Monitoring On-orbit radiometric stability of the L7 ETM+, Terra MODIS, & IRS-P6 AWiFS sensors using pseudo-invariant test sites

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U.S. Department of the Interior

U.S. Geological Survey

Outline

- Background
- RSR Comparison
- Methodology
- Cross-calibration Results
- Summary

Need for cross-calibration

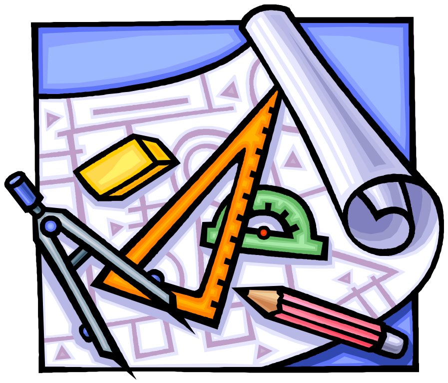
- **The ability to detect and quantify changes in the Earth's environment depends on sensors that can provide calibrated, consistent measurements of the Earth's surface features through time**
- **A critical step in this process is to put image data from different sensors onto a common radiometric scale**
- **The cross-calibration techniques use a well-calibrated sensor as a form of transfer radiometer to achieve characterization of other sensors using near-simultaneous observations of the Earth**
  - Cross-calibration is the only viable solution to tie similar sensors (TM) and differing sensors (TM-ETM+) onto a common radiometric scale, thus providing an important role in **mission continuity, interoperability, and data fusion**
  - Cross-calibration is useful in situations where on-board references are not available or where vicarious calibration is not feasible
  - Cross-calibration between sensors is critical to coordinate observations from different sensors, exploiting their individual spatial resolutions, temporal sampling, and information content to monitor surface processes over broad scales in both time and space

Multi-Sensor Solutions (MSS) Architecture

- Increasingly, data from multiple sensors are used to gain a more complete understanding of land surface processes at a variety of scales
- The success of MSS architecture depends on how well the contributed sensors achieve **“Interoperability“**
- Here, interoperability is that condition wherein differences among systems are not a barrier to a task that spans those sensors
- The focus is on how sensors work together
- The MSS architecture should provide the specifications of just those "few things that must be similar”

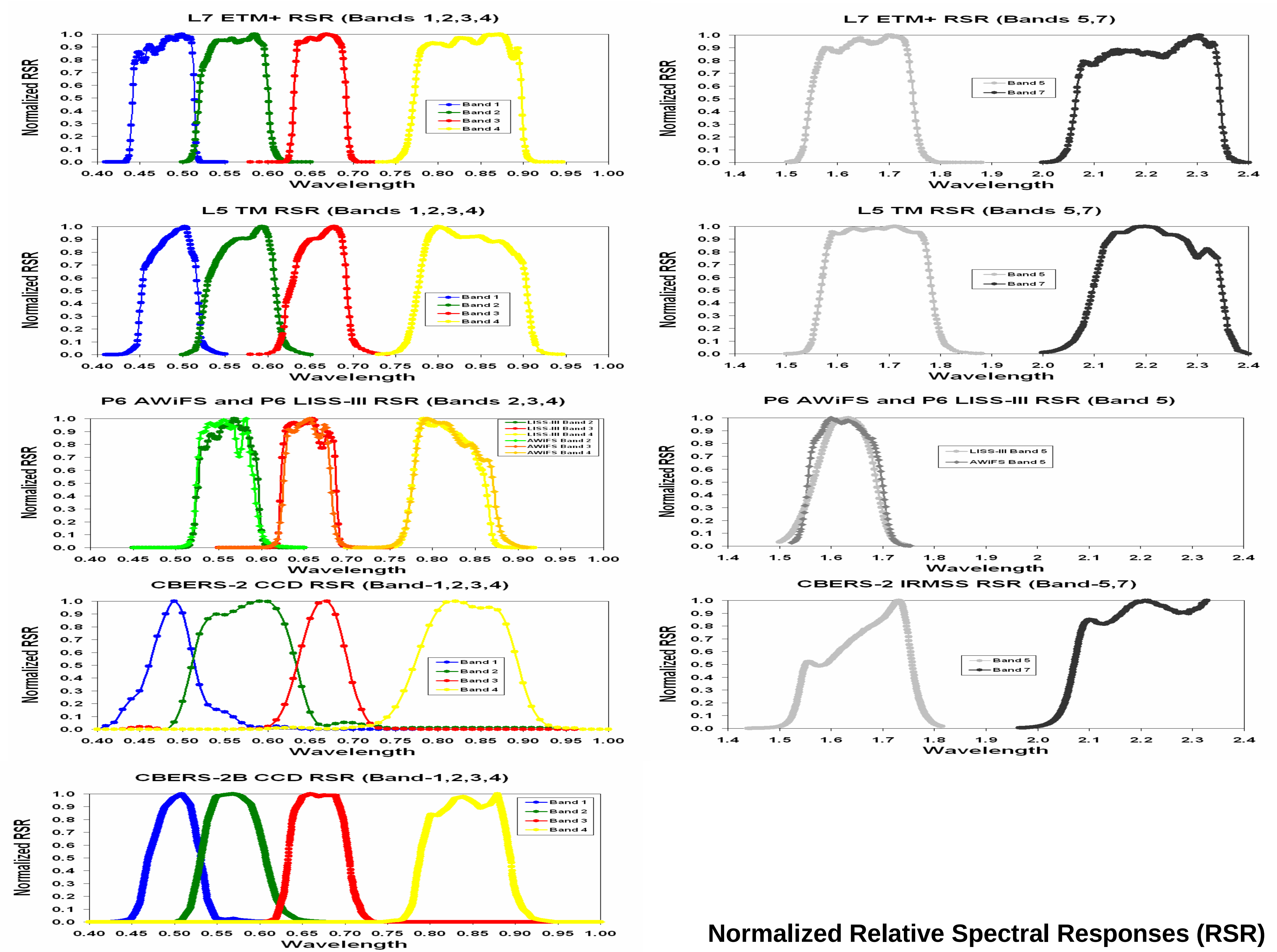
- **Interoperability Arrangements – “What few things must be the same so that everything else can be different?”**

Eliot Christian



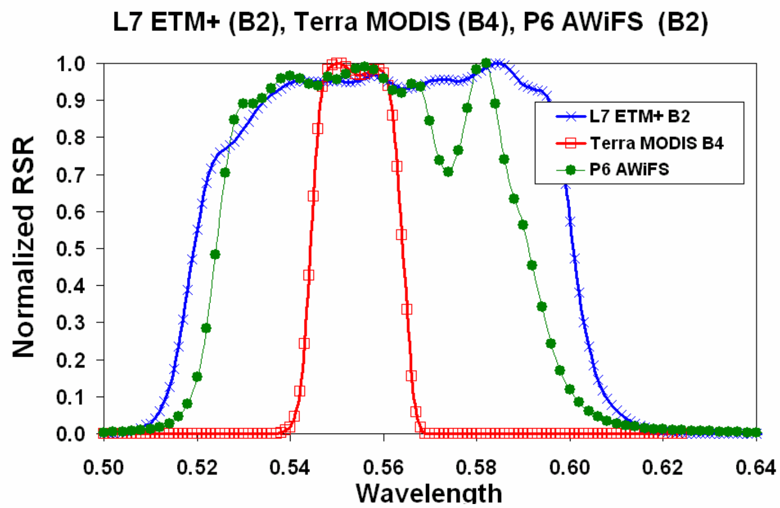
Sensor Overview

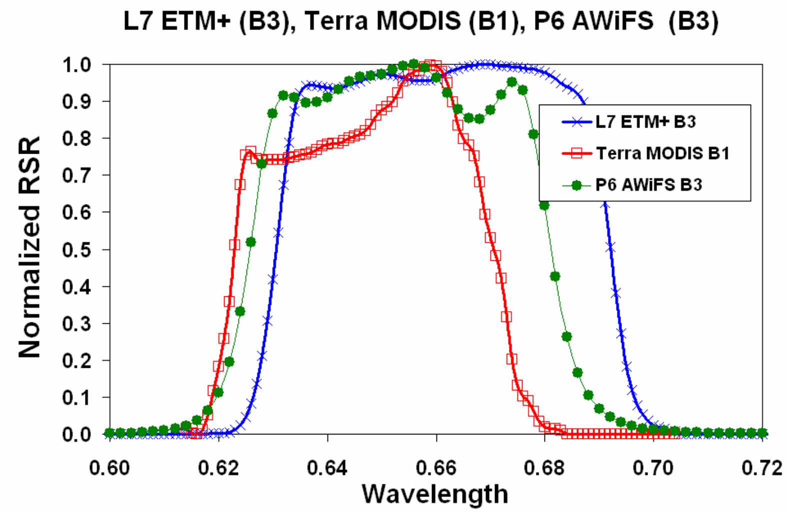
Platform	Terra	Landsat 7	IRS-P6
Sensor	MODIS	ETM+	AWiFS
Number of bands	36	8	4
Spatial resolution	250 m, 500 m, 1 km	15 m, 30 m, 60 m	56 m (near nadir), 70 m (near edge)
Swath	2360 km	187 km	740 km
Spectral coverage	0.4~14 μm	0.4~12.5 μm	0.52~1.7 μm
Pixel quantization	12 bit	8 bit	10 bit
Launch date	Dec 18, 1999	Apr 15, 1999	Oct 17, 2003
Orbit type	Sun synchronous	Sun synchronous	Sun synchronous
Altitude	705 km	705 km	817 km

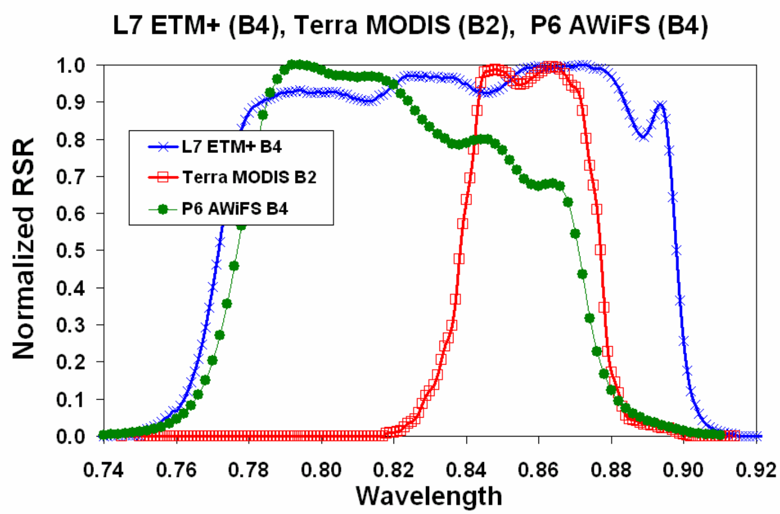


Normalized Relative Spectral Responses (RSR)

