# Multi-temporal cross-calibration of Terra MODIS and Landsat 7 ETM+ reflective solar bands

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MODIS Characterization Support Team
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*Acknowledgements: Dennis Helder, Nischal Mishra, Taeyoung (Jason) Choi, Gyanesh Chander, Aisheng Wu, Dave Doelling, Ben Scarino*

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- Sensor and Site Overview
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- Methodology
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  - Spectral mismatch correction using EO-1 Hyperion (comparison with SCIAMACHY and MODTRAN)
- Results
  - Long-term stability
  - Comparison after BRDF correction
- Summary and Future Work

*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", IEEE Transactions on Geoscience and Remote Sensing, vol. 51, issue 4, pp. 1870-1882, 2013.*

# Sensor Overview

Landsat 7 (Apr 15, 1999)

Terra (Dec 18, 1999)

Earth Observing 1 (Nov 21, 2000)

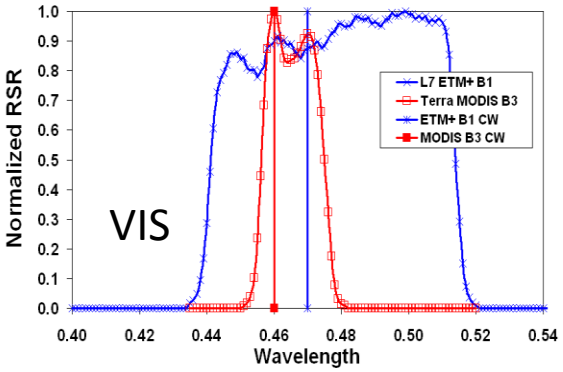


*Images obtained from NASA's Earth Observing System website*

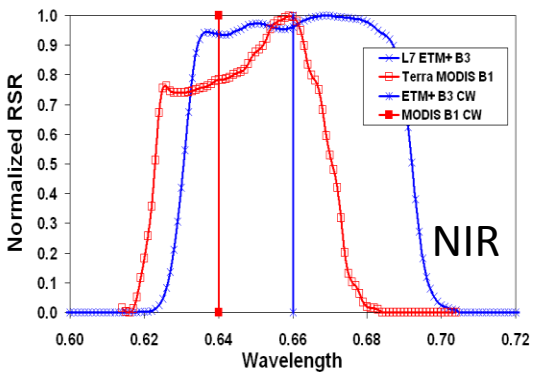
# Sensor Overview

| Platform | Terra | Landsat 7 | EO-1 |
|---|---|---|---|
| Sensor | MODIS | ETM+ | Hyperion |
| Number of bands | 36 | 8 | 220 |
| Spatial resolution | 250 m, 500 m, 1 km | 15 m, 30 m, 60 m | 30 m |
| Swath | 2330 km | 187 km | 7 km |
| Spectral coverage | 0.4~14 µm | 0.4~12.5 µm | 0.4~2.5 µm (10 nm) |
| Launch date | Dec 18, 1999 | April 15, 1999 | Nov 21, 2000 |
| Altitude | 705km | 705km | 705 km at launch |

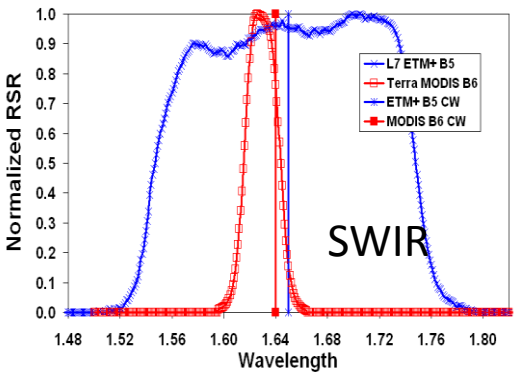
L7 ETM+ (B1) and Terra MODIS (B3)




L7 ETM+ (B3) and Terra MODIS (B1)




L7 ETM+ (B5) and Terra MODIS (B6)



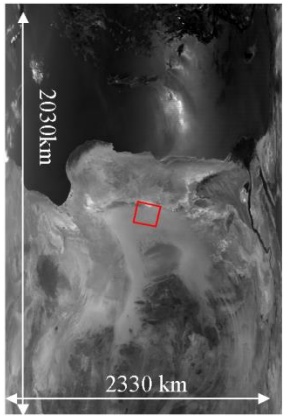
# Motivation

- **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 angle 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, … )

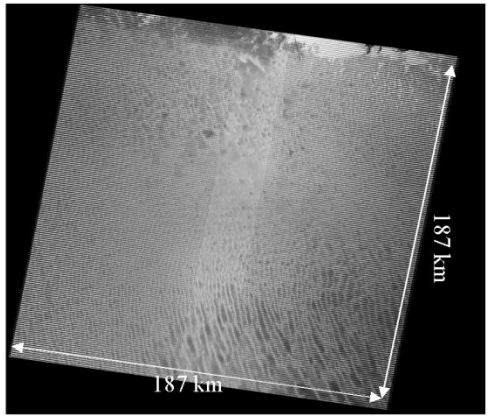
Hardly any single ground target can meet all the “requirements”
Multiple sites should be considered, depending on the specific applications

# Libya 4 Site Overview

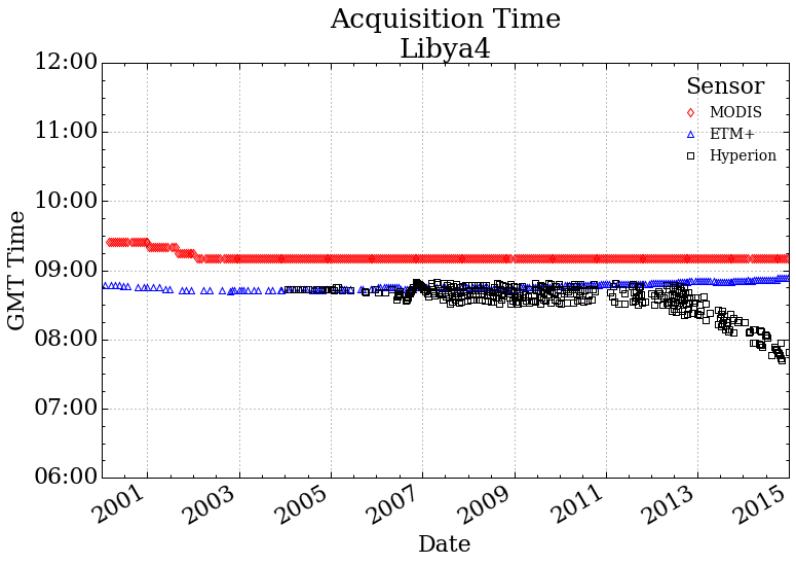
- L7 Repeat Cycle is 16 days
- Near-simultaneous pairs (same-day)
- ROI is close to nadir angle for Terra
- After May 31, 2003, the L7 ETM+ SLC-off products were used

