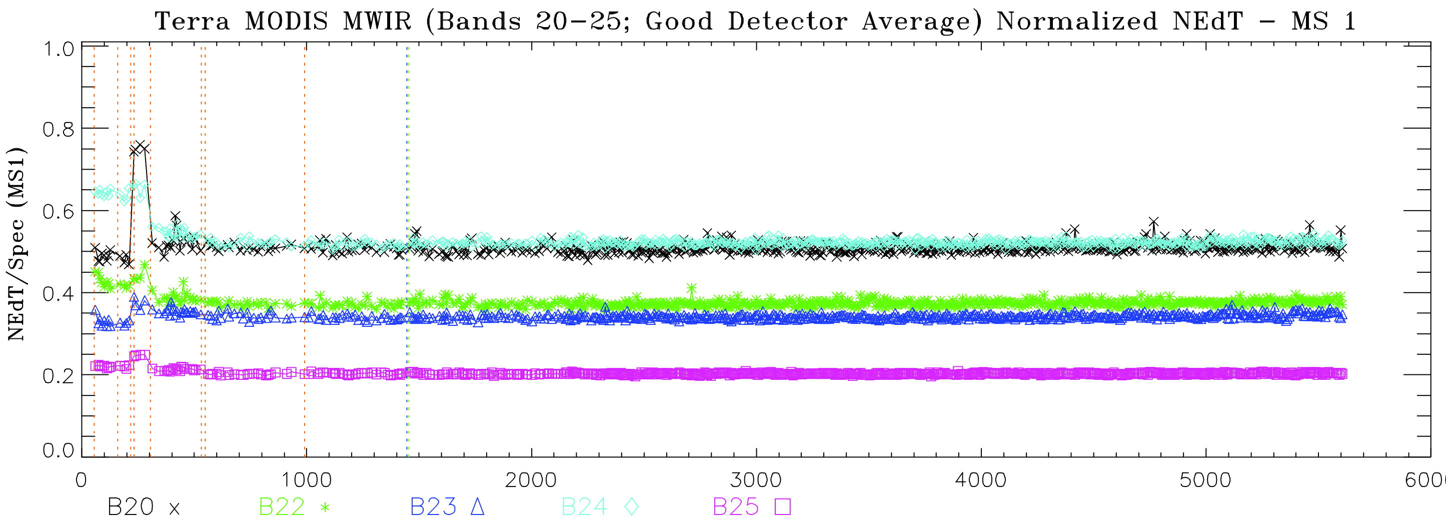
A-MODIS TEB Response Trend

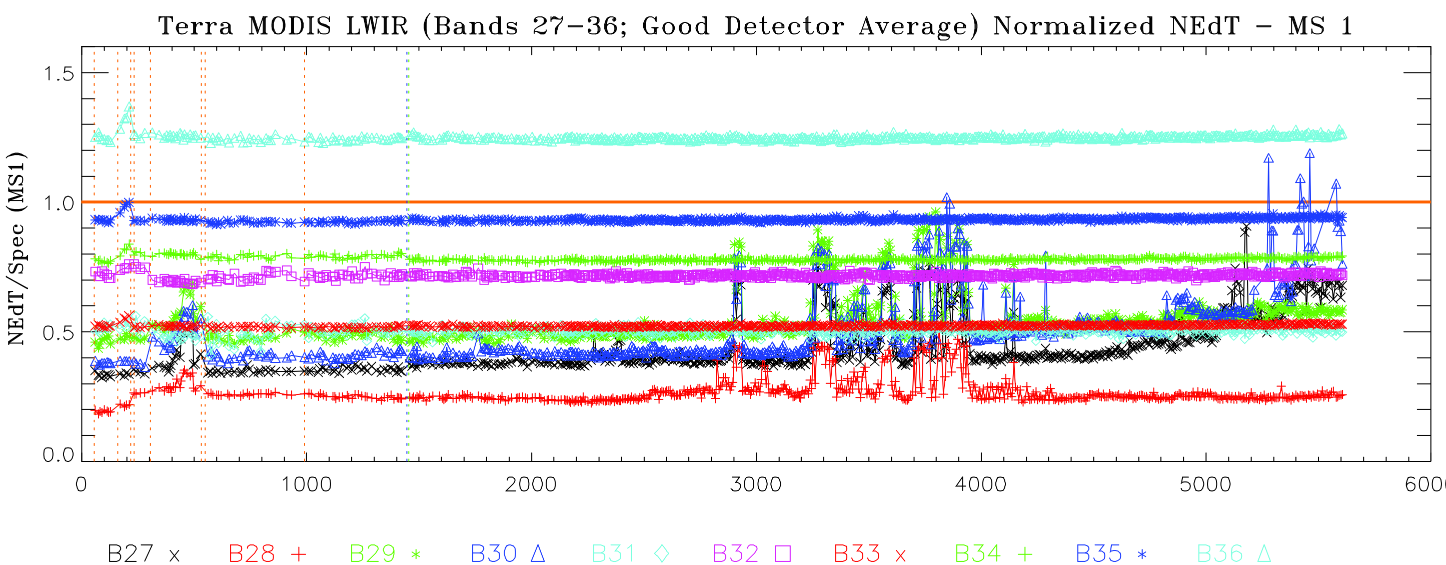




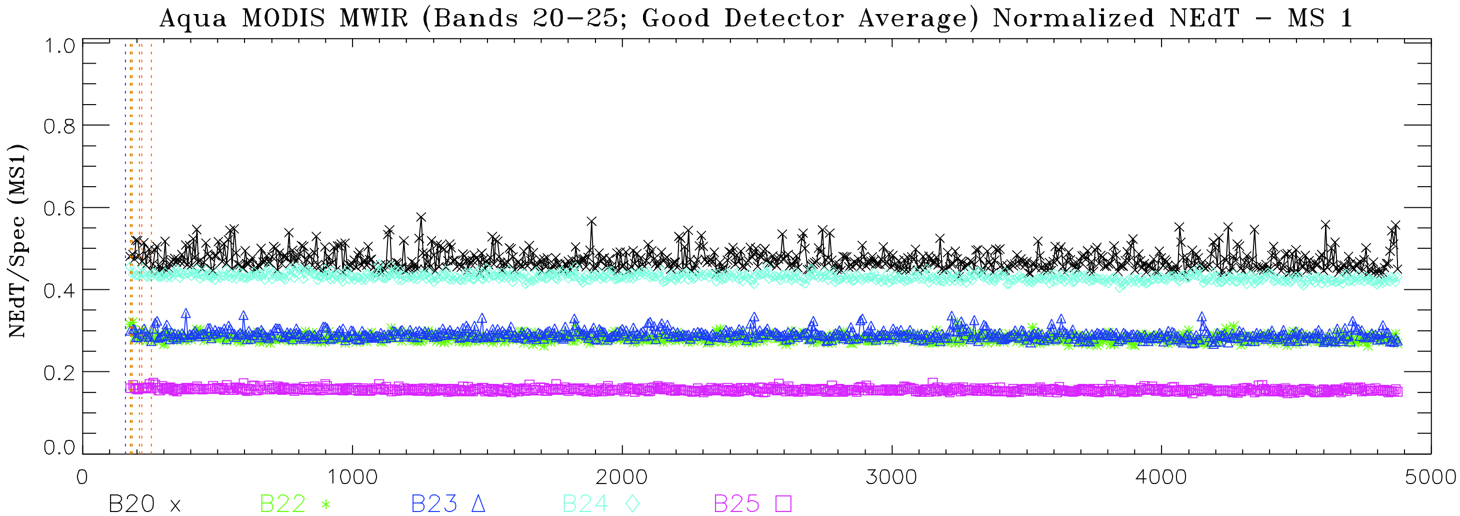
Band	Percent Change
20	0.20
22	0.24
23	1.60
24	1.40
25	0.70
27	-0.61
28	-0.93
29	-2.15
30	-1.47
31	-1.14
32	1.43
33	-1.93
34	-1.89
35	-1.93
36	-2.02

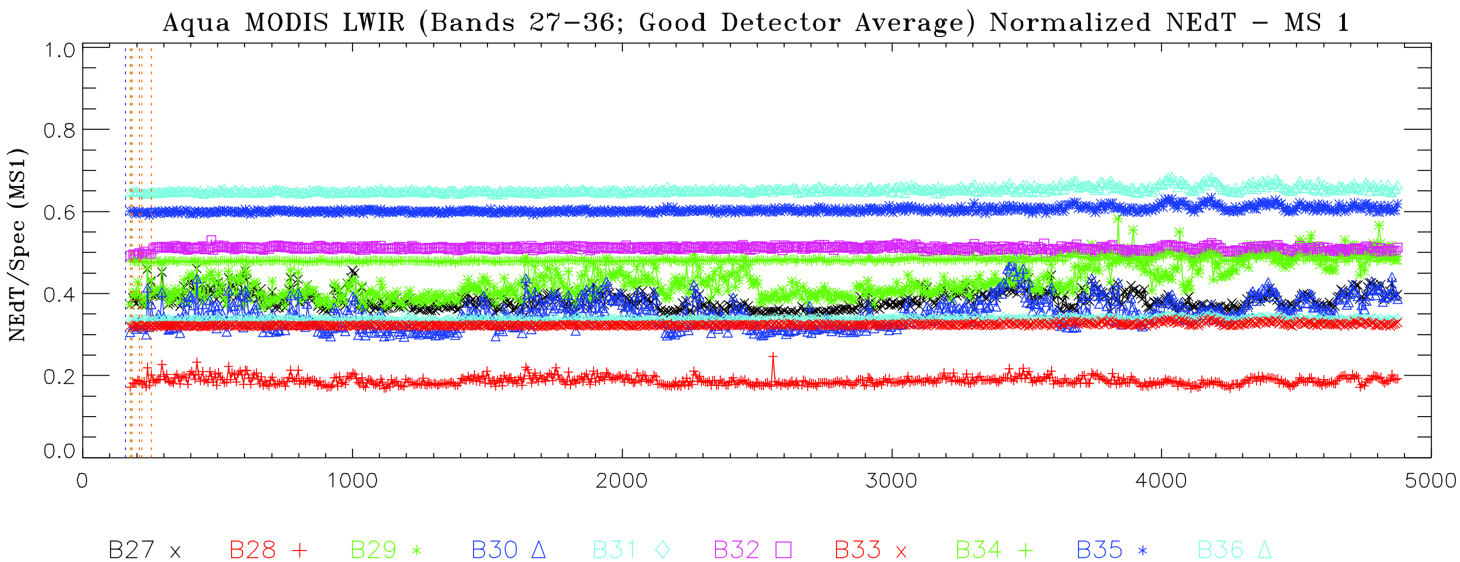
T-MODIS TEB Noise Trend





A-MODIS TEB Noise Trend





TEB Noisy Detector History

Detectors in Product Order

T-MODIS

Band	Detector	Status	Date Classified
27	1	Noisy	Dec-03
	2	Noisy	Nov-08
	3	Noisy	Jul-07
	6	Noisy	Jul-00
	8	Noisy	Feb-06
28	1	Noisy	Jun-04
	8	Noisy	Dec-03
	9	Noisy	Nov-05
	10	Noisy	Apr-04
29	6	Inoperable	Aug-06
30	1	Noisy	Nov-08
	3	Noisy	Jun-06
	5	Noisy	Aug-00
	8	Noisy	Jan-01
33	1	Noisy	at launch
34	6	Noisy	Jun-00
	7	Noisy	at launch
	8	Noisy	at launch
36	1-10	Noisy	Pre- launch

A-MODIS

Band	Detector	Status	Date Classified
21	**2-3, 9**	**Noisy**	**Jan-15**
27	3	Noisy	Jan-05
29	2	Noisy	Feb-08
	8	Noisy	Dec-11
	6	Noisy	Feb-12
36	5	Inoperable	Pre-Launch

Total TEB Detectors = 160

Noisy Detectors:

Terra = 27, Aqua = 7

Inoperable Detectors:

Terra = 1, Aqua = 1

TEB On-orbit Performance Summary

- Stable instrument and detector response for both T- and A-MODIS (excluding sensor configuration changes and instrument reset events)

  Largest Gain Change (in terms of %)

  - MWIR PV bands : T-Band 20, 22 – ~ 2.4% , A-Band 23 – ~1.6%
  - LWIR PV bands : T-Band 27, 30 – ~15.0%, A-Band 29 – ~2.1%
  - LWIR PC bands : T-Band 33 – ~1.2%, A-Band 36 – ~2.0%
- 3 new noisy / inoperable detectors since last STM
  - **A-MODIS Band 21, Detectors 2-3, 9 are classified as 'noisy' since Jan 2015**
- T-MODIS has 27 noisy detectors and 1 inoperable detector
  - PV Detectors in LWIR Focal plane are getting noisier
- A-MODIS has 7 noisy detectors and 1 inoperable detector

TEB Performance Key References

[1] X. Xiong, A. Wu, B. N. Wenny, S. Madhavan, Z. Wang, Y. Li, N. Chen, W. Barnes, and V. Salomonson, "Terra and Aqua MODIS Thermal Emissive Bands On-orbit Calibration and Performance", IEEE Trans. Geosci. Remote Sens., (accepted), 2015.

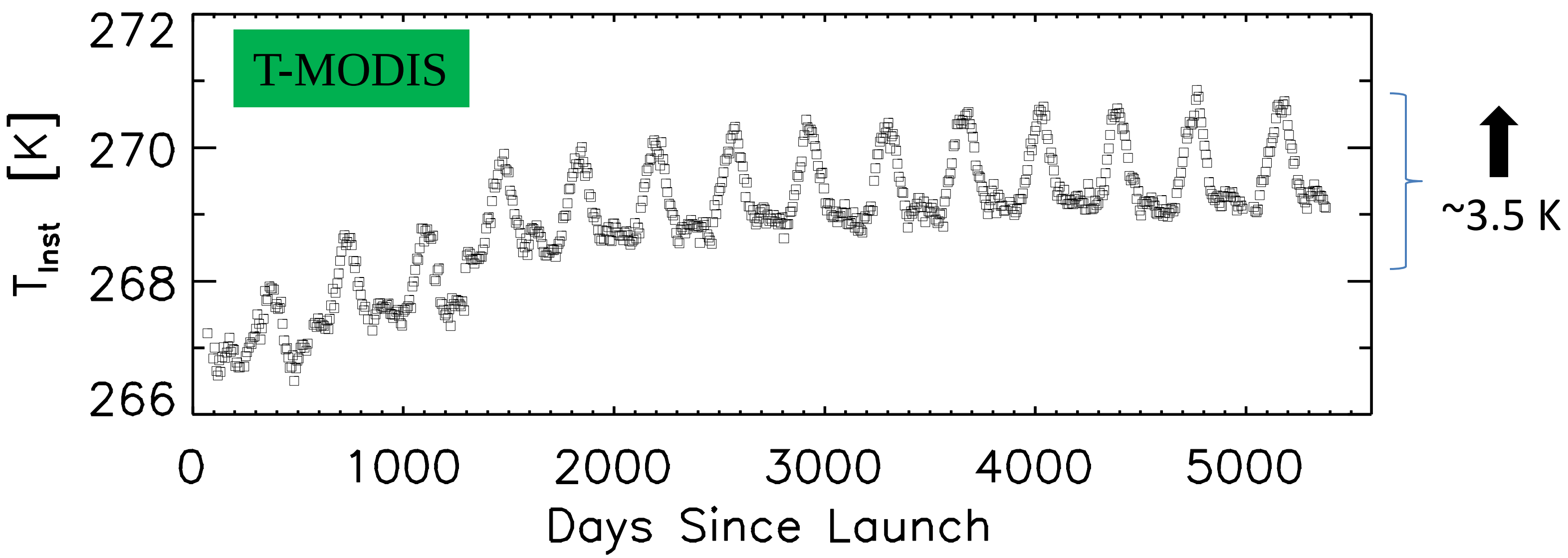
[2] Xiong, X., B. Wenny, A. Wu, and W. Barnes, "MODIS On-board Blackbody Function and Performance", IEEE Trans. Geosci. Remote Sens., vol. 47, issue 10, 2009.

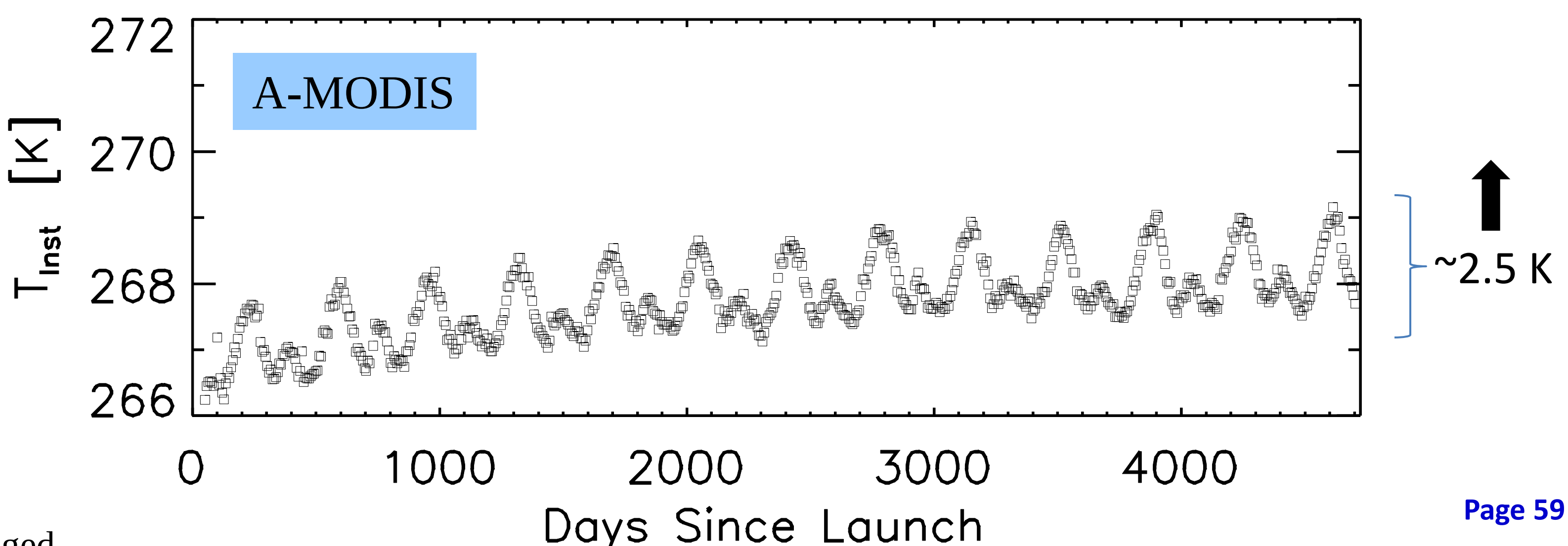
[3] X. Xiong, K. Chiang, A. Wu, W. Barnes, B. Guenther, and V. Salomonson, "Multiyear on-orbit calibration and performance of Terra MODIS thermal emissive bands," *IEEE Trans. Geosci. Remote Sensing*, vol. 46, no. 6, 1790-1803, 2008.

[4] K. Chiang, X. Xiong, A. Wu, and W. Barnes, "MODIS thermal emissive bands calibration uncertainty analysis, Earth Observing Systems IX", *Proc. SPIE*, vol. 5542, pp. 437-447, 2004.