Spectral Band Comparison







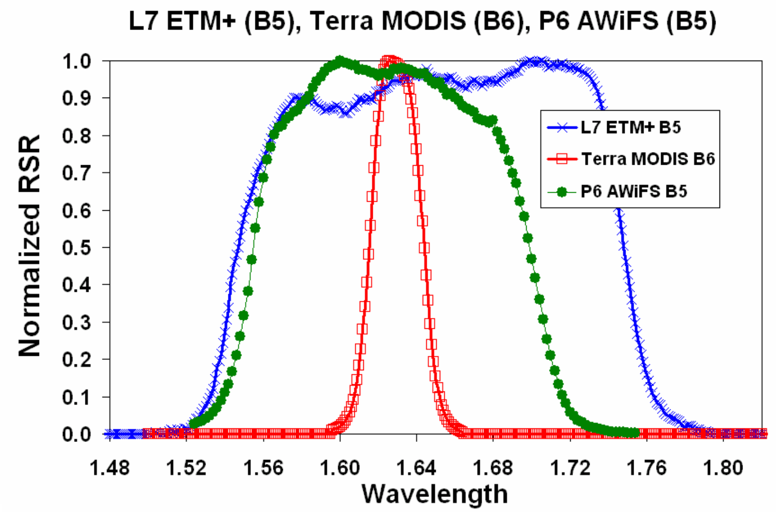
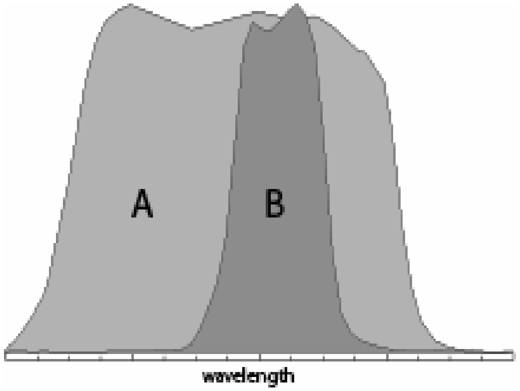


Figure of Merit (alpha)

- **The Figure of Merit ("alpha") is defined as the intersecting areas of two spectral response functions divided by the union of the two areas**
  - alpha = 1.0 indicates complete spectral agreement between two bands
  - alpha = 0.0 indicates complete disagreement

$$\alpha = \frac{A \cap B}{A \cup B}$$

where *A* & *B* represent the areas under the RSR curves



- **The figure of merit approach is plagued by the lack of spectral scene content information, but at least provides a non-unity factor**
  - For a spectrally flat scene, the RSR differences will not matter
- **The figure of merit can be viewed more as a quantization of 'potential' differences in cross-cal between the sensors**

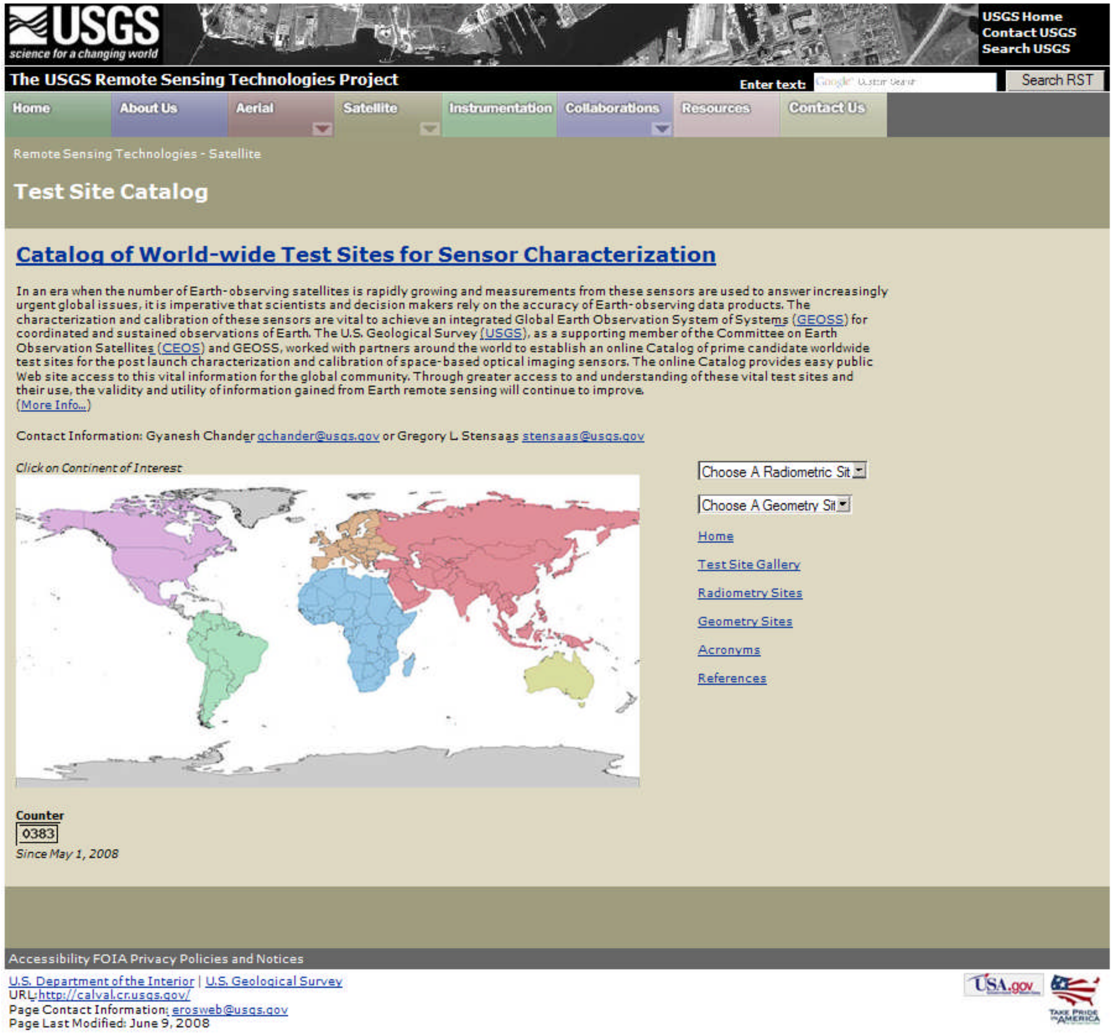
Spectral Band Comparison

L7 ETM+			Terra MODIS			IRS-P6 AWiFS		
Band	(µm)	Res.(m)	Band	(µm)	Res.(m)	Band	(µm)	Res.(m)
1	0.450 - 0.515	30	3	0.459-0.479	500			
2	0.525 - 0.605	30	4	0.545-0.565	500	2	0.520-0.590	56
3	0.630 - 0.690	30	1	0.62-0.67	250	3	0.620-0.680	56
4	0.775 - 0.900	30	2	0.841-0.876	250	4	0.770-0.860	56
5	1.550 - 1.750	30	6	1.628-1.652	500	5	1.550-1.700	56
7	2.090 - 2.350	30	7	2.105-2.155	500			

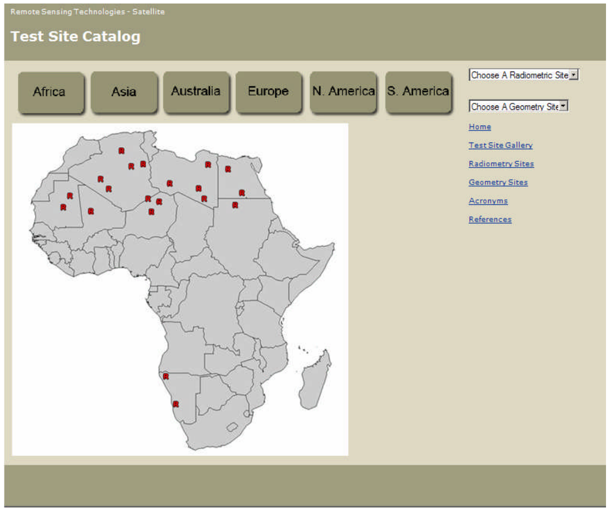
Figure of Merit

Figure of Merit (alpha)			
P6 AWiFS FOM comparison			
Bands	ETM+	TM	MODIS
2	0.819	0.674	0.285
3	0.608	0.620	0.655
4	0.543	0.504	0.136
5	0.687	0.556	0.233

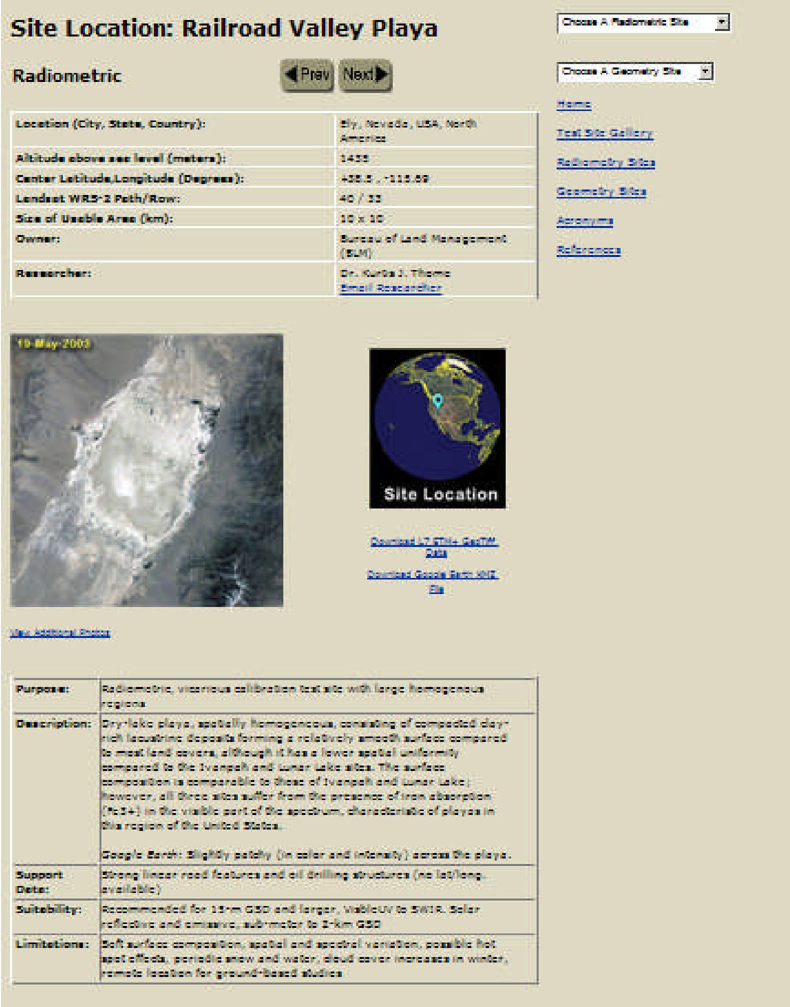
Catalog of World-wide Test Sites
http://calval.cr.usgs.gov/