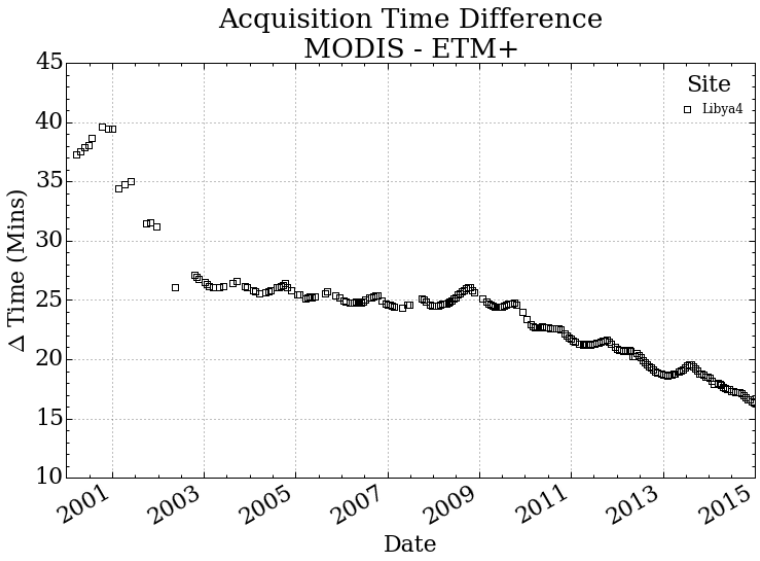



MODIS




ETM+ Libya 4 Test Site

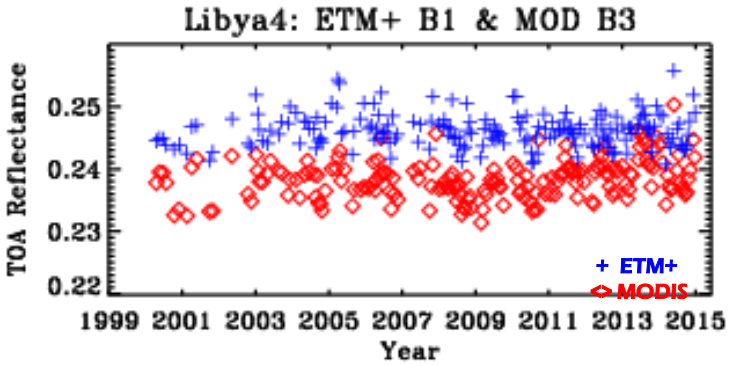


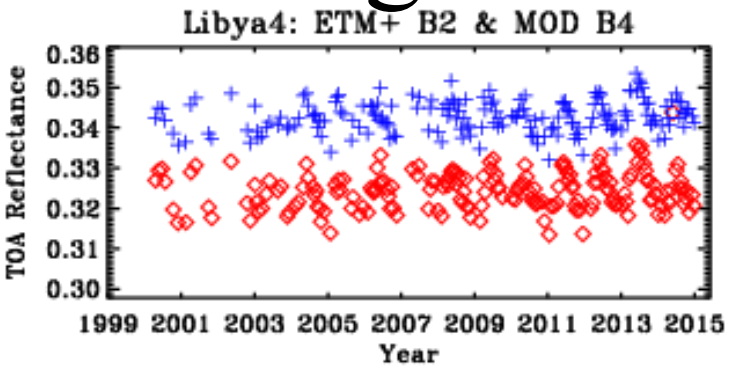



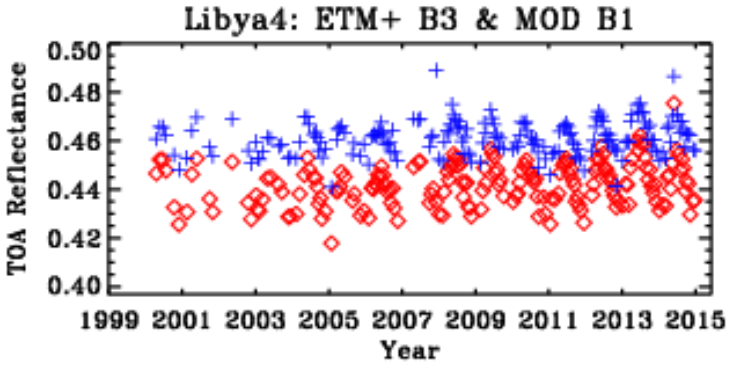
# Methodology

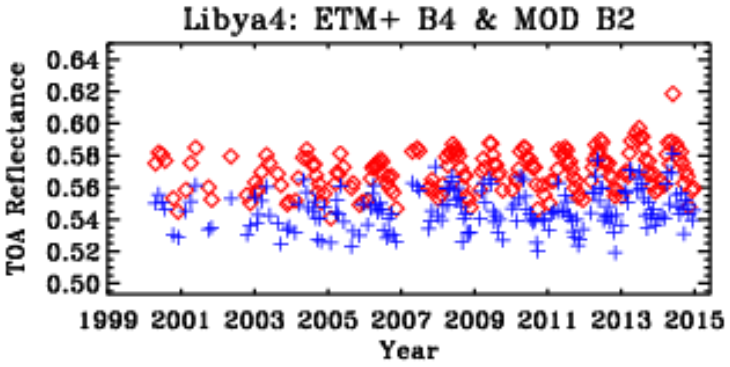
- MRTSwath Reprojection was used on Terra MODIS 5min-Swath to match ETM+ L1T UTM product format
  - MODIS Collection 6 data and ETM+ products downloaded from MODAPS LAADS and USGS EarthExplorer in Feb, 2015
- Co-located areas (CNES specified ROI: Lacherade et.al) extracted for each MODIS and ETM+ image pair
  - ROI chosen from (28.45$^{o}$,23.29$^{o}$) to (28.65$^{o}$,23.49$^{o}$)
  - Near-nadir observations are chosen (minimal BRDF impact)
  - Only same-day scenes are considered
  - Brightness Temperature thresholds used to eliminate cloud contaminated pairs
- At-sensor reflectance were computed for all scenes, and a semi-empirical BRDF correction was derived
- RSR difference compensated using EO-1 Hyperion spectral signatures of Libya 4
  - Lifetime spectral difference factors were computed