BACK Up

Key Instrument Telemetry Performance



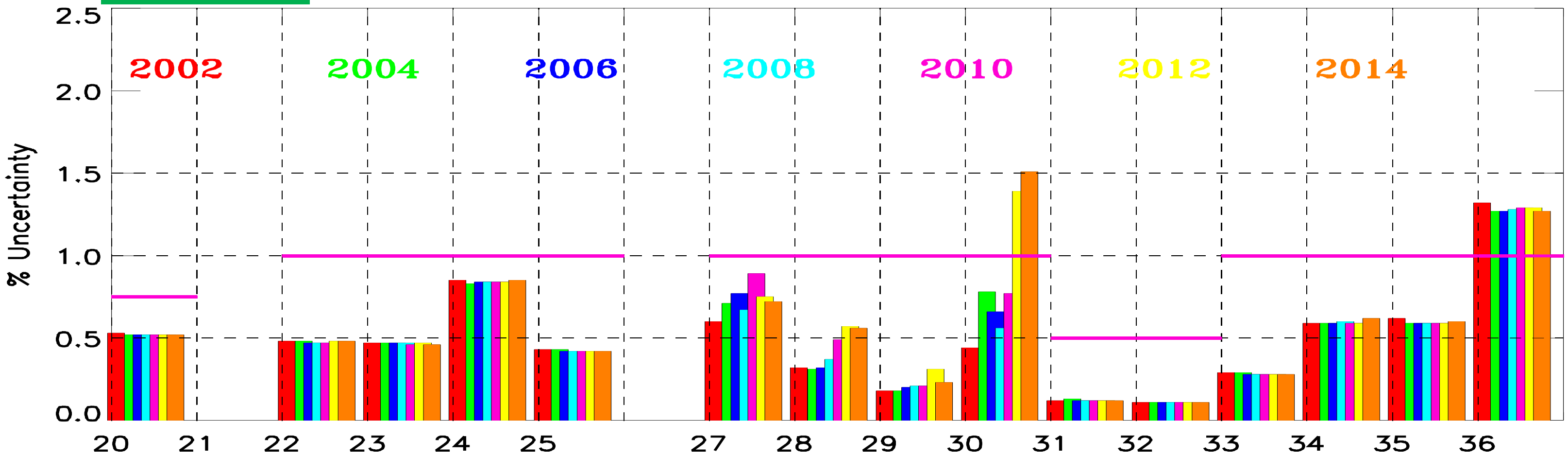


Weekly averaged

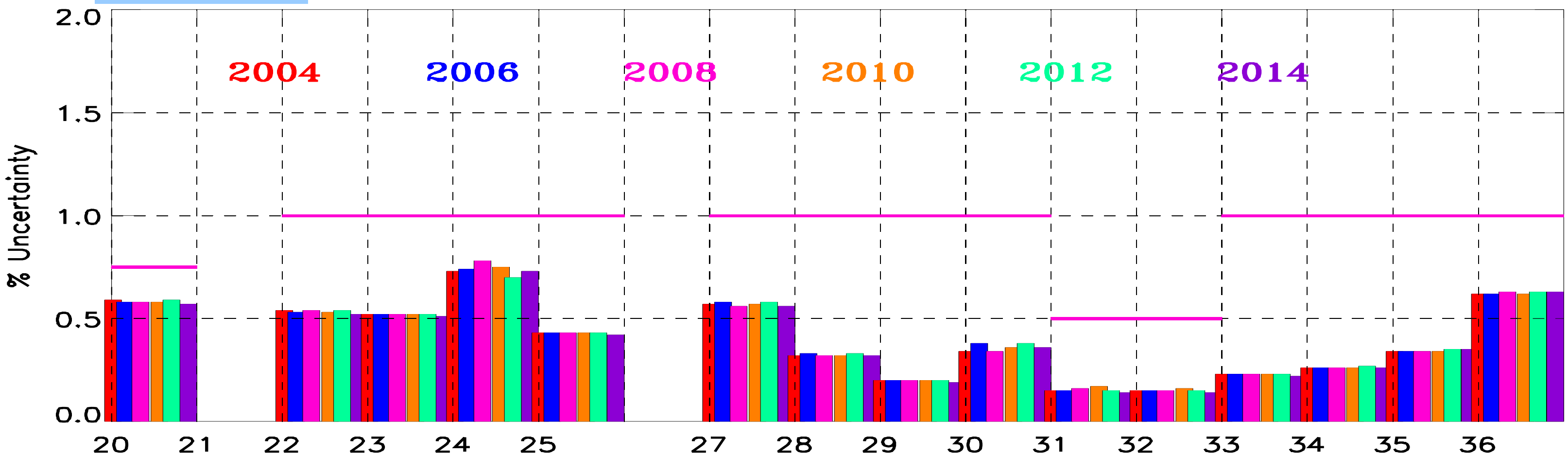
TEB Yearly Uncertainty Trend

Uncertainty evaluated at L_{typ} and at 'nadir' AOI

T-MODIS



A-MODIS



Electronic Crosstalk Update
T-MODIS Band 27

MODIS Characterization Support Team

05/18/2015

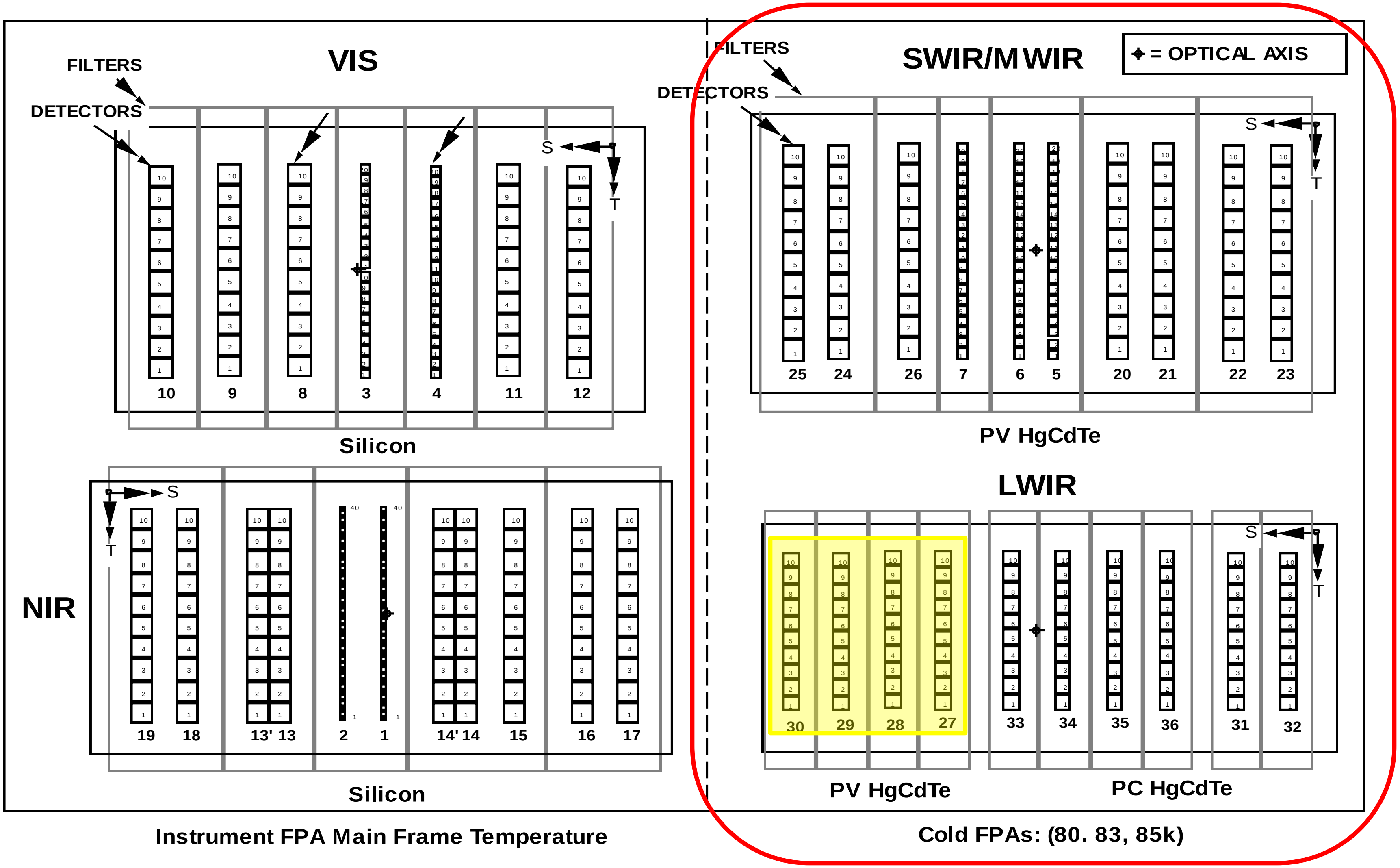
Terra Band 27 Crosstalk Phenomena

- Inspection of EV images (Baja Peninsula) show evidence of a change in performance over time – in terms of signal leak and striping
  - *First signal leak was clearly observed in late 2004 image*

- MODIS Characterization Support Team (MCST) received several recent inquiries regarding possible problems with band 27 (water vapor product users)

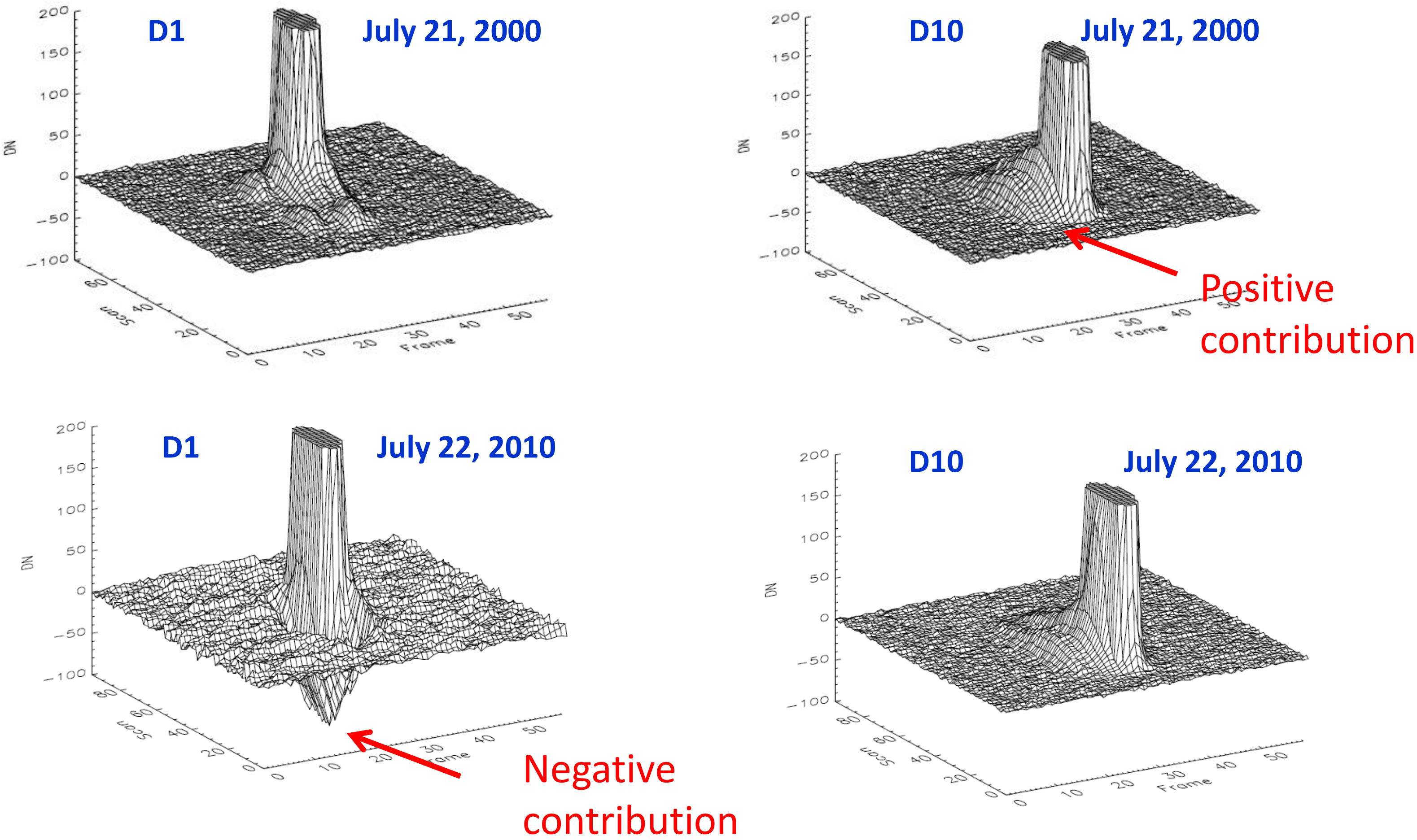
- Lunar data shows change in crosstalk behaviour
  - *From bands 28-30*

MODIS – FPAs



Warm FPA: VIS and NIR; **Cold FPA: SMIR and LWIR**

Terra Band 27 Lunar Images



Algorithms for Band 27 Crosstalk Removal

- Linear Algorithm

$$dn_{B27}^{xtalk}(D,F)=\sum_{i,j}c_{ij}(D)dn_{B_i}(D_j,F+\Delta F_i)$$

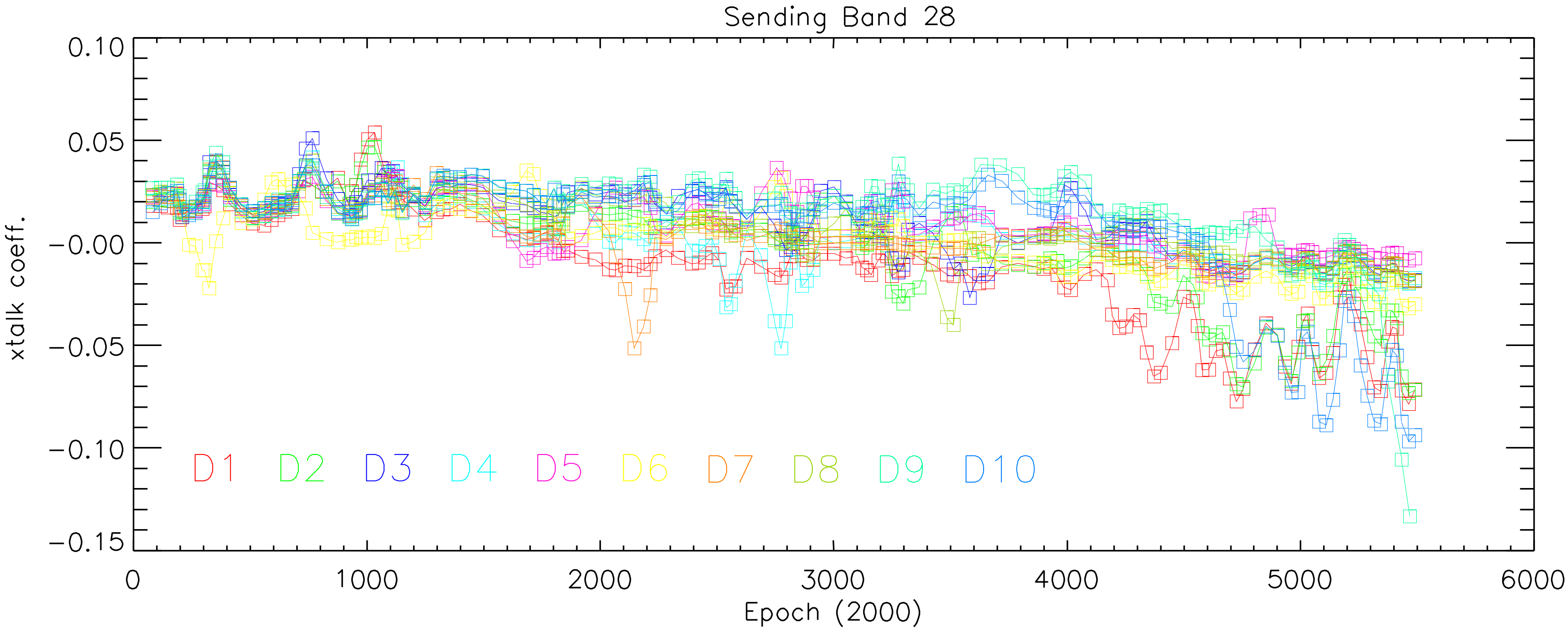
i = 0, 1 & 2 (B28, 29 & 30)

$$dn_{B27}^{corrected}(D,F)=dn_{B27}(D,F)-dn_{B27}^{xtalk}(D,F)$$

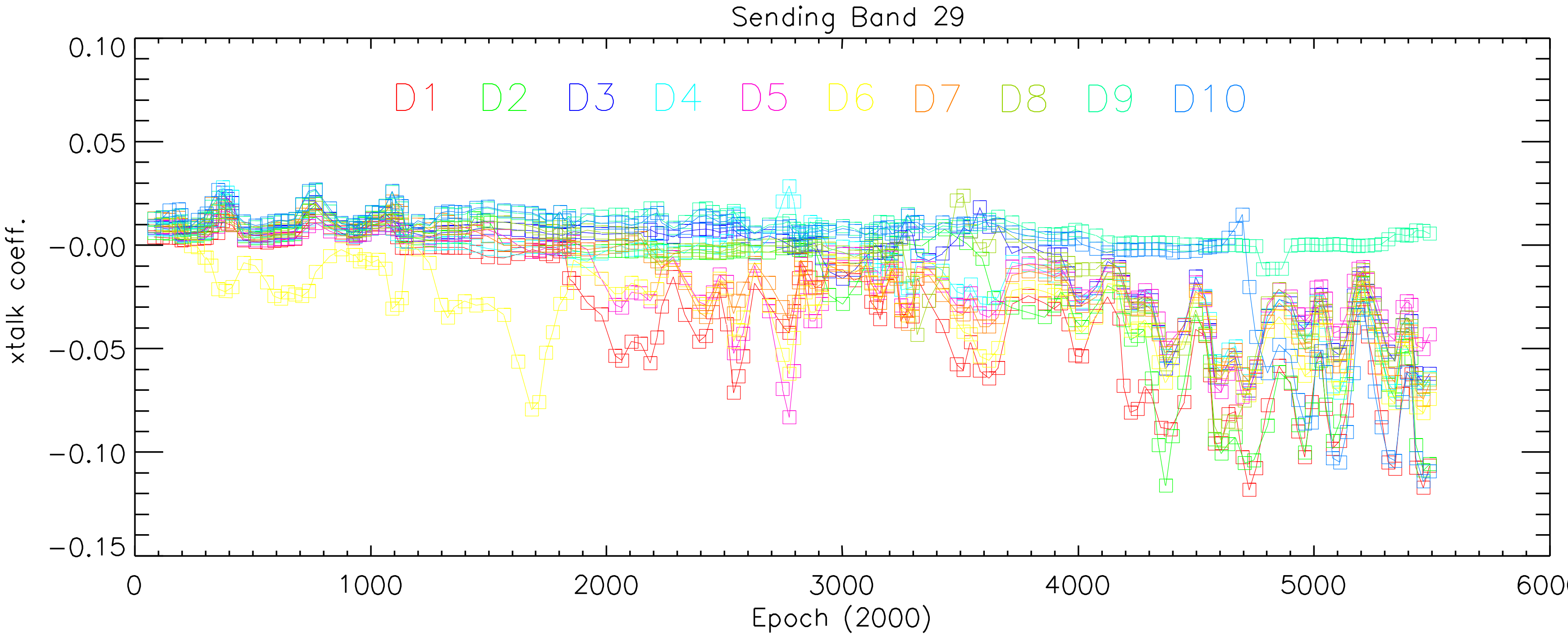
$$dn_{B27}^{xtalk}(D,F)=\sum_{i}C_i(D)\left\langle dn_{B_i}(D_j,F+\Delta F_i)\right\rangle_{D_j}$$

