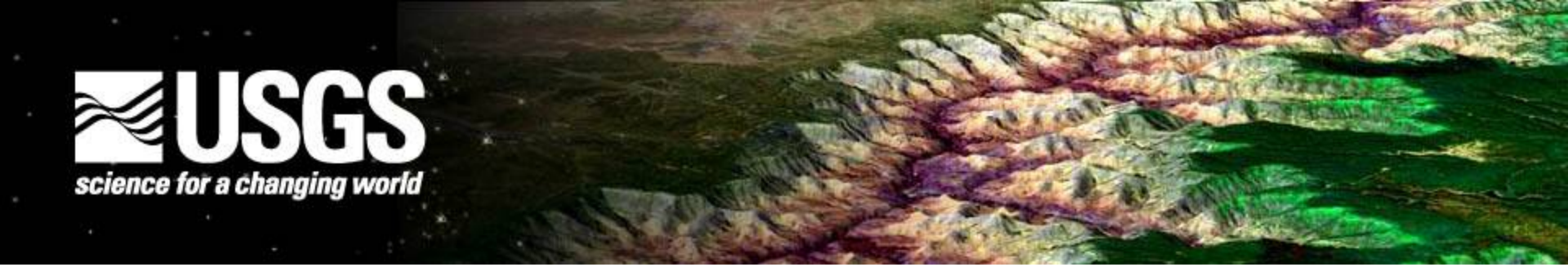

Radiometric & Geometric Assessment of the Data from RapidEye Constellation of Satellites

JACIE Meeting

March 16-18, 2010

Md. Obaidul Haque, Aparajithan Sampath, Gyanesh Chander

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*Work performed under USGS contract 08HQCN0005

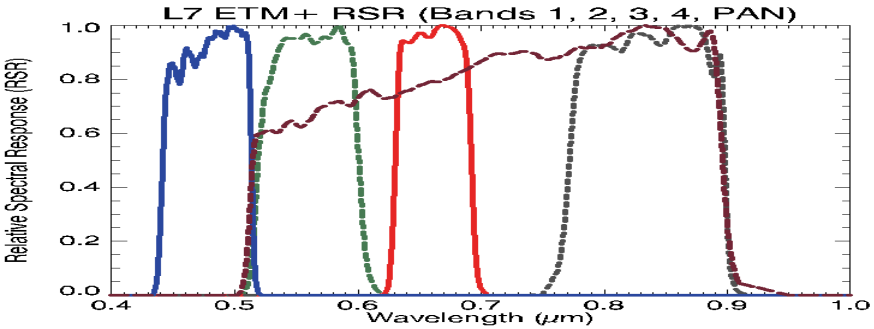
Outline

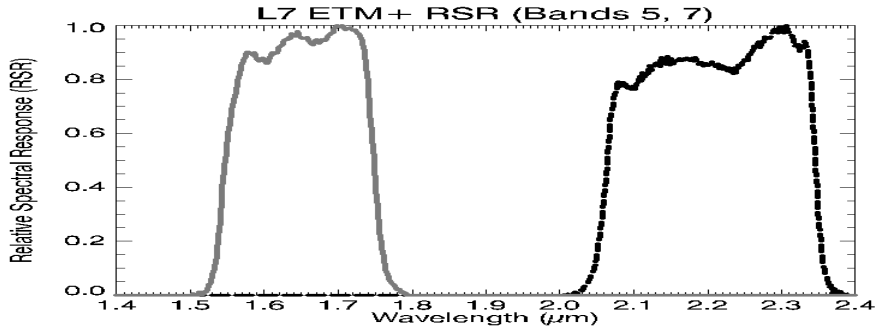
- Sensor Overview
- Cross-comparison
  - RE to RE
  - RE to Landsat 5 TM
  - RE to Landsat 7 ETM+
- Geometry Assessment
  - Band-to-Band
  - Image-to-Image
- Summary