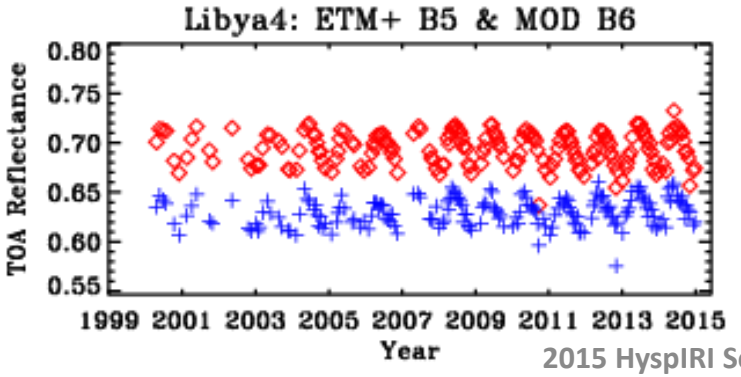
# TOA reflectance trending result

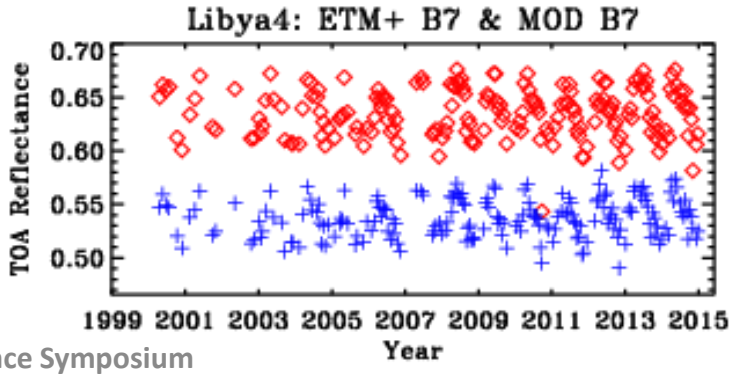


# BRDF Correction

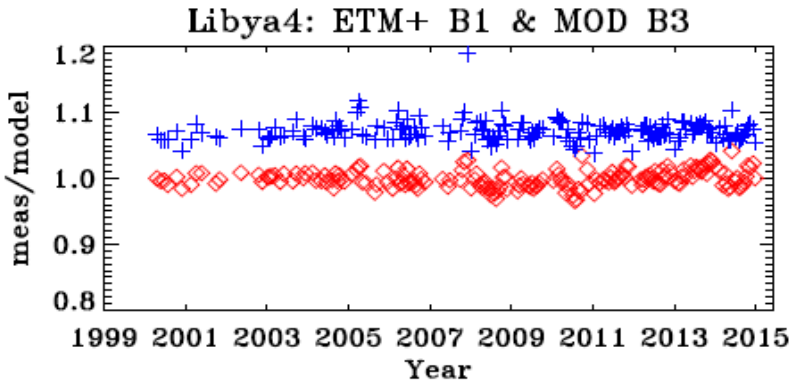
- Since only near-nadir acquisitions (within 30 min) are chosen, a solar/sensor geometry based correction was developed
- Using the first 3-years of Terra MODIS measurements over the Libyan desert, a semi-empirical bi-directional reflectance function (BRDF) consisting of two kernel-driven components (Roujen et.al) was used:

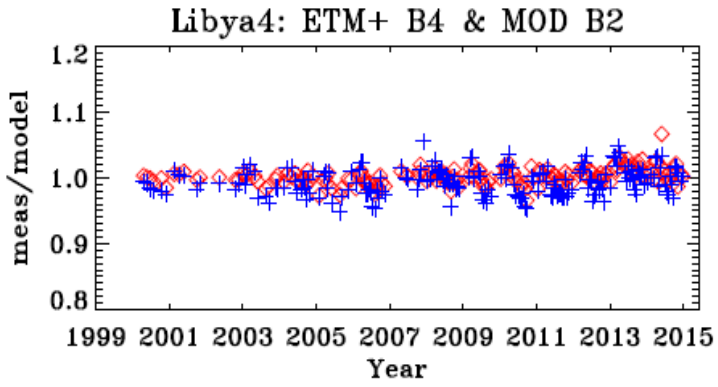
$$\hat{\rho} = k_0 + k_1 f_1(\theta_s, \theta_v, \phi) + k_2 f_2(\theta_s, \theta_v, \phi)$$

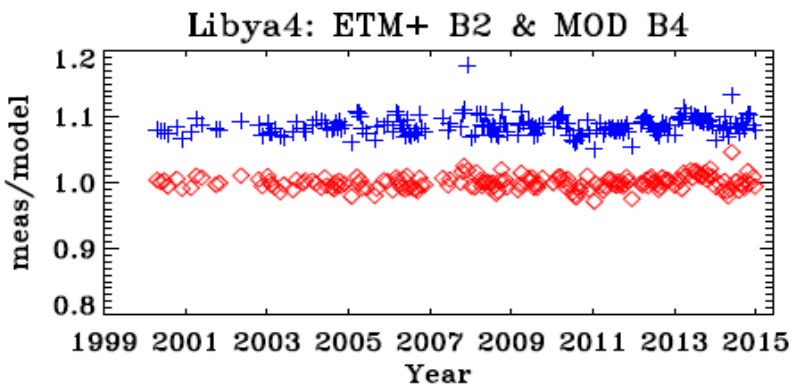
- The derived coefficients applied to lifetime MODIS and ETM+ measurements
  - Applying MODIS-based coefficients to ETM+ also provides an estimate of the spectral mismatch (due to RSR differences) between the two sensors

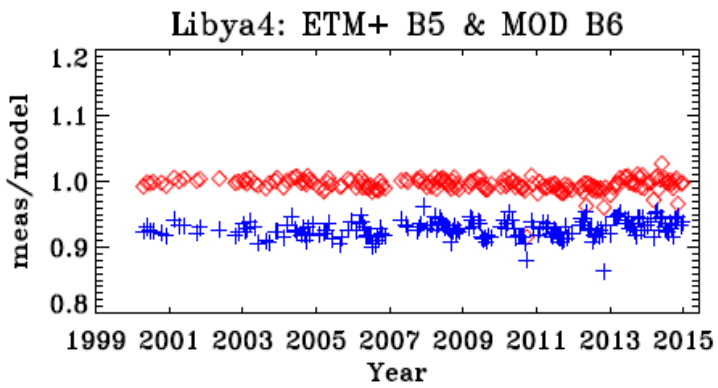
J. L. Roujen, M. J. Leroy, and P. Y. Deschamps, "A bidirectional reflectance model of the Earth's surface for the correction of remote sensing data," *J. Geophys. Res.*, vol. 97, no. D18, pp. 20 455–20 468, Jan. 1992.

