Using Ground Targets for Sensor On-orbit Calibration Support

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Outline

- **Background**
- **Previous and Current Activities**
- **Sensor Calibration and Inter-comparison Using Libya-4**
  - Stability Monitoring
  - Calibration Inter-comparisons
  - Other Applications
- **Summary**

Focus on reflective solar spectral region and open for discussions

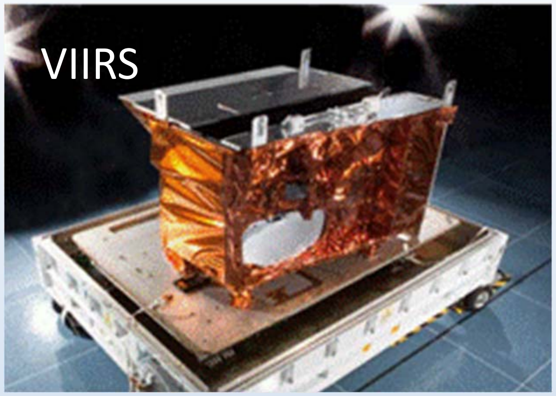
Background

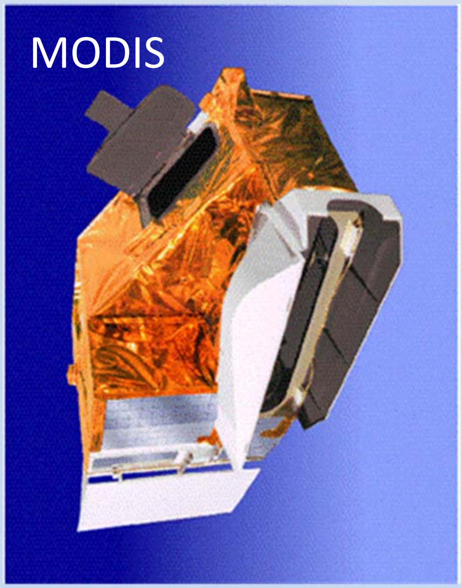
- **Why Use Ground Targets?**
  - Not all sensors have on-board calibrators
  - On-board calibrators degrade (need a stability monitor)
  - On-board calibrators may not be sufficient (difference between on-orbit calibration and EV observations, full-aperture versus partial aperture, OBC and EV data view angel difference)
- **Selection of Ground Targets**
  - Data availability
  - Site accessibility (ideally with ground "truth")
  - Stability (temporal)
  - Uniformity (spatially)
  - Well-defined spectral characteristics
  - Others (reflectance level, atmospheric conditions, …

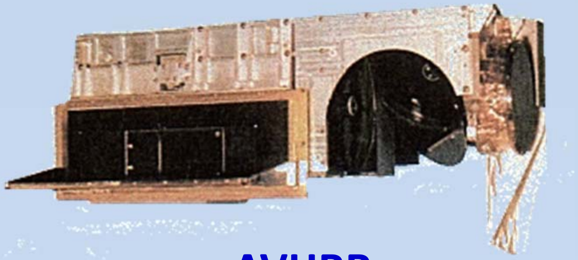
Hardly any single ground target can meet all the "requirements"
Multiple sites should be considered, depending on the specific applications

Previous and Current Activities

- **Activities**
  - NASA MCST effort
  - Joint effort with USGS EROS (G. Chander)
  - Joint effort with NOAA STAR (C. Cao and X. Wu)
- **Sensors**
  - Terra and Aqua MODIS
  - AVHRR (N15-19 and Metop-A)
  - L7 ETM+
  - Others (e.g. EO-1 Hyperion, L5 TM, and VIIRS)
- **Ground Targets**
  - N. African pseudo-invariant sites (Libya 4 included)
  - Sonoran desert
  - Dome C

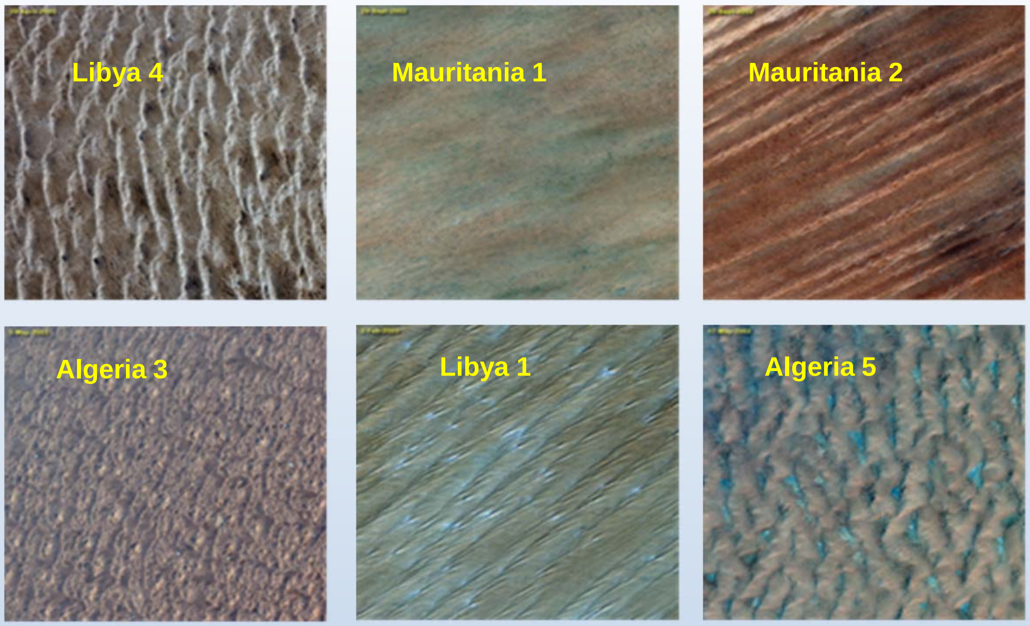


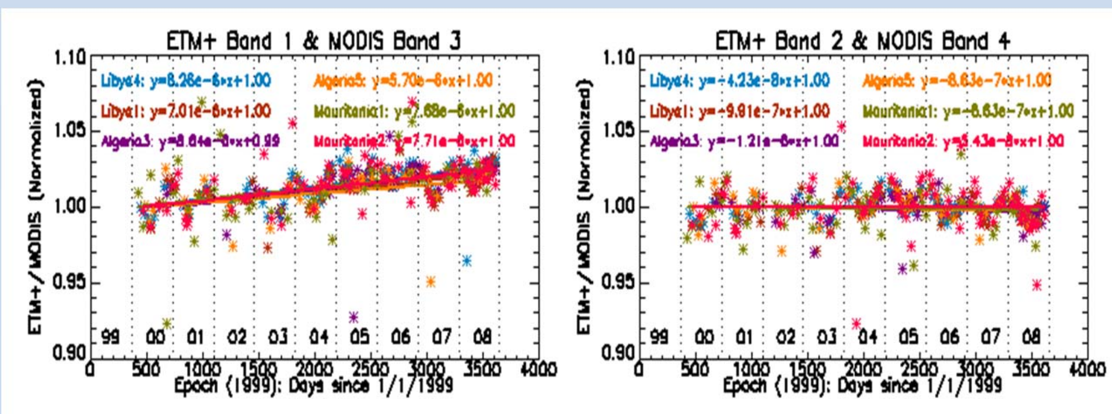




AVHRR

Terra MODIS and L7 ETM+ Cross-calibration Using N. African Pseudo-Invariant Sites





CEOS endorsed top-6 pseudo-invariant calibration sites

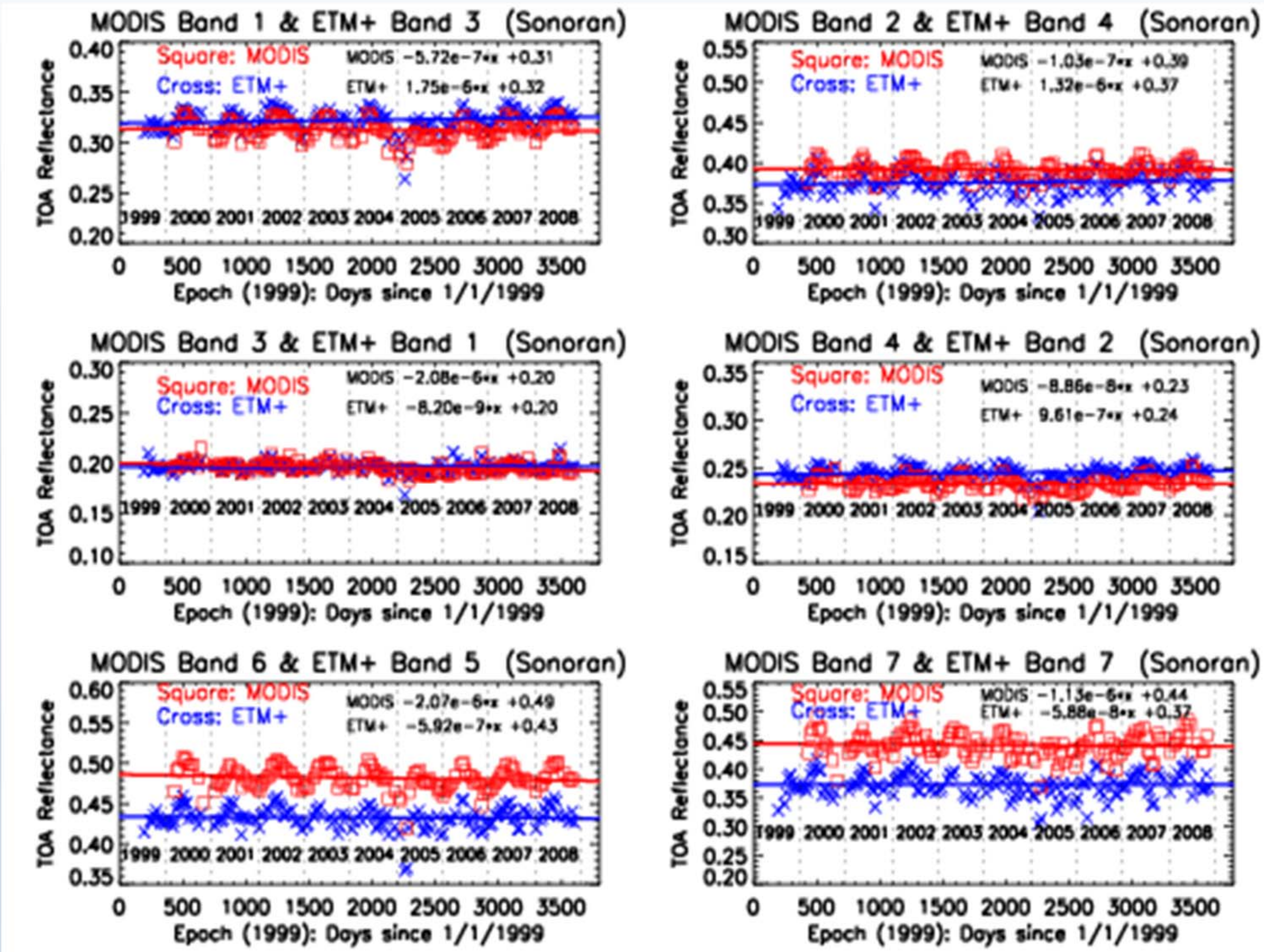
Long-term stability monitoring for the spectrally matching Terra MODIS and L7 ETM+ reflective solar bands (RSB)

MODIS Collection 5 data used in this study

Long-term bias identified in the shorter wavelength band-pair: MODIS band 3 (460 nm) and ETM+ band 1 (469 nm)

Chander G, X. Xiong, T. Choi, and A. Angal, "Monitoring on-orbit calibration stability of the Terra MODIS and Landsat 7 ETM+ sensors using pseudo-invariant test sites" *Remote Sens. Environ*. 114, 925-939, 2010 [doi:10.1016/j.rse.2009.12.003]