Radiometry Sites



Online Catalogue Example: Railroad Valley Playa, North America



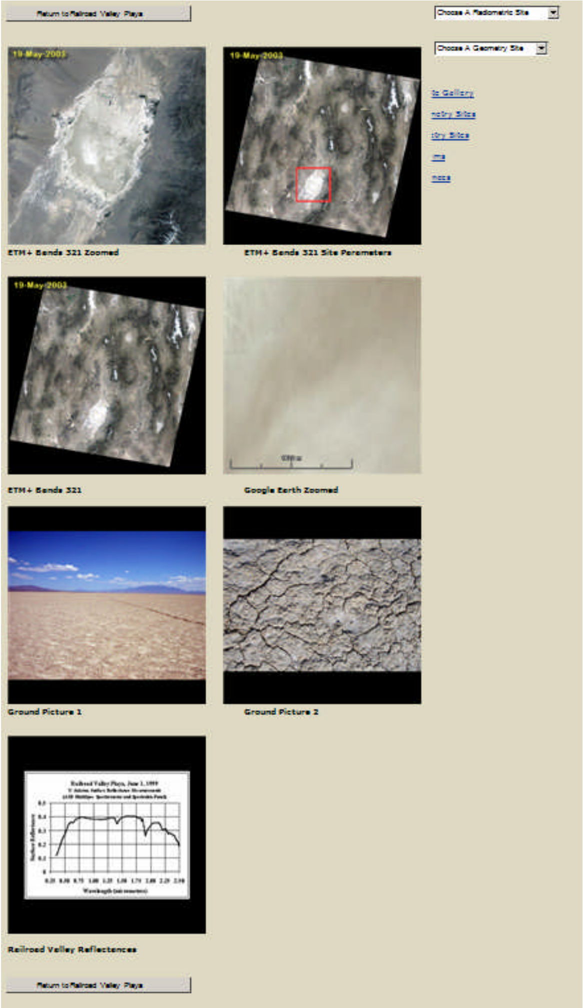
Site Location: Railroad Valley Playa

Radiometric

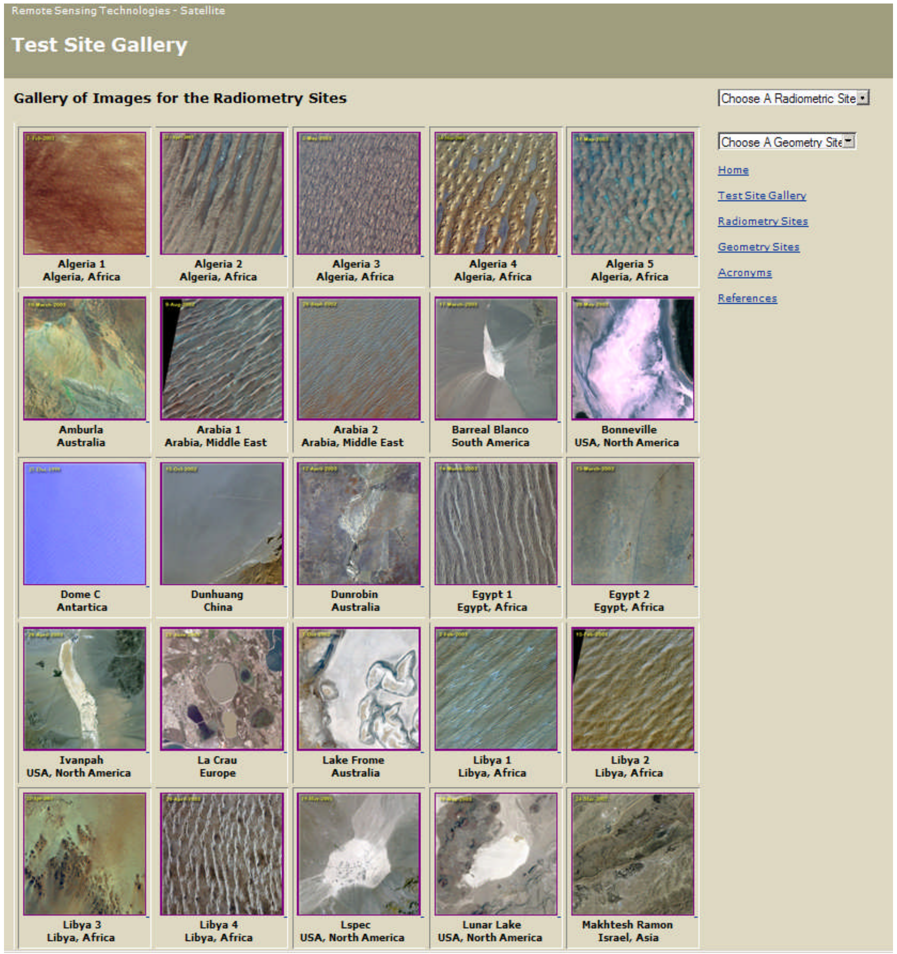
Location (City, State, Country):	Ely, Nevada, USA, North America
Altitude above sea level (meters):	1435
Center Latitude,Longitude (Degrees):	+38.5 , -115.69
Landsat WRS-2 Path/Row:	40 / 33
Size of Usable Area (km):	10 x 10
Owner:	Bureau of Land Management (BLM)
Researcher:	Dr. Kurtis J. Thome Email Researcher

View Additional Photos

Purpose:	Radiometric, vicarious calibration test site with large homogeneous regions
Description:	Dry-lake playa, spatially homogeneous, consisting of compacted clay-rich lacustrine deposits forming a relatively smooth surface compared to most land covers, although it has a lower spatial uniformity compared to the Ivanpah and Lunar Lake sites. The surface composition is comparable to those of Ivanpah and Lunar Lake; however, all three sites suffer from the presence of iron absorption (Fe3+) in the visible part of the spectrum, characteristic of playas in this region of the United States. Google Earth: Slightly patchy (in color and intensity) across the playa.
Support Data:	Strong linear road features and oil drilling structures (no lat/long. available)
Suitability:	Recommended for 15-m GSD and larger, Visible/UV to SWIR. Solar reflective and emissive, sub-meter to 2-km GSD
Limitations:	Soft surface composition, spatial and spectral variation, possible hot spot effects, periodic snow and water, cloud cover increases in winter, remote location for ground-based studies



Test Sites Gallery



Test Sites (Libya 4 & RVPN)

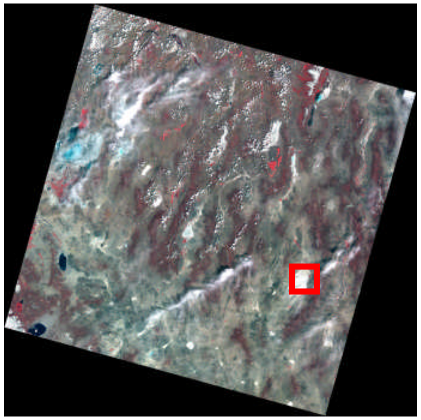
- Location (City, State, Country): Libya, Africa
- Altitude above sea level (meters): 118
- Center Latitude, Longitude (Degrees): +28.55 , +23.39
- Landsat WRS-2 Path/Row: 181 / 40
- High reflectance in visible bands
- Large sand dunes with no vegetation
- Used extensively for long-term stability monitoring

- Location (City, State, Country): Ely, Nevada, USA
- Altitude above sea level (meters): 1435
- Center Latitude, Longitude (Degrees): +38.5 , -115.69
- Landsat WRS-2 Path/Row: 40 / 33
- Used extensively for field campaigns

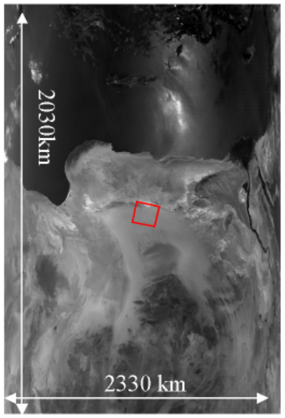
ETM+ Bands: 321 Zoomed

Image Pairs Selection Criteria

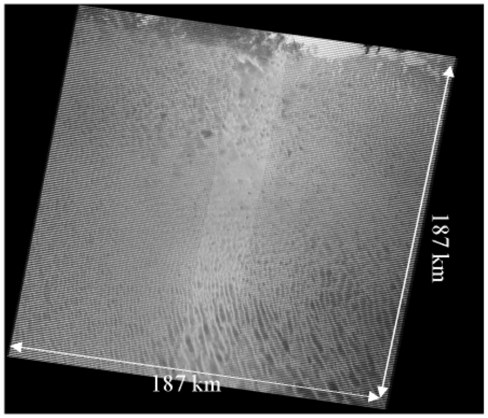
- **Near-simultaneous pairs (within 30 min)**
- **Repeat Cycle in days**
  - ETM+ (16), MODIS (1) AWiFS (5)
- **Cloud free**
- **ROI is close to nadir angle for MODIS & ETM+**



AWiFS



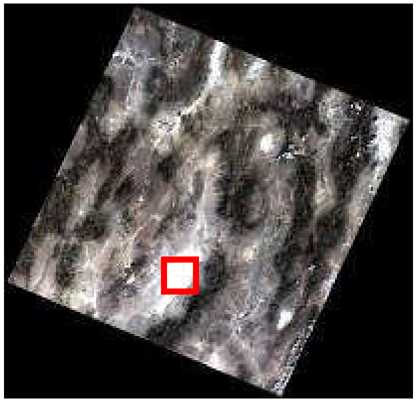
MODIS



ETM+

Libya 4 Test Site

MODIS



ETM+

RVPN Test Site

Methodology

- **Each sensor is well-characterized radiometrically & geometrically**
- **Co-located areas identified for each image pairs**
- **At-sensor radiance ($W/m^2/sr/\mu m$) and at-sensor reflectance [0,1] were computed for all scenes**
- **Linear fits, average percent differences and RMSE's computed for each band**

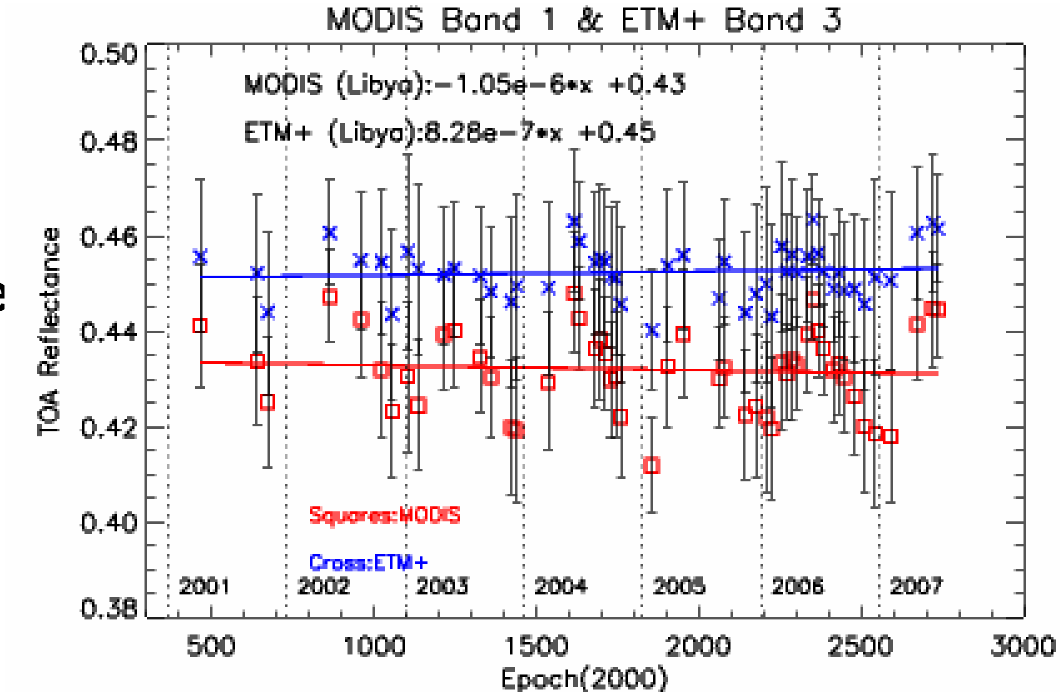
$$\rho_P = \frac{\Pi \bullet L_\lambda \bullet d^2}{ESUN_\lambda \bullet \cos\theta_s}$$