  - D, F: detector, frame
  - B_i, D_j: ith sender band, jth detector
  - Df_i: distance between band 27 and the ith sending band on the LWIR focal plane
  - c_{ij}: coefficient for the xtalk from B_i, D_i to B27, D
- Derive the xtalk coefficients from lunar observations
- Apply them in both Black Body calibration coefficients (b_1) calculation and EV dn responses

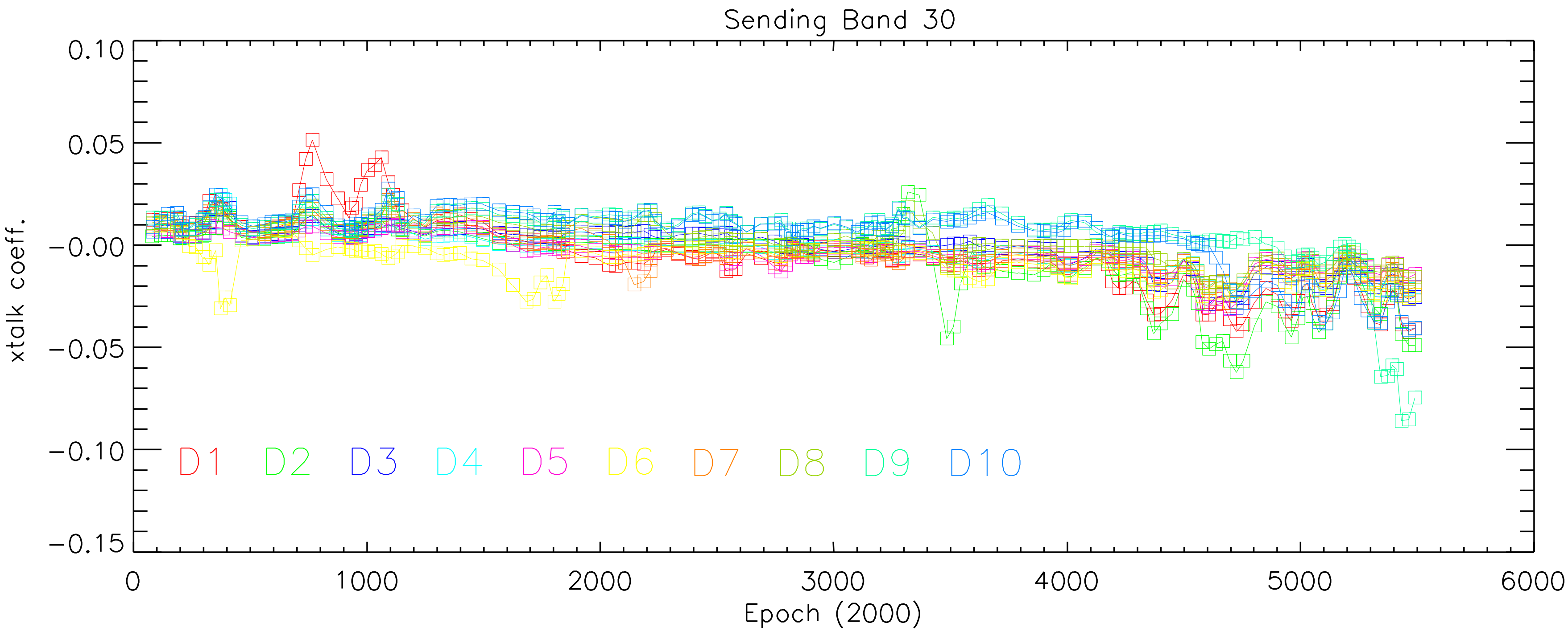
Crosstalk Coefficients for Receiving Band 27



Crosstalk Coefficients for Receiving Band 27



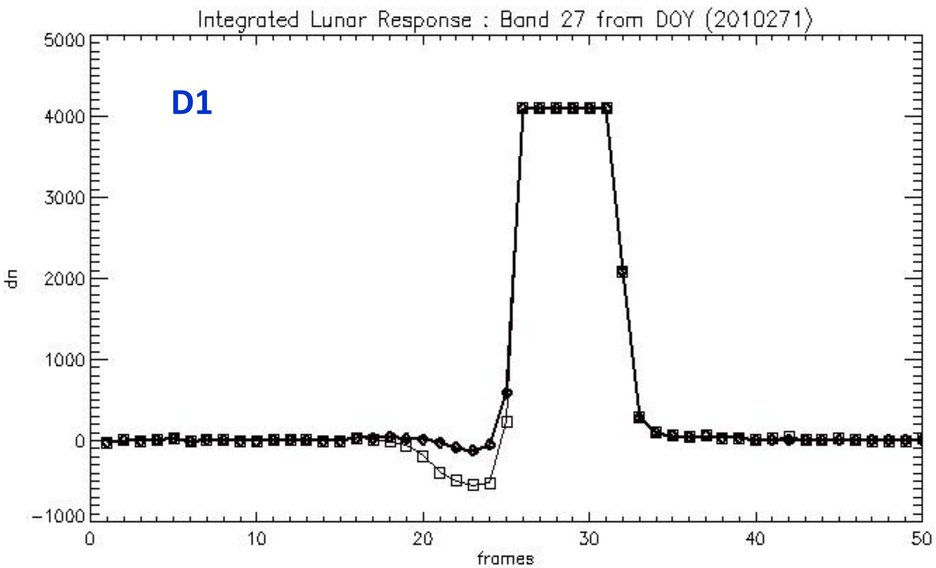
Crosstalk Coefficients for Receiving Band 27



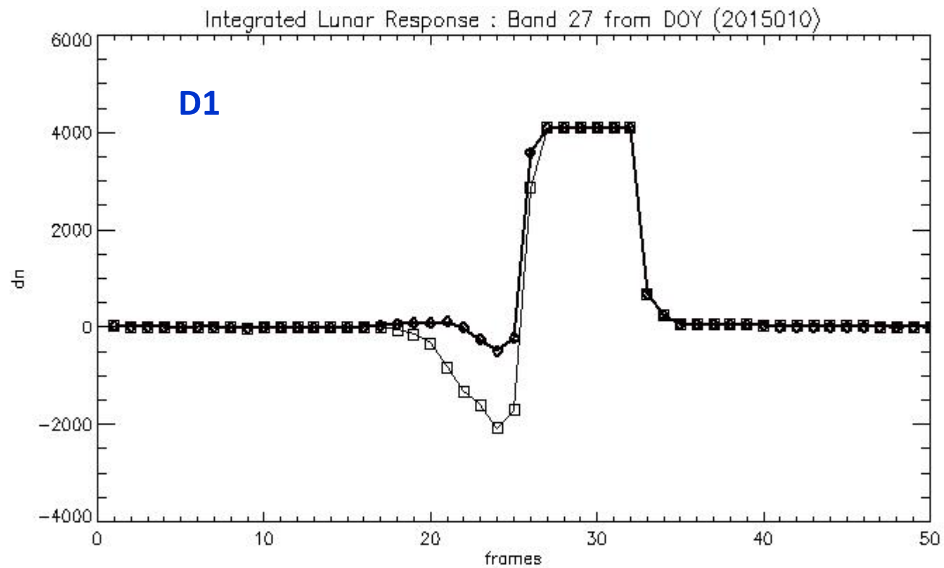
Band 27 Crosstalk Removal in Lunar Responses

Examples:

2010



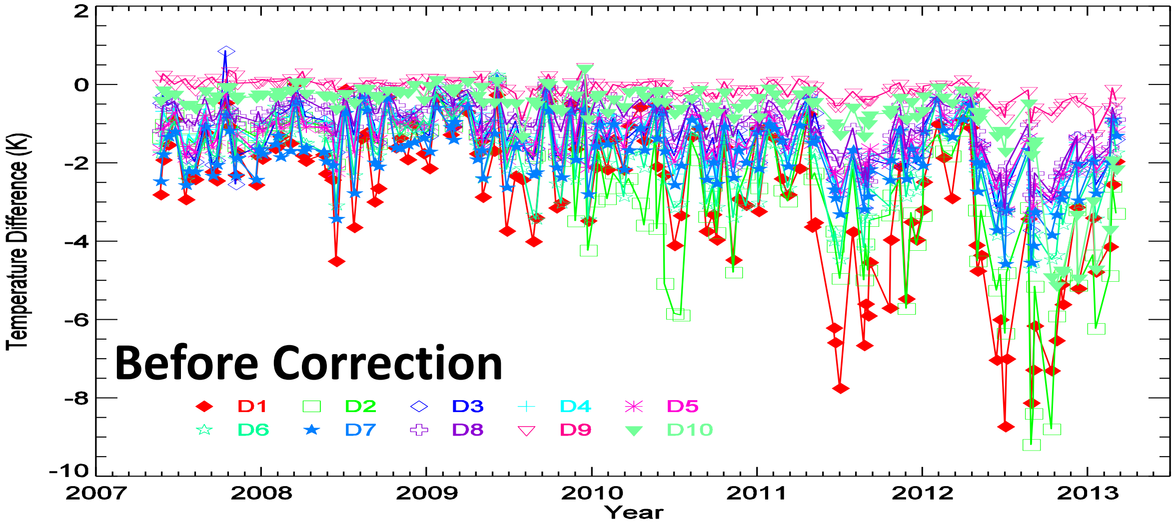
2015

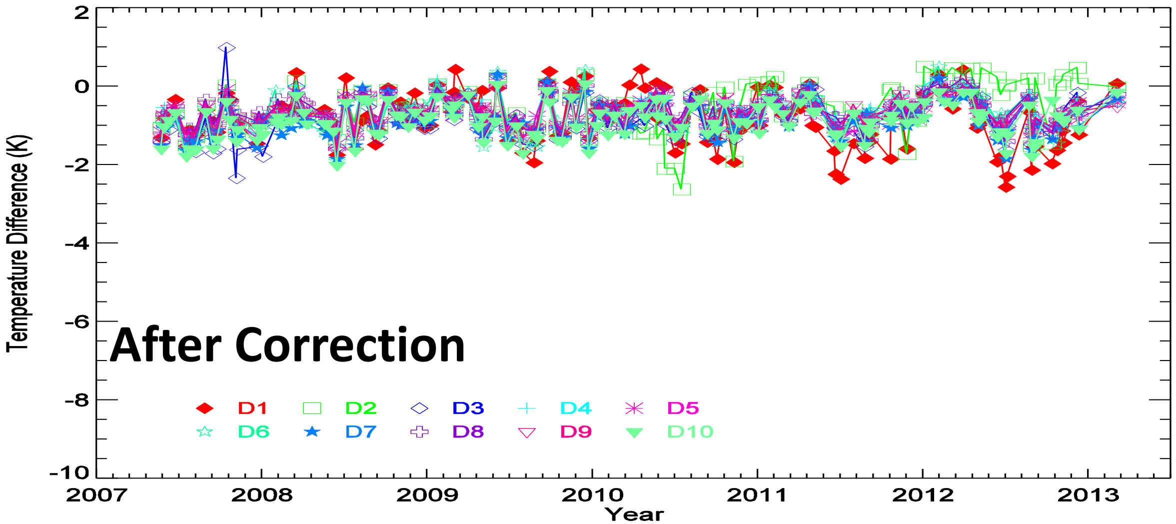


□ : Before Correction

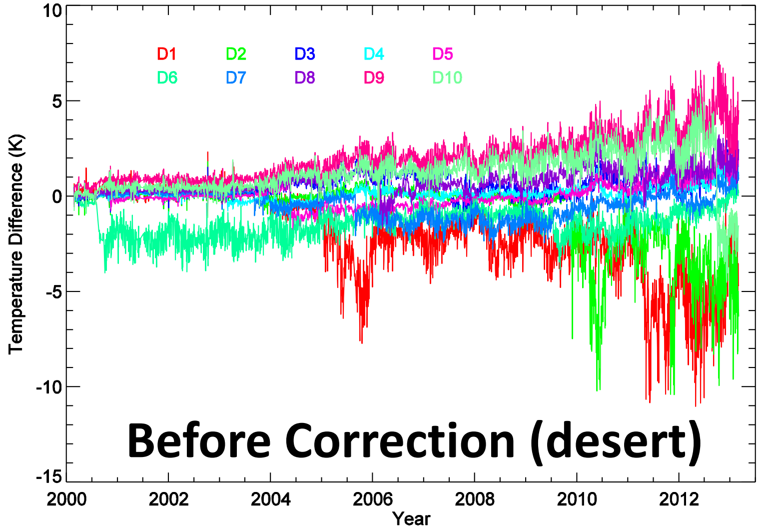
◊ : After Correction

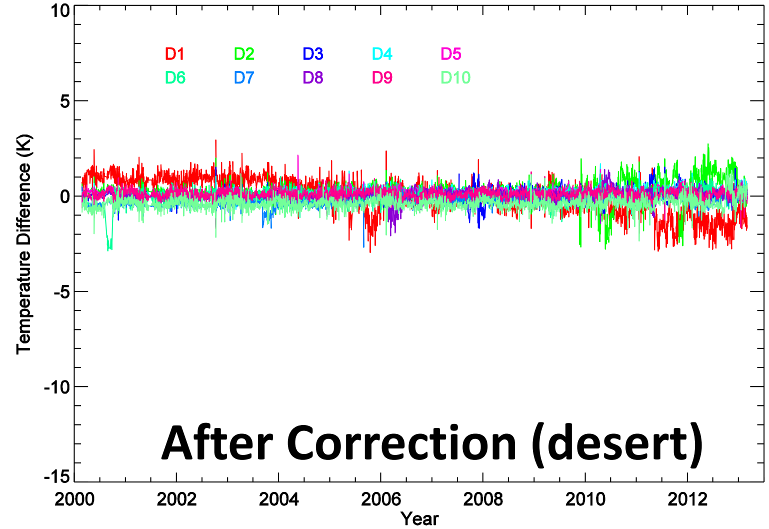
Radiometric Impact of Band 27 Crosstalk Correction in Comparison with IASI SNO

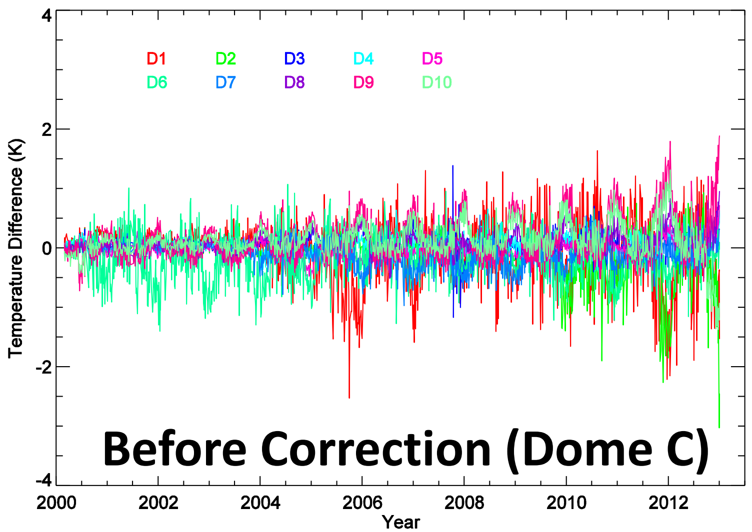


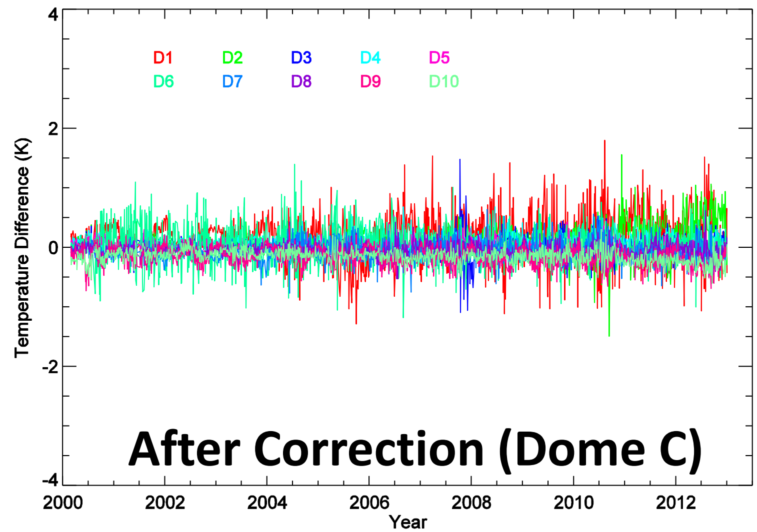


Impact on Detector-to-Detector Differences



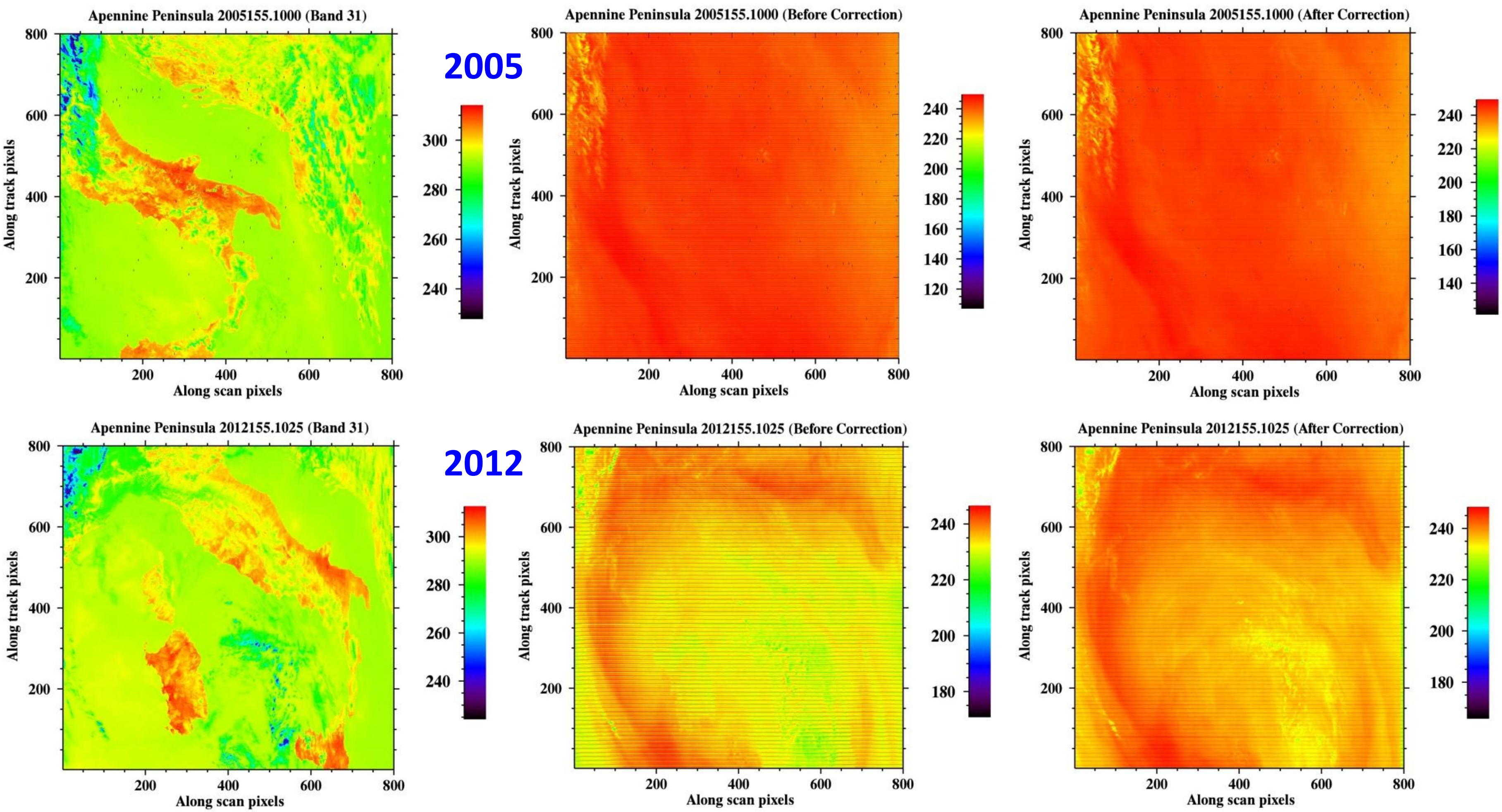






Examples of Image before and after Correction

Band 31 | Band 27 (before) | Band 27 (after)



Summary

- T-MODIS band 27 is severely affected by crosstalk with sending bands 28-30.
- The crosstalk impact is observed in lunar images and a linear correction algorithm is developed using lunar responses.
- Crosstalk coefficient trends from the sending bands show increase in magnitude from mid 2010 onwards till date.
- Correction is applied in both BB and EV dn responses.
- Initial L1B testing has begun in preparation for implementation in future collection.