Terra MODIS and L7-ETM+ Long-term Stability Monitoring over the Sonoran Desert



Sonoran desert (32.35, -114.65) located on the US-Mexico border

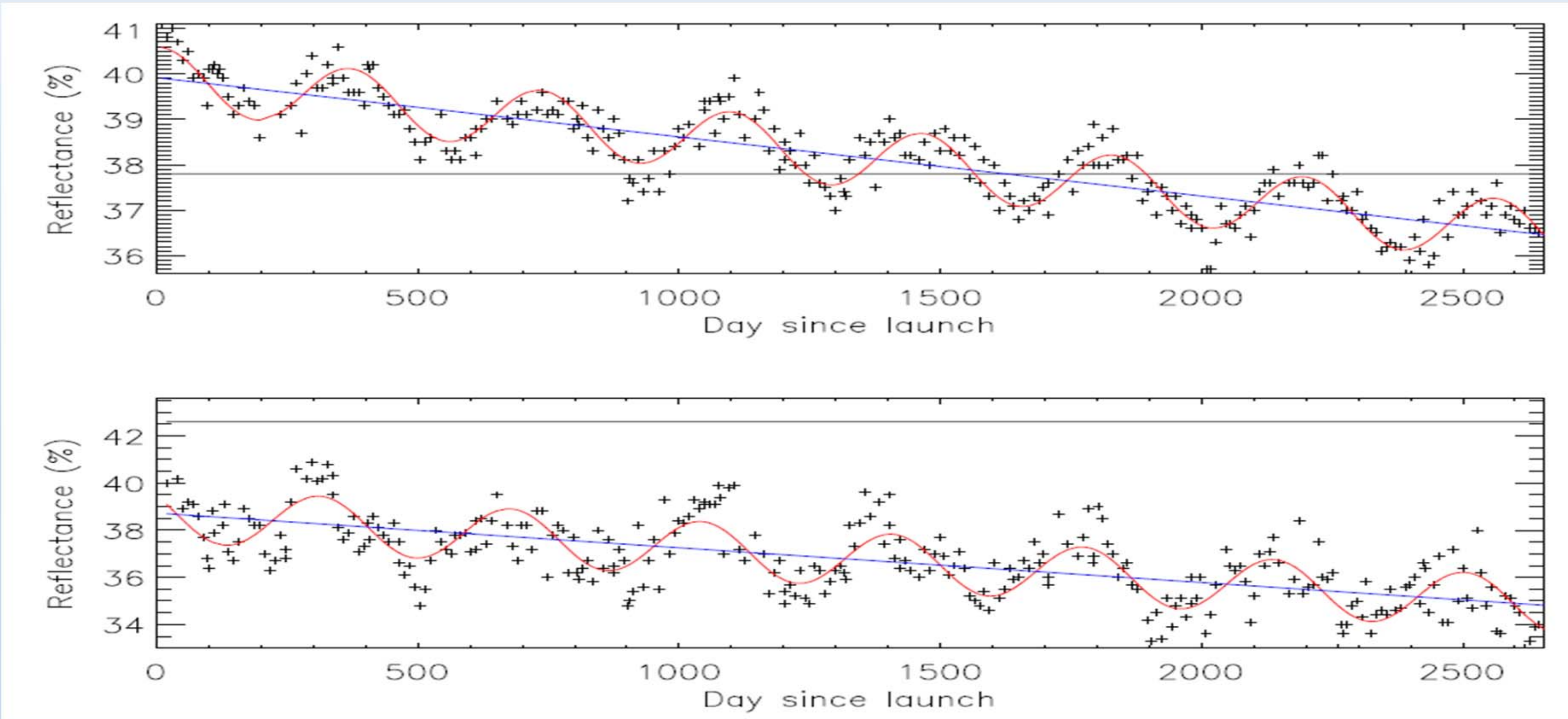
Pseudo-invariant target located in the CONUS and hence more ETM+ data availability

Concerns with the site stability (impact of increased soil moisture in early months of 2005

Angal A, X. Xiong, T. Choi, G. Chander, and A. Wu, "Using the Sonoran and Libyan Desert Test Sites to monitor the temporal stability of reflective solar bands for Landsat 7 ETM+ and Terra MODIS Sensors," *J. Appl. Remote Sens*, Vol. 4, no. 1, p. 043525-12, April 2010 [doi:10.1117/1.3424910]

AVHRR On-orbit Calibration Stability Monitoring Using Libyan Desert

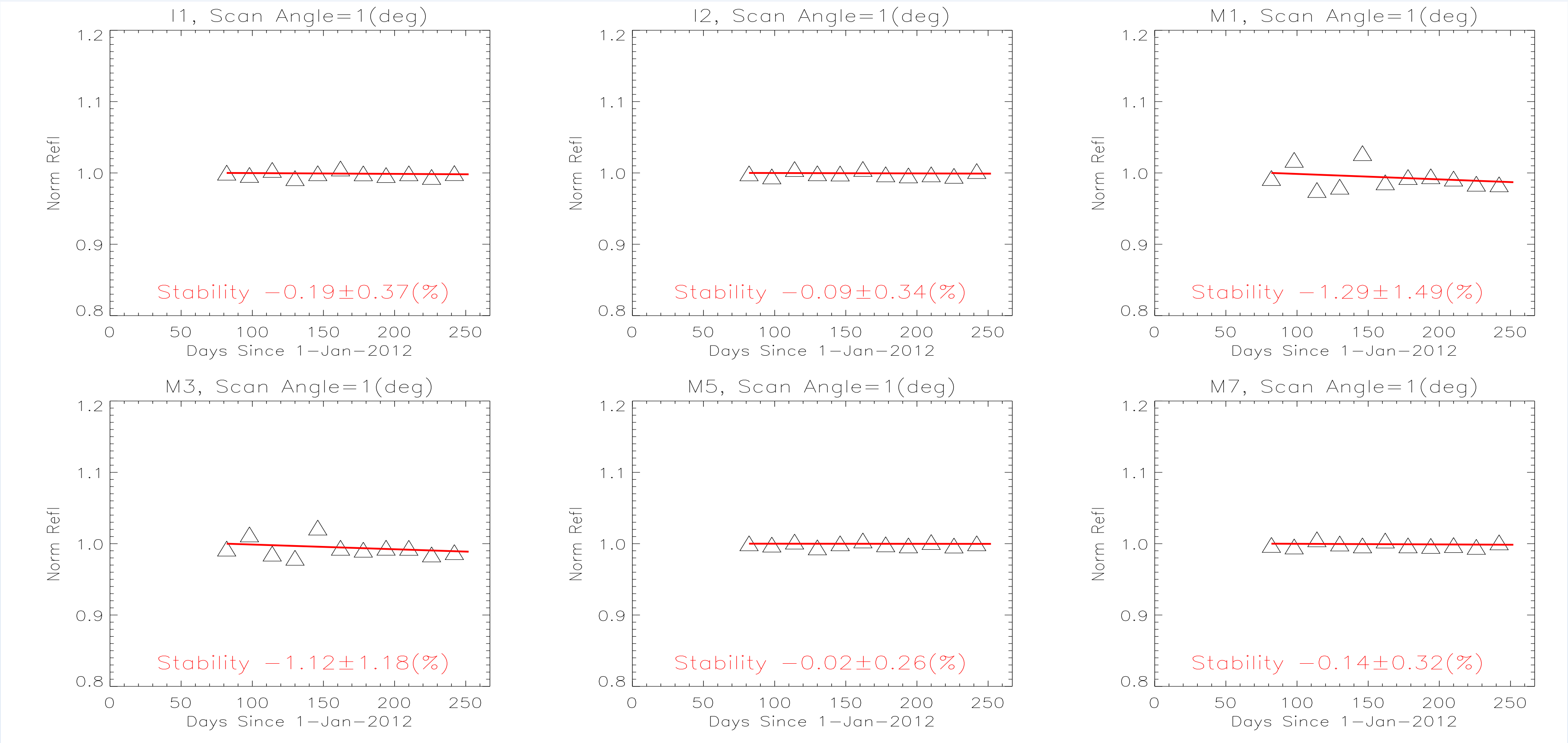
N18/AVHRR Libyan desert reflectance measurements and modeling results (updated on 8/29 /2012). The symbols are the reflectance using prelaunch cal coefficients. The red curves are regression results and the blue lines illustrate the averaged degradation. The black lines are the nominal reflectance of the target.



(updated plots from Fred Wu / Tim Chang, NOAA STAR)

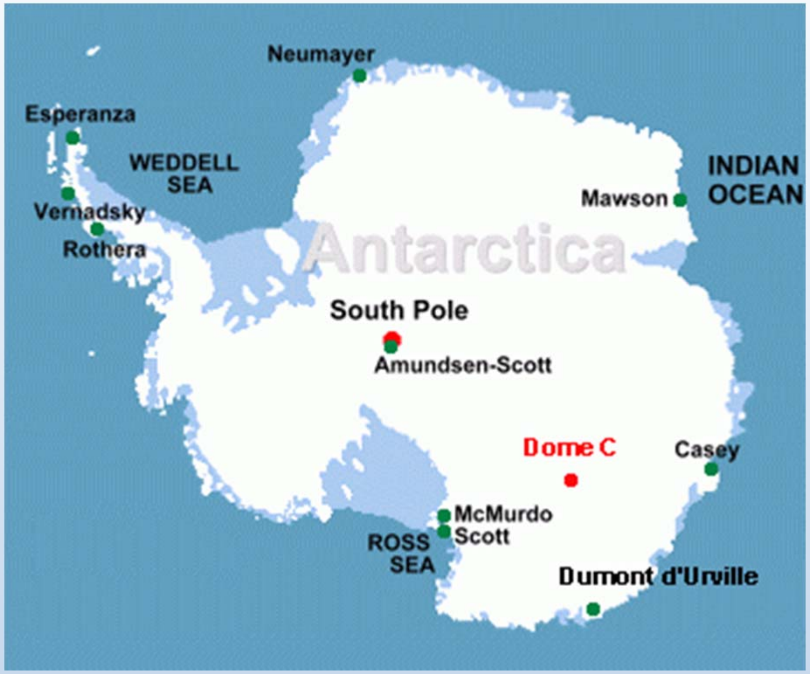
S-NPP VIIRS Reflectance Trends Over Libya-4 (preliminary)