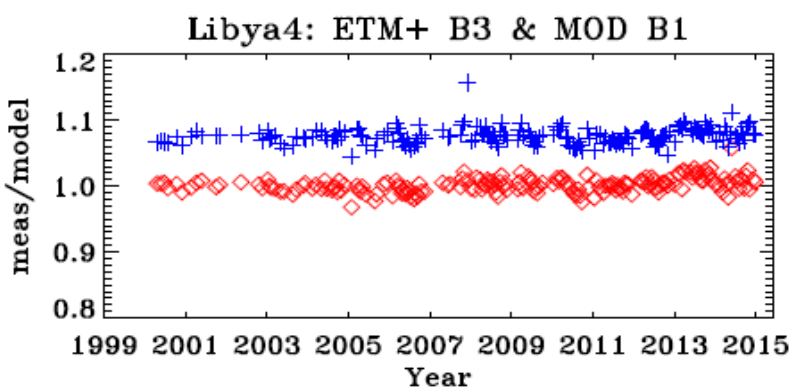
# BRDF Correction

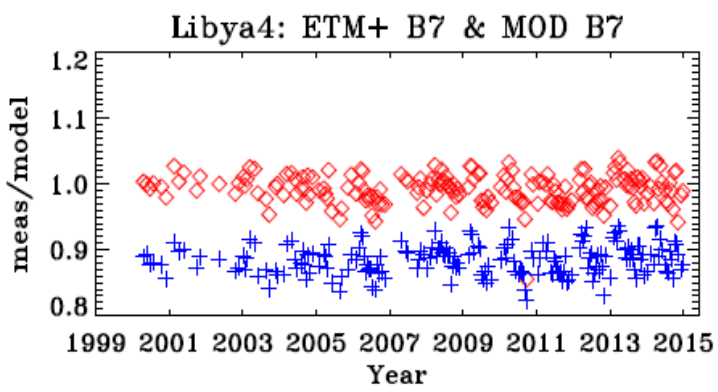


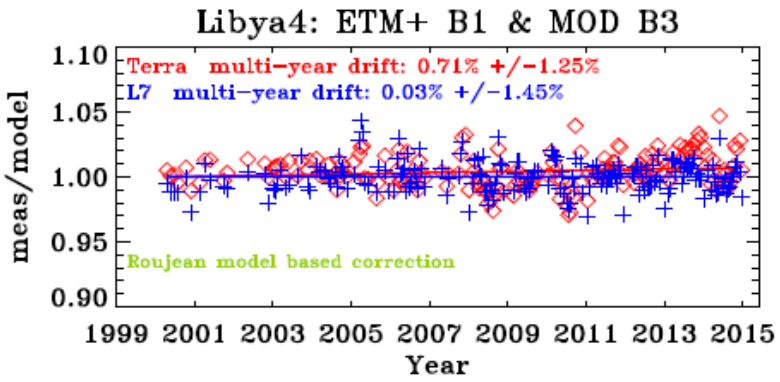



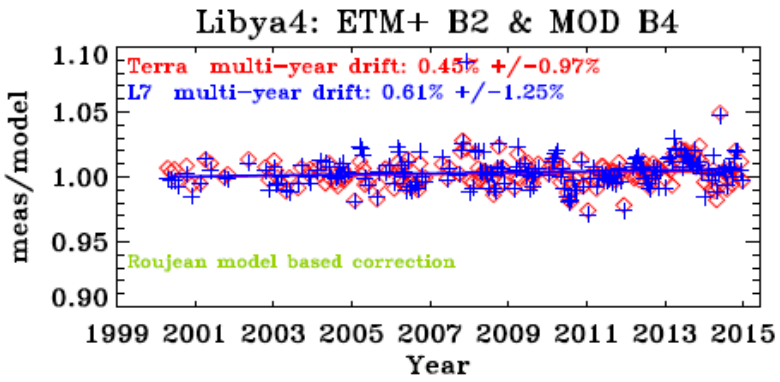



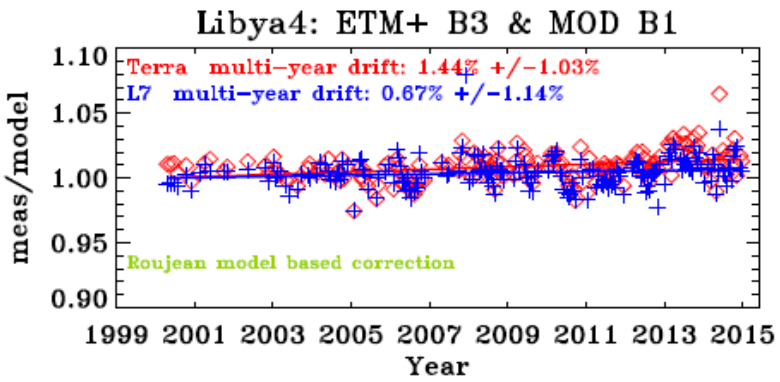



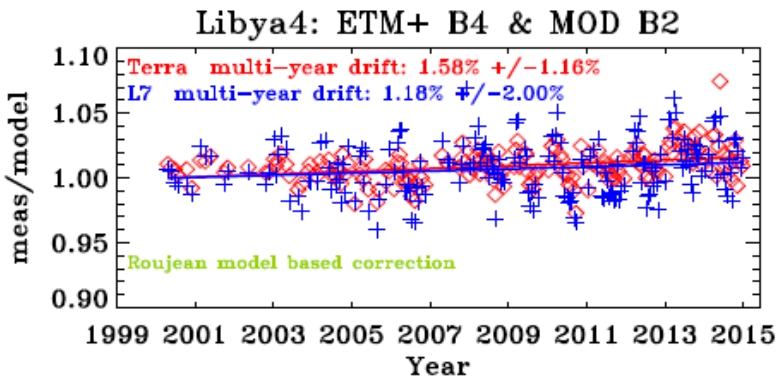



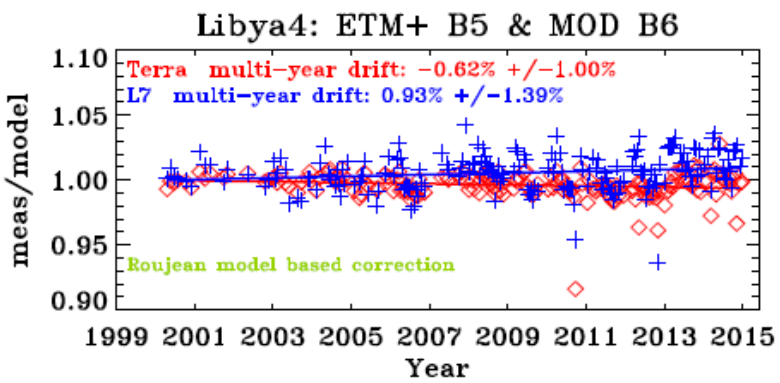
# Long-term stability

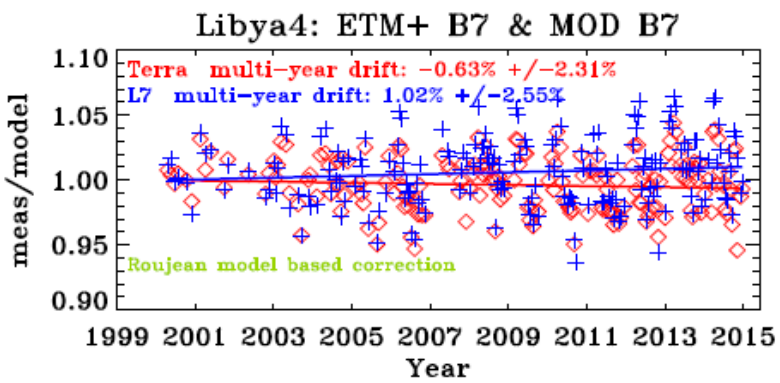


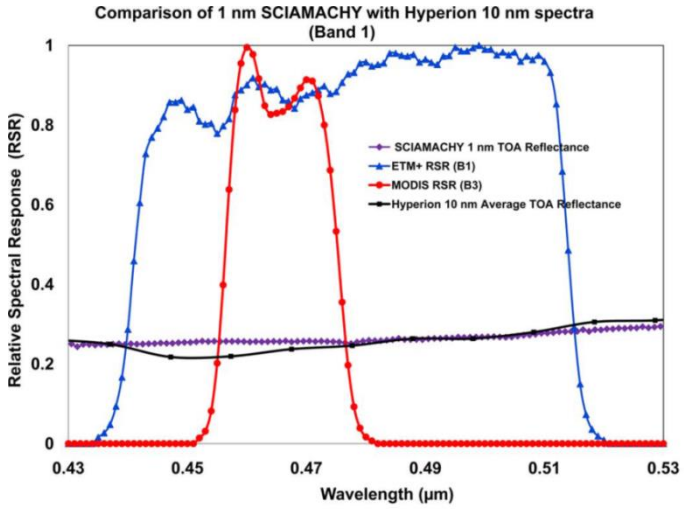



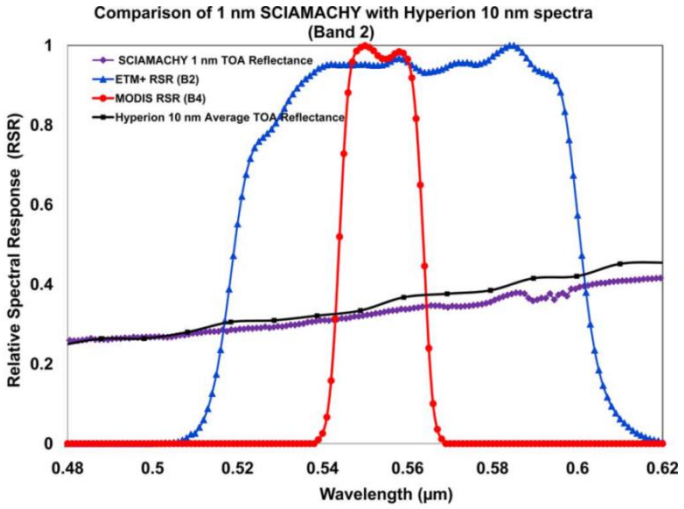



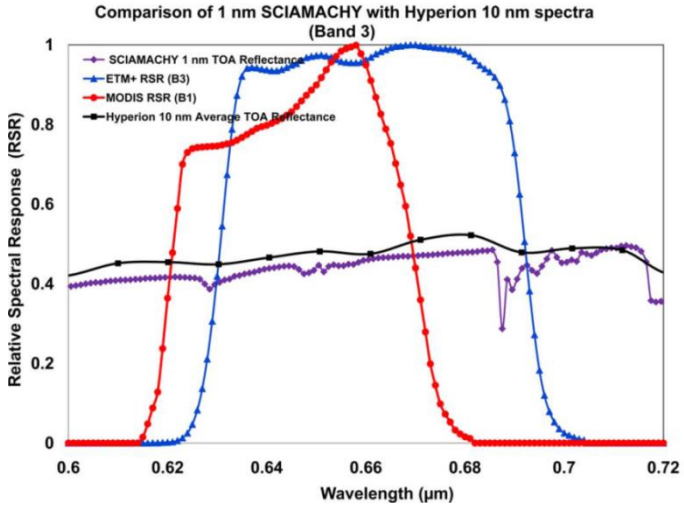