References

- J. Sun, S. Madhavan, B. Wenny, and X. Xiong, "Terra MODIS band 27 electronic crosstalk: cause, impact, and mitigation", Proceedings of SPIE – Sensors, Systems, and Next-Generation Satellites XV, vol. 8176, no. 81760Z, 2011.
- J. Sun, X. Xiong, S. Madhavan, and B. N. Wenny, "Terra MODIS Band 27 Electronic Crosstalk Effect and Its Removal", IEEE Transactions on Geoscience and Remote Sensing, vol. 52, issue 3, pp. 1551-1561, 2014.
- J. Sun, X. Xiong, Y. Li, S. Madhavan, A. Wu, and B. N. Wenny, "Evaluation of Radiometric Improvements With Electronic Crosstalk Correction for Terra MODIS Band 27", IEEE Transactions on Geoscience and Remote Sensing, vol. 52, issue 10, pp. 6497 - 6507, 2014.
- S. Madhavan, J. Sun, X. Xiong, B. N. Wenny, A. Wu, “Statistical Analysis of the Electronic Crosstalk Correction in Terra MODIS Band 27”, Proc. SPIE 9218, Earth Observing Systems XIX, 9218-75, 2014.
- J. Sun, S. Madhavan, X. Xiong, and M. Wang, "Electronic crosstalk correction for terra long wave infrared photovoltaic bands ", Proc. SPIE 9264, Earth Observing Missions and Sensors: Development, Implementation, and Characterization III, 926412, 2014.

MODIS Aqua and Terra EV-based RVS for bands 1&2

MODIS Characterization Support Team
05/18/2015

Overview for Aqua

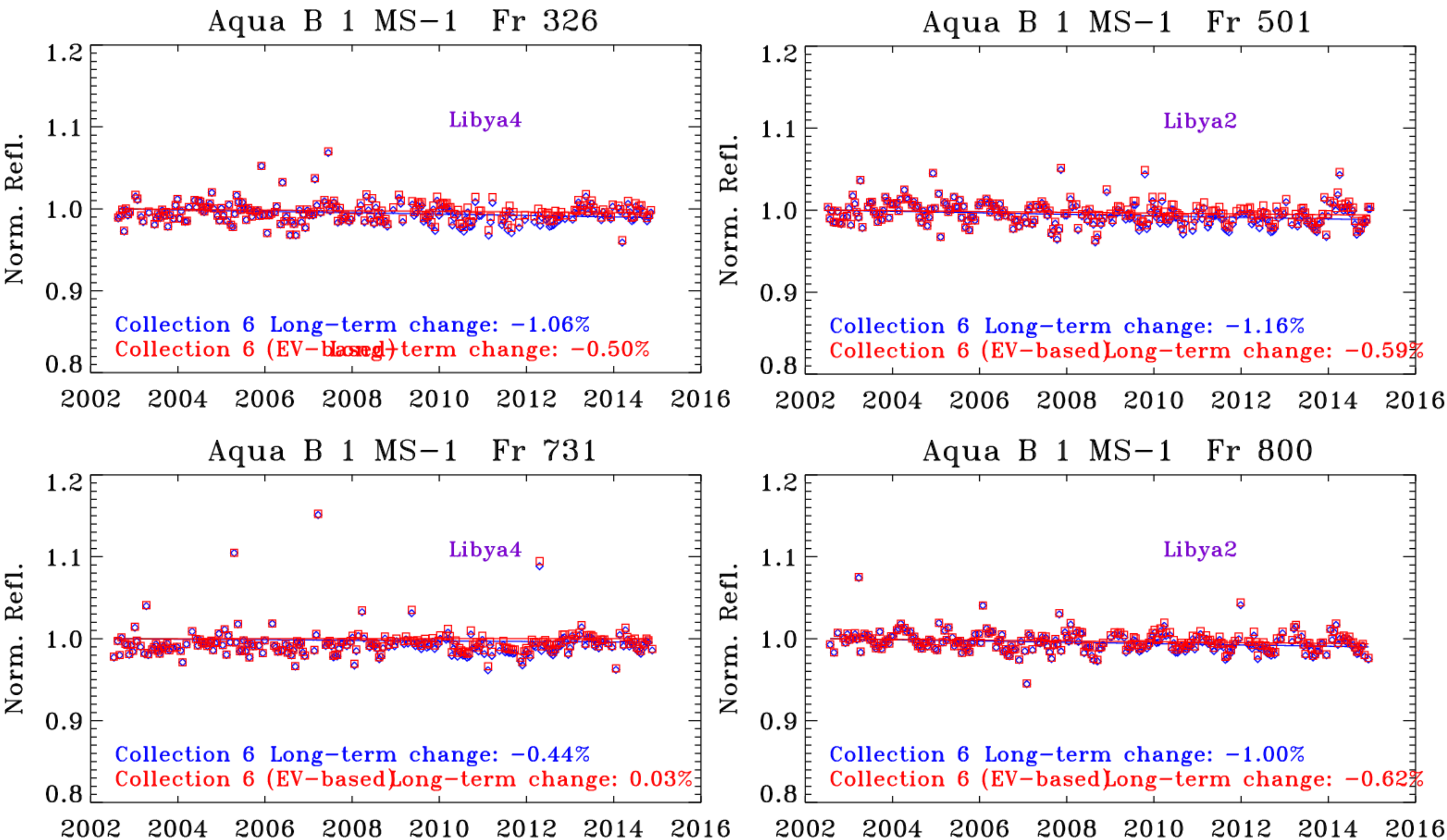
- **Aqua C6 RVS currently uses on-board calibrators (SD & lunar) in addition to EV and SRCA MS ratios for bands 1-4**

  - MCST regularly evaluates the long-term desert/Dome C trends to monitor the calibration stability for these bands

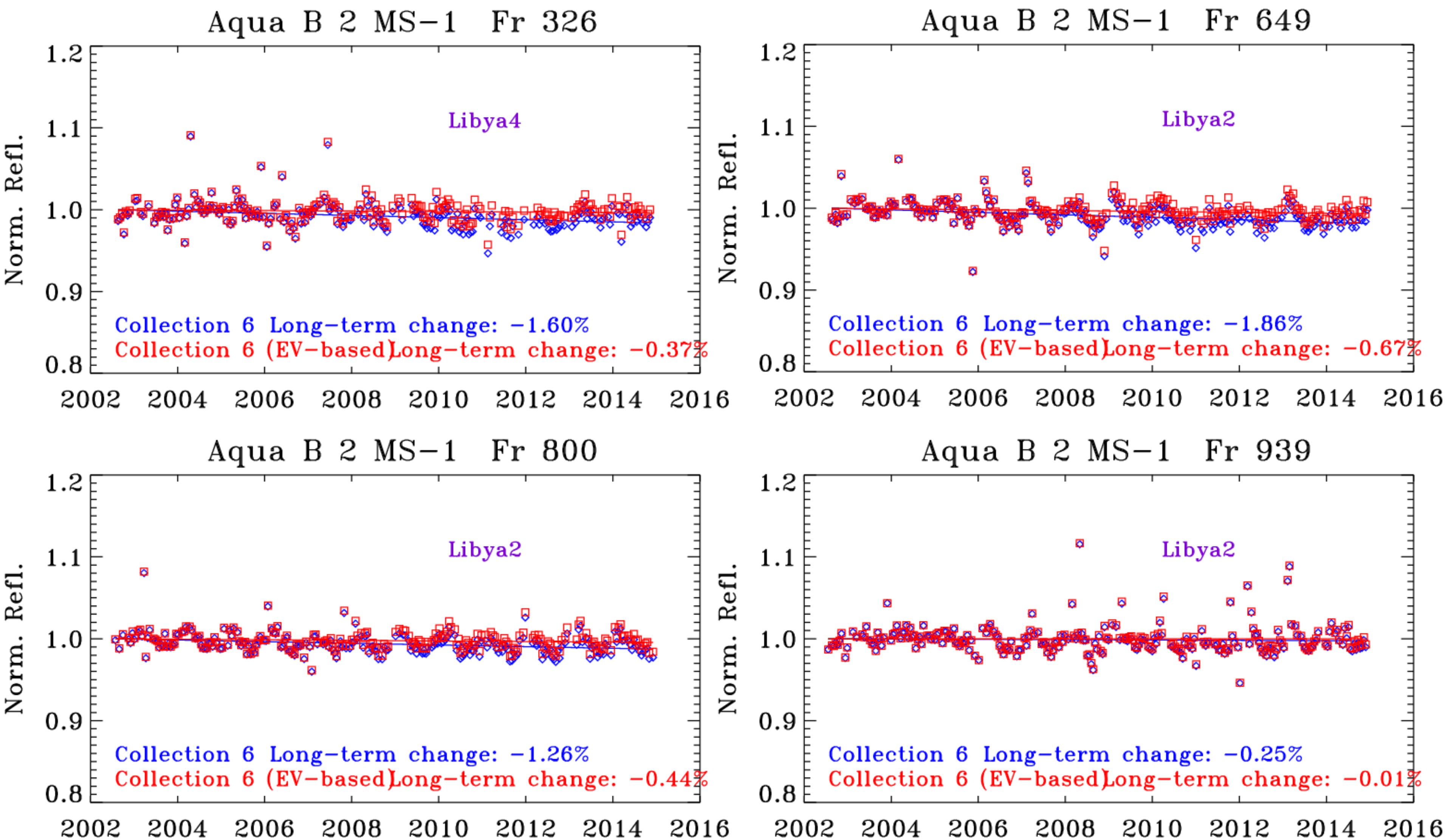
  - Recent trends for bands 1 and 4 (especially) at nadir indicate a need to extend the current approach used for bands 8 and 9 to bands 1-4

  - Normalized TOA reflectance trending at various scan-angles shown in the next slides

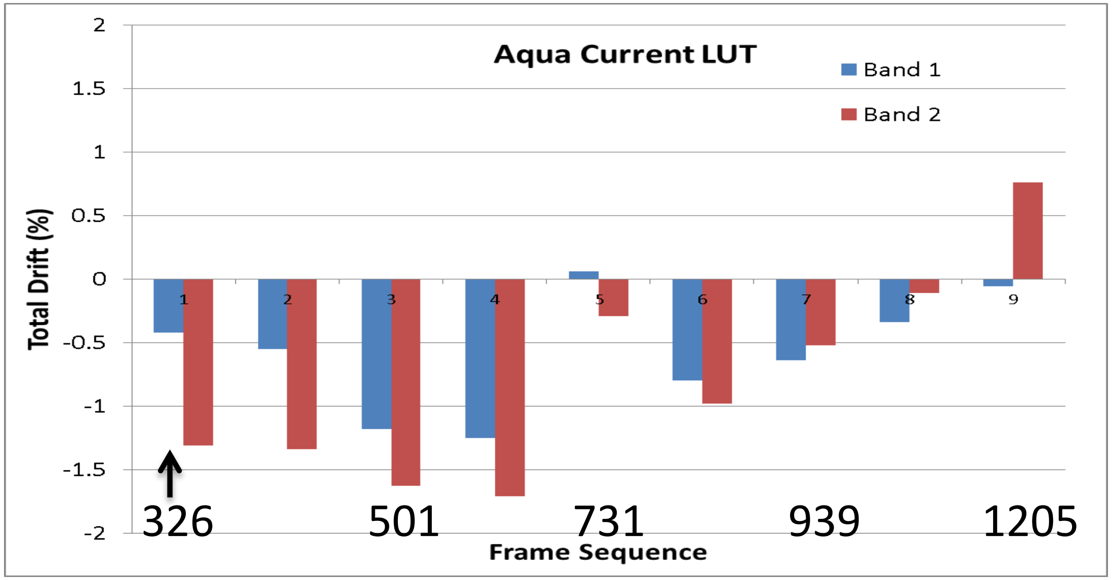
Aqua band 1 reflectance trends over desert

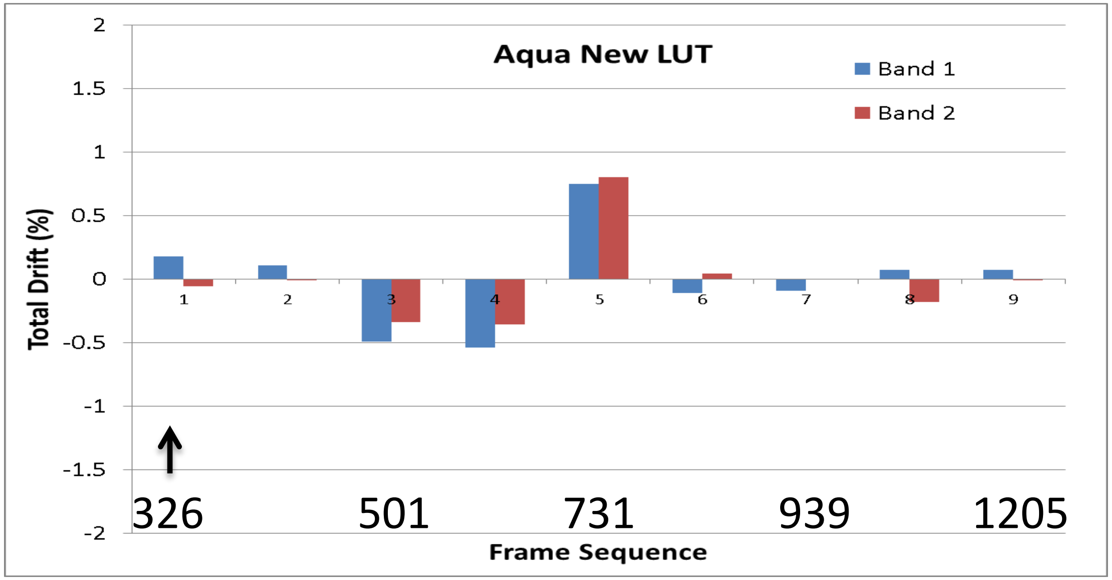


Aqua band 2 reflectance trend over desert



Impact of testing LUT on Aqua bands 1&2 for desert reflectance trends





Frame Index

1 – 326
2 – 445
3 – 501
4 – 649
5 – 731
6 – 800
7 – 939
8 – 1055
9 – 1205

Summary for Aqua EV-based RVS for bands 1-2

- A measurable downward drift ~ 1 % (but mostly within 2 %) is seen near nadir for bands 1-2 from the desert and Dome C trending
- Trends within 1% at the larger AOI, including the SD, therefore indicating that SD calibration is sufficient in accurately characterizing the sensor change at SD AOI
- The EV-based RVS approach, previously applied to bands 8 and 9, is extended to apply to bands 1-4 and currently under science testing
- The goal is to maintain the accuracy for the forward LUT

Overview for Terra

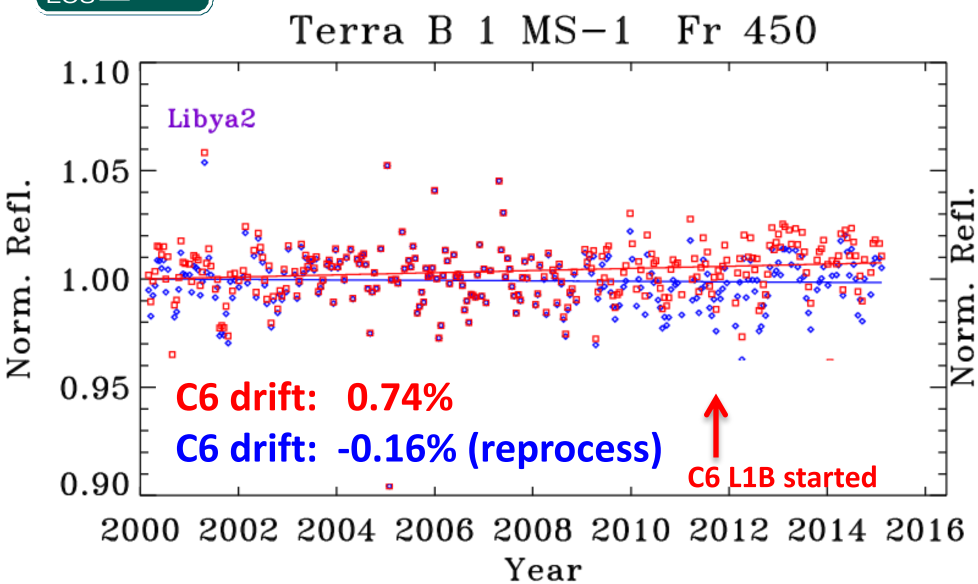
- **Terra C6 RVS currently uses on-board (SD & lunar) measurements and EV response trends at multiple AOI for bands 1-4, 8-10**