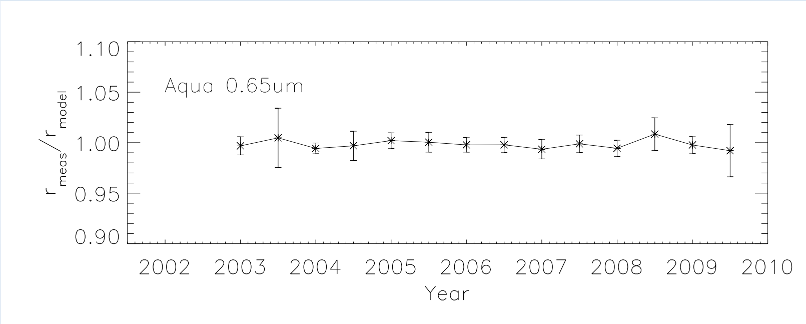
Nadir View, HAM-A side

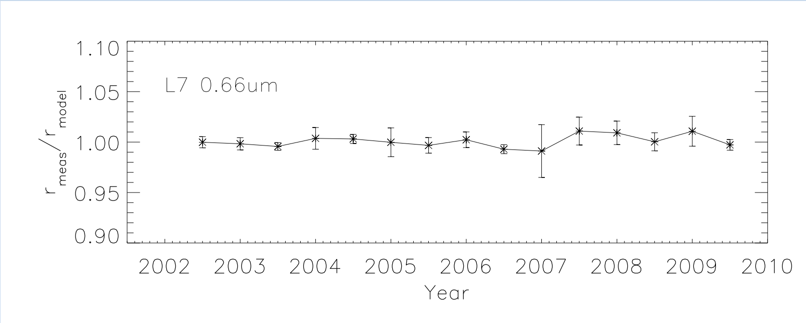


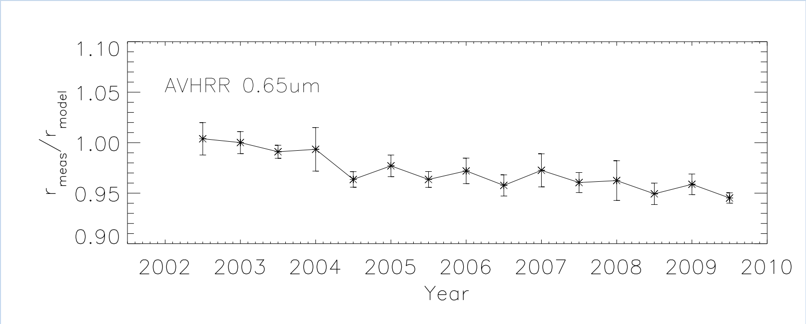
- SDR reflectances collected for ± 2.5^{o} of a fixed scan angle (5^{o} SA range)
- Average over the ROI (20 km x 10 km) for each HAM side
- Values are used if standard error over the ROI < 0.02

Sensor Stability Monitoring and Inter-comparisons Using Dome C (examples)









Xiong X, A. Wu, B. Wenny, J. Choi, and A. Angal, "Progress and Lessons from MODIS Calibration Inter-comparison Using Ground Test Sites," *Canadian Journal of Remote Sensing Special Issue*, 36 (5), 540-552, 2010 [doi: 10.5589/m10-082]

Calibration and Inter-Comparison Using Libya-4

- **Stability Monitoring**
- **Calibration Inter-comparisons**

Calibration Inter-comparison of T-MODIS and L7 ETM+ Over Libya-4

- **Other Applications**

On-orbit Characterization of MODIS Response Versus Scan-angle (RVS)

Calibration Stability Monitoring and Inter-comparison of Terra MODIS and L7 ETM+ Over Libya-4

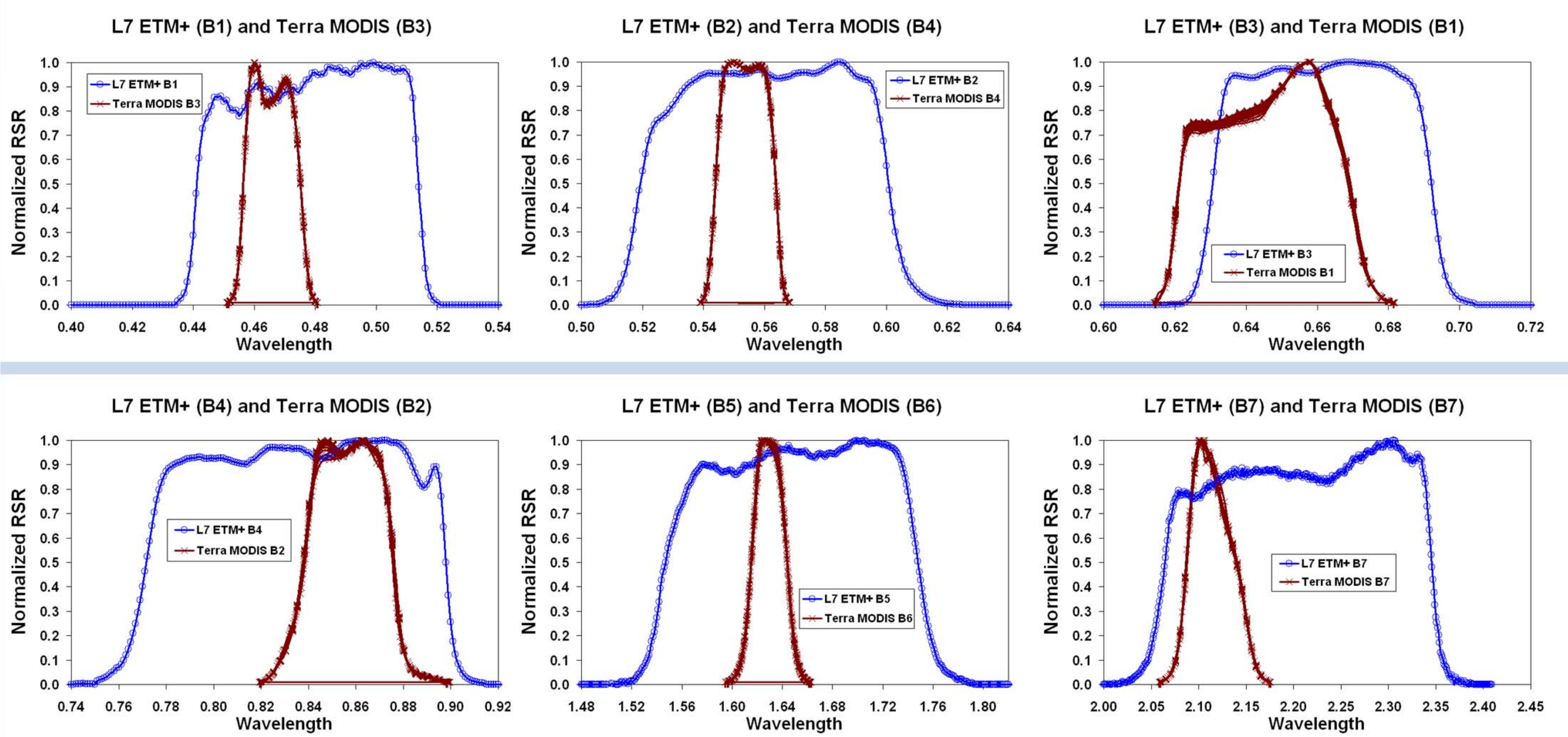
Sensor Overview

Platform	Terra	Landsat 7
Sensor	MODIS	ETM+
Number of bands	36	8
Spatial resolution	250 m, 500 m, 1 km	15 m, 30 m, 60 m
Swath	2360 km	187 km
Spectral coverage	0.4~14 µm	0.4~12.5 µm
Pixel quantization	12bit	8bit
Launch date	Dec 18, 1999	April 15, 1999
Orbit type	Sun synchronous	Sun synchronous
Altitude	705km	705km

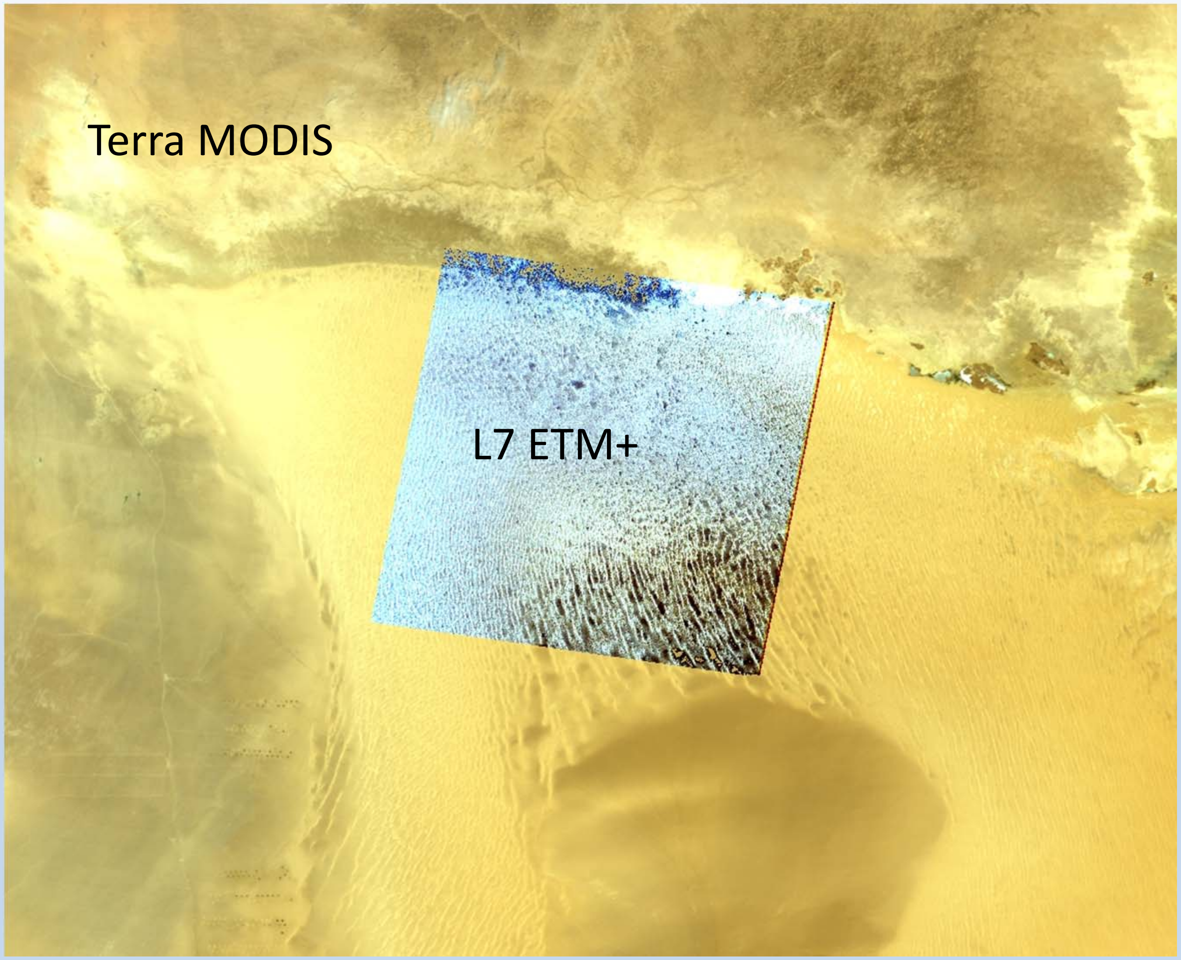
Part of the "AM Constellation" with Terra 30 min behind L7

Terra MODIS and L7 ETM+ RSR

RSR: Relative Spectral Response; SRF: Spectral Response Function



Site Description



Libya-4 site (+28.55, +23.39)

Corner co-ordinates :
Latitude (min & max):
28.45 28.65
Longitude (min & max):
23.29 23.49

Elevation: 118 m (above sea level)

Near-nadir MODIS acquisitions and all available ETM+ data sets (1 every 16 days)