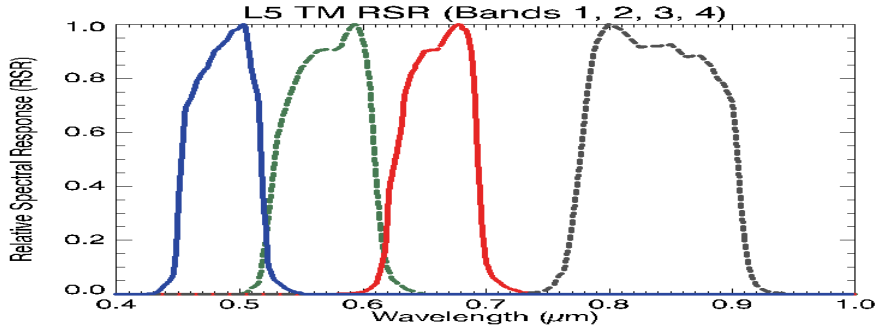
RapidEye Overview

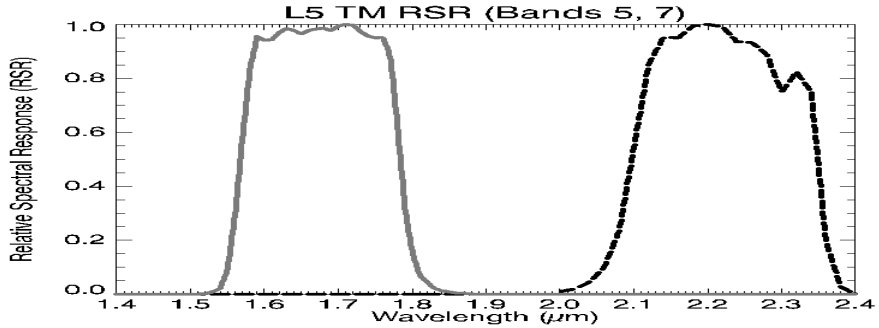
- The five-satellite RapidEye commercial EO constellation was launched on Aug. 29, 2008
- The multispectral imager (MSI) is a pushbroom sensor used to collect data in five discrete bands of the EM spectrum at a generic spatial resolution of 6.5 m

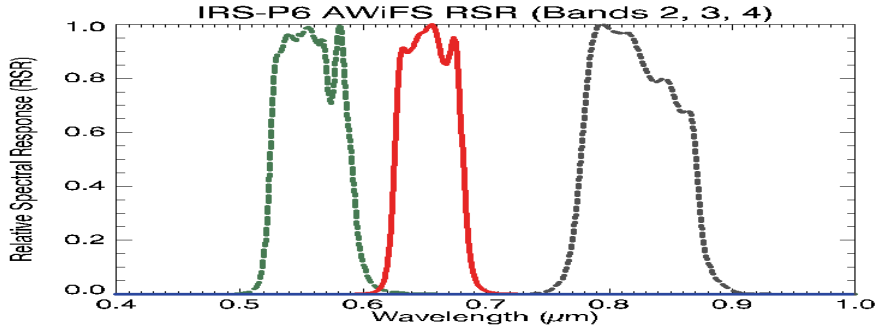
Platform	Landsat 5	Landsat 7	Terra	IRS-P6	RapidEye
Sensor	TM	ETM+	MODIS	AWiFS	MSI
Number of Bands	7	8	36	4	5
Spatial Resolution (m)	30, 120	15, 30, 60	250, 500, 1 km	56 (nadir), 70	5
Swath (km)	183	183	2330	740	77
Spectral Coverage (µm)	0.4~12.5	0.4~12.5	0.4~14	0.52~1.7	0.4~0.85
Pixel Quantization (bits)	8	8	12	10	12
Launch Date	1-Mar-84	15-Apr-99	18-Dec-99	17-Oct-03	29-Aug-08
Orbit Type	Sun synchronous	Sun synchronous	Sun synchronous	Sun synchronous	Sun synchronous
Equatorial Crossing Time	10:00 AM	10:00 AM	10:30 AM	10:30 AM	11:00 AM
Altitude (km)	705	705	705	817	630

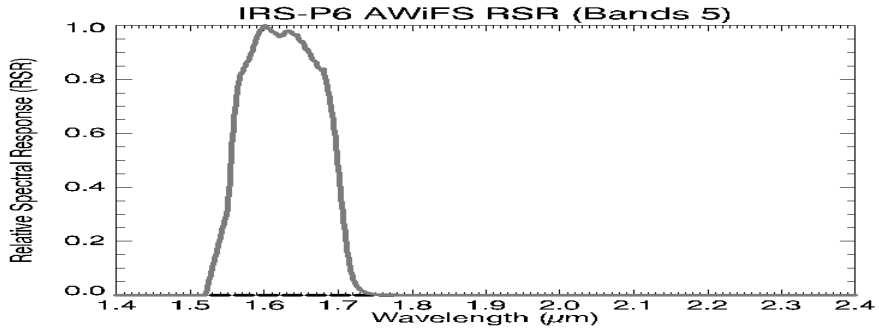

L7 ETM+ RSR (Bands 1, 2, 3, 4, PAN)
Relative Spectral Response (RSR)
Wavelength (μm)