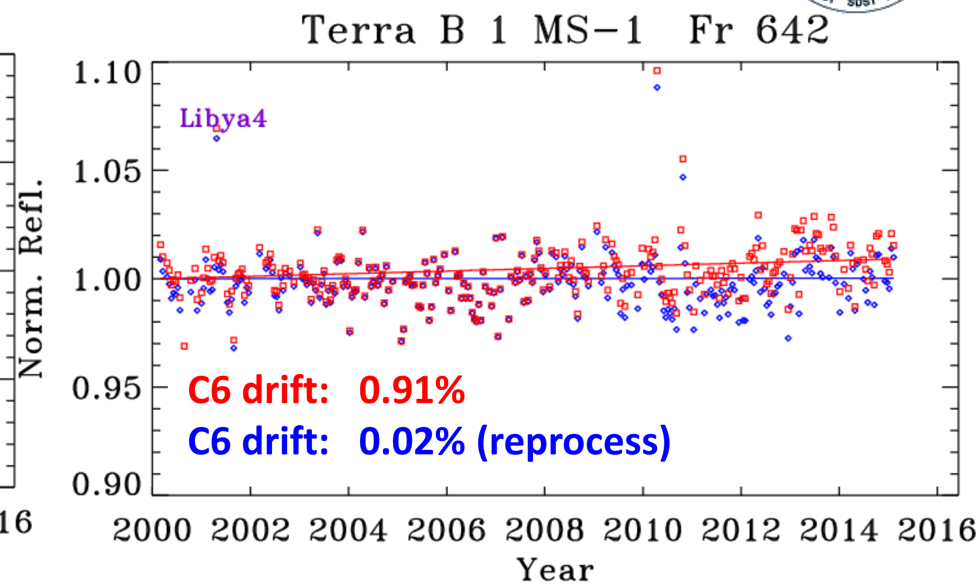
  - Exception for bands 1 and 2 is that lunar measurements are excluded in the calculation of RVS due to response trend mismatch between lunar and EV data

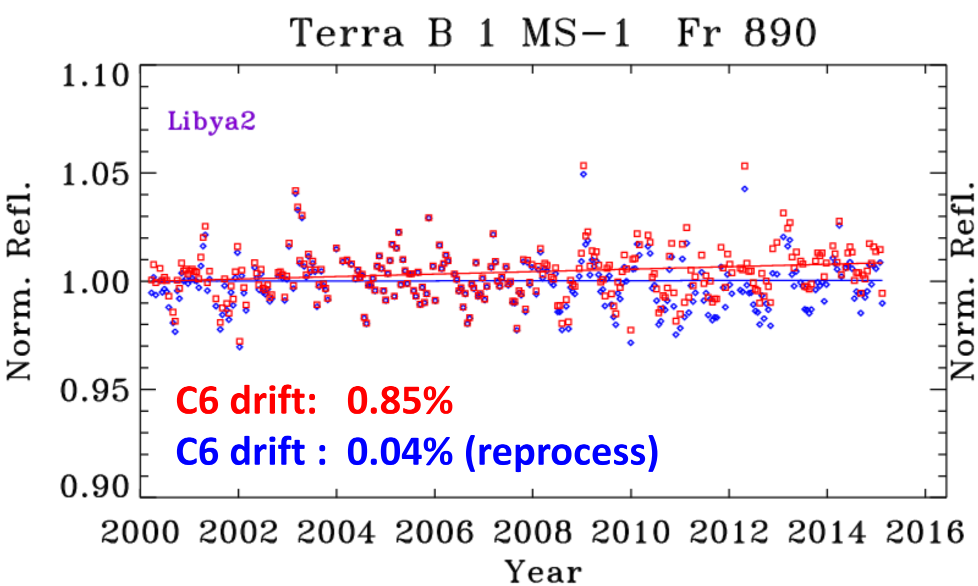
  - Recent trends for bands 1 and 2 indicate there is an upward drift ~ 1 % at all AOI. Currently this is considered due to combination of forward LUT update in SD and EV data

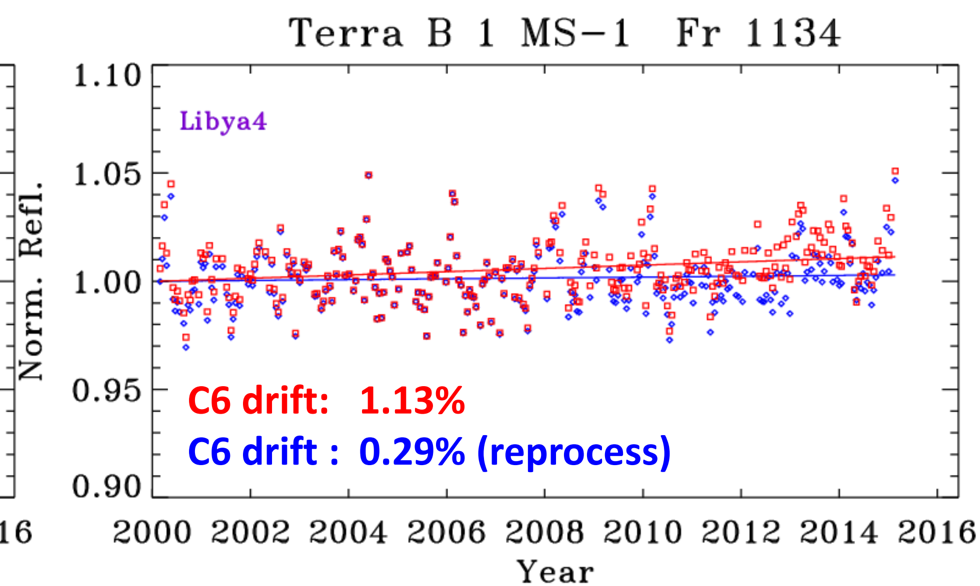
  - Normalized TOA reflectance trending at various scan-angles and our internal LUT testing results shown in the next slides

Terra band 1 reflectance trends at different AOI over desert

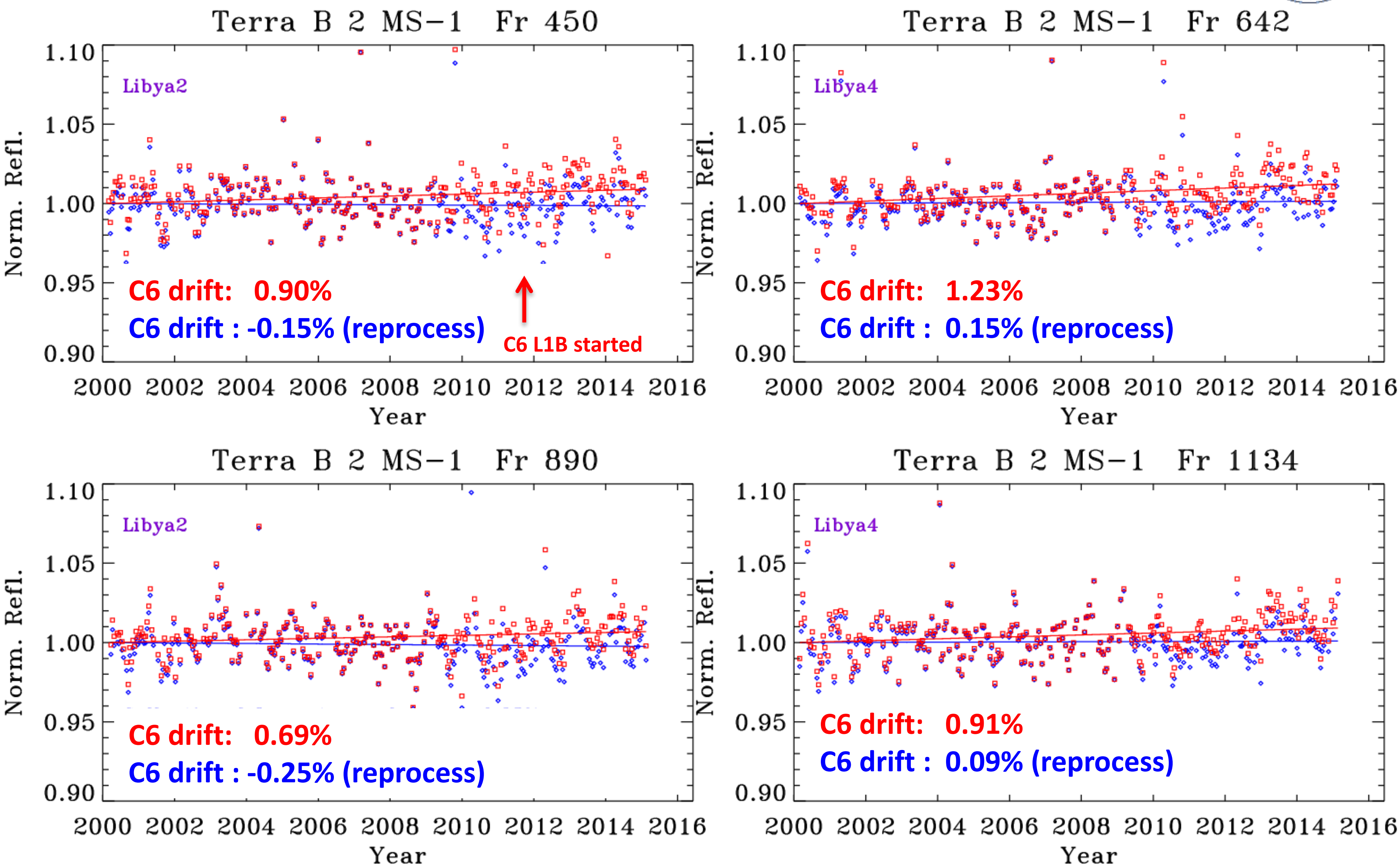




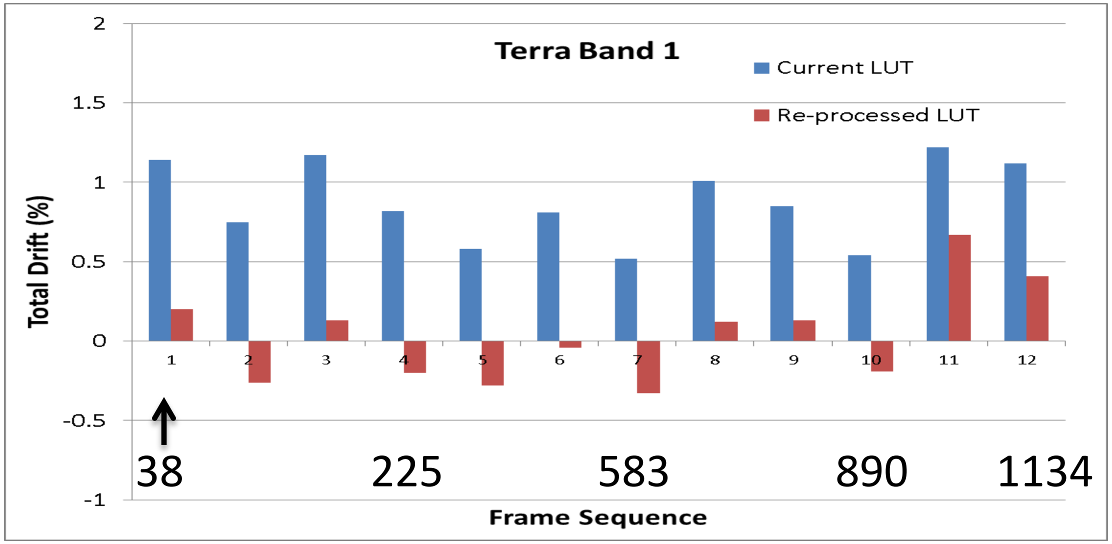


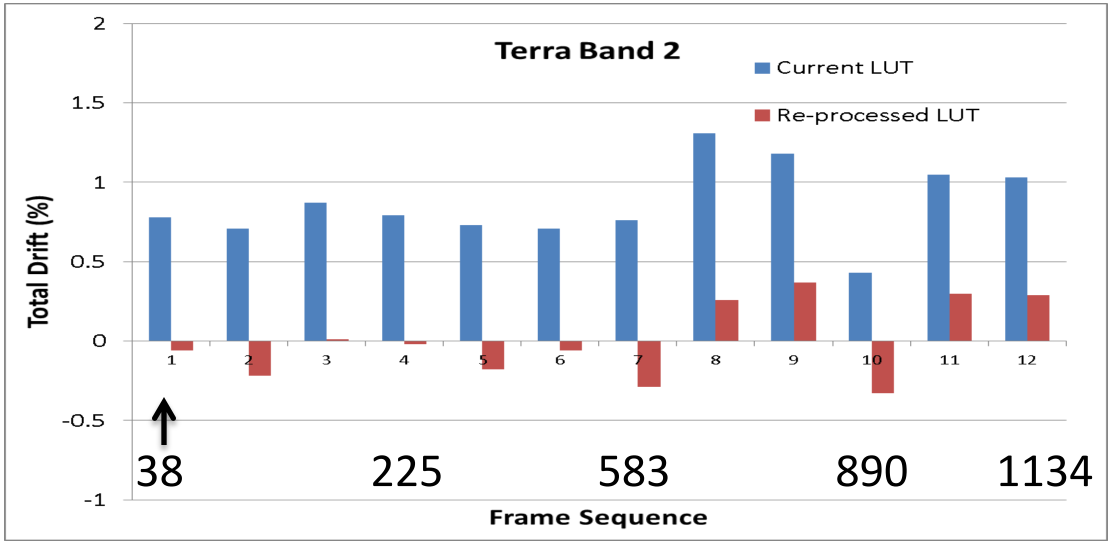


Terra band 2 reflectance trends at different AOI over desert



Impact of testing C6 LUT on Terra bands 1&2 for desert reflectance trends





Frame Index

1 – 38
2 – 111
3 – 146
4 – 225
5 – 325
6 – 450
7 – 583
8 – 642
9 – 745
10 – 890
11 – 1040
12 – 1134

*** Total drifts are well within 0.5% if data from half of the mission period (2000-2007)**

Summary for Terra EV-based RVS for bands 1-2

- A noticeable upward drift ~ 1% is seen at nearly all AOI for bands 1-2 from the desert and Dome C trending
- Trends derived using reprocessed calibration data shows that they are well within 1%.
- Comparison between the trends before and after the reprocess shows the upward drift starts from year 2012 (when C6 started), indicating that there are due to errors in LUT forward update.
- MCST has recently adjusted LUT forward update procedure (SD and EV data) to achieve better accuracy.

Tracking MODIS on-orbit polarization sensitivity

MODIS Characterization Support Team
05/18/2015

Methodology

Standard polarization correction (OBPG) using desert EV TOA reflectancs and 6SV simulations

$$L_m / L_t = M11 *(1 + m12 * Q / I + m13 * U/ I)$$

L_m /L_t : measured TOA radiance/reflectance after normalization to the 1st point (L_t can be from other sensor measurements without polarization sensitivity)

Q/I , U/I : normalized linear Stokes components, modeled from 6SV for desert*

*note it is assumed that relative changes such as Q/I and U/I can be derived more accurately by model than the absolute values.

Sample input of 6SV

0	[User defined geometry]
40.0 100.0 45.0 50.0 7 23	[SZA, SAZ, MODISZA, MODISAZ, month, day]
8	[User-defined molecular atm, H2O and O3]
3.0 3.5	[Water Vapor and Ozone content]
4	[User-defined aerosol components]
0.25 0.25 0.25 0.25	[fractions of four aerosol components]
0	[use AOT input card]
0.05	[AOT at 0.55 μm]
-0.2	[target altitude]
-750.0	[sensor altitude]
49	[MODIS B8]
0	[homogeneous surface]
0	[target reflectance model]
3	[sand ground reflectance]
-1	

Sample Output of 6SV

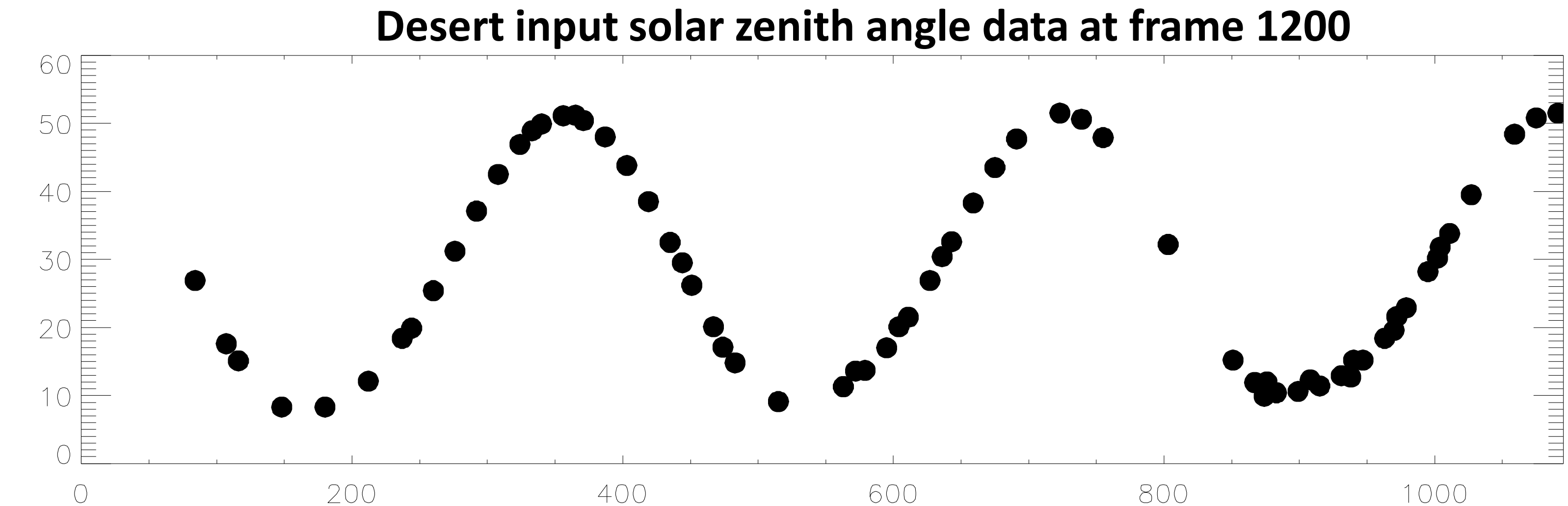
```
*********************************************************************
*                                                                   *
*        integrated values of  :                                    *
*        --------------------                                       *
*                                                                   *
*             downward      upward       total                      *
*  global gas. trans. :   0.95353     0.95013     0.91220           *
*  water   "    "   :   0.98364     0.98255     0.97120             *
*  ozone   "    "   :   0.97268     0.97044     0.94403             *
*  co2     "    "   :   1.00000     1.00000     1.00000             *
*  oxyg    "    "   :   0.99674     0.99660     0.99525             *
*  no2     "    "   :   1.00000     1.00000     1.00000             *
*  ch4     "    "   :   1.00000     1.00000     1.00000             *
*  co      "    "   :   1.00000     1.00000     1.00000             *
*                                                                   *
*                                                                   *
*  rayl.  sca. trans. :   0.96297     0.96002     0.92447           *
*  aeros. sca.   "    :   1.00000     1.00000     1.00000           *
*  total  sca.   "    :   0.96294     0.95998     0.92441           *
*                                                                   *
*                                                                   *
*                                                                   *
*                       rayleigh    aerosols    total               *
*                                                                   *
*  spherical albedo  :    0.05205     0.00000     0.05237           *
*  optical depth total:   0.05870     0.00000     0.05870           *
*  optical depth plane:   0.05870     0.00000     0.05870           *
*    reflectance I     :  0.03485     0.00000     0.03485           *
*    reflectance Q     :  0.00373     0.00000     0.00373           *
*    reflectance U     :  -0.00494    0.00000     -0.00494          *
*    polarized reflect. : 0.00619     0.00000     0.00619           *
*    degree of polar.  :  17.77       0.00        17 %              *
*    dir. plane polar. :  -26.49      -45.00      -26.49            *
*  phase function I  :    1.26026     0.00000     1.26026           *
*  phase function Q  :    -0.21911    0.00000     -0.21911          *
*  phase function U  :    -1.19913    0.00000     -1.19913          *
*  primary deg. of pol:   -0.17386    0.00000     -0.17386          *
*  sing. scat. albedo :   1.00000     0.00000     1.00000           *
*                                                                   *
*                                                                   *
*********************************************************************
```