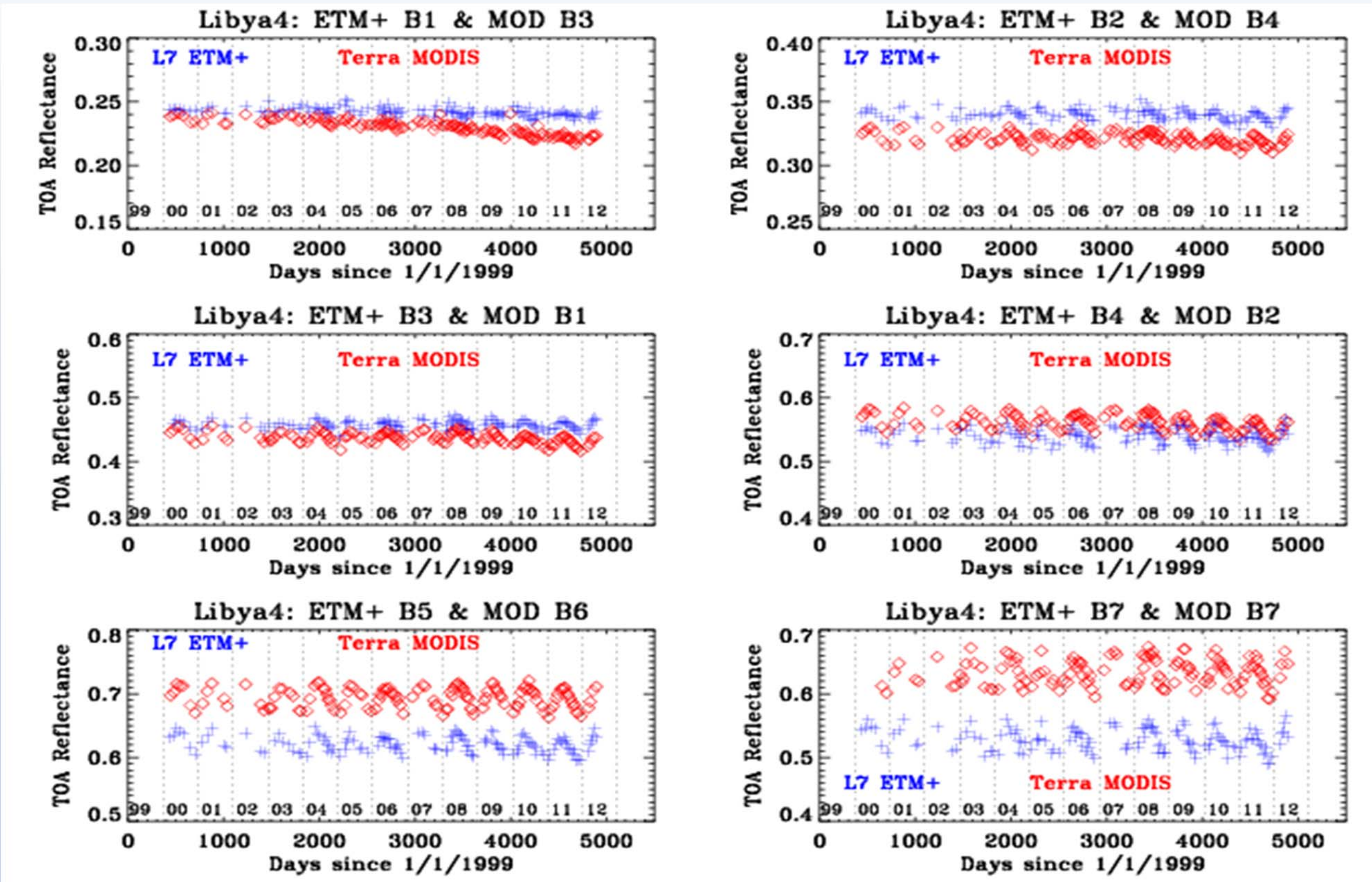
Near-simultaneous images from May 25, 2001

Methodology

- MRTSwath Reprojection was used on Terra MODIS scenes to match ETM+ L1G UTM product format
  - MRTSwath Tool also corrects 'bow tie' effects
- All ETM+ scenes were re-sampled (pixel aggregation) to MODIS 250/500 m
- Co-located areas identified for each of MODIS and ETM+ image pairs
- At-sensor radiance ($W/m^2/sr/\mu m$) and at-sensor reflectance were computed for all scenes
  - Linear fits, average percent differences, and RMSE's computed for each band
- Corrections for BRDF effect and RSR difference

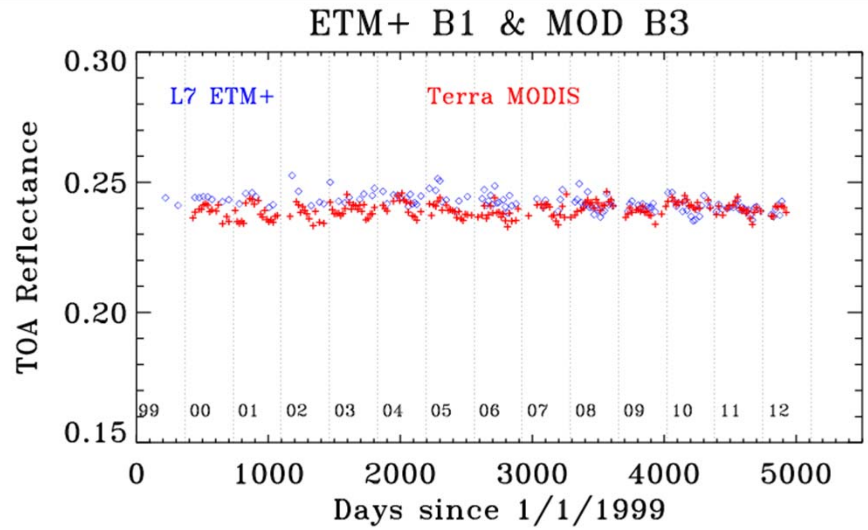
TOA Reflectance from Terra MODIS and L7 ETM+

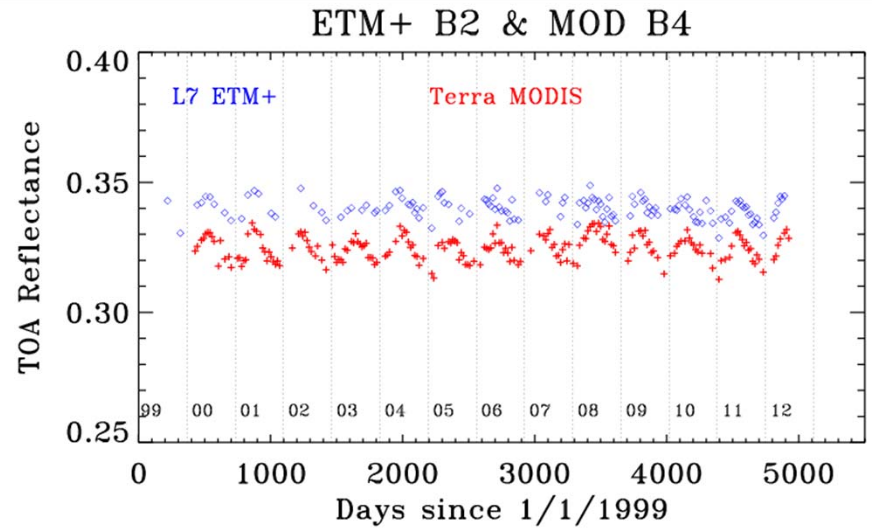
MODIS Collection 5 Results



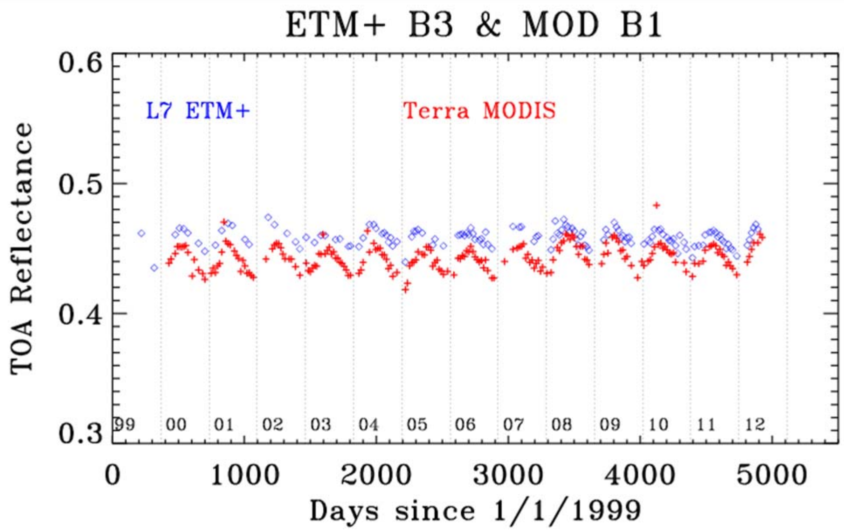
TOA Reflectance from Terra MODIS and L7 ETM+

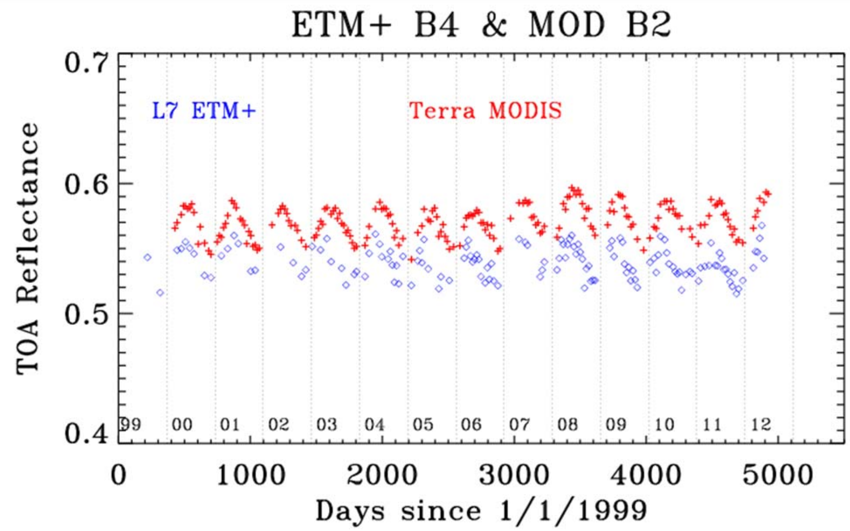
MODIS Collection 6 Results

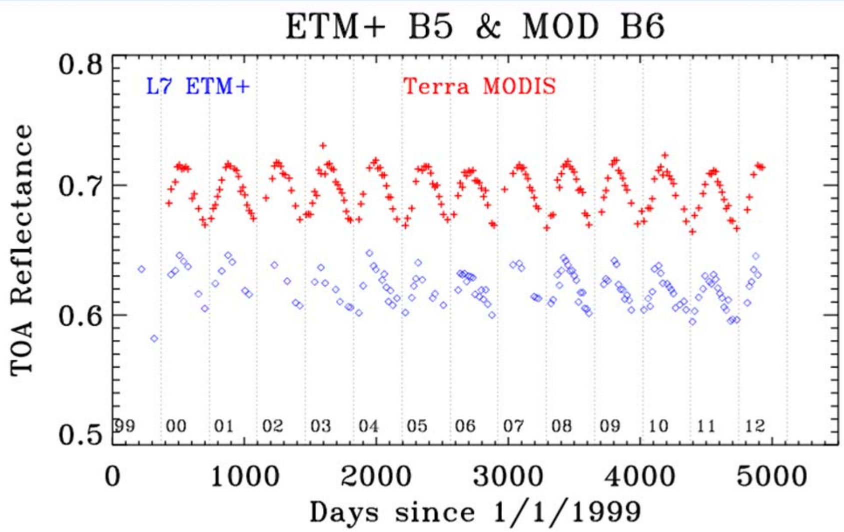


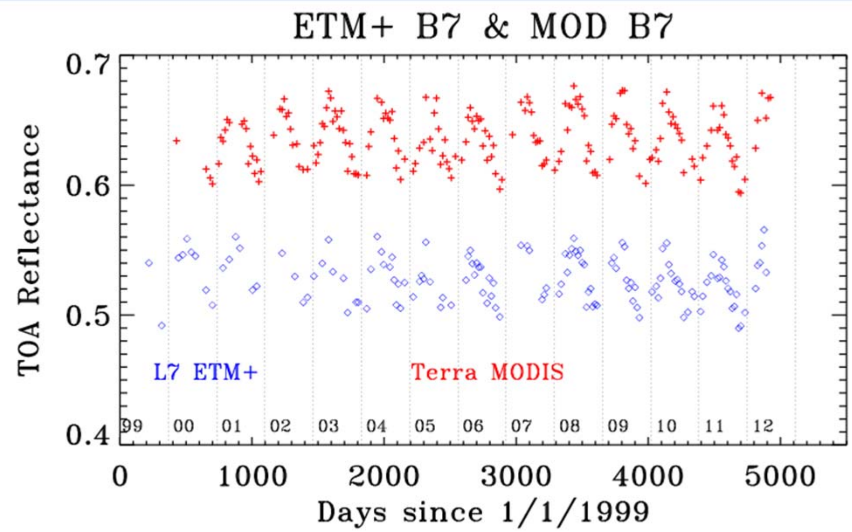


MODIS collection 6 significantly removed/reduced the long-term drifts seen in collection 5 for a few VIS spectral bands