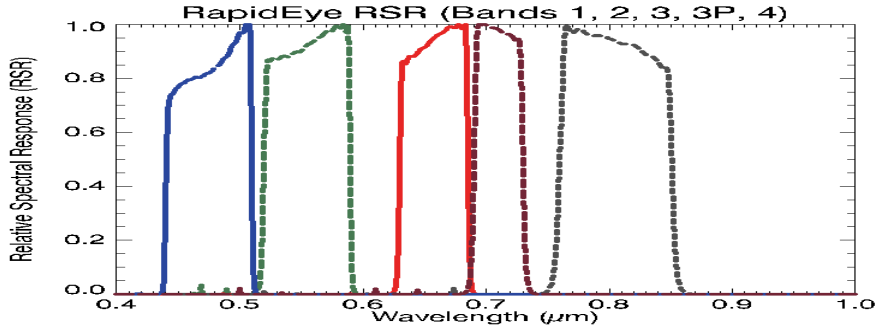

L7 ETM+ RSR (Bands 5, 7)
Relative Spectral Response (RSR)
Wavelength (μm)


L5 TM RSR (Bands 1, 2, 3, 4)
Relative Spectral Response (RSR)
Wavelength (μm)


L5 TM RSR (Bands 5, 7)
Relative Spectral Response (RSR)
Wavelength (μm)


IRS-P6 AWiFS RSR (Bands 2, 3, 4)
Relative Spectral Response (RSR)
Wavelength (μm)


IRS-P6 AWiFS RSR (Bands 5)
Relative Spectral Response (RSR)
Wavelength (μm)


RapidEye RSR (Bands 1, 2, 3, 3P, 4)
Relative Spectral Response (RSR)
Wavelength (μm)

Conversion to at-sensor spectral radiance (Q_{cal}-to- L_λ)

- Landsat TM/ETM+ sensor

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{cal\,\max} - Q_{cal\,\min}} \right) (Q_{cal} - Q_{cal\,\min}) + LMIN_\lambda$$

  - The $LMIN_\lambda$ and $LMAX_\lambda$ are a representation of how the output Landsat Level 1 data products are scaled in at-sensor radiance units
  - The scenes processed using LPGS include a header file (.MTL), which lists these values

- RapidEye sensor

$$L_\lambda = \frac{Q_{cal}}{100}$$

  - Radiance product: (W/m^2 sr µm) / (Radiometric Scale Factor)
  - The Radiometric Scale Factor is 1/100
  - For instance, a product pixel value of 1510 would represent radiance units of 15.1 W/m^2 sr µm

Conversion to TOA Reflectance

- When comparing images from different sensors, there are three advantages to using TOA reflectance instead of at-sensor spectral radiance
  - First, it removes the cosine effect of different solar zenith angles due to the time difference between data acquisitions
  - Second, TOA reflectance compensates for different values of the exoatmospheric solar irradiance arising from spectral band differences
  - Third, the TOA reflectance corrects for the variation in the Earth-Sun distance between different data acquisition dates. These variations can be significant geographically and temporally

Conversion to TOA Reflectance (L_λ-to- ρ_P)

- A reduction in scene-to-scene variability can be achieved by converting the at-sensor spectral radiance to exoatmospheric reflectance:

RapidEye						
Band	CHKUR	Thuillier	SIRS	WRC	Kurucz	New Kurucz
1 (Blue)	1950	2003	1989	1969	2003	1998
2 (Green)	1815	1824	1848	1853	1816	1863
3 (Red)	1566	1541	1531	1562	1573	1560
4 (Red Edge)	1352	1399	1362	1387	1392	1395
5 (NIR)	1121	1117	1100	1127	1121	1124

$ESUN_\lambda$ (Thuillier Model)		
Band	L7 ETM+	L5 TM
1	1997	1983
2	1812	1796
3	1533	1536
4	1039	1031
5	230.8	220.0
7	84.90	83.44
PAN	1362	

Where:

- ρ_λ = Planetary directional TOA reflectance for lambertian surfaces [unitless]
- π = Mathematical constant approximately equal to 3.14159 [unitless]
- L_λ =Spectral radiance at the sensor's aperture [W/(m^2 sr µm)]
- d = Earth-Sun distance [astronomical units]
- $ESUN_\lambda$ = Mean exoatmospheric solar irradiance [W/(m^2 µm)]
- θ_s = Solar zenith angle [degrees]