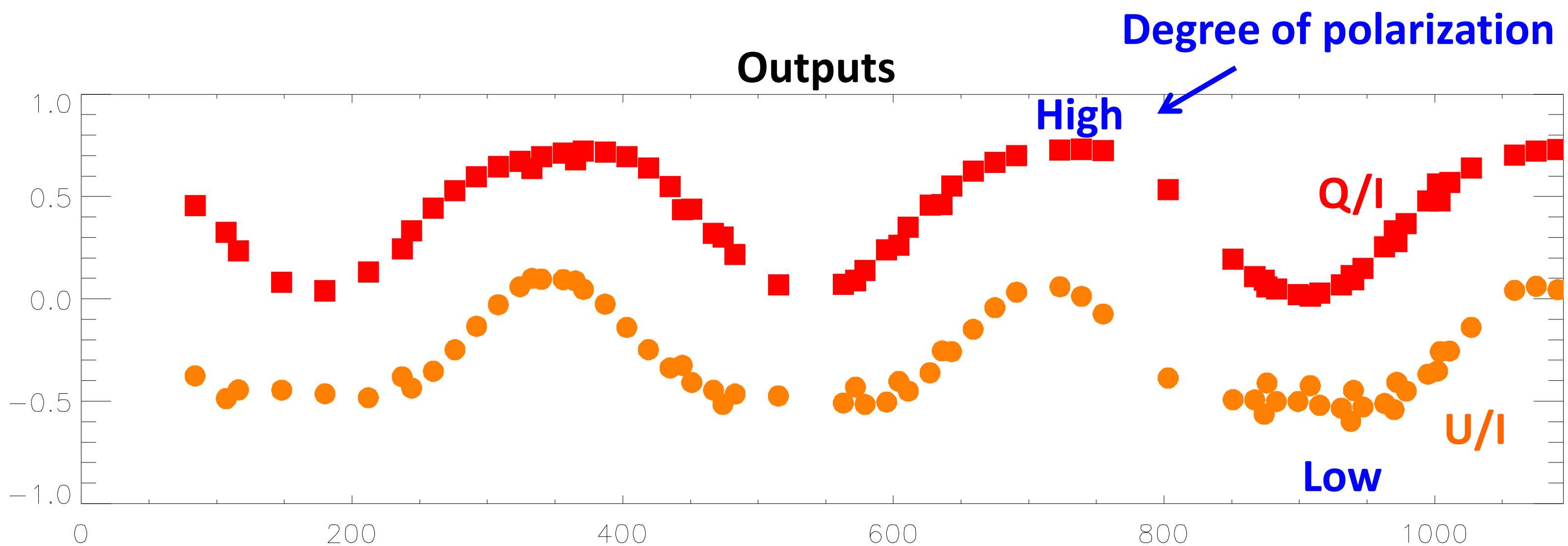
"Total" is from atmosphere only, Unpolarized surface contribution not included here.

$$DOP = (Q^2+U^2)^{1/2}/I$$

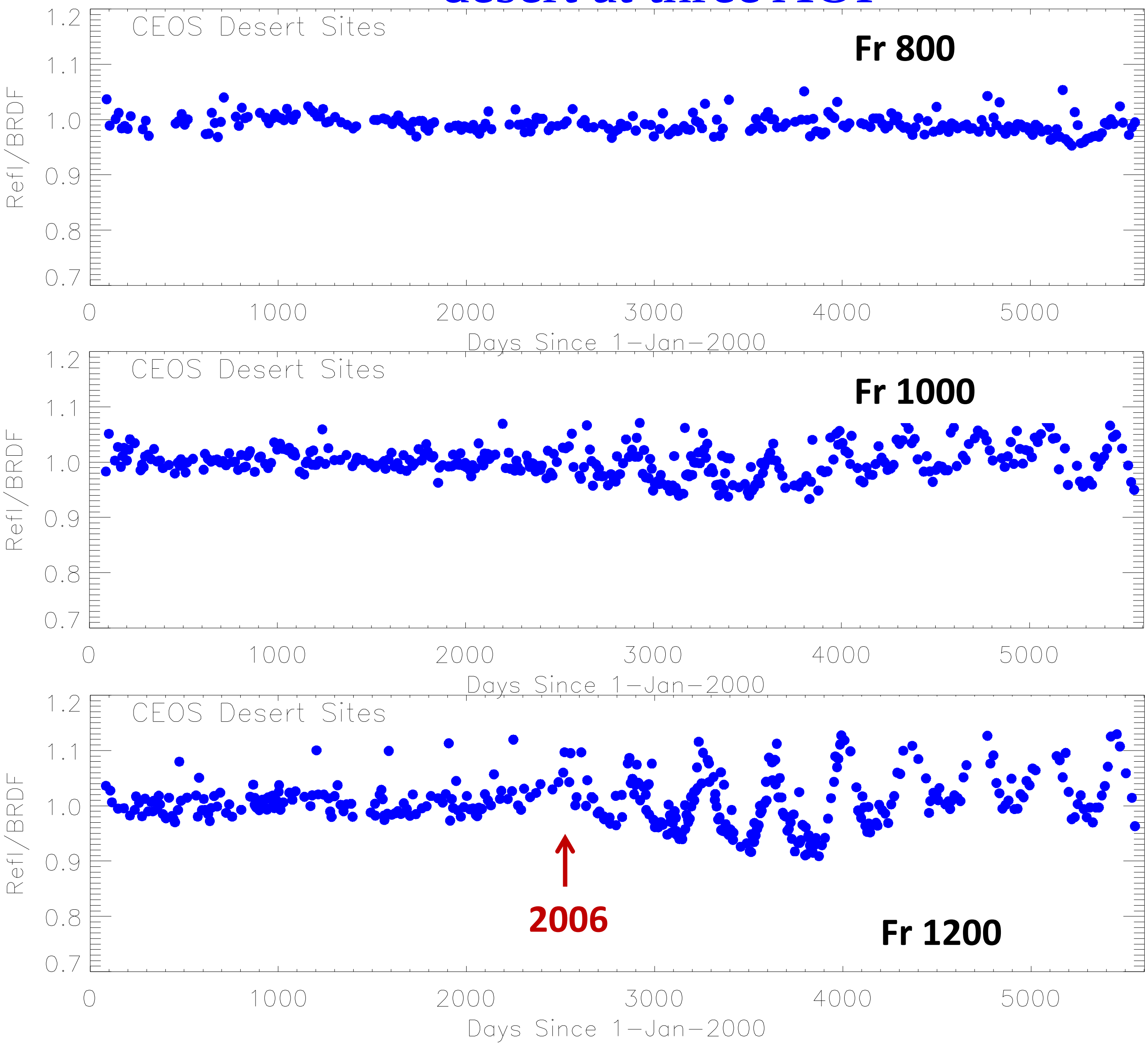
$$\Psi = (1/2)\tan^{-1}(U/Q)$$

6SV inputs and outputs for desert



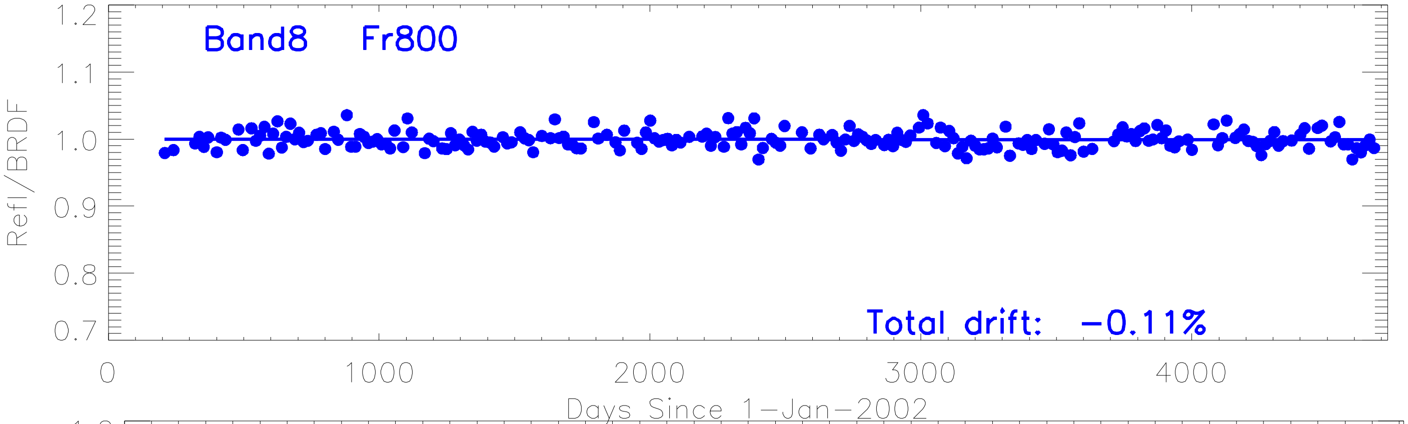


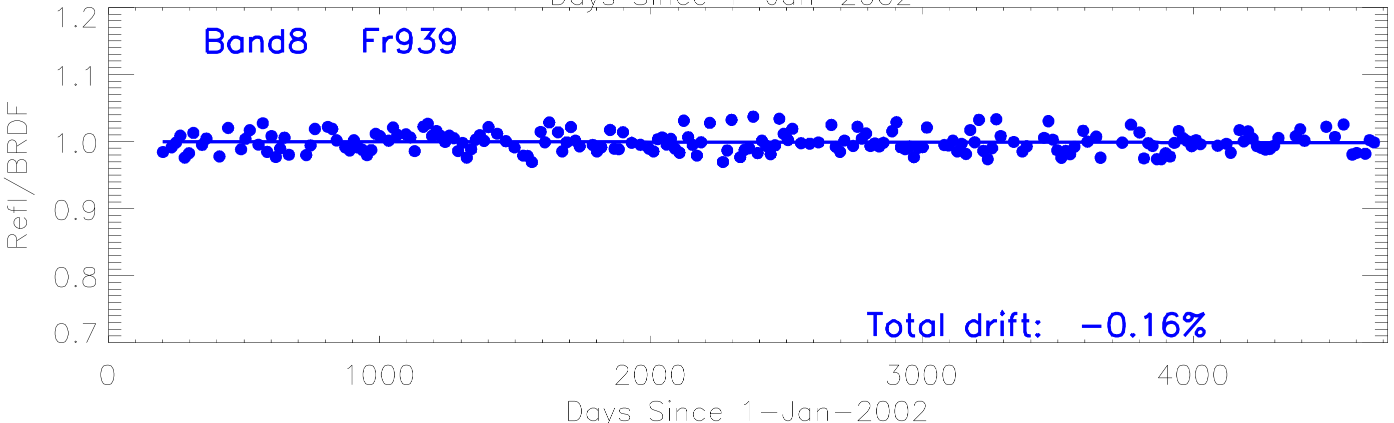
Terra band 8 TOA reflectance trends over desert at three AOI

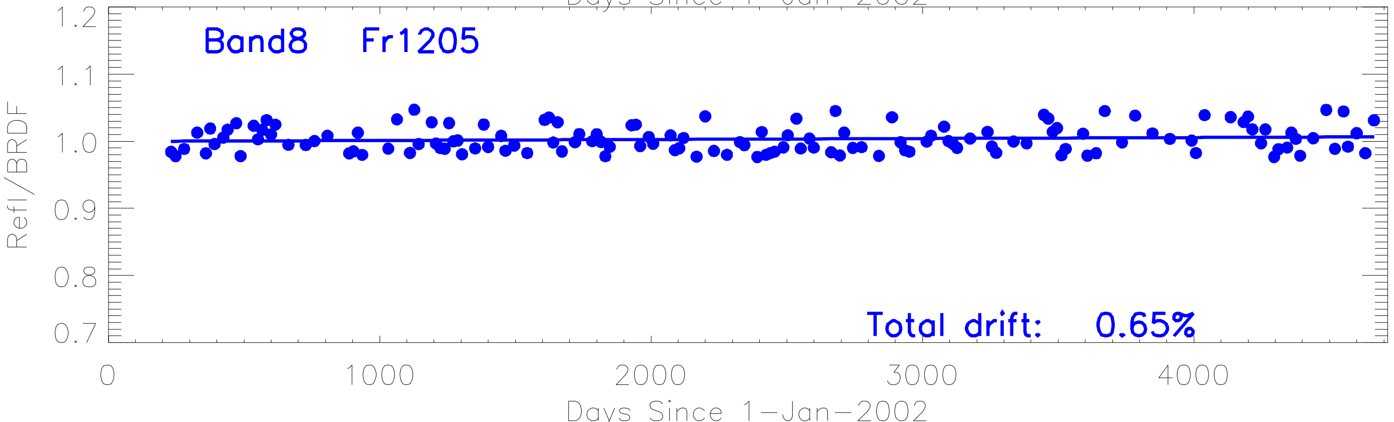


Increased polarization sensitivity with AOI after 2006

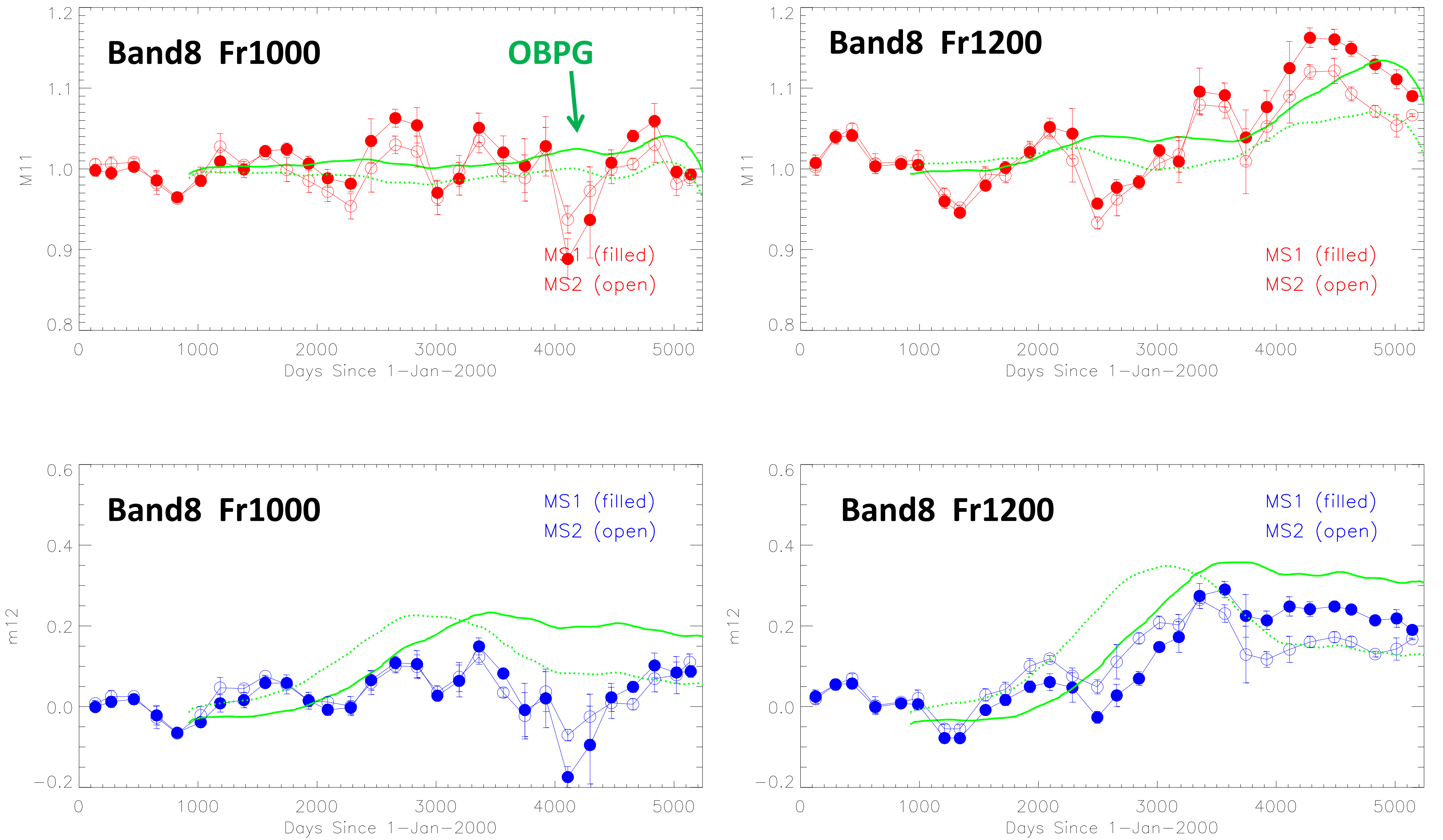
Aqua band 8 TOA reflectance trends over desert at three AOI