ρ_P=unitless planetary reflectance
L_λ=spectral radiance at the sensor's aperture
d=Earth-Sun distance in astronomical units
$ESUN_\lambda$=Solar exoatmospheric mean irradiances
θ_s=solar zenith angle in degrees

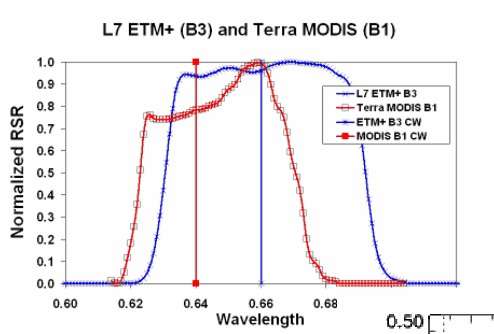
Exoatmospheric Solar Spectral Irradiances					
ESUN UNITS = $W/m^2\ \mu m$					
ETM+ (CHKUR)		MODIS (WRC)		AWiFS (CHKUR)	
1	1969	3	2015.1		
2	1840	4	1859.1	2	1849.82
3	1551	1	1606.1	3	1579.37
4	1044	2	991.72	4	1075.11
5	225.7	6	239.63	5	235.83
7	82.07	7	89.385		

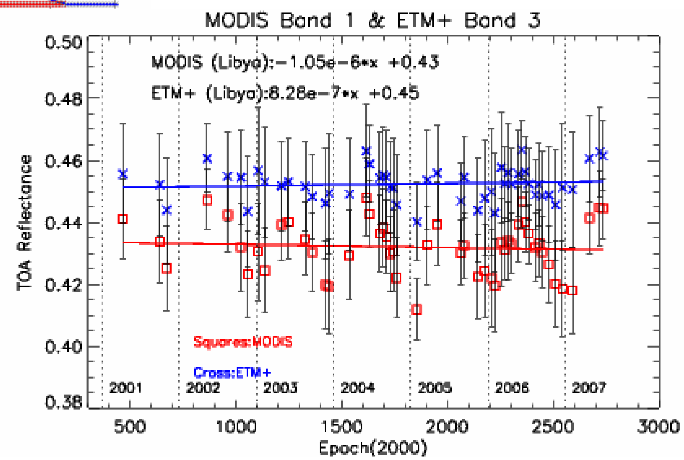
Results

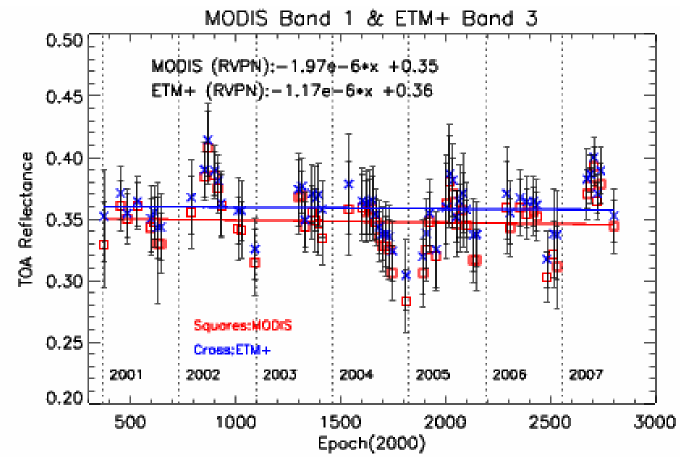
- **Scene standard deviation bars are added**
- **Linear equations are fitted**
  - Slope values are very small
  - There are constant offsets
- **The annual oscillation were caused by BRDF effect**
- **The slope values prove the long term stability of the two sensors**
- **The residue standard deviation values are within the 2% of radiometric specifications**