ETM+ B3 & MOD B1
L7 ETM+
Terra MODIS
TOA Reflectance
Days since 1/1/1999

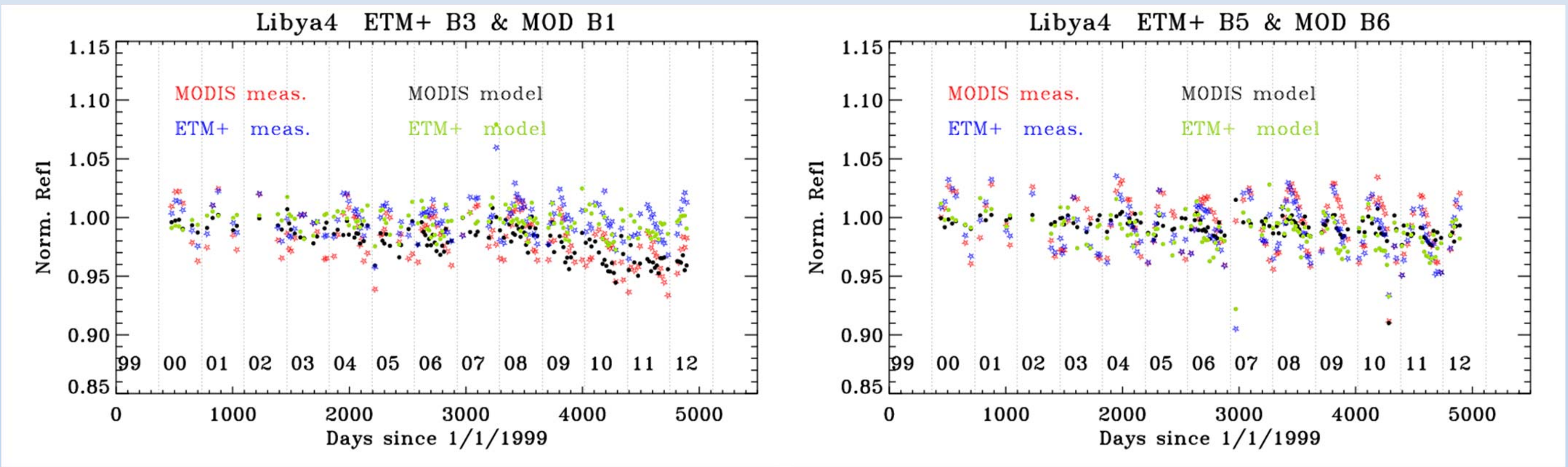

ETM+ B4 & MOD B2
L7 ETM+
Terra MODIS
TOA Reflectance
Days since 1/1/1999


ETM+ B5 & MOD B6
L7 ETM+
Terra MODIS
TOA Reflectance
Days since 1/1/1999

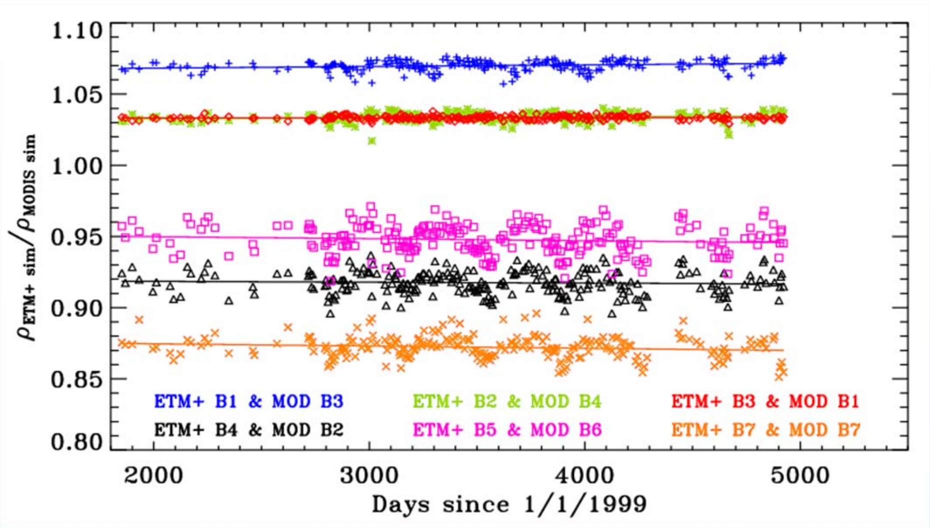

ETM+ B7 & MOD B7
L7 ETM+
Terra MODIS
TOA Reflectance
Days since 1/1/1999

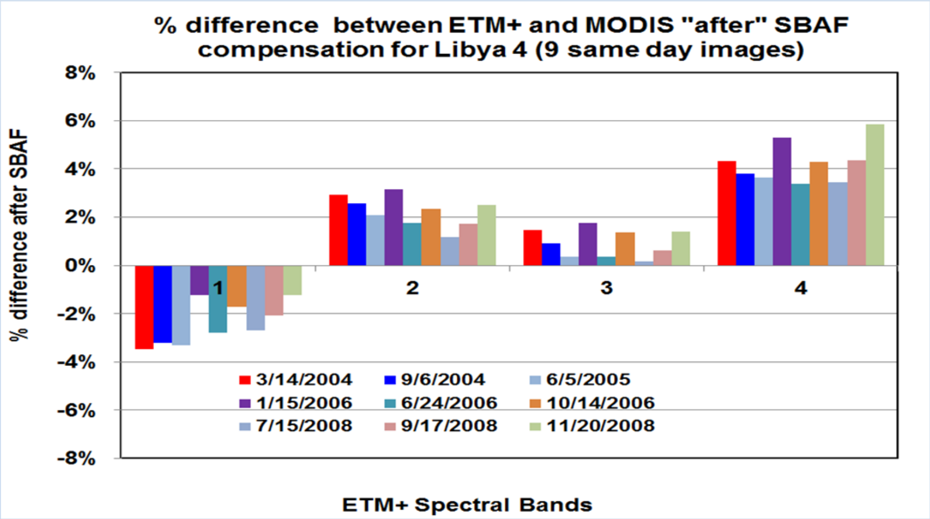
BRDF Correction

- For desert, a semi-empirical bi-directional reflectance function (BRDF) consisting of two kernel-driven components (f1 and f2)
  - BRDF (θ,ψ,ϕ)= K0 + K1 f1(θ,ψ,ϕ)+ K2 f2(θ,ψ,ϕ)
  - θ, ψ, ϕ - solar zenith, view zenith and relative azimuth angle
  - K0, K1 and K2 – site-dependent coefficients



Spectral Band Adjustment Factor (SBAF) to Correct Impact Due to Sensor RSR Difference





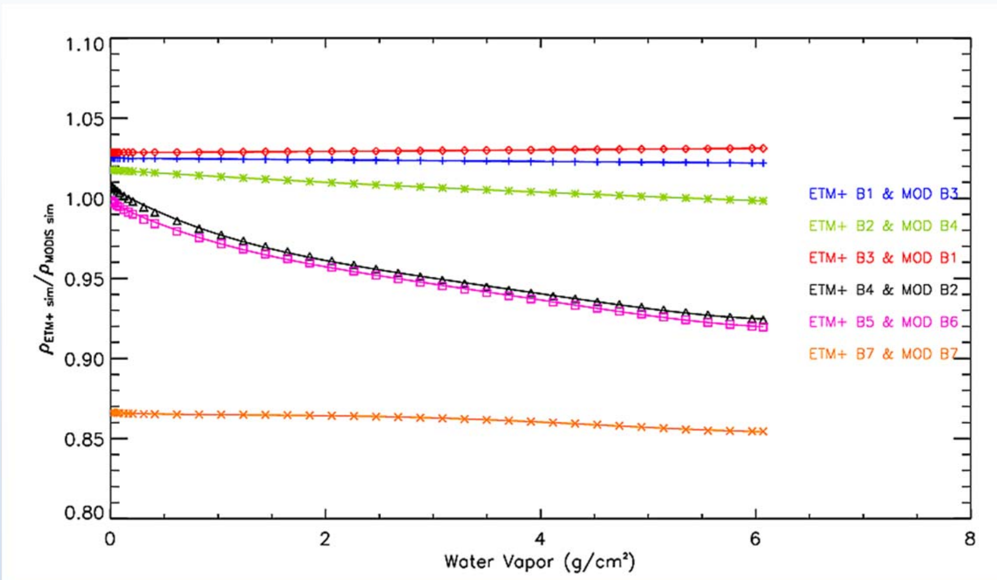
Using near-simultaneous EO-1 Hyperion measurements to characterize the differences due to RSR mismatch

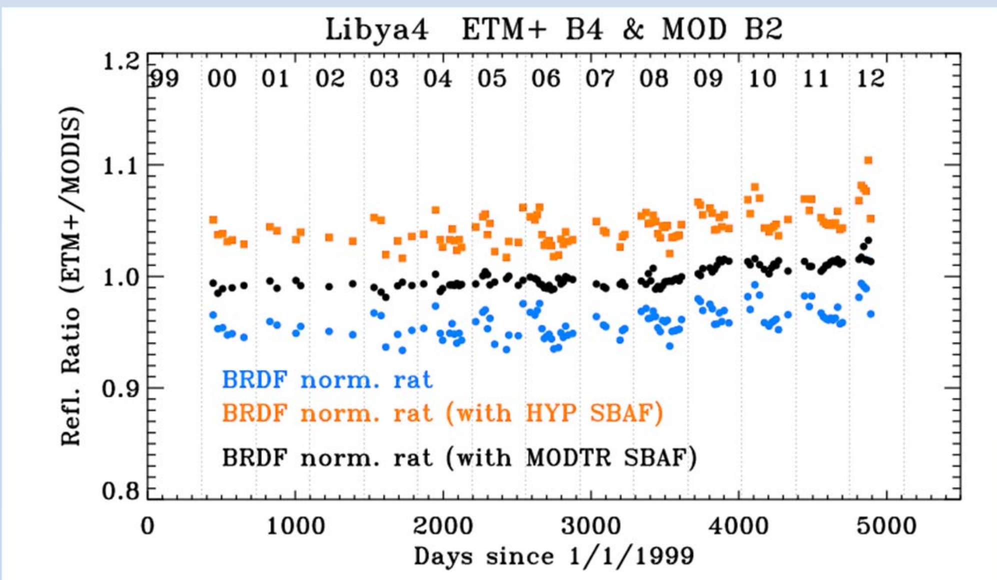
Limitation of the spectral resolution of EO-1 Hyperion was overcome using the Sciamachy measurements at a finer spectral resolution (1 nm)

MODTRAN profiles can also be used to characterize the spectral mismatch between any given sensor-pair

Chander G, N. Mishra, D. Helder, D. B. Aaron, A. Angal, T. Choi, X. Xiong and D. Doelling, "Using Spectral Band Adjustment Factors (SBAF) for Accurate Cross-calibration of Multispectral Sensors", (IEEE TGRS in press), 2012