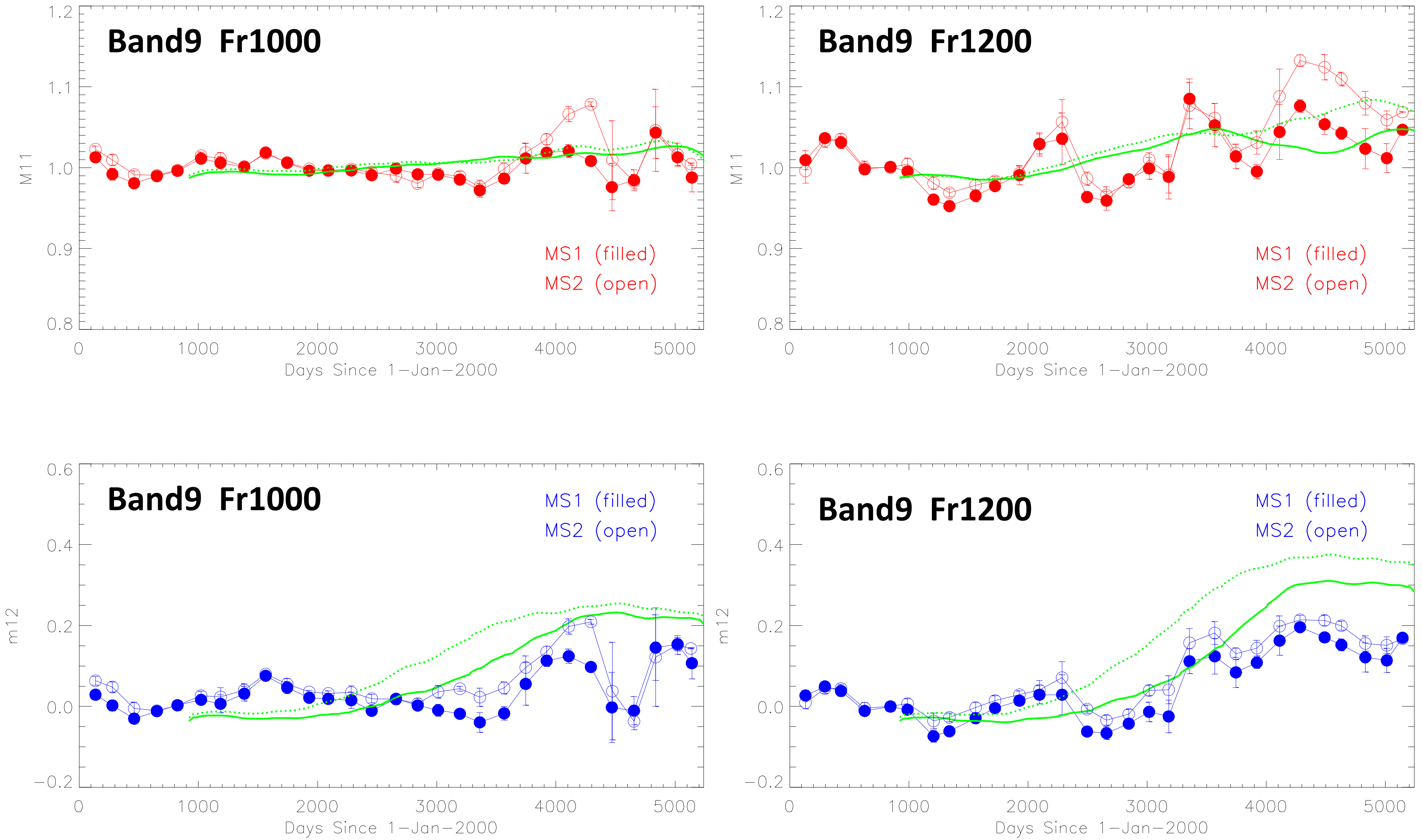




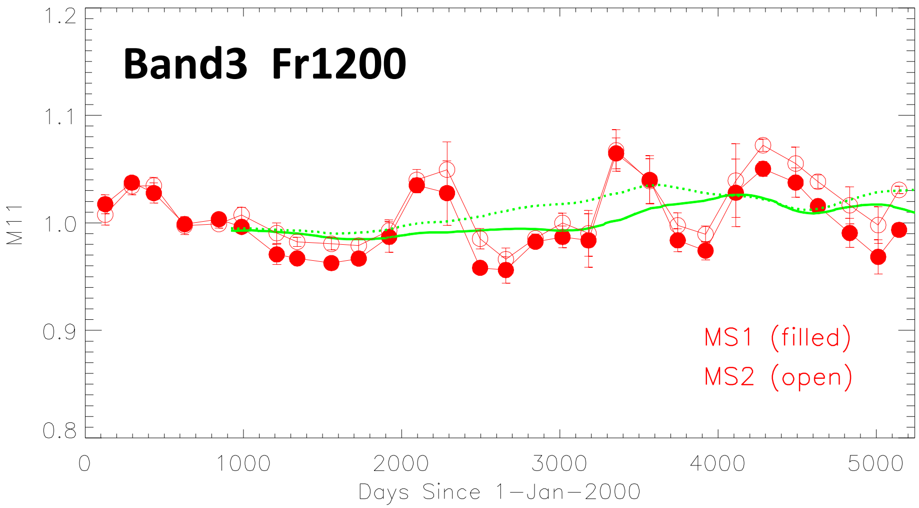
Trends of Terra B8 polarization parameters (M11 and m12) at frames 1000 & 1200

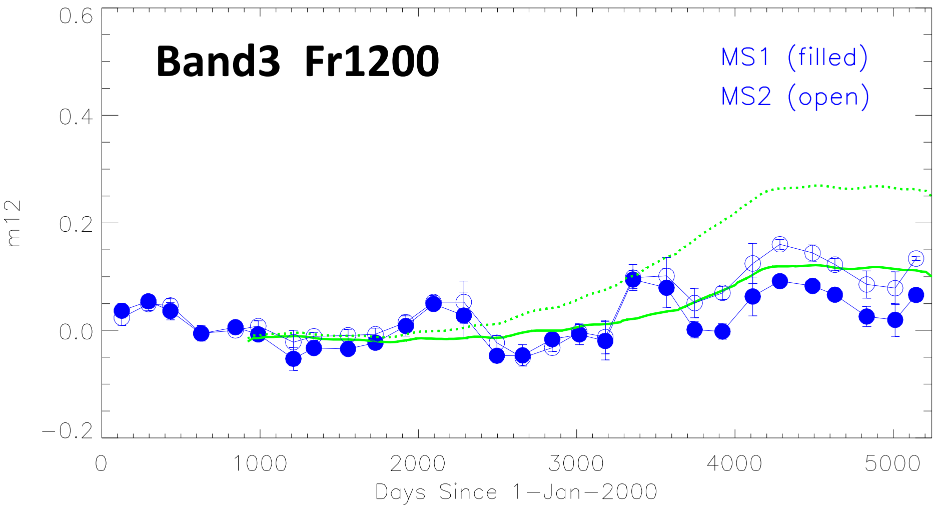


Trends of Terra B9 polarization parameters (M11 and M12) at frames 1000 & 1200

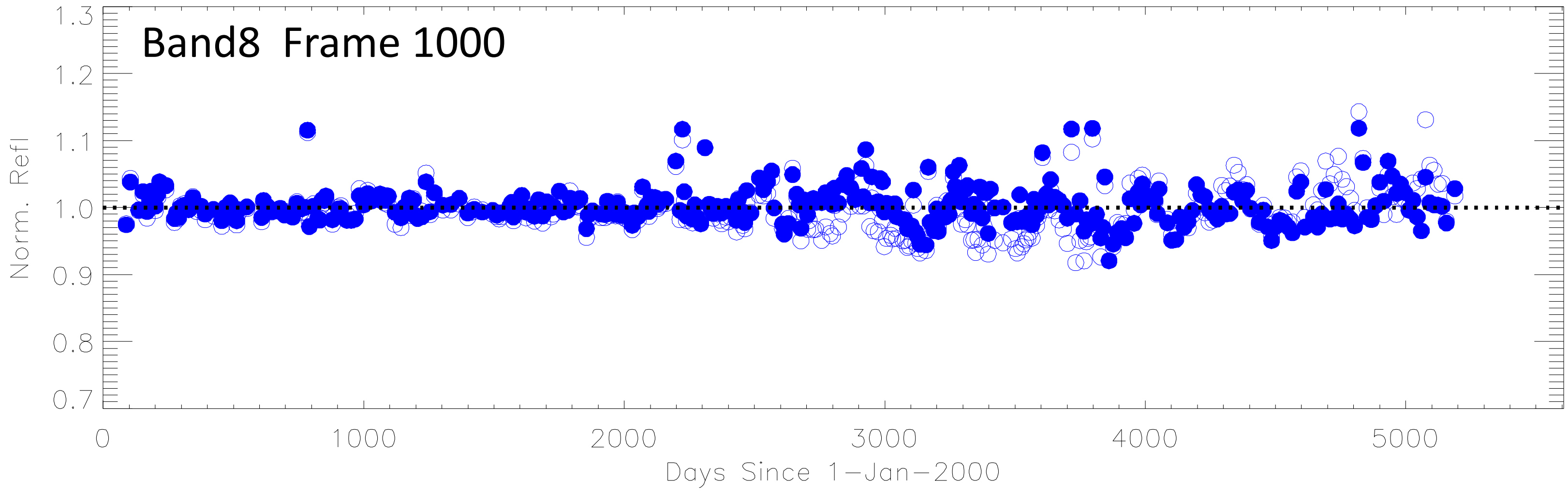


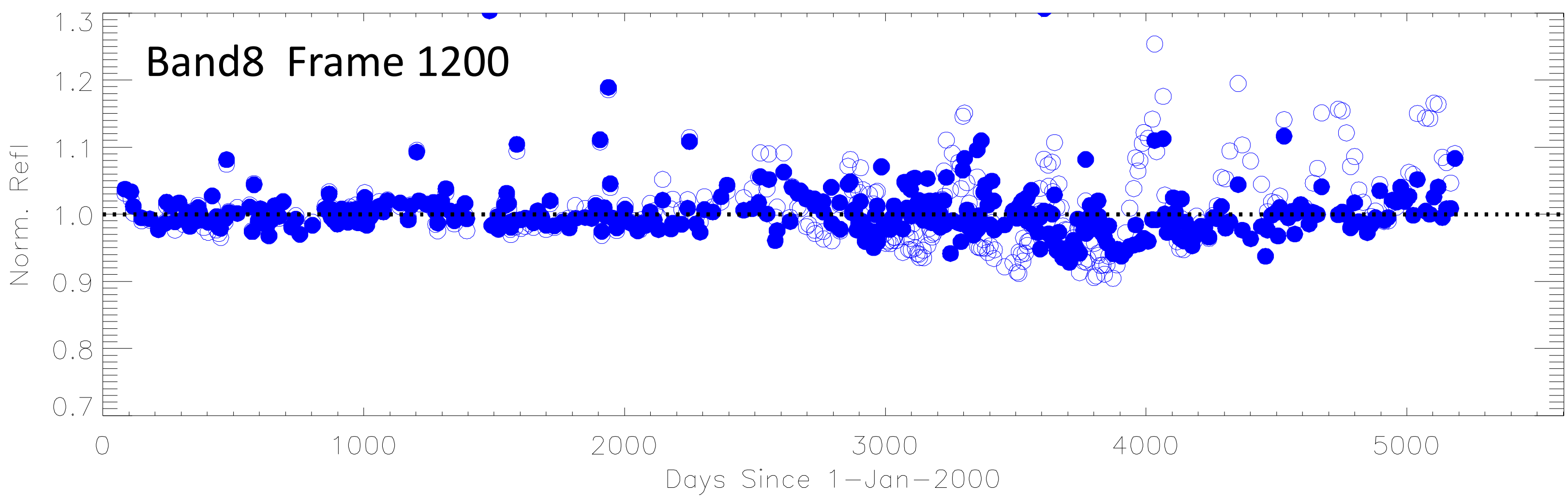
Trends of Terra B3 polarization parameters (M11 and M12) at frame 1200



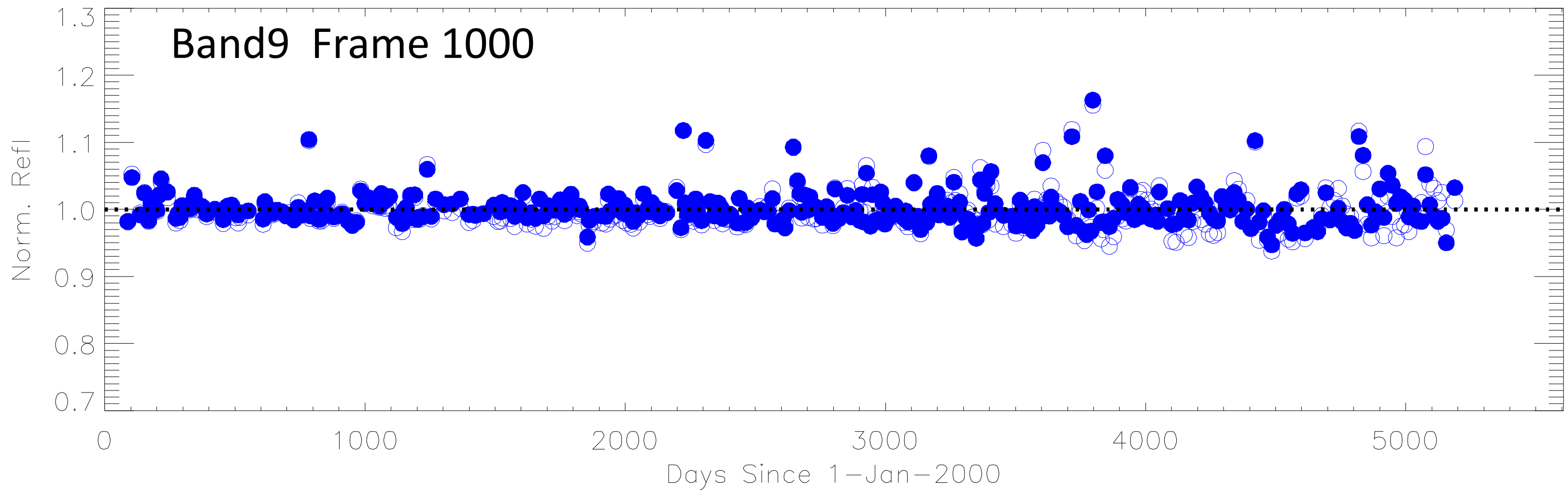


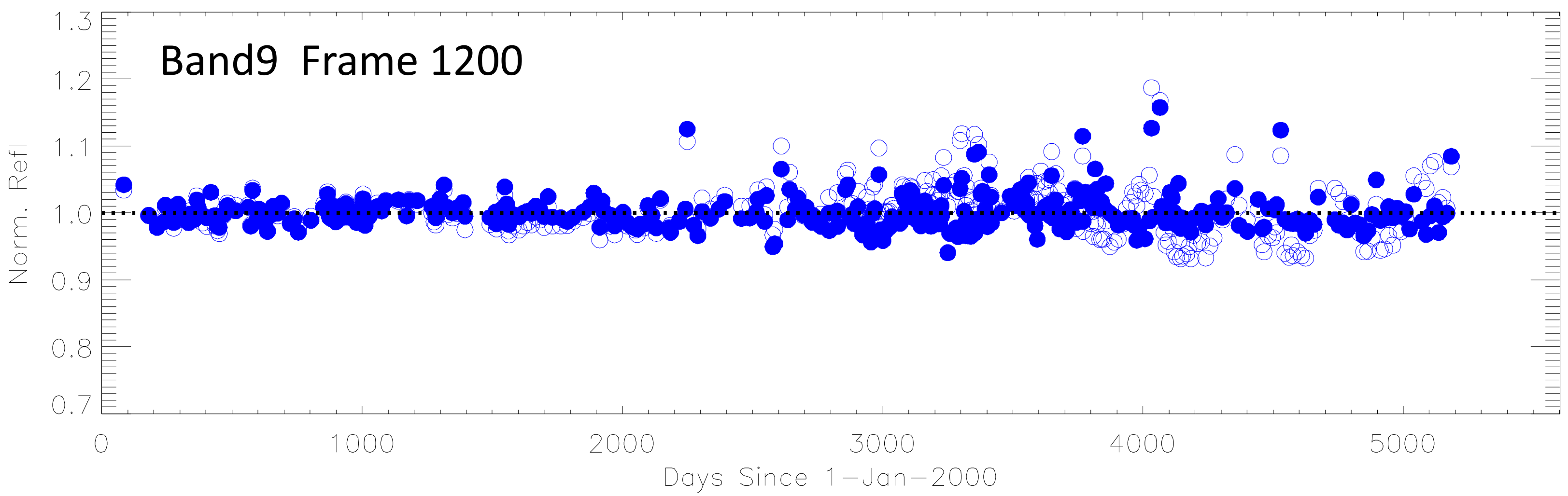
Effectiveness of polarization correction for Terra B8 at frames 1000 & 1200



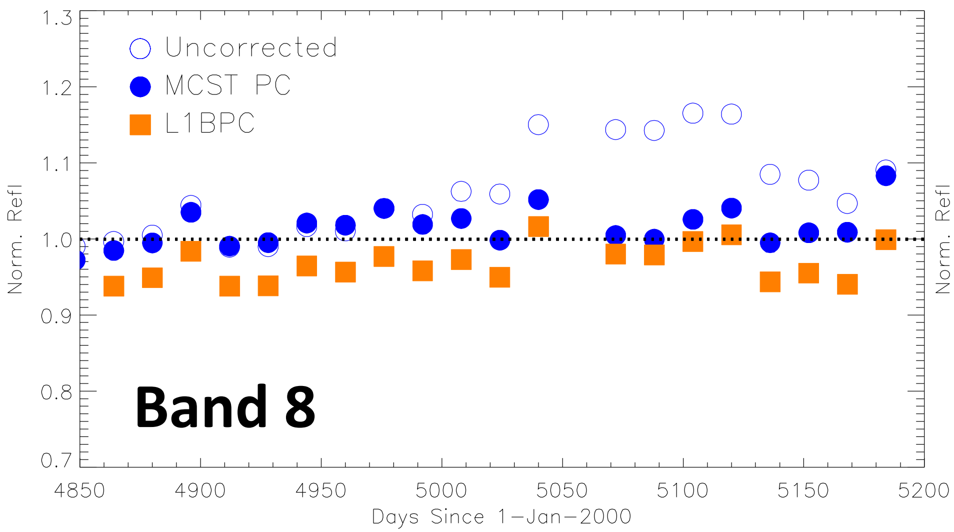


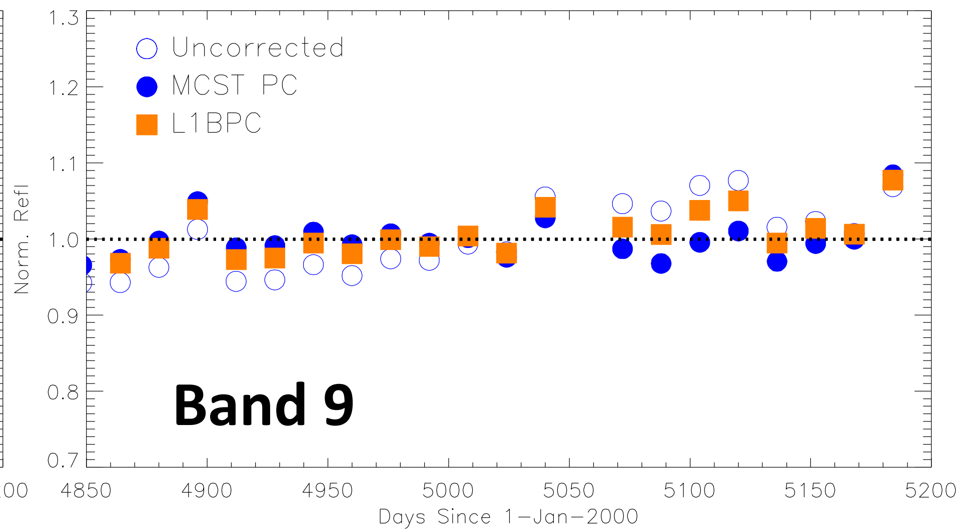
Effectiveness of polarization correction for Terra B9 at frames 1000 & 1200