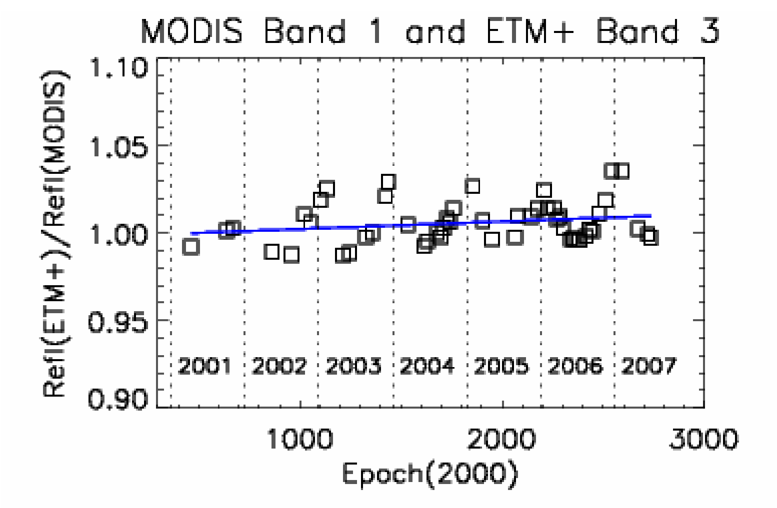


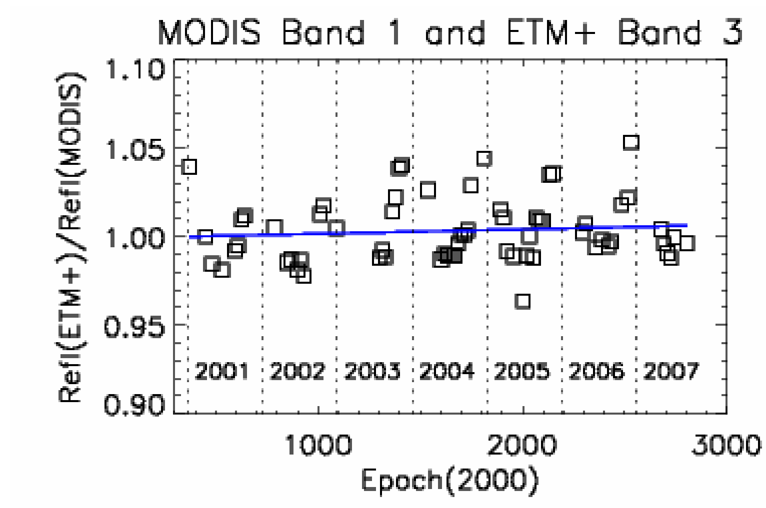
ETM+ B3 & MODIS B1







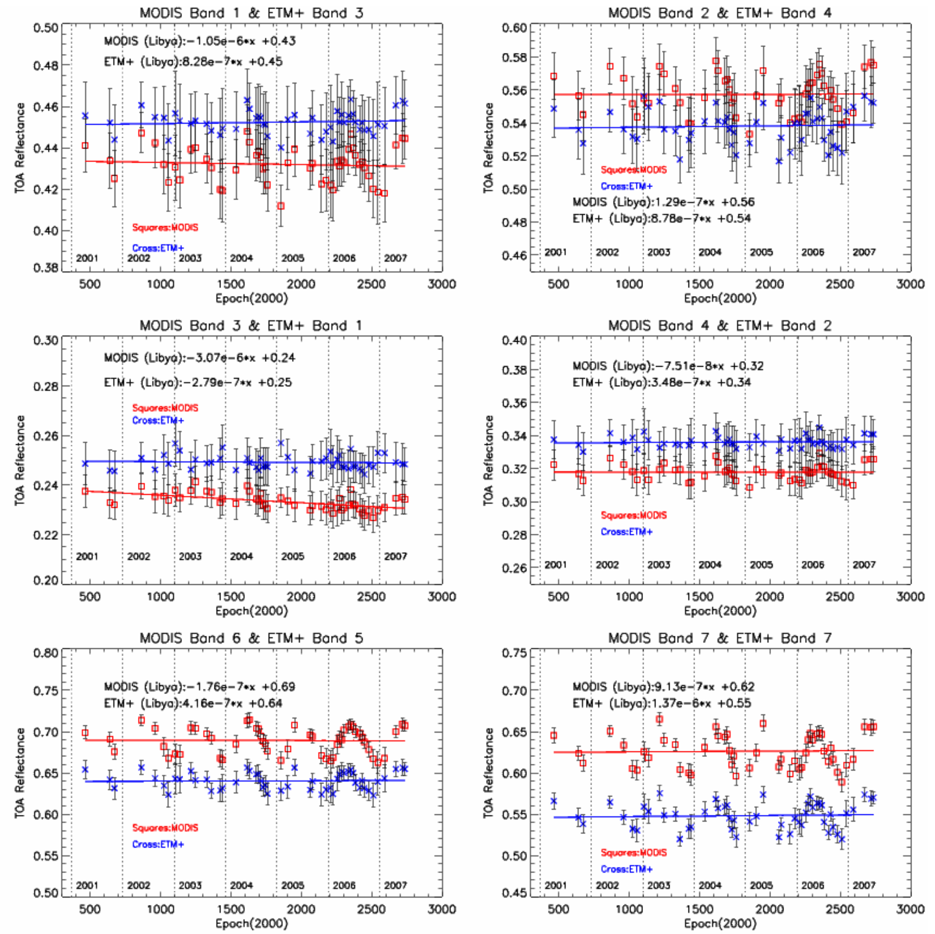


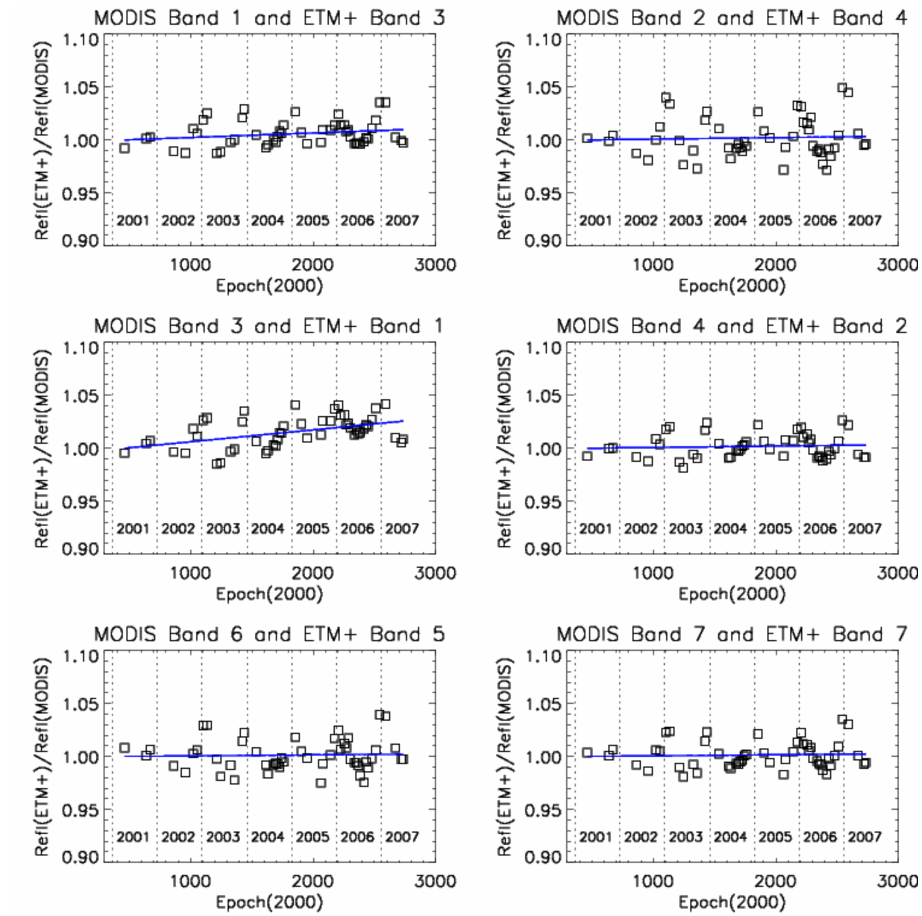


Libya 4

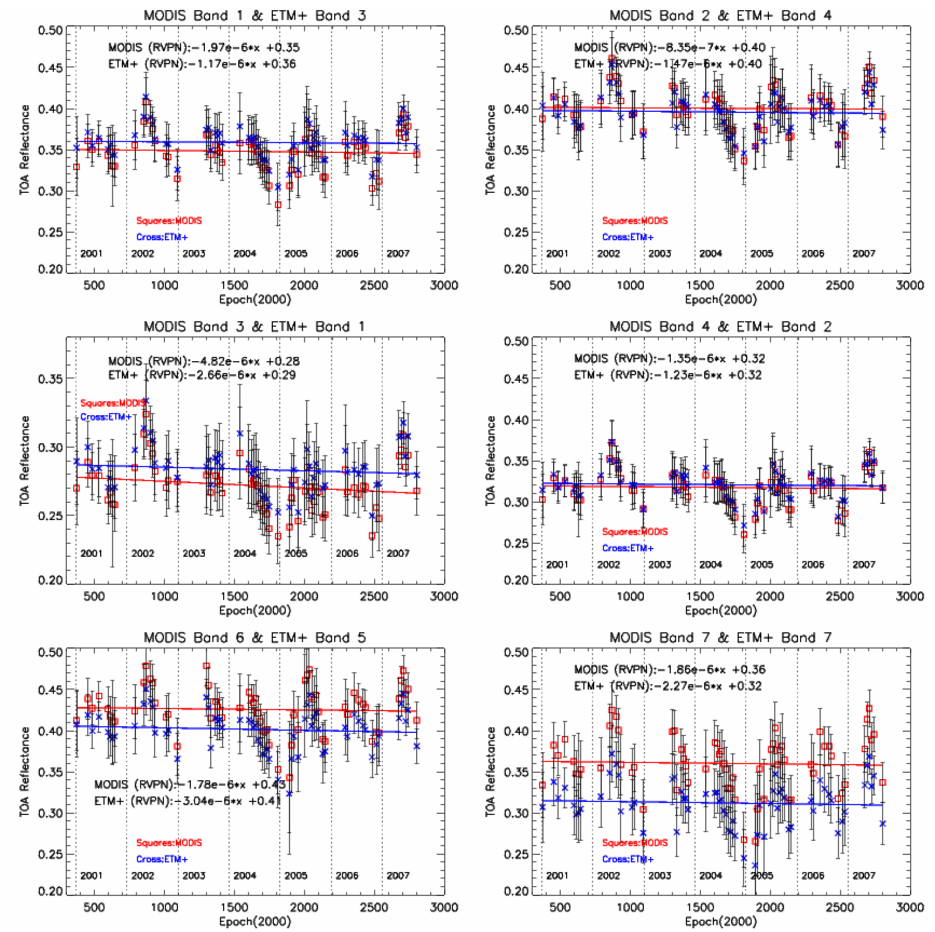
RVPN

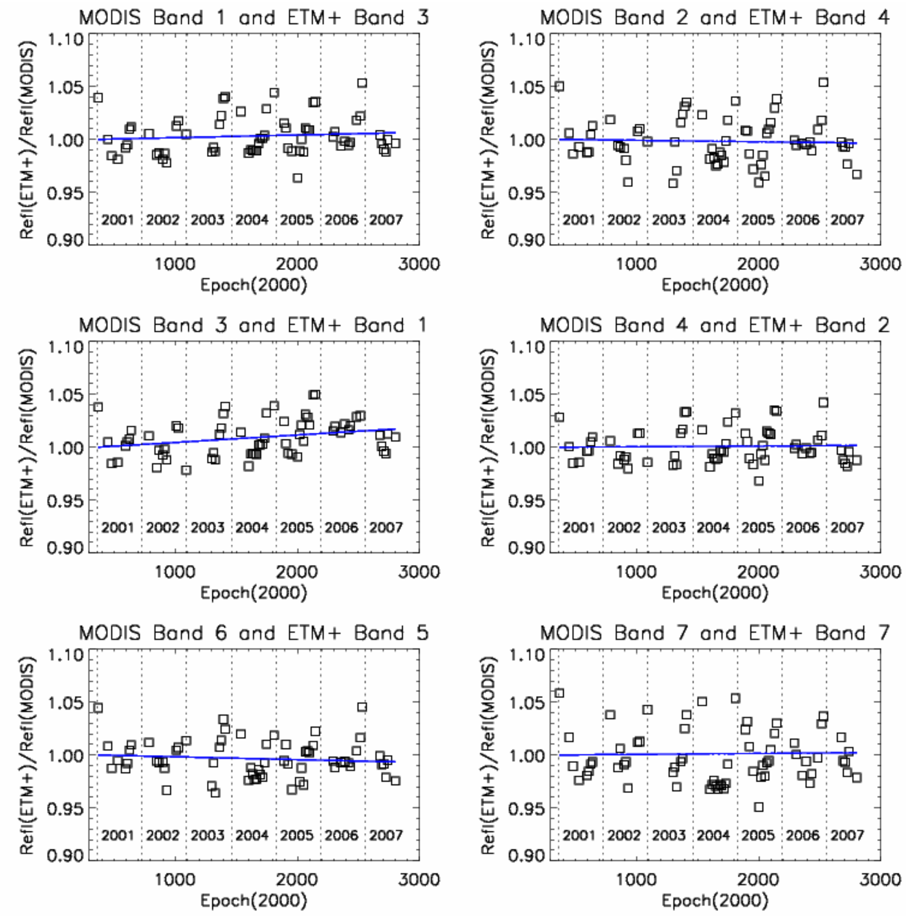
Time Series: Libya 4



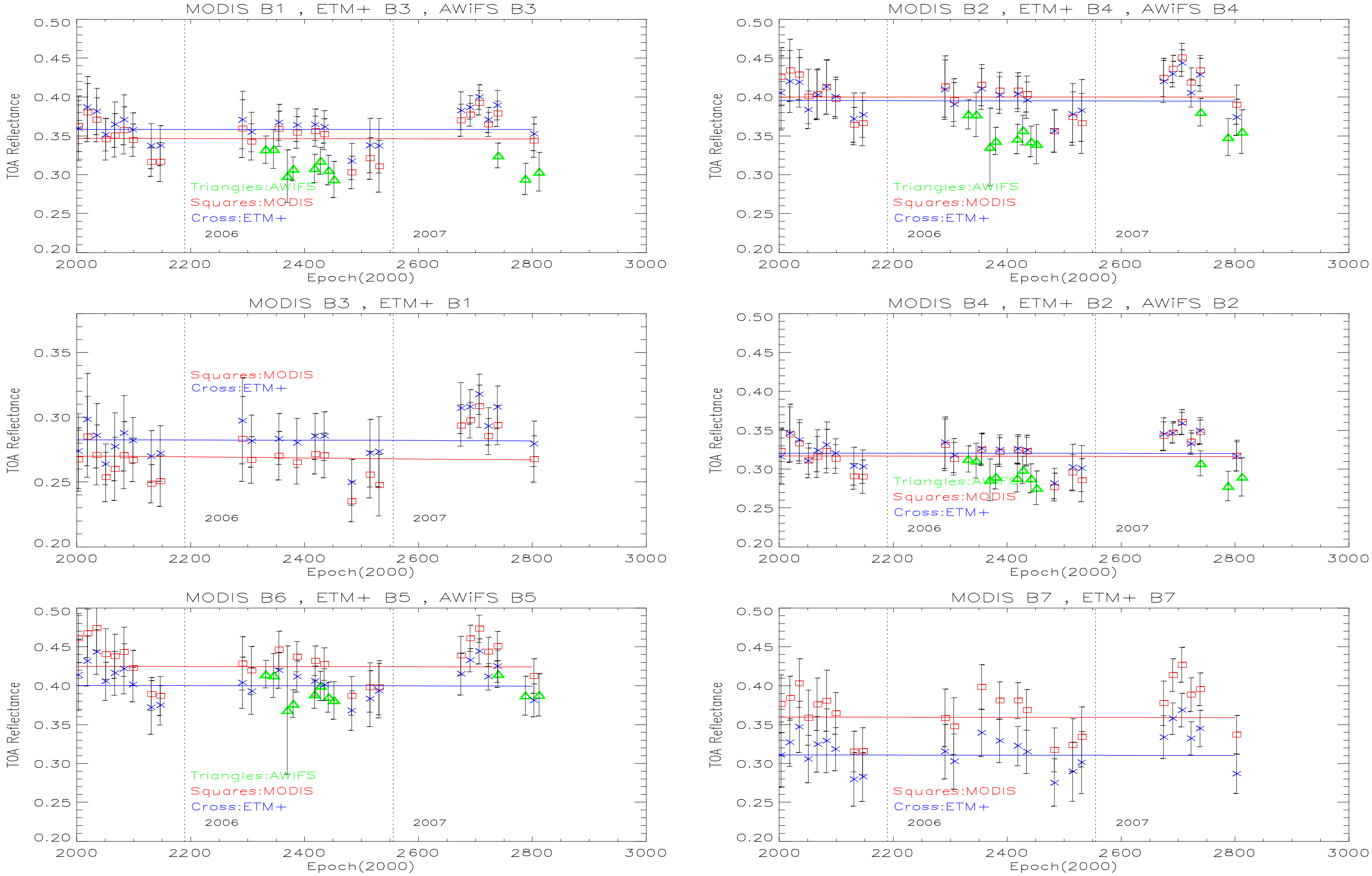


Time Series: RVPN

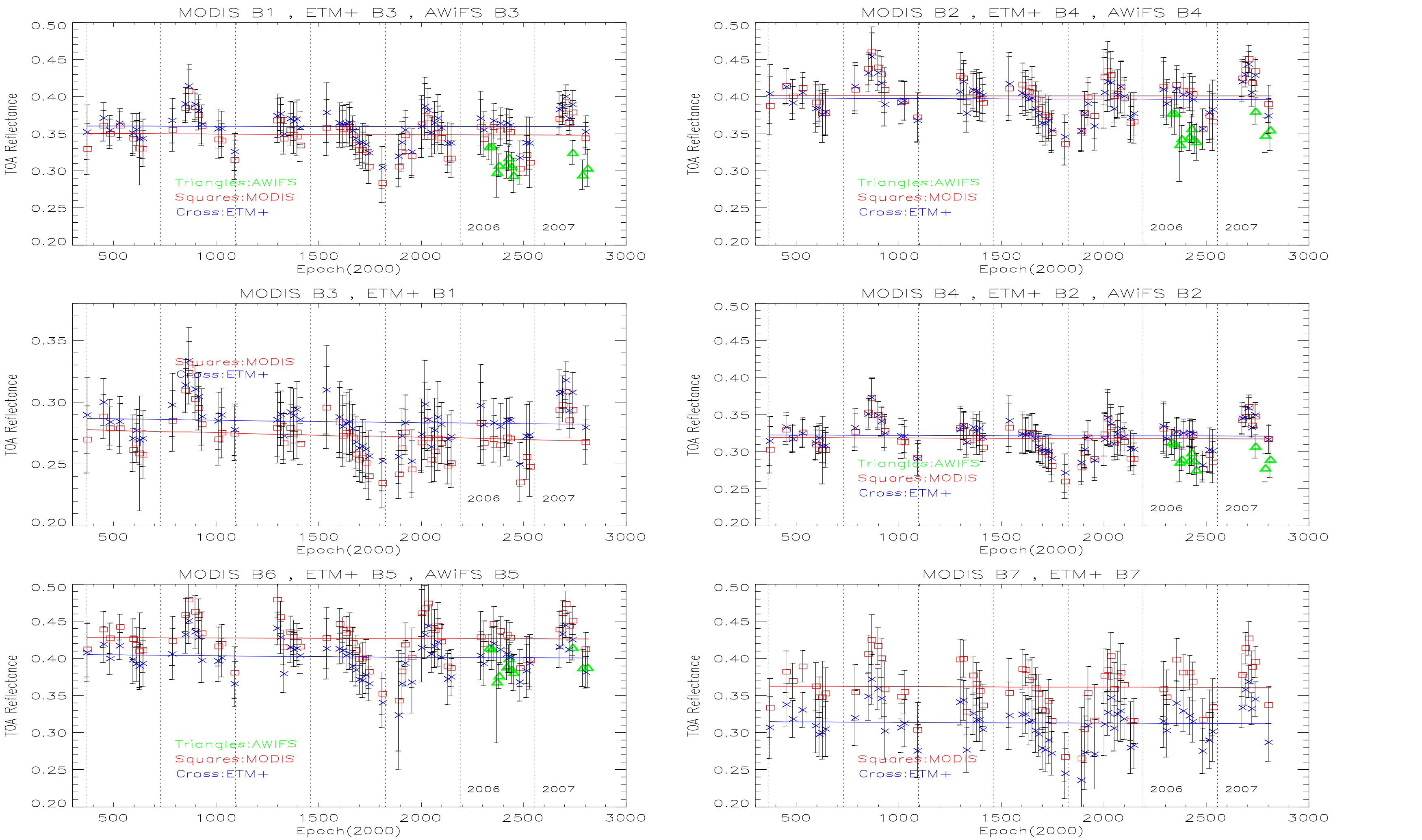


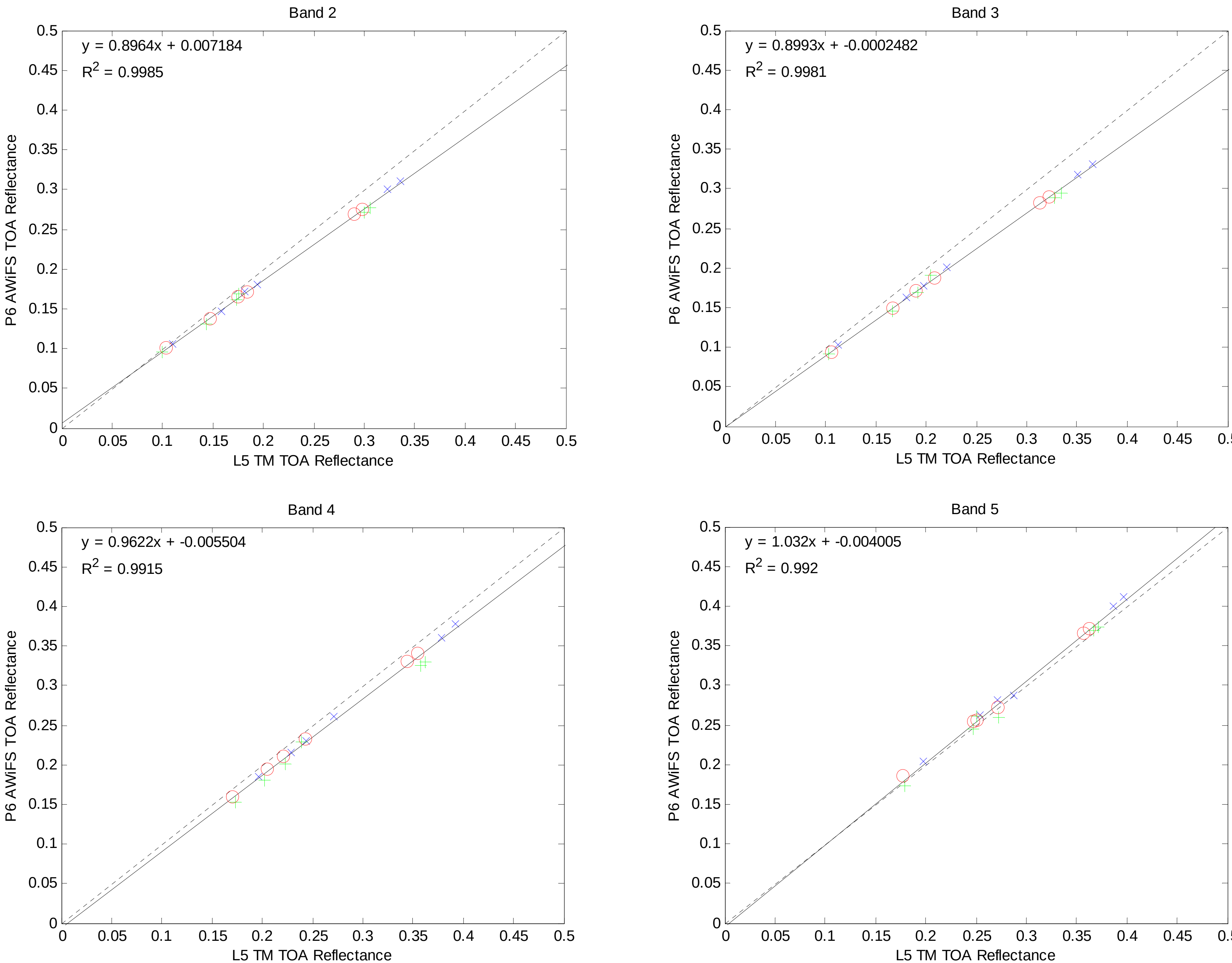


Time Series: RVPN



Time Series: RVPN




Band 2
y = 0.8964x + 0.007184
R2 = 0.9985
P6 AWiFS TOA Reflectance
L5 TM TOA Reflectance
Band 3
y = 0.8993x + -0.0002482
R2 = 0.9981
P6 AWiFS TOA Reflectance
L5 TM TOA Reflectance
Band 4
y = 0.9622x + -0.005504
R2 = 0.9915
P6 AWiFS TOA Reflectance
L5 TM TOA Reflectance
Band 5
y = 1.032x + -0.004005
R2 = 0.992
P6 AWiFS TOA Reflectance
L5 TM TOA Reflectance

Comparison Table

MODIS					ETM+				
Band	**Slope**	**Intercept**	**Image STD**	**Residue STD**	**Band**	**Slope**	**Intercept**	**Image STD**	**Residue STD**
Libya 4 Site									
1	-1.1E-6	0.43	0.018	0.007	**3**	8.3E-7	0.45	0.011	0.005
2	1.3E-7	0.56	0.019	0.011	**4**	8.8E-7	0.54	0.020	0.011
3	-3.1E-6	0.24	0.012	0.003	**1**	-2.8E-7	0.25	0.009	0.002
4	-7.5E-8	0.32	0.014	0.004	**2**	3.5E-7	0.34	0.010	0.003