Spectral difference and atmospheric water-vapor impact



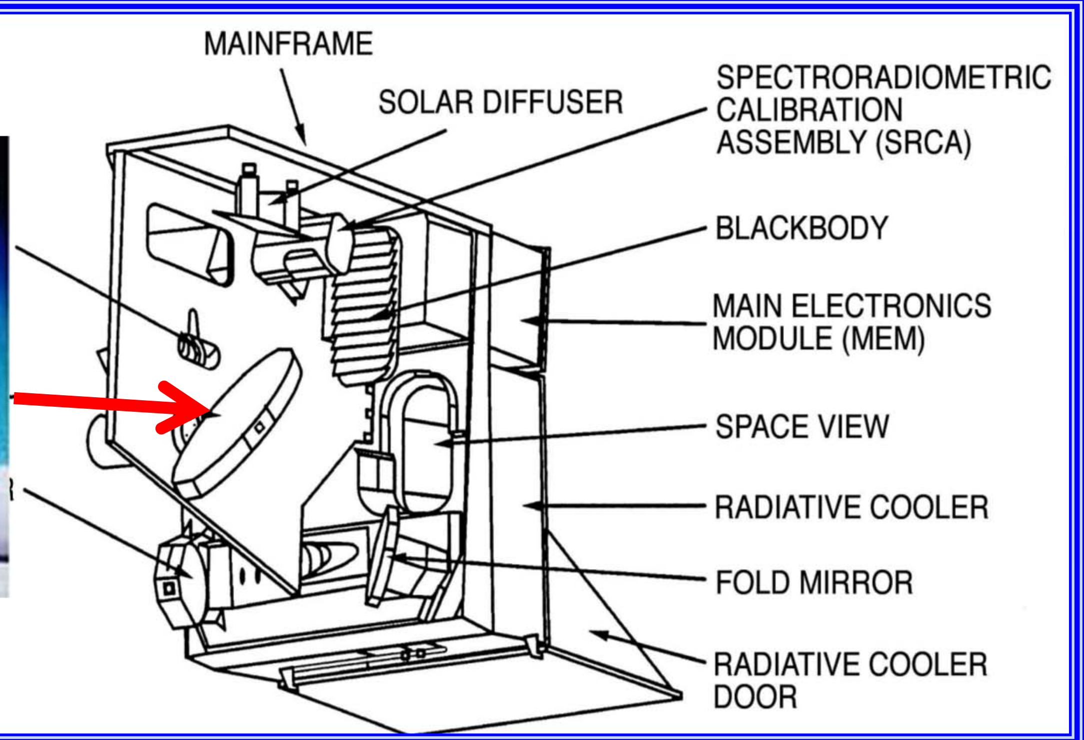


- Semi-empirical BRDF model to mitigate the impact due to seasonal effects
- RSR mismatch correction using MODTRAN 5.0 (mid-latitude desert profile)
- Demonstrate the impact of columnar atmospheric water-vapor on the observed differences
- Water-vapor retrieved from MODIS water-vapor product (MOD05_L2)

Angal A., X. Xiong, A. Wu, G. Chander and T. Choi, "Multitemporal Cross-calibration of the Terra MODIS and Landsat 7 ETM+ Reflective Solar Bands" (under review IEEE TGRS)

On-orbit Characterization of MODIS RSB Response Versus Scan-angle (RVS)

- MODIS is a scanning radiometer using a two-sided scan mirror with data collected from its on-board calibrators (OBC) at fixed angle of incidence (AOI) and the earth view (EV) over a wide range of AOI
- On-orbit changes in sensor RVS (mainly due to mirror response degradation)

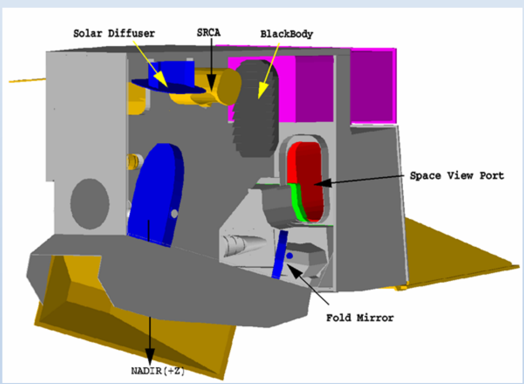


MODIS RSB Calibration Using SD and Moon

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

gain $\propto 1/m_1$

SD and lunar observations are made at different AOI



$$m_1 = \frac{f(view\_geometry)}{< dn^*_{Moon} >}$$

Δ_{SD}: SD degradation factor

Γ_{SD}: SD screen vignetting function

d: Earth-Sun distance

dn*: Corrected digital number

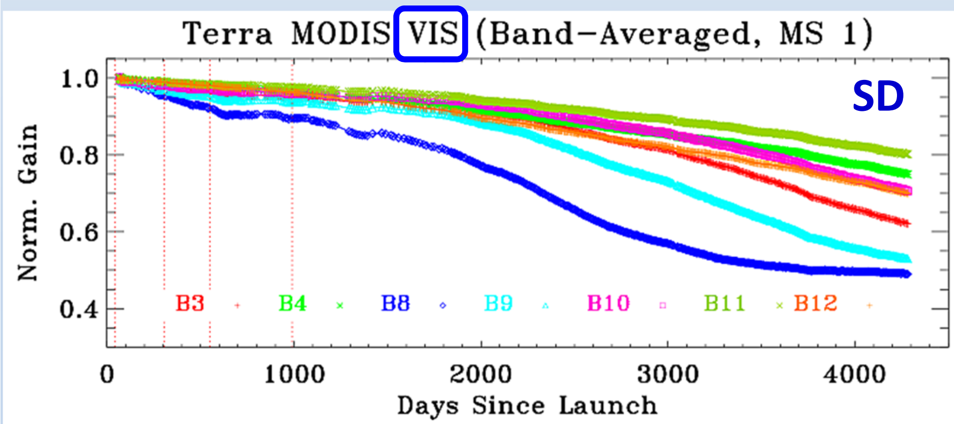
dc: Digital count of SDSM

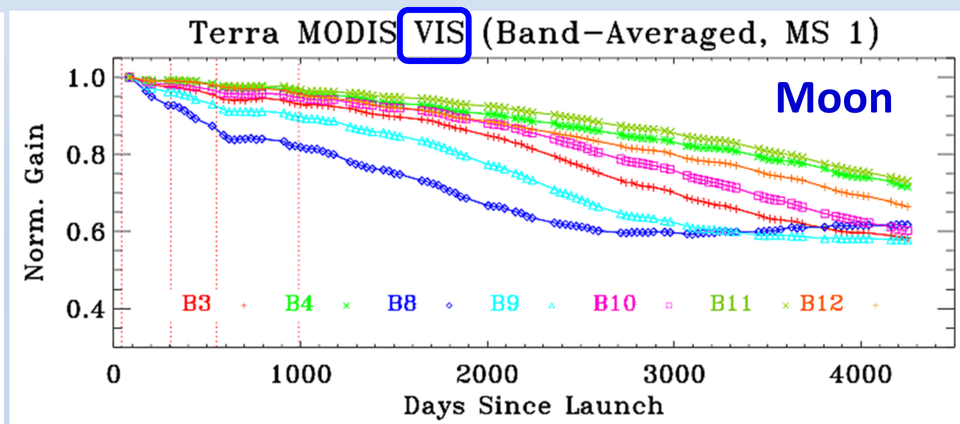
Geometric Factors

$$f = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{over-sampling}}{d^2_{Sun-Moon} \cdot d^2_{Modis-Moon}}$$

MODIS RSB RVS Characterization Approach

- Data Sets
  - Response trending from SD (AOI fixed at 50°)
  - Response trending from the Moon (AOI fixed at 11°)
  - Response trending over multiple EV targets (AOIs over a wide range)
    - CEOS recommended calibration reference sites (deserts)
  - Mirror side ratios from OBC and EV



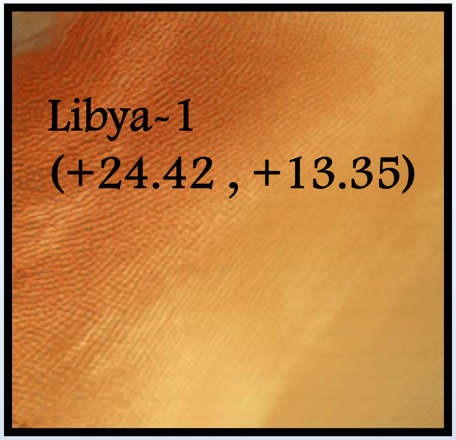


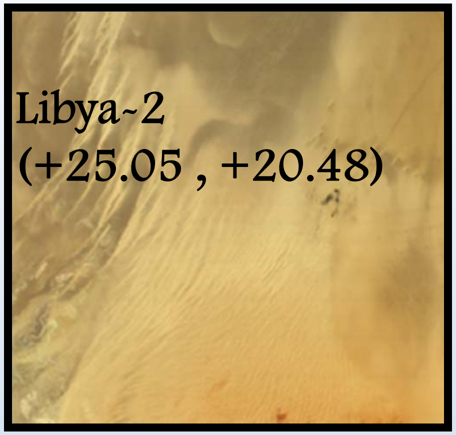
For spectral bands with large changes in responses (gains): SD and lunar data sets are no longer sufficient

MODIS RSB RVS Characterization Approach

- For bands with no changes in RSV
  - Pre-launch RVS is applied
- For spectral bands with small changes in RVS
  - Use SD and lunar trending for mirror side 1 (MS1) RVS
  - Use SD, lunar, and EV mirror side ratios for mirror side 2 (MS2) RVS
  - Fit each response trending over time, normalize to SD response, and then fit over AOI
- For spectral bands with large changes in RVS
  - Use lunar and EV trending for MS1 RVS
  - Fit each response trending over time, normalize to lunar response, and then fit over AOI
  - Same approach for MS2 RVS
- For some bands with large detector to detector difference
  - Detector dependent RVS applied for several VIS bands (B8-12)

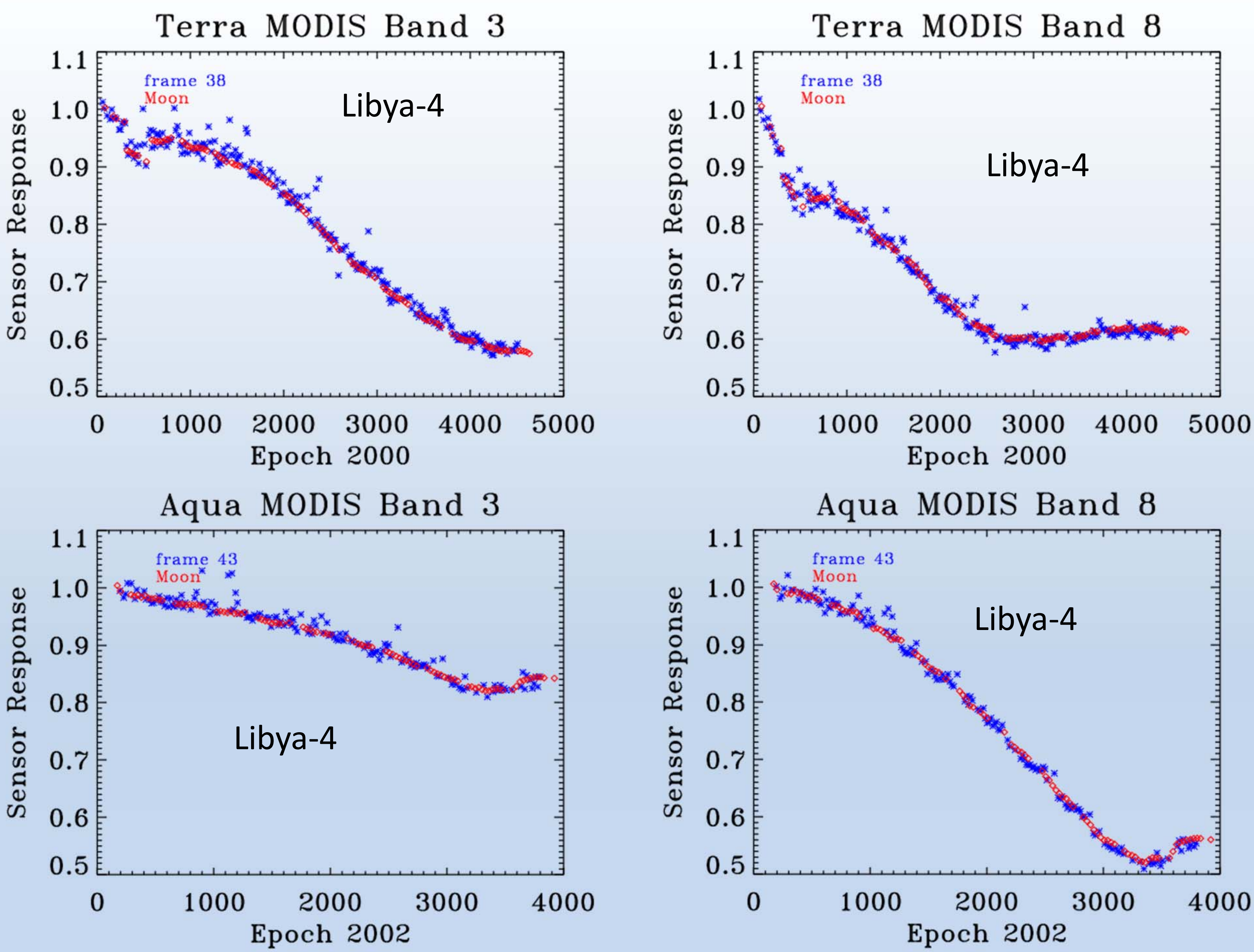
Ground Targets Used for MODIS RVS Characterization