$$\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos\theta_s}$$

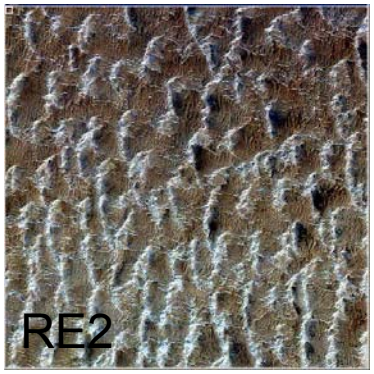
Libya-4 Test Site

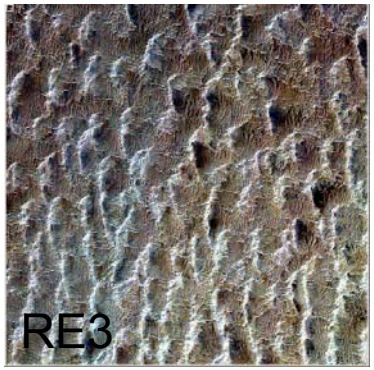
- Libya 4 is a high reflectance site
  - The Libyan Desert site is made up of sand dunes with no vegetation
  - Though the presence of sand dunes at the test site does not satisfy the criterion of flat terrain, this site exhibits reasonable spatial, spectral, & temporal uniformity for medium resolution sensors & has minimal cloud cover
- Aerosol loading is typically low

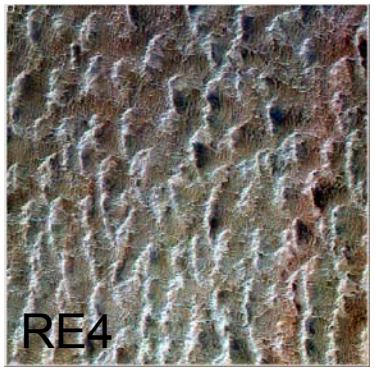
- Location (City, State, Country): Libya, Africa
- Altitude above sea level (meters): 118
- Center Lat, Long (Degrees): +28.55 , +23.39
- Landsat WRS-2 Path/Row: 181 / 40
- Size of Usable Area (km): 75 x 75

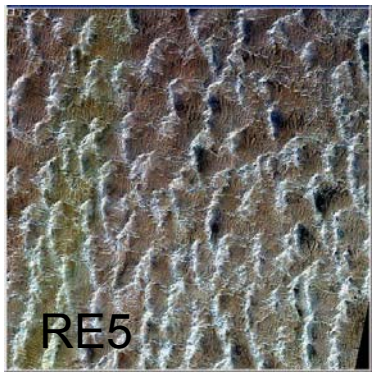
RE Over Libya 4 (Metadata Summary)

	RE1	RE2	RE3	RE4	RE5
Acquisition Date	8/17/2009	8/27/2009	8/14/2009	8/15/2009	9/4/2009
Illumination Azimuth Angle	155.75	154.70	150.36	151.32	162.55
Azimuth Angle	99.43	278.40	100.25	99.70	99.20
Illumination Elevation Angle	73.45	69.69	73.81	73.59	67.61
radiometricScaleFactor	0.01	0.01	0.01	0.01	0.01
Across Track Incidence Angle	11.29	8.87	-7.16	-9.19	8.75
Earth Sun Distance (d)	1.0124	1.0103	1.0129	1.0127	1.0084