6	-1.8E-7	0.69	0.019	0.013	**5**	4.2E-7	0.64	0.016	0.010
7	9.1E-7	0.62	0.031	0.020	**7**	1.4E-6	0.55	0.0302	0.016
RVPN Site									
1	-1.9E-6	0.35	0.065	0.023	**3**	-1.1E-6	0.36	0.057	0.020
2	-8.3E-7	0.4	0.063	0.025	**4**	-1.4E-6	0.40	0.057	0.022
3	-4.8E-6	0.28	0.061	0.017	**1**	-2.6E-6	0.29	0.058	0.016
4	-1.3E-6	0.32	0.065	0.021	**2**	-1.2E-6	0.32	0.059	0.019
6	-1.7E-6	0.43	0.070	0.028	**5**	-3.0E-6	0.41	0.061	0.024
7	-1.8E-6	0.36	0.1	0.034	**7**	-2.2E-6	0.32	0.087	0.027

Summary and Future Work

- **A long-term radiometric stability evaluation between Terra MODIS and L7 ETM+ was performed using near-simultaneous scene pairs over the uniform Libyan 4 (56 image pairs) desert target and RVPN (78 image pairs) covering the lifetime of the two sensors**
- **ETM+ and MODIS sensors showed excellent long-term TOA reflectance stability generally within 2%**
  - Results are consistent between Libya 4 and RVPN sites
- **Results from AWiFS sensors show short term stability**
  - Need to monitor the long term trends & absolute calibration
- **ISRO should acquire and archive imagery over five top tier sites!**
  - Get access to AWiFS data from NRSA & ASRC archive
- **Additional work is underway to characterize the uncertainties due to spectral mismatches, spatial, BRDF, and atmospheric impacts**