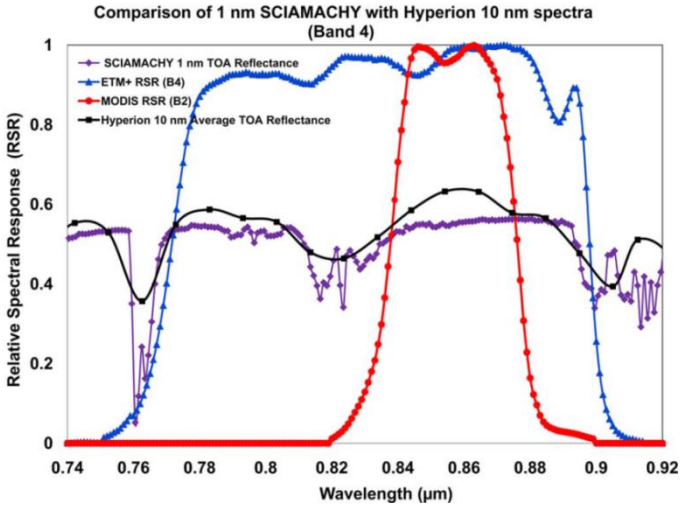



# Spectral Band Adjustment Factor (SBAF) to Correct Impact Due to RSR Difference



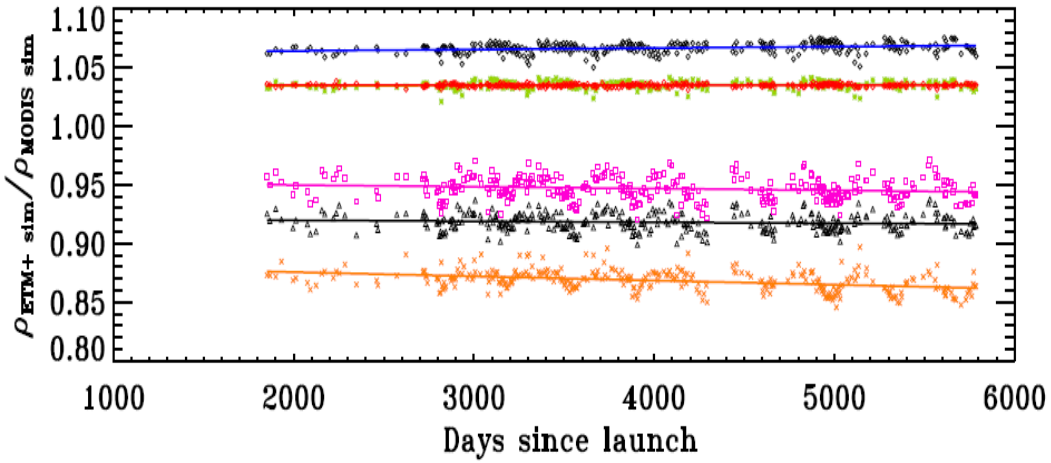



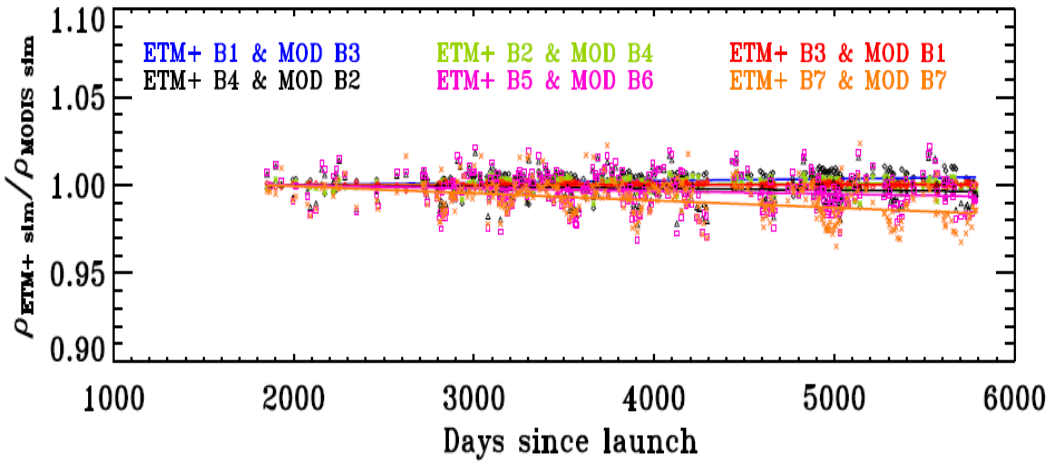

ENVISAT Sciamachy provides a hyperspectral signature of Libya 4 at 1 nm spectral resolution

Lifetime Sciamachy reflectance profiles over Libya 4 provided by Ben Scarino and Dave Doelling, NASA Langley