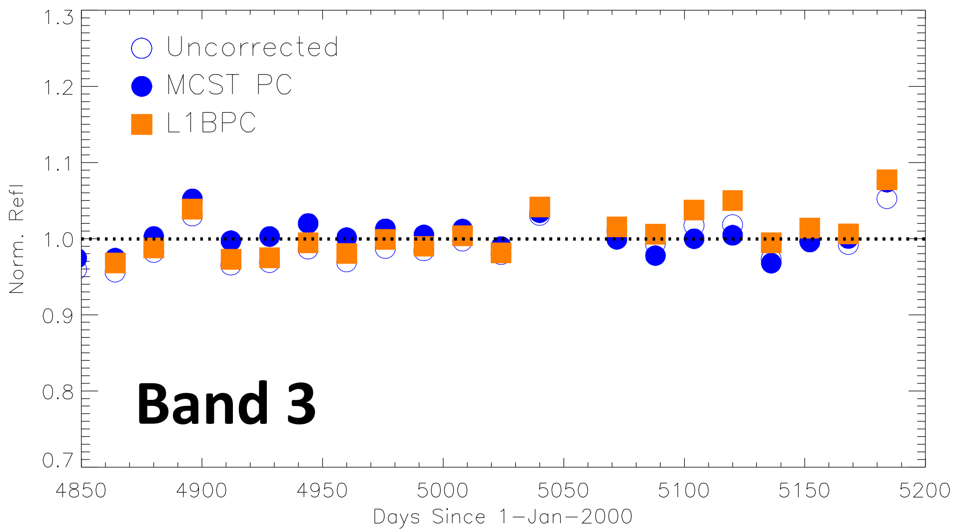


Comparison of polarization correction over desert sites for Terra band 8, 9 & 3 at frame 1200





One-year period from mid 2013 to mid 2014



Summary

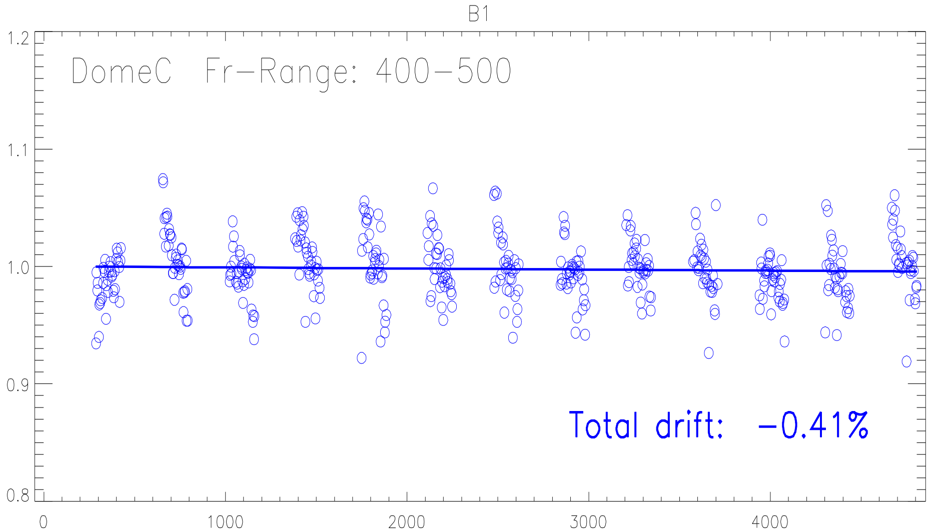
- Terra MODIS shows increased polarization sensitivity at large AOI (> frame 800) for bands 8, 9 and 3.
- Relatively large impact is observed from mirror side 2
- Polarization sensitivity reaches a peak over 30% at 0.41 μm near the end of 2009 and all three bands show a stable performance since then.
- A general good agreement is found between MCST and OBPG polarization corrected reflectances over desert siets.

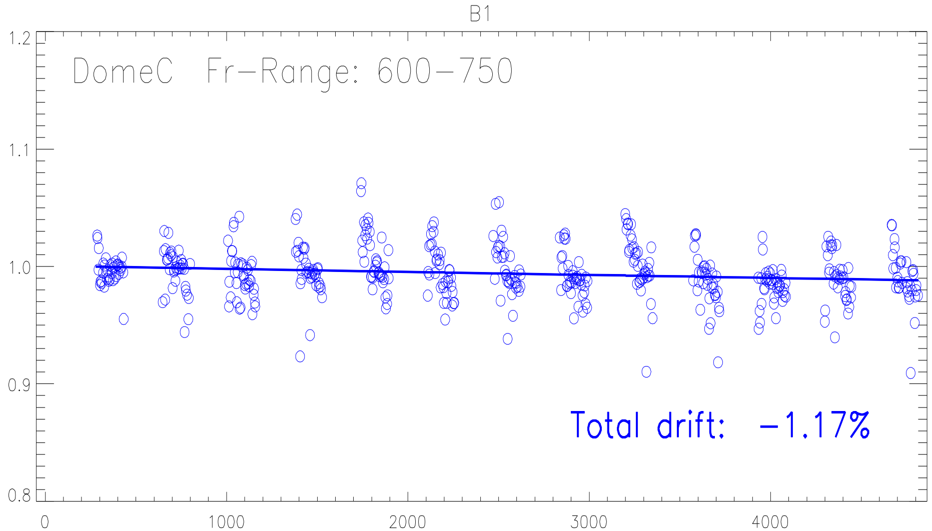
Back-up Charts

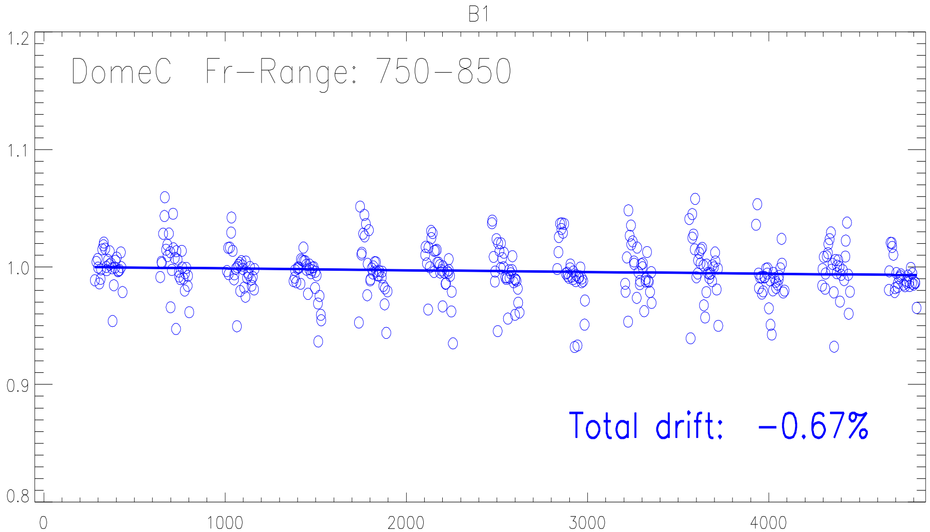
Terra Crosstalk Historical Background

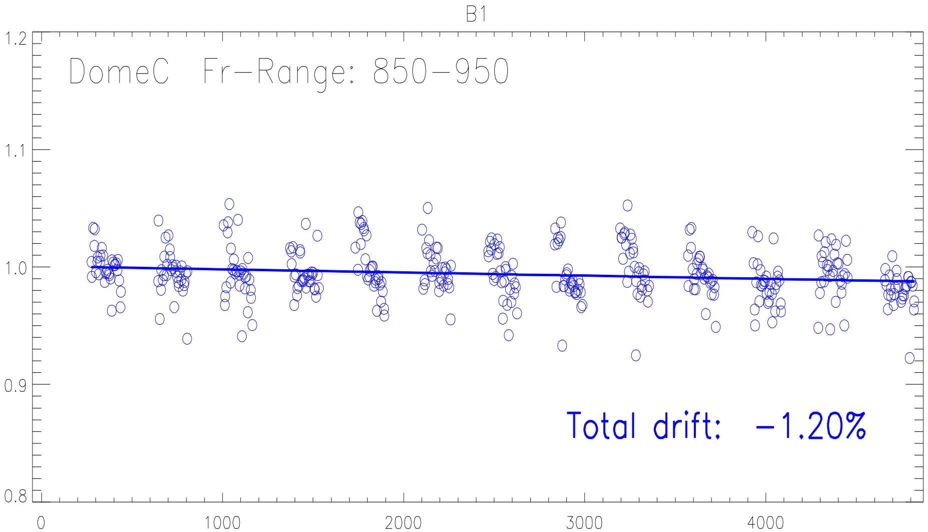
- Electronic crosstalk is a critical issue for remote sensing instruments
- Terra MODIS SWIR bands
  - Electronic Crosstalk was found in prelaunch characterization as well as on-orbit observations
  - MODIS SWIR (bands 5-7 and 26) and MWIR (bands 20-25)
  - Phenomenon is well understood
  - Algorithms developed to characterize and mitigate the impact are not completely successful due to the complex nature of the electronic Crosstalk phenomena
- Terra band 2 Crosstalk
  - Crosstalk effect is of a much smaller magnitude compared to SWIR bands
  - Attention was not paid to band 2 Crosstalk prelaunch or early in the mission
  - Involves less bands and is simpler to investigate compared to SWIR bands

Aqua band 1 reflectance trending at different AOI over Dome C

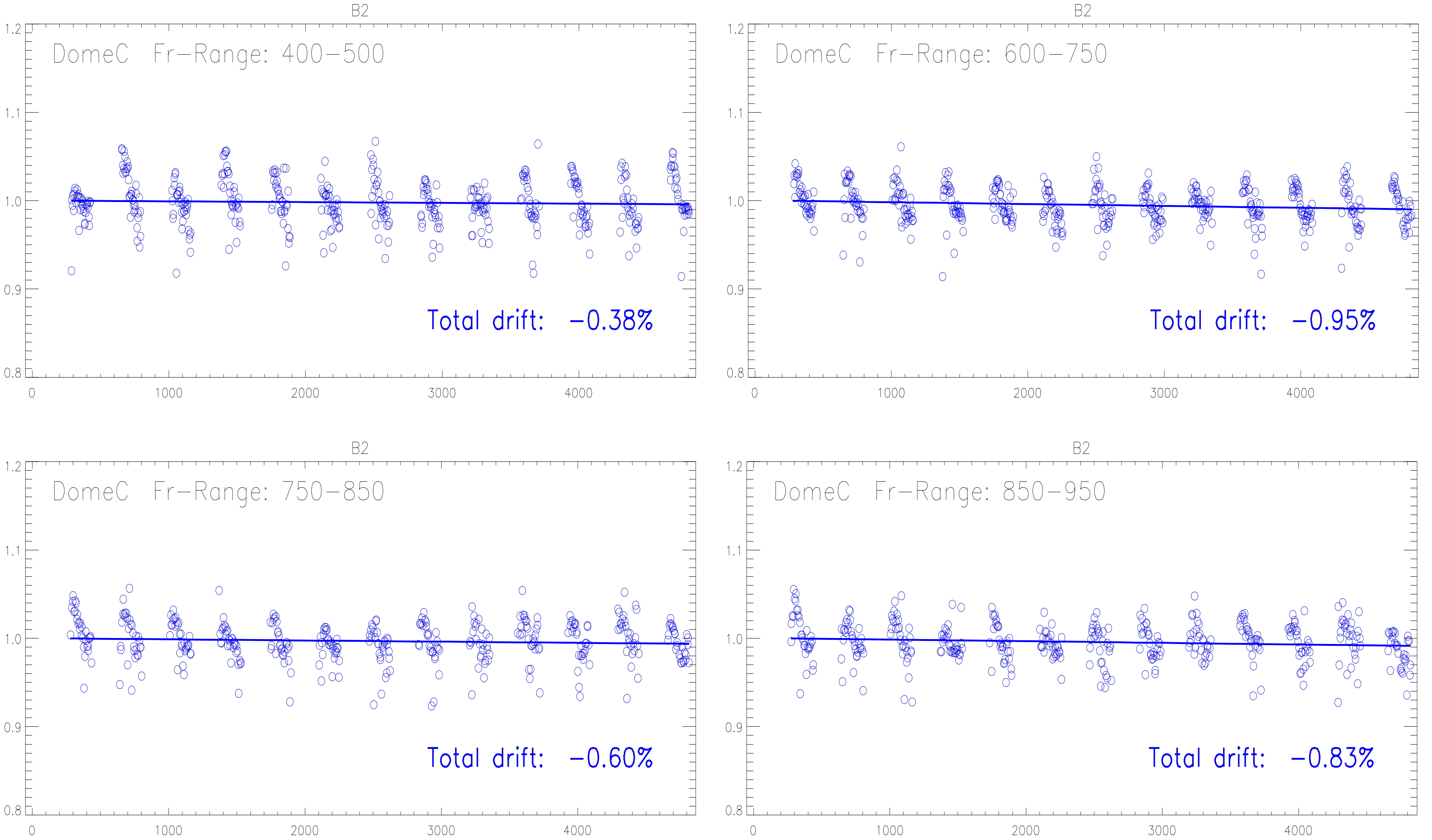




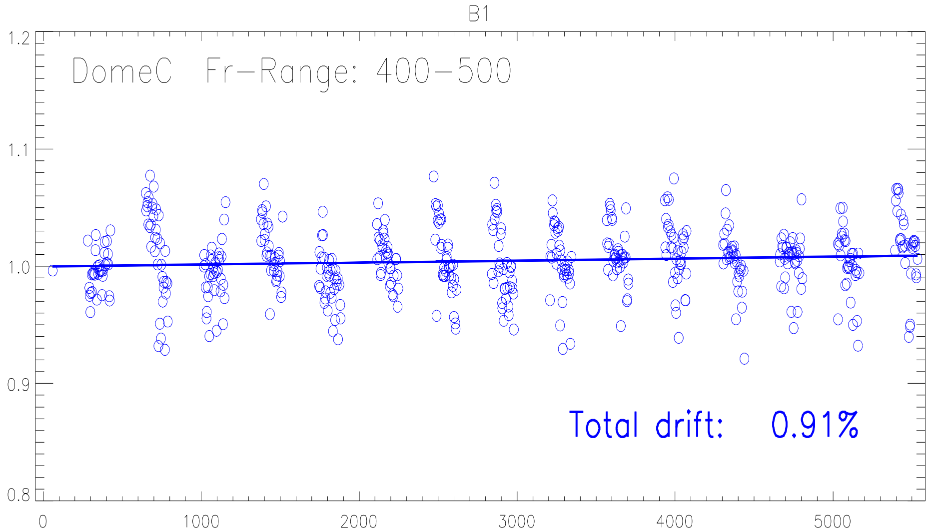


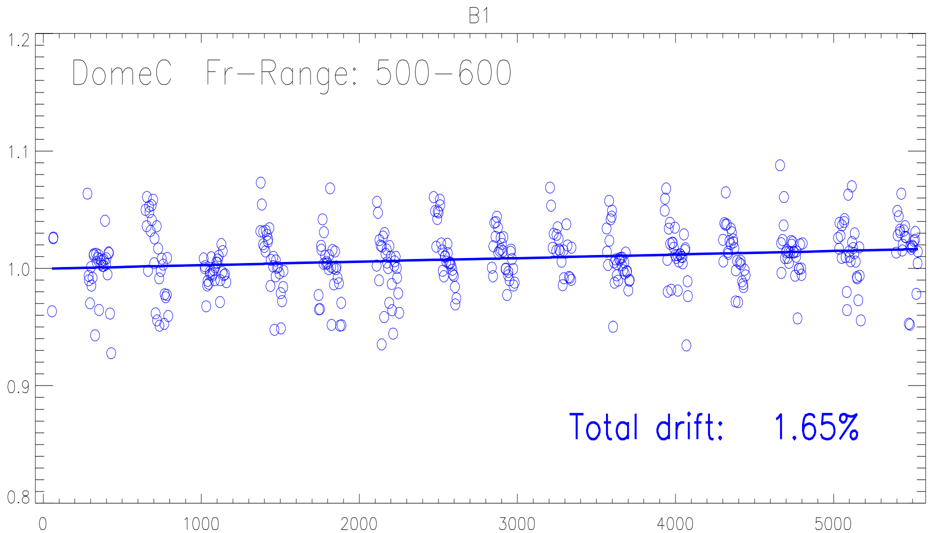


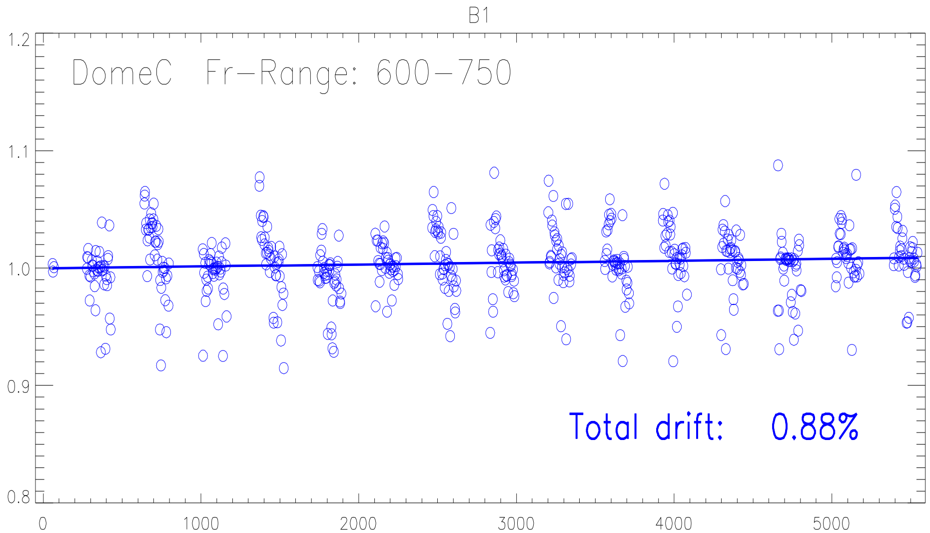
Aqua band 2 reflectance trending at different AOI over Dome C

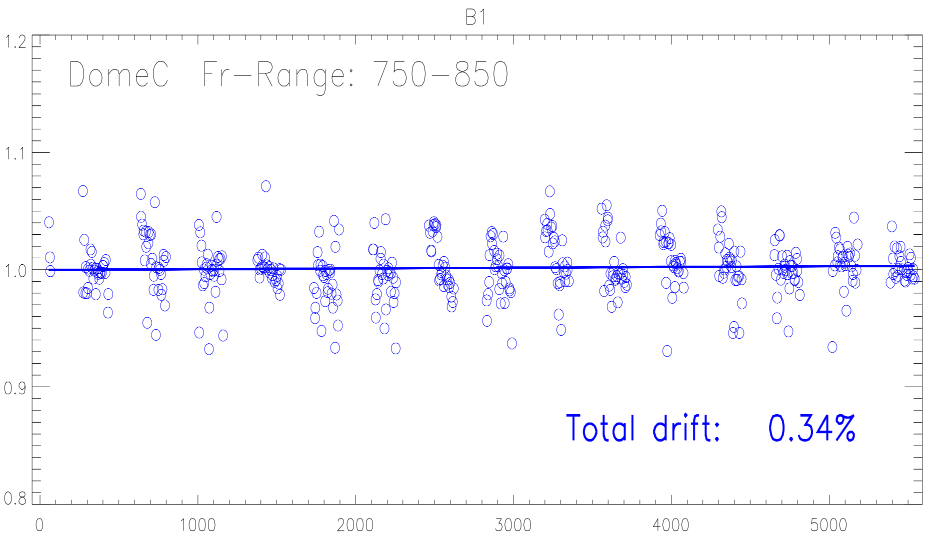


Terra band 1 reflectance trends at different AOI over Dome C









Terra band 1 reflectance trends at different AOI over Dome C