Backup Slides

CEOS IVOS-19 Test sites
Discussion Summary

#	Site Name	Center Latitude	Center Longitude
Invariant Sites			
1	Libya 4	28.55	23.39
2	Mauritania 1	19.40	-9.30
2	Mauritania 2	20.85	-8.78
3	Algeria 3	30.32	7.66
4	Libya 1	24.42	13.35
5	Algeria 5	31.02	2.23
Core Instrumented Sites			
1	Railroad Valley Playa	38.50	-115.69
2	Ivanpah Playa	35.57	-115.40
3	Lspec Frenchman Flat	36.81	-115.93
4	La Crau	43.47	4.97
5	Dunhuang	40.13	94.34
6	Negev, Southern Israel	30.11	35.01
7	Tuz Golu	38.83	33.33
8	Dome C	-74.50	123.00

Mauritania (consider as one site)

Core "Instrumented" IVOS Sites (Total=8) LANDNET

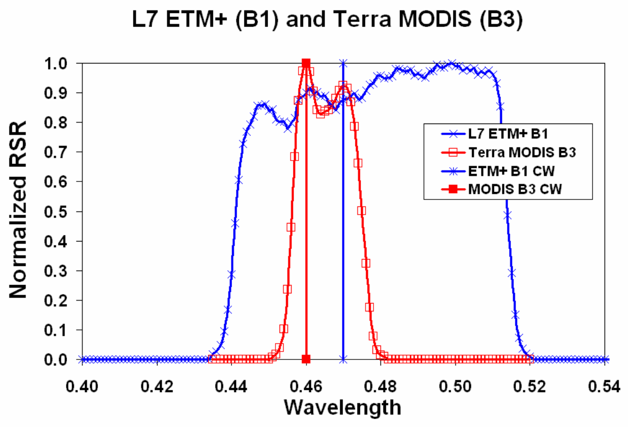
1. **Railroad Valley Playa, NV, USA, North America**
   - Dr. Kurtis J. Thome (kthome@email.arizona.edu**)** – University of Arizona, USA
2. **Ivanpah, NV/CA, USA, North America**
   - Dr. Kurtis J. Thome (kthome@email.arizona.edu**)** – University of Arizona, USA
3. **Lspec Frenchman Flat, NV, USA, North America**
   - Mark C. Helmlinger (mark.helmlinger@ngc.com) – NGST, USA
4. **La Crau, France, Europe**
   - Patrice Henry (patrice.henry@cnes.fr) – CNES, France
5. **Dunhuang, Gobi Desert, Gansu Province, China, Asia**
   - Fu Qiaoyan (fqy@cresda.com) – CRESDA, China
6. **Negev, Southern Israel, Asia**
   - Arnon Karnieli (karnieli@bgu.ac.il) – Ben Gurion University, Israël
7. **Tuz Golu, Central Anatolia, Turkey, Asia**
   - Selime Gurol (selime.gurol@uzay.tubitak.gov.tr) – TUBITAK UZAY, Turkey
8. **Dome C, Antartica**
   - Dr. Stephen Warren (sgw@atmos.washington.edu) – University of Washington, USA

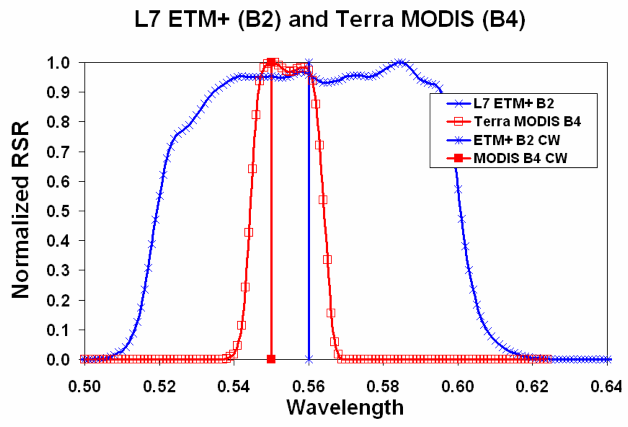
Core “Instrumented” IVOS Sites (Total=8)

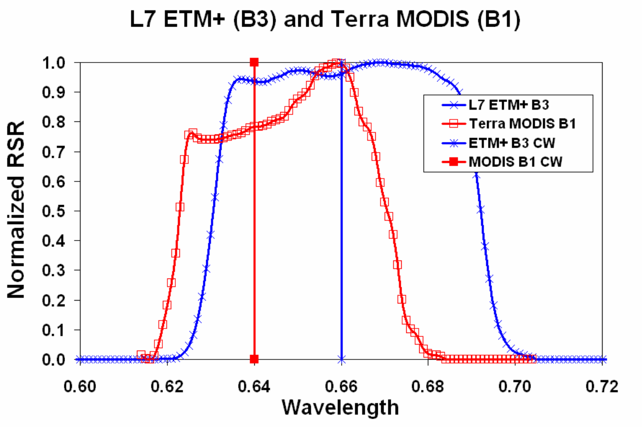
"Invariant" IVOS Sites (Total=5)

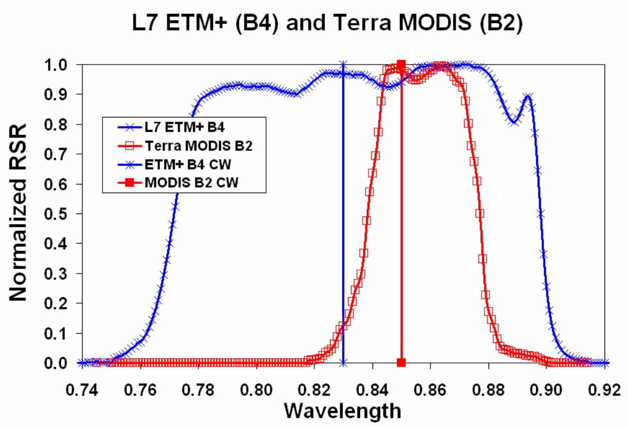
- Libya 4
- Mauritania 1/2
- Algeria 3
- Libya 1
- Algeria 5

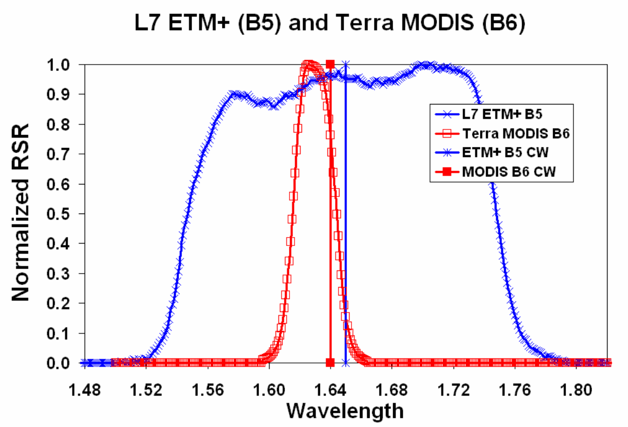
Spectral Band Comparison

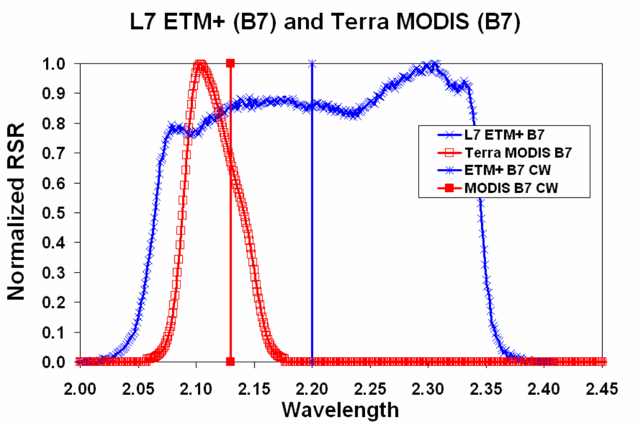




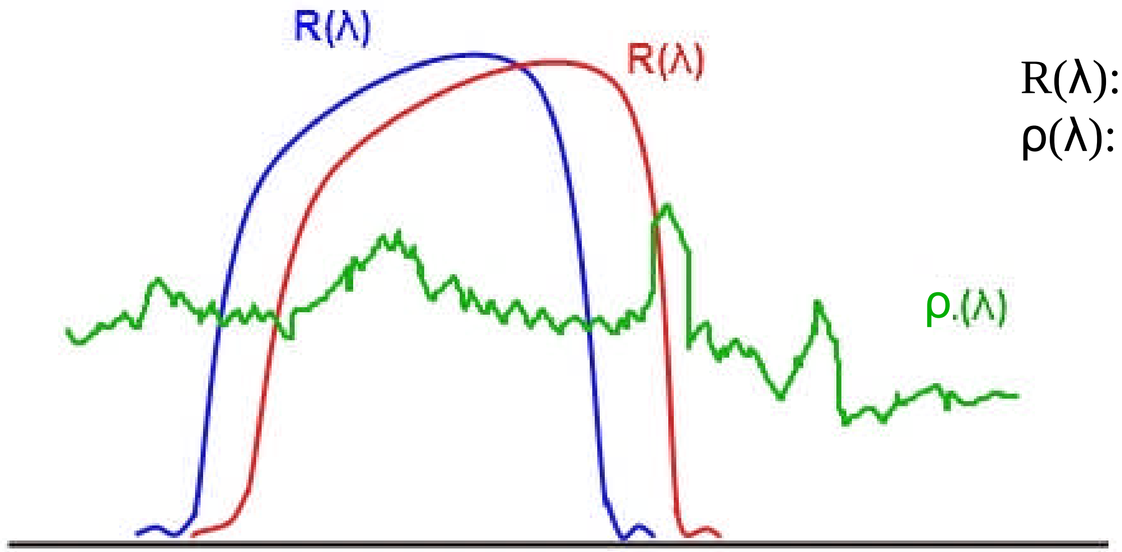








Spectral Band Adjustment Factors (SBAF)