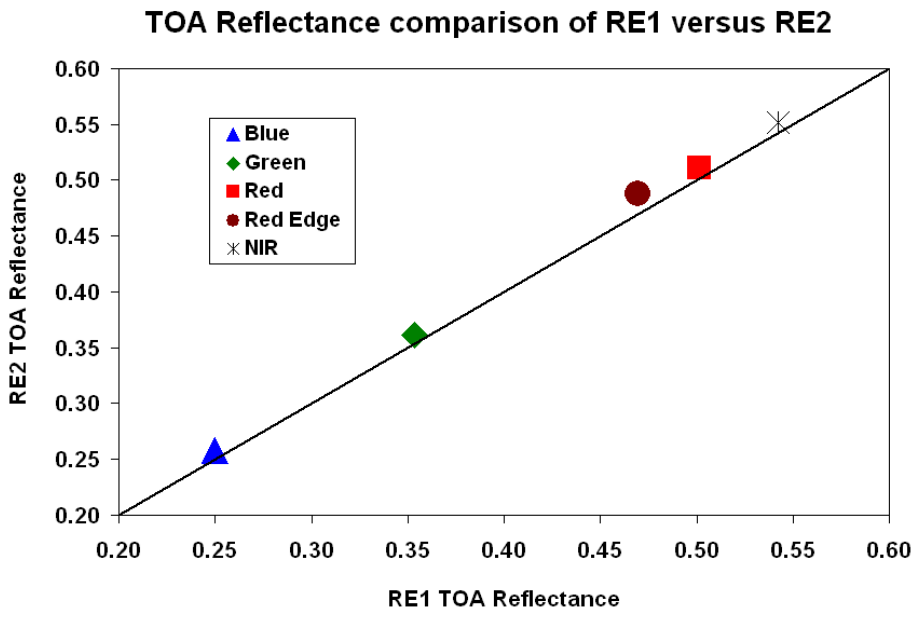


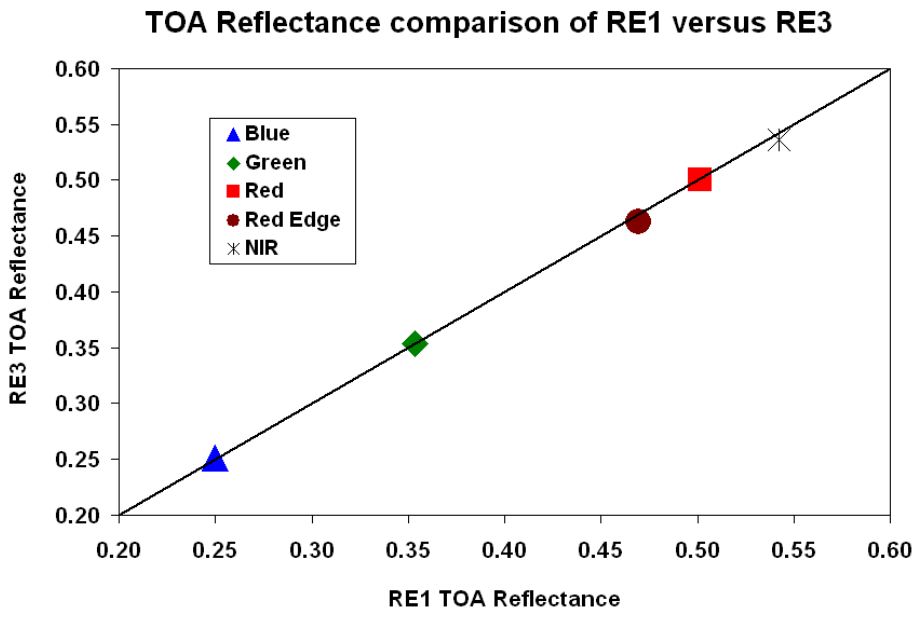
RE to RE Comparison Methodology

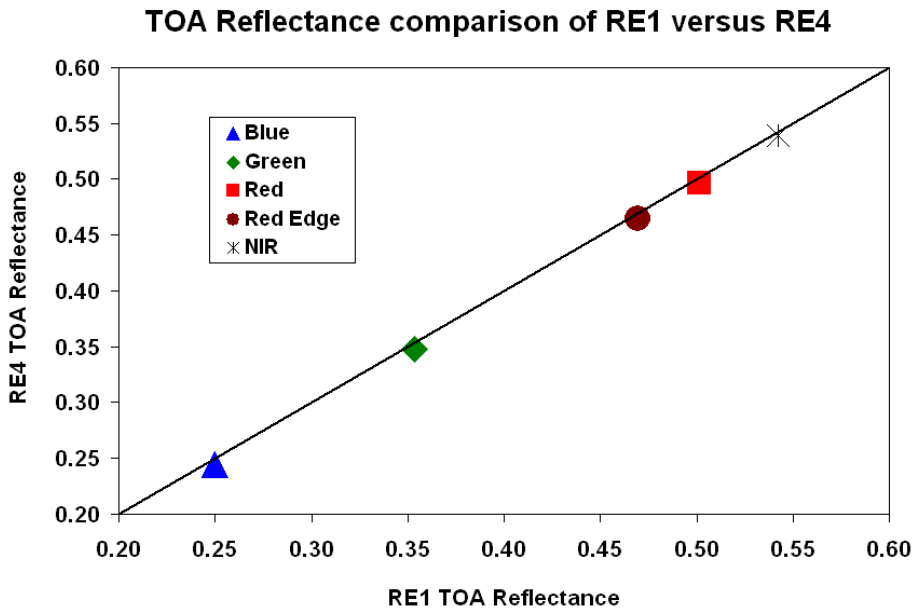
- Processing level:
  - RapidEye ortho (3As): radiometric, sensor and geometric corrections
  - Radiance product: radiometricScaleFactor: 1/100: (W/m^2 sr µm)