G. Chander, N. Mishra, D. Helder, D. Aaron, A. Angal, T. Choi, X. Xiong, and D. Doelling, "Applications of spectral band adjustment factors (SBAF) for cross-calibration," *IEEE Trans.Geosci. Remote Sens.*, vol. 51, no. 3, pp. 1267–1281, Mar. 2013.

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



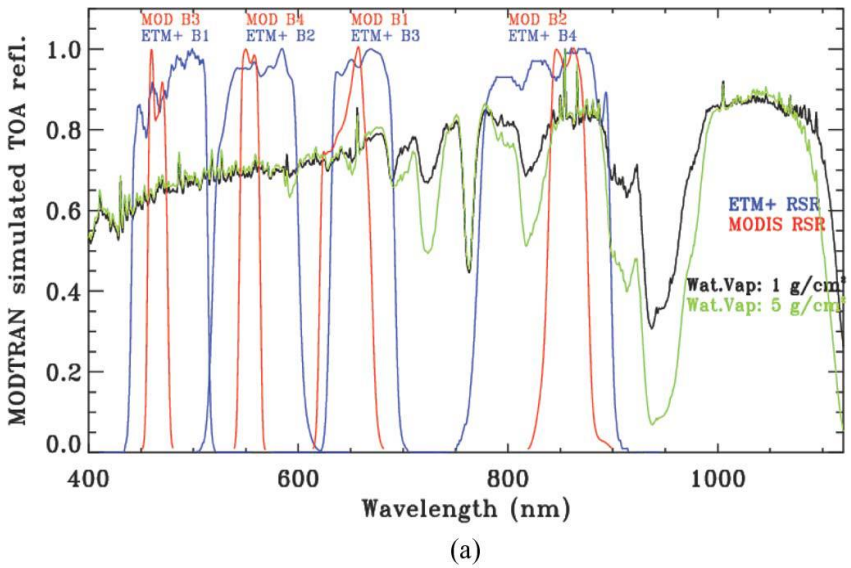

Using all-available EO-1 Hyperion measurements to characterize the differences due to RSR mismatch

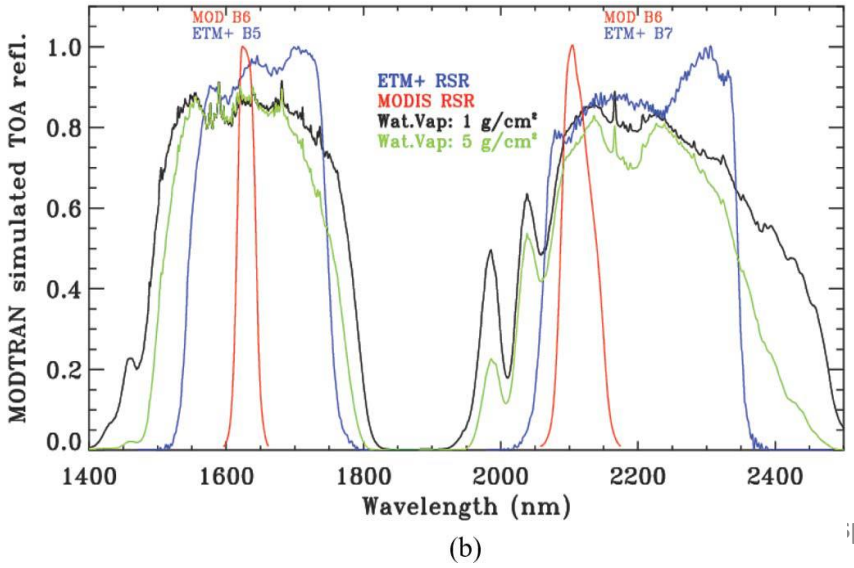
Seasonal variations evident for some bands (BRDF, water-vapor variations)