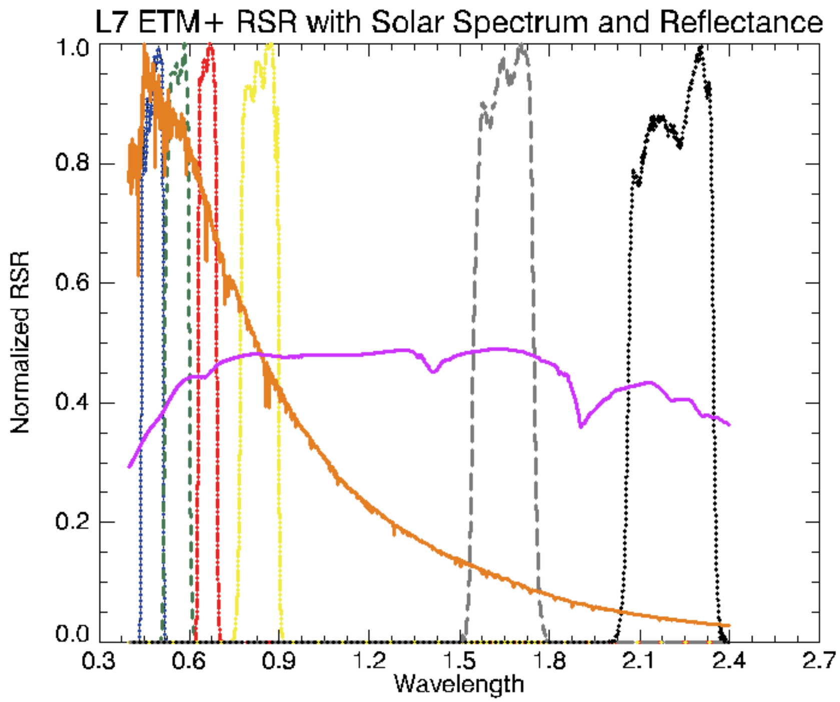


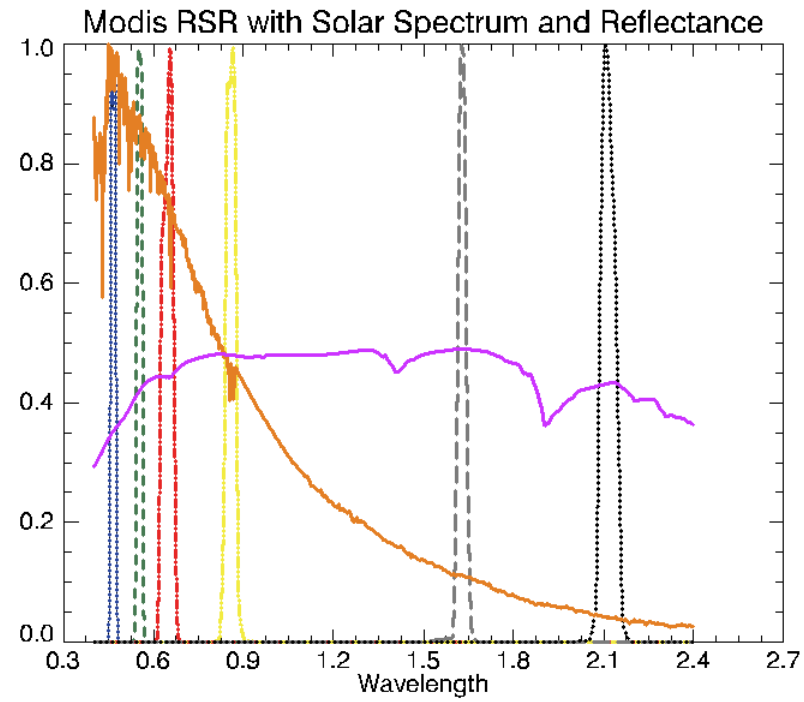
R(λ): RSR Profile
ρ(λ): Spectral Signature of Target

$$\mathrm{SBAF} = \frac{\left(\int \rho(\lambda) \cdot E_o(\lambda) \cdot R(\lambda) \cdot d\lambda \,/\, \int E_o(\lambda) \cdot R(\lambda) \cdot d\lambda\right)}{\left(\int \rho(\lambda) \cdot E_o(\lambda) \cdot R(\lambda) \cdot d\lambda \,/\, \int E_o(\lambda) \cdot R(\lambda) \cdot d\lambda\right)}$$

Simulated ETM+ $\rho^*(\lambda)'_{ETM+} = \mathrm{SBAF} \cdot \rho^*(\lambda)_{MODIS}$

SBAF: RVPN Site (Surface Reflectance)

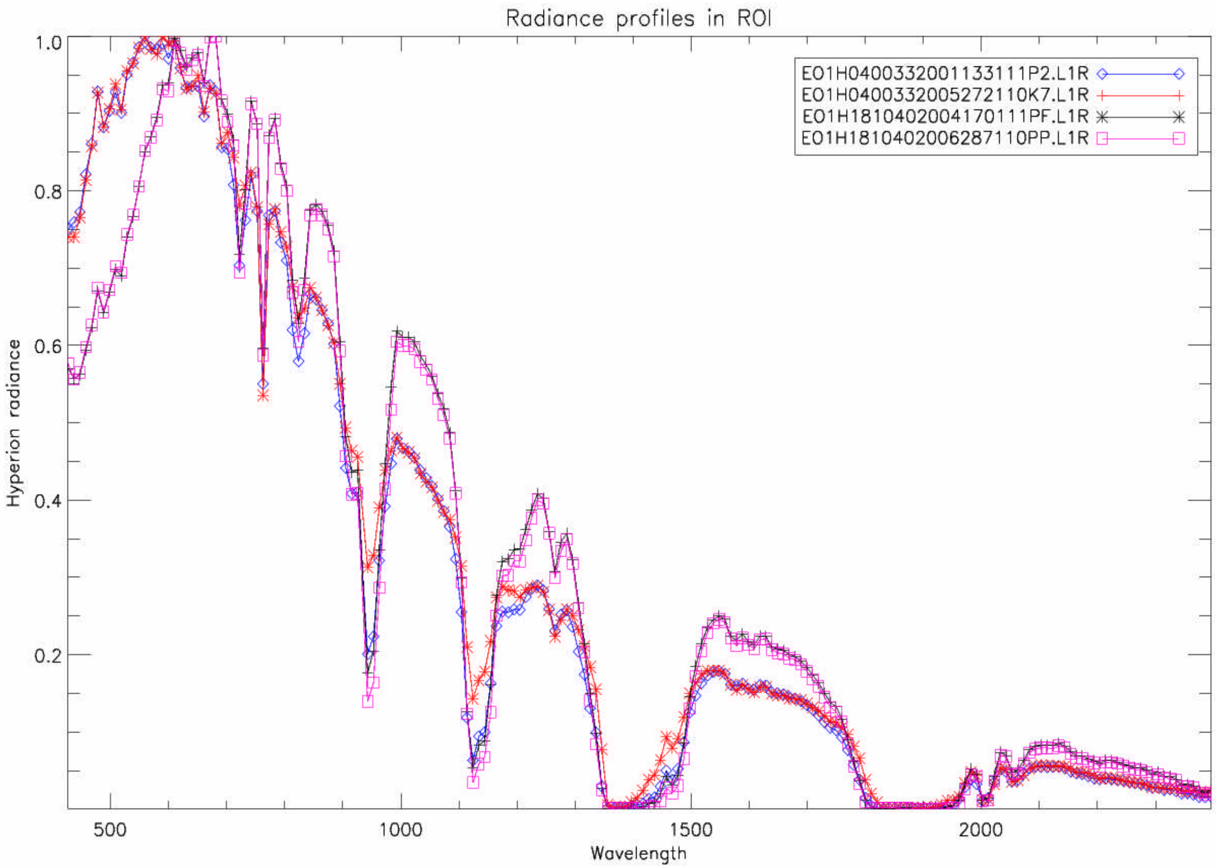


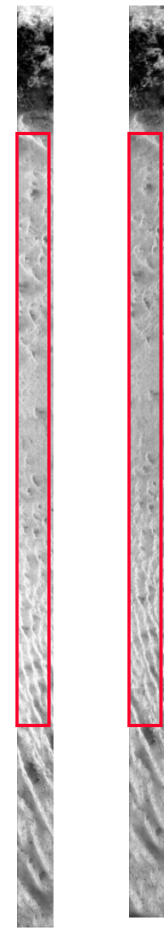


2005-08-12
2004-12-15
2004-07-08
2004-03-18
2003-07-22
2002-06-17

RVPN Surface reflectance spectra were kindly provided by UoA RS Group

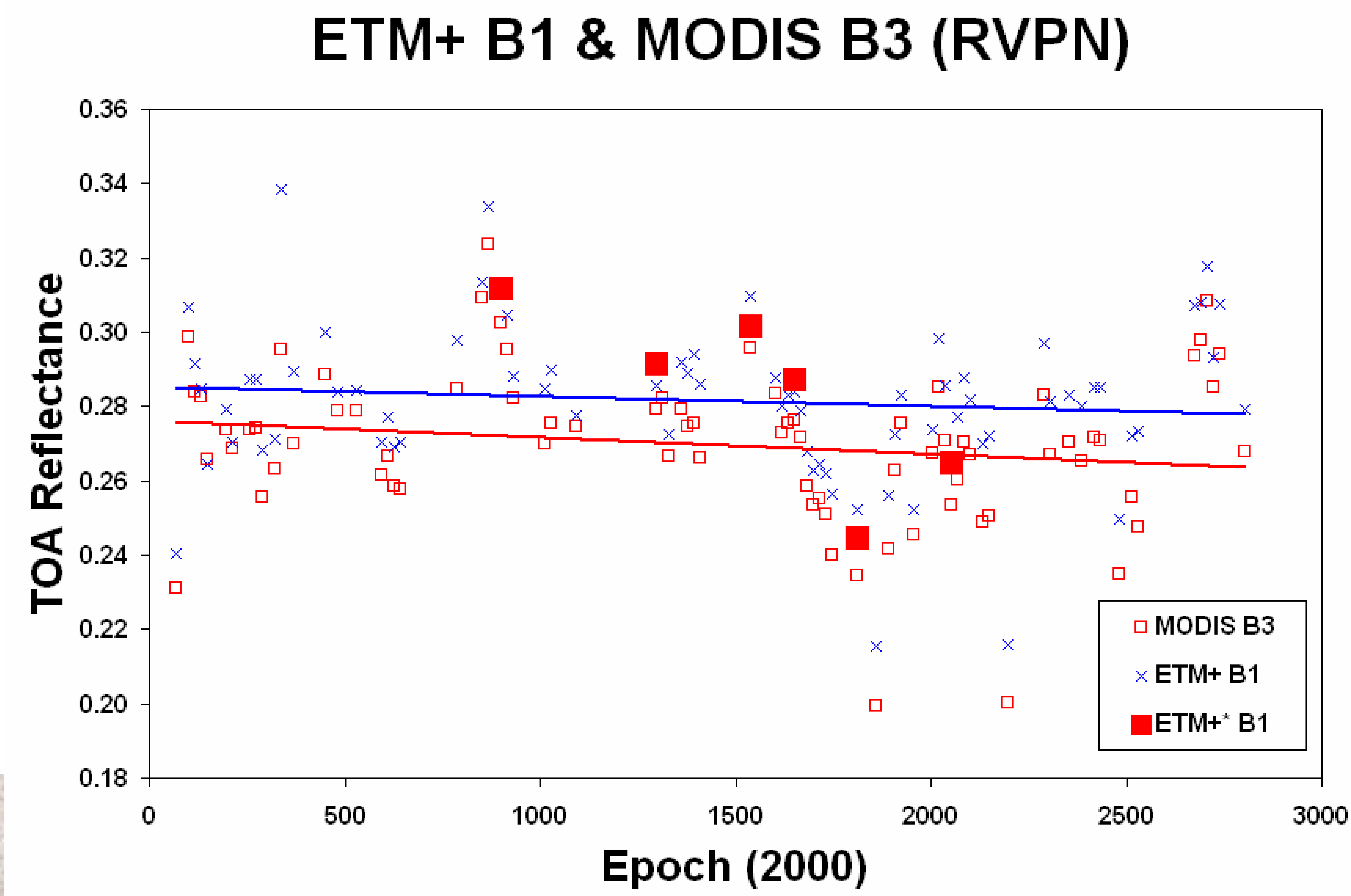
SBAF: Libya 4 Site (EO-1 Hyperion Data)





Libya 4

SBAF for RVPN Dataset



SBAF for Libya 4 Dataset