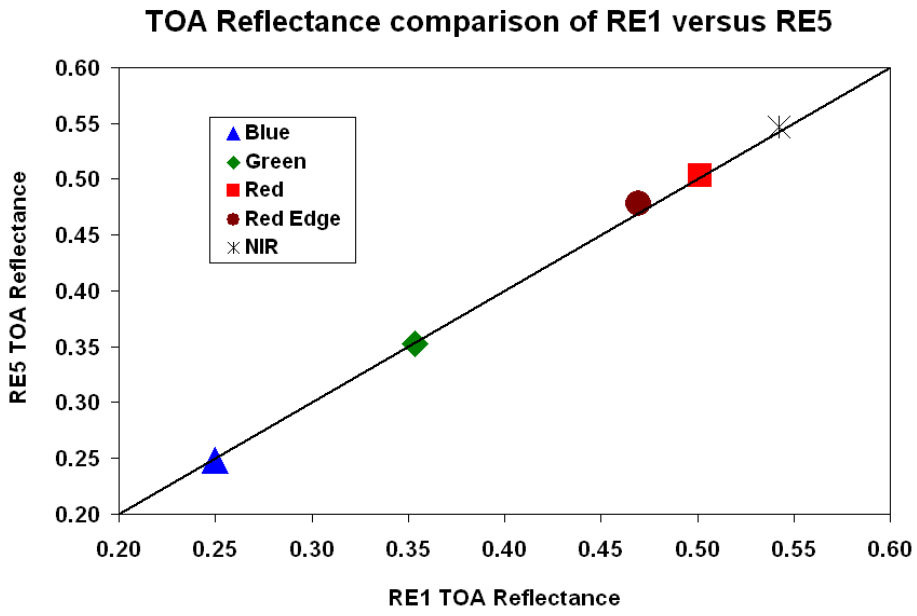
- Pseudo-invariant site Libya 4 was used
  - 81 ROIs, 500 X 500 pixels each, were selected and registered using cross-correlation
  - Mean TOA reflectance & standard deviation from each ROI were calculated
  - Overall mean of all the ROI were calculated for each band

- TOA reflectance of RE1, RE2, RE3, RE4 & RE5 were compared with that of the average of all RE sensors