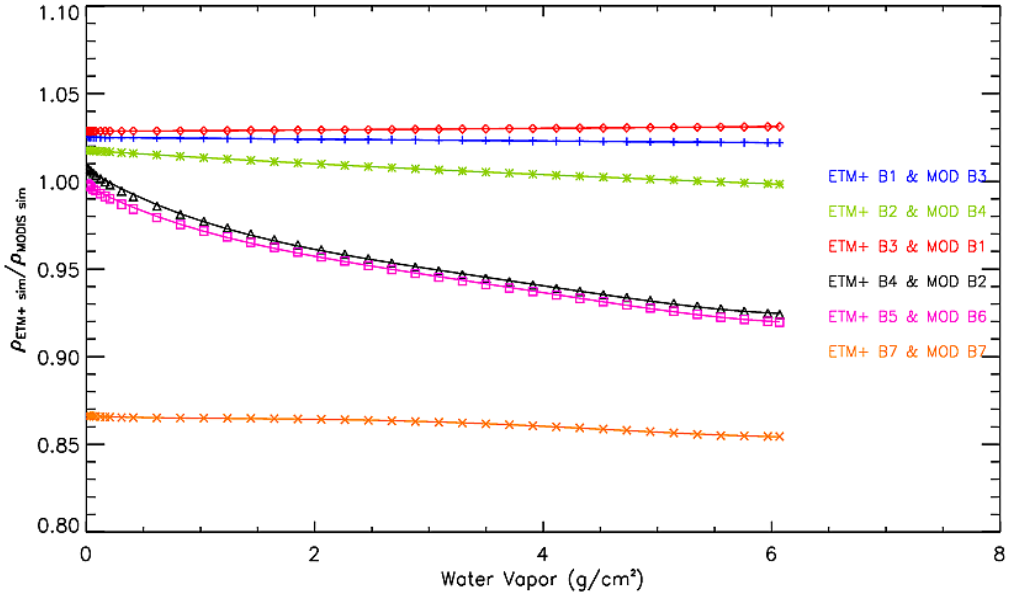
Long-term drift (~2 %) evident in the SWIR band (Hyperion band 193-219)

Temporal SBAF is desirable, but due to lack of near-simultaneous collects, lifetime-average SBAF computed

# Spectral difference and atmospheric water-vapor impact

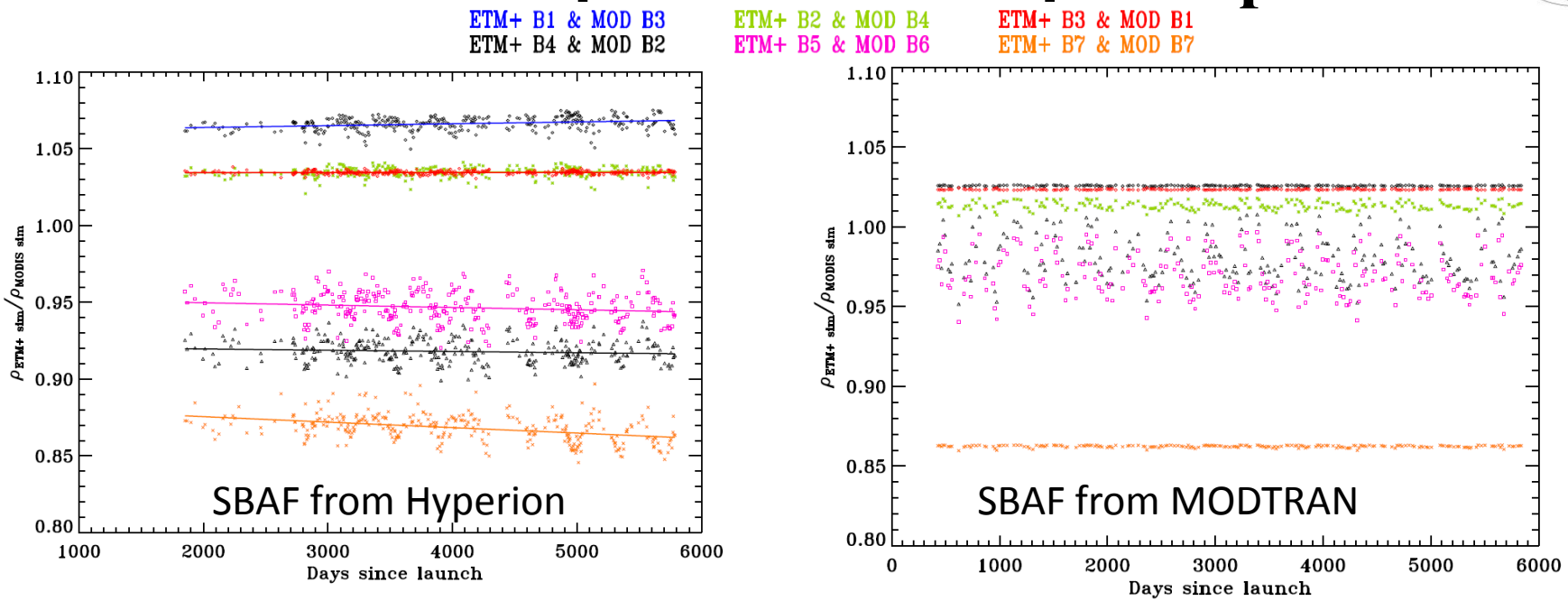


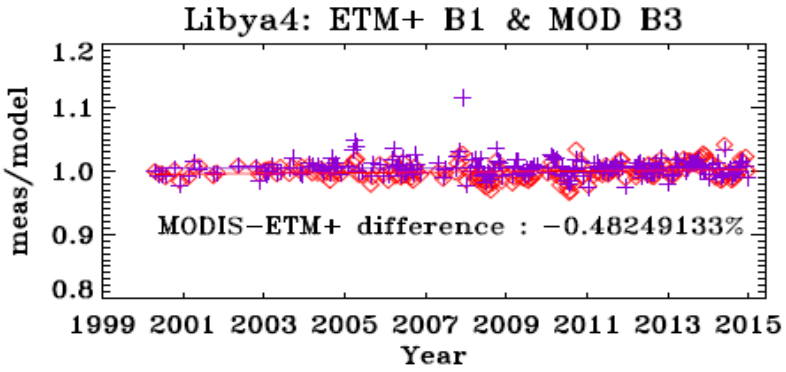

- RSR mismatch correction using MODTRAN 5.0 (mid-latitude desert profile)
- Impact of columnar atmospheric water-vapor on the observed differences
- Real-time columnar atmospheric water-vapor can be retrieved from MODIS MOD05_L2 product

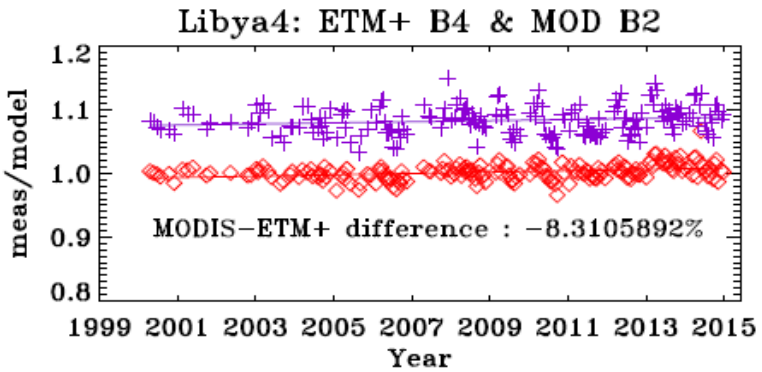
# Spectral difference and atmospheric water-vapor impact