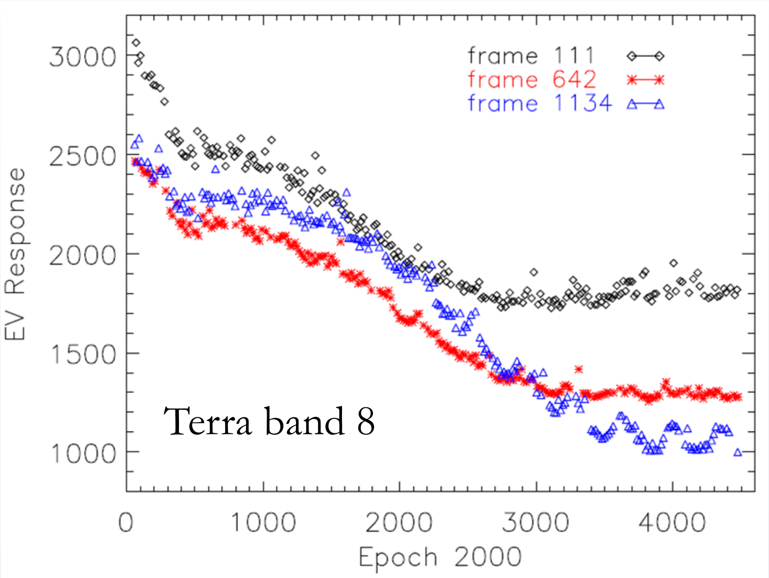


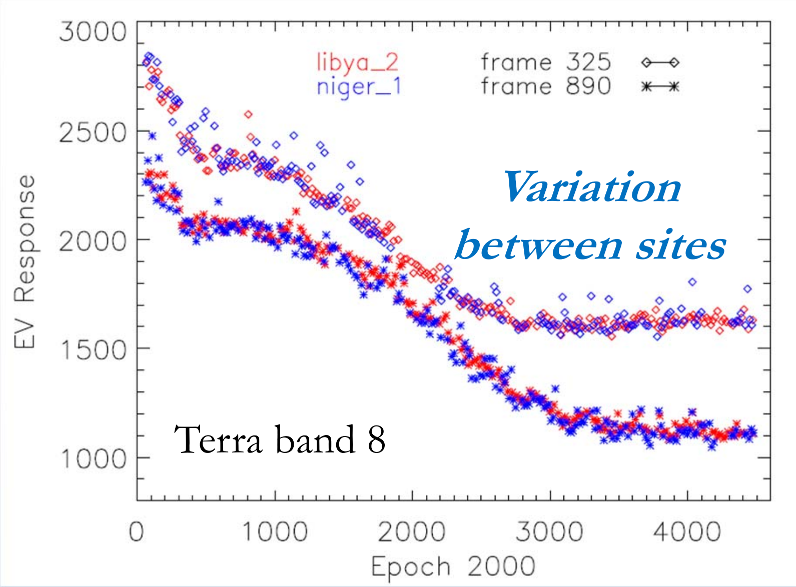
- Terra AOIs (degree): 11.2 (lunar), 16.9, 22.0, 23.8, 28.9, 32.6, 36.7, 42.7, 46.7, 53.4, 59.4, 64.2
- Aqua Frames are slightly different from those of Terra
- A semi-empirical BRDF model developed by Roujean et al is used to perform the BRDF correction in order to de-trend the data
- For each AOI, the instrument response is fitted to smoothly connected analytical functions
- Applied to Terra Bands 1-4 ,8, 9 and Aqua Bands 8, 9, 3