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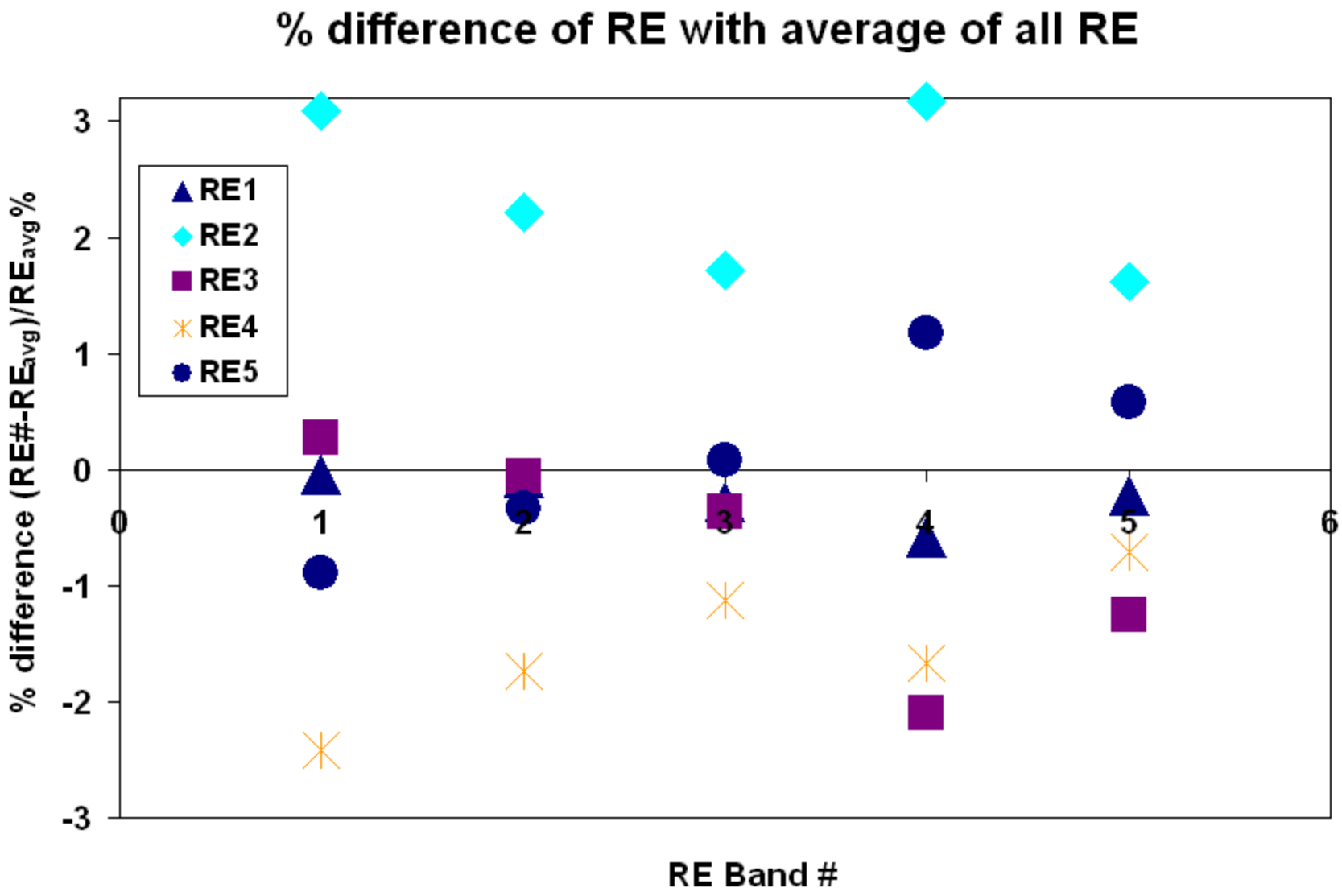
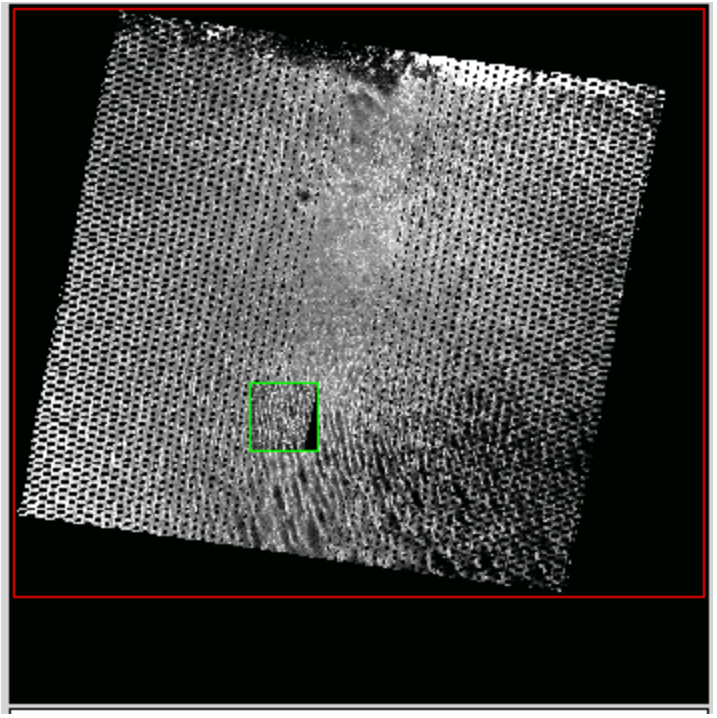
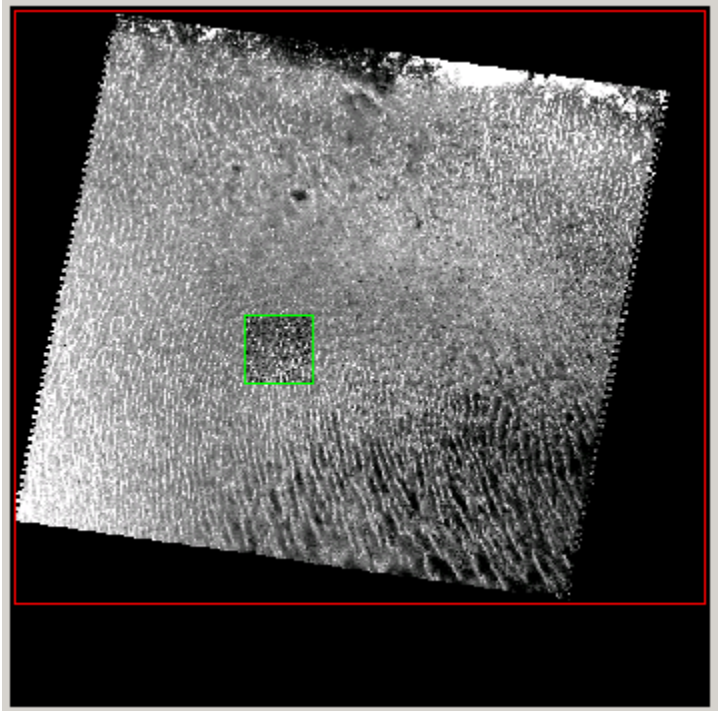

% difference of RE with average of all RE
RE1
RE2
RE3
RE4
RE5
% difference (RE#-REavg)/REavg%
RE Band #
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
6