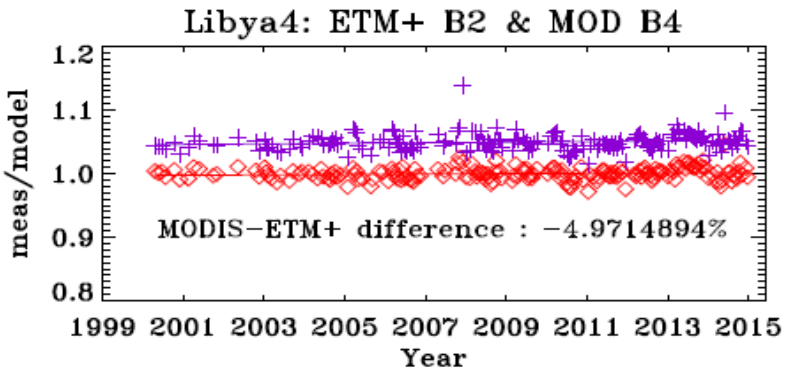


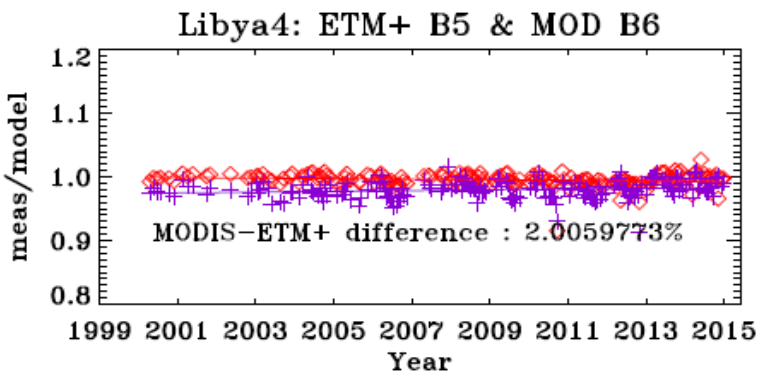

| Band pair | Hyperion SBAF | Sciamachy SBAF | MODTRAN SBAF | Sciamachy-Hyperion % | MODTRAN Hyperion % |
|---|---|---|---|---|---|
| E-B1 & M-B3 | 1.07 | 1.02 | 1.03 | 4.23 | 3.96 |
| E-B2 & M-B4 | 1.03 | 1.02 | 1.01 | 1.17 | 2.10 |
| E-B3 & M-B1 | 1.03 | 1.02 | 1.02 | 1.17 | 1.08 |
| E-B4 & M-B2 | 0.92 | 0.94 | 0.98 | -2.56 | -6.36 |
| E-B5 & M-B6 | 0.95 | 0.92 | 0.97 | 2.73 | -2.41 |
| E-B7 & M-B7 | 0.87 | N/A | 0.86 | N/A | 0.68 |

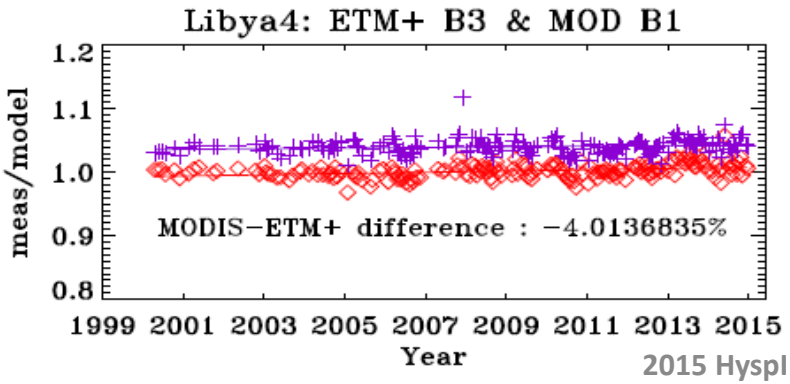
# MODIS-ETM+ Differences after correction (BRDF + SBAF)

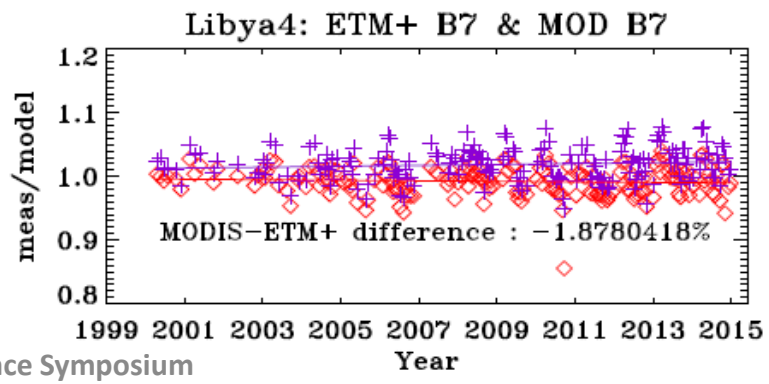


# Summary and Future Work (1)

- A methodology to monitor the long-term stability of Terra MODIS and Landsat 7 ETM+ RSB using PICS has been developed
  - Long-term drift for all bands within 2% over 14+ years
- EO-1 Hyperion collects were used to characterize the RSR differences between the two sensors
  - Results compared with Sciamachy and MODTRAN based SBAFs.
  - Columnar water-vapor retrieved from the MODIS MOD05_L2 product which is used as an input to MODTRAN
  - Most differences observed at the shortest wavelength with temporal variations (due to atmospheric water-vapor) observed in ETM+ band 4 and MODIS band 2
- After application of the SBAFs, difference between the two sensors is less than 5% for most bands (exception : MODIS band 2 and ETM+ band 4)
  - ETM+ band 4 RSR has a water-vapor absorption feature absent from MODIS RSR. Need a better understanding of the results

# Summary and Future Work (2)

- EO-1 Hyperion provides an excellent resource to characterize the spectral differences between the two sensors
  - Lowering of the orbit reduces the number of near-simultaneous opportunities with ETM+ and MODIS collects
  - Long-term drift in the SWIR channels of EO-1 Hyperion adds more uncertainties to the SBAF computation
  - Spectral resolution of 10 nm can be inadequate especially in the regions of water-vapor absorption
- Similar methodology to be extended to other African PICS and other sites (covering different part of the dynamic range)
- Methodology to be extended to Landsat 8 OLI, Landsat 5 TM and Aqua MODIS comparison