Comparison of Lunar Trending with EV trending at Lunar AOI

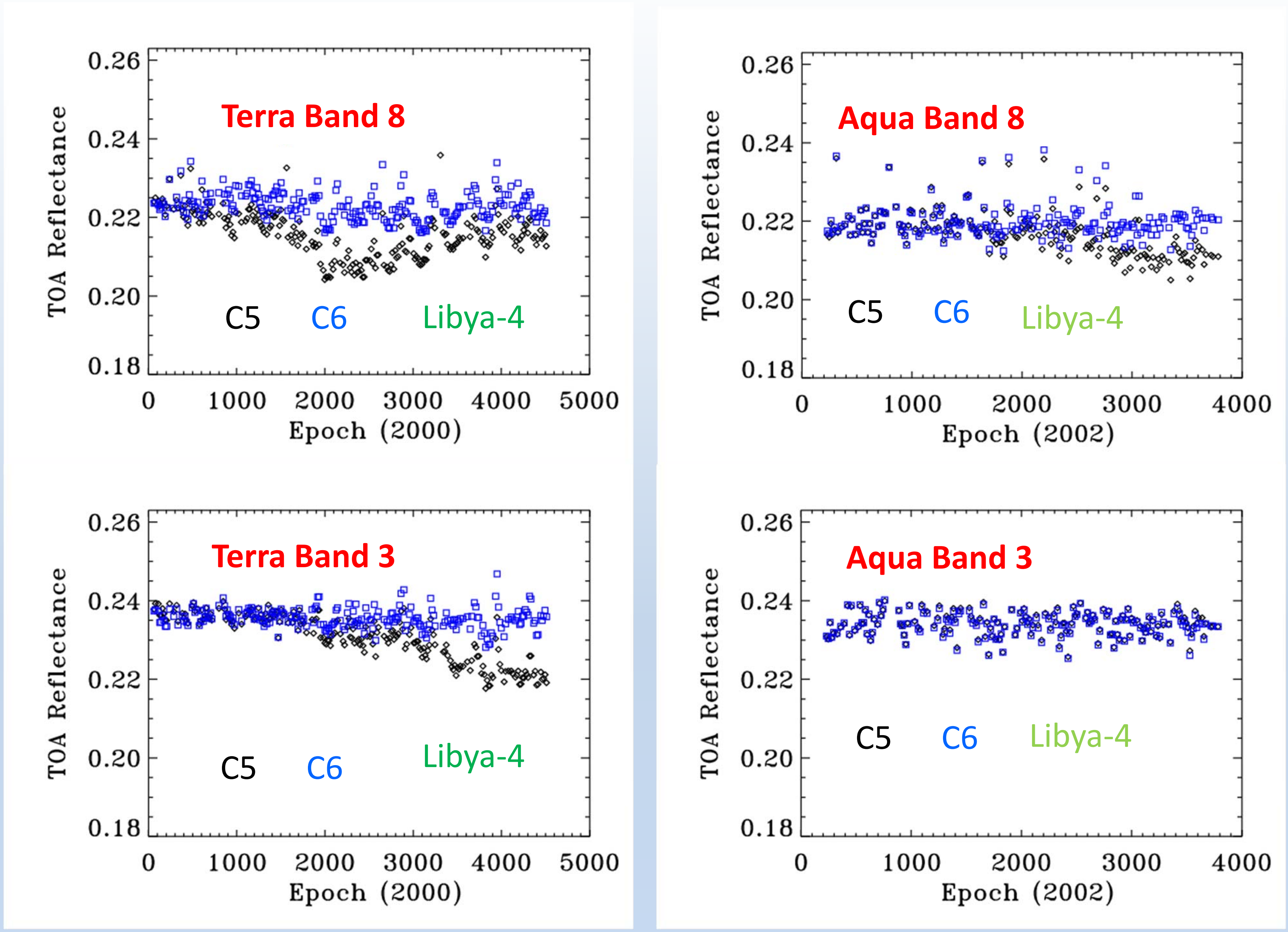


Trending at Different AOIs from Different Sites





Collection 6 RVS Improvements

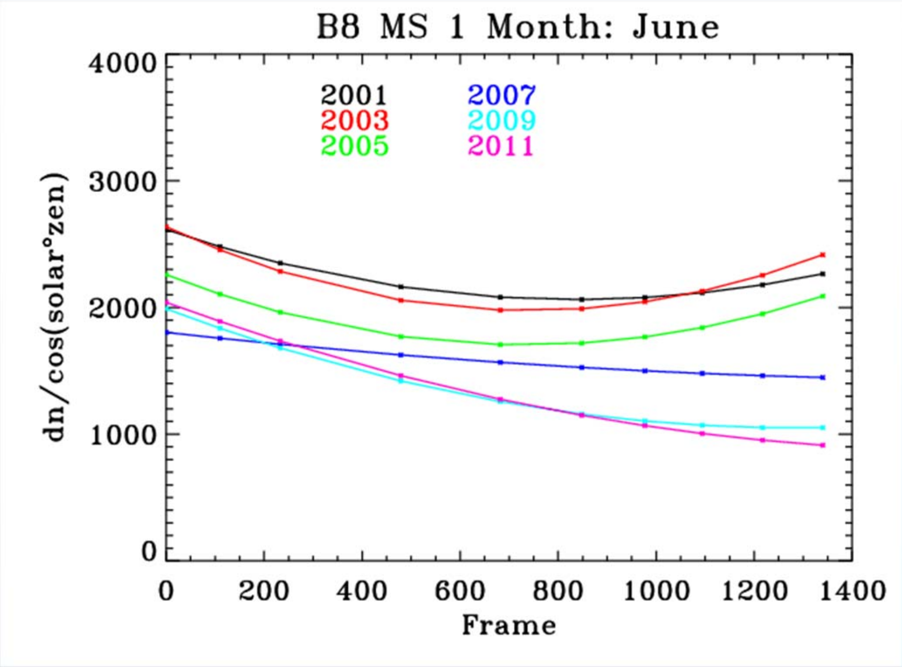


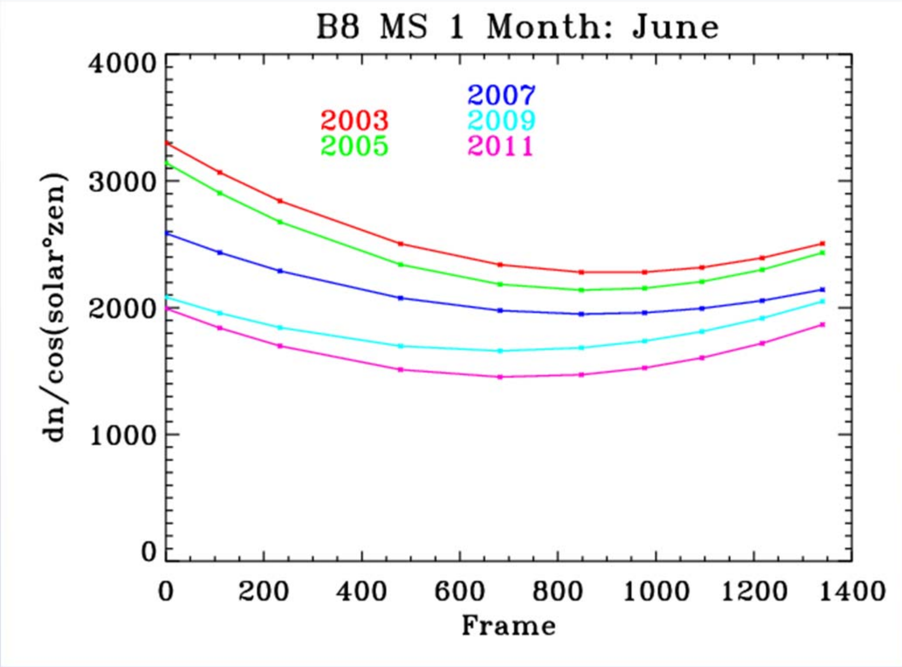
Future RVS Characterization Approach

- Multiple sites (same data sets used in current approach)
  - Response trending from the Moon (AOI fixed at 11°)
  - Average over a fixed time period (data from different sites may be collected at different time) and normalize to initial time (different signals at different sites)
  - Fit over AOI, normalize to the lunar trending, then fit each selected AOI over time
- Single site (entire AOI range)
  - Response trending from the Moon (AOI fixed at 11°)
  - Response trending from a single site over a wide range of AOI (same month in each year)
  - Fit over AOI, normalize to the lunar trending, then fit each selected AOI over time

Improvements over current approach

Future RVS Characterization Approach





Summary

- Ground targets can be used effectively for sensor calibration stability monitoring and cross-sensor inter-comparisons
  - Libya 4 has been one for most widely used calibration sites
- Site dependent BRDF effects and spectral band RSR differences need to be corrected for high quality calibration work
  - Vigorous efforts on the uncertainty assessment remain to be enhanced
- Long-term site dependent reflectance drifts (or variations), if exist, need to be characterized and corrected for sensor calibration stability monitoring
- Collaboration among different agencies and/or organizations will greatly benefit the science and user community

Changes in MODIS Collection 6

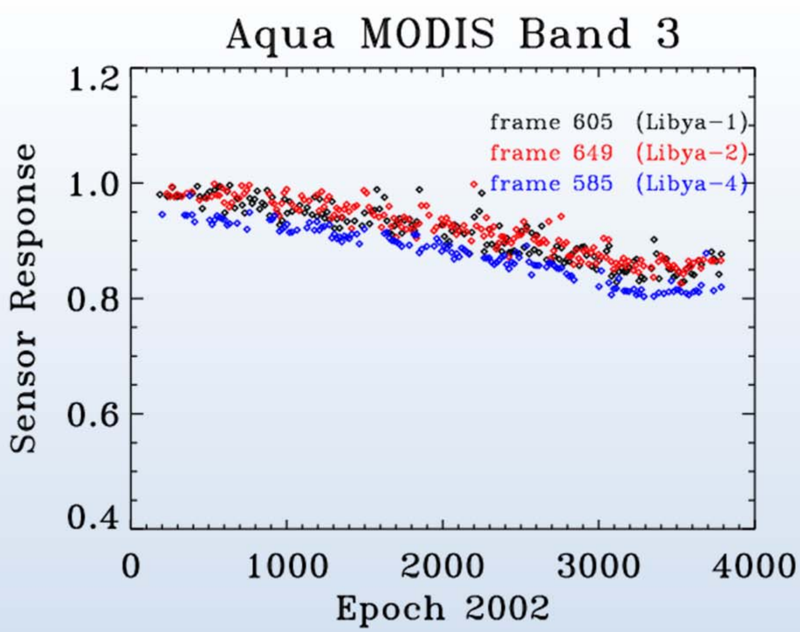
- **SD degradation at 936 nm is applied**
  - Previous SD degradation is normalized at this wavelength
  - A correction of 0.6% in Aqua over 10 years (also applied in C5)
- **Time dependent RVS applied to bands 13-16**
  - Approach developed to monitor bands 13-16 lunar calibration stability (some pixels saturate when viewing the Moon)
- **Detector dependent RVS**
  - Mainly applied to VIS bands (e.g. bands 8-12)
- **Some RSB calibration coefficients (m1) and RVS are derived at the same time using observations to the SD, Moon, and "pseudo-invariant" EV targets at different AOIs**
  - Mainly applied to VIS bands (e.g. bands 8-9)

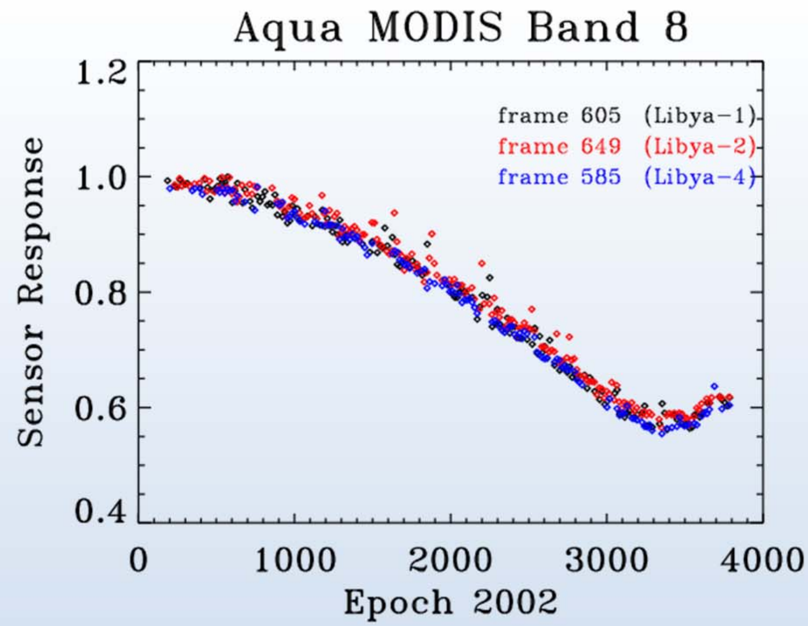
Apply to both Terra and Aqua MODIS

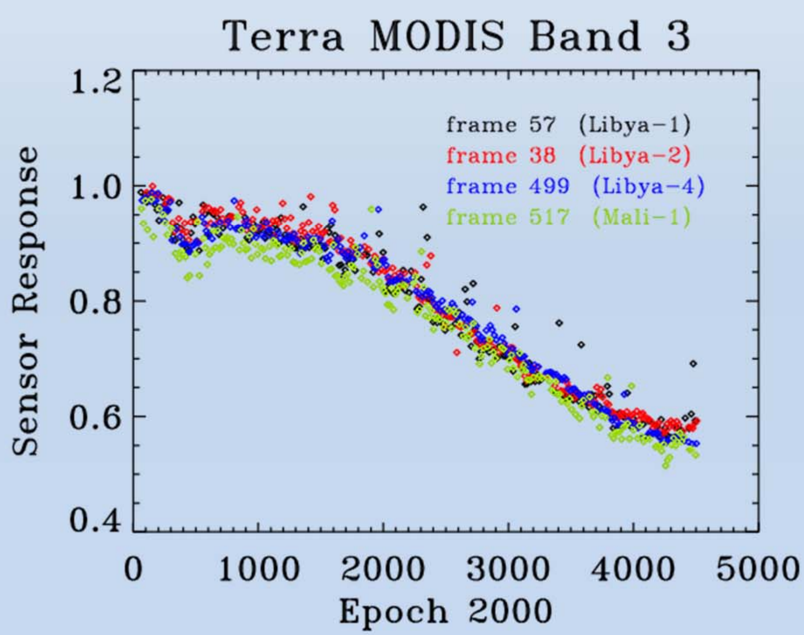
RSB and TEB calibration; QA and uncertainty implementation

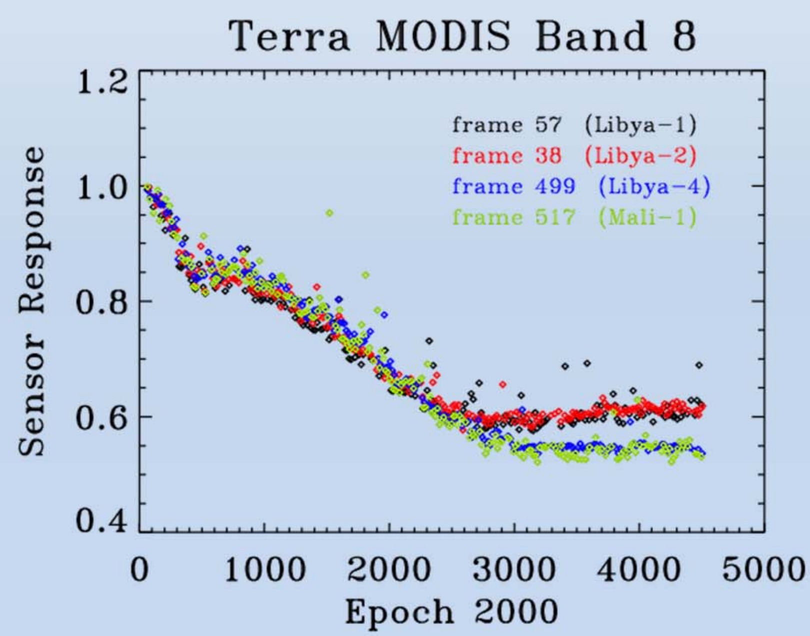
Changes in MODIS Collection 6

- **Revised approach for derivation of offset and nonlinear terms for TEB calibration**
  - Improves cold EV scene brightness temperature retrievals
- **FPA temperature correction is applied to default b1 (TEB linear calibration coefficient)**
  - Default b1 only used when T_{BB} is above T_{SAT} for Aqua bands 33, 35, and 36 during BB WUCD
- **Explicit fill value (SI = 65531) is used in L1B for inoperable detectors**
  - Interpolation was applied in C5
- **New detector QA flag for noisy and inoperable sub-samples**
  - SI = 65525 for inoperable sub-samples (only apply to bands 1-7)
- **Improved algorithms for uncertainty (UC) calculation in L1B**
  - UC is computed based on L1B calibration and retrieval algorithms and sensor on-orbit performance (scene, time, AOI dependent)


Aqua MODIS Band 3
1.2
1.0
0.8
0.6
0.4
Sensor Response
frame 605 (Libya−1)
frame 649 (Libya−2)
frame 585 (Libya−4)
0
1000
2000
3000
4000
Epoch 2002


Aqua MODIS Band 8
1.2
1.0
0.8
0.6
0.4
Sensor Response
frame 605 (Libya−1)
frame 649 (Libya−2)
frame 585 (Libya−4)
0
1000
2000
3000
4000
Epoch 2002


Terra MODIS Band 3
1.2
1.0
0.8
0.6
0.4
Sensor Response
frame 57 (Libya−1)
frame 38 (Libya−2)
frame 499 (Libya−4)
frame 517 (Mali−1)
0
1000
2000
3000
4000
5000
Epoch 2000


Terra MODIS Band 8
1.2
1.0
0.8
0.6
0.4
Sensor Response
frame 57 (Libya−1)
frame 38 (Libya−2)
frame 499 (Libya−4)
frame 517 (Mali−1)
0
1000
2000
3000
4000
5000
Epoch 2000