Landsat TM/ETM+ to RapidEye



L7 ETM+ & RE 5 (Libya 4)
ACQUISITION_DATE = 2009-09-04

Libya 4	RE5	L7 ETM+
Acquisition Date	9/4/2009	9/4/2009
Illumination Azimuth Angle	162.55	128.41
Illumination Elevation Angle	67.61	58.17
Across Track Incidence Angle	8.75	nadir



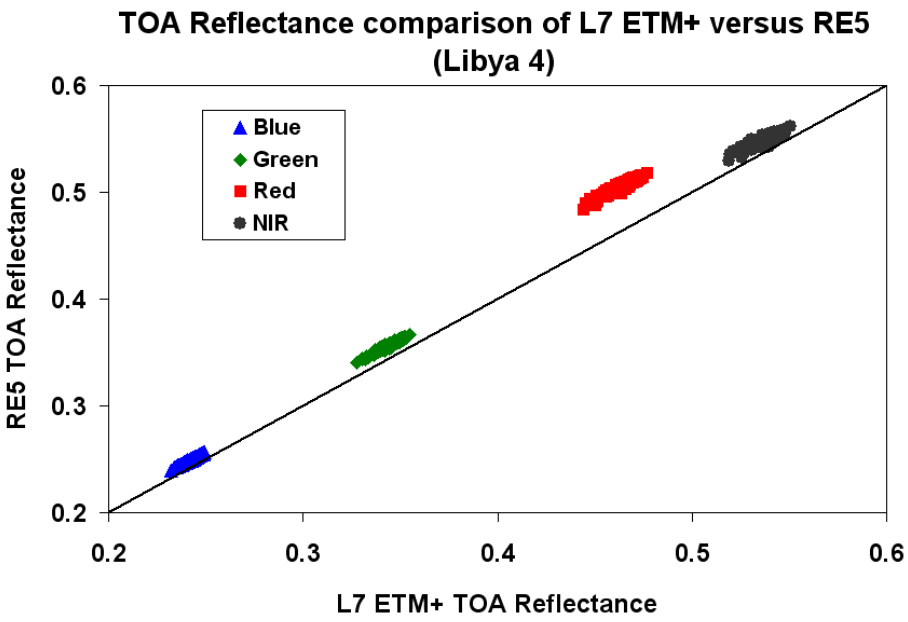
L5 TM & RE3 (Libya 4)
ACQUISITION_DATE = 2009-08-27

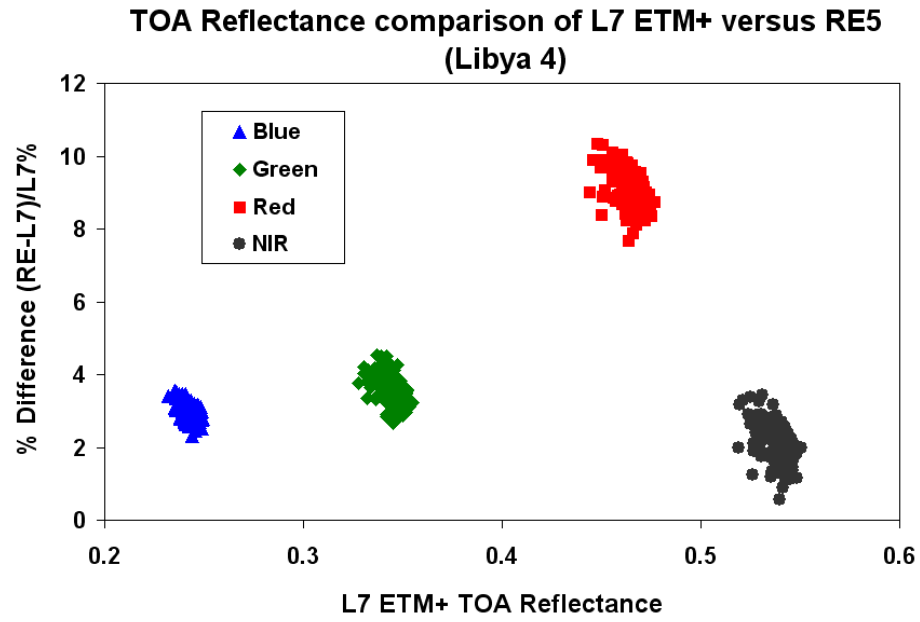
Libya 4	RE3	L5 TM
Acquisition Date	8/14/2009	8/27/2009
Illumination Azimuth Angle	150.36	123.36
Illumination Elevation Angle	73.81	59.62
Across Track Incidence Angle	-7.16	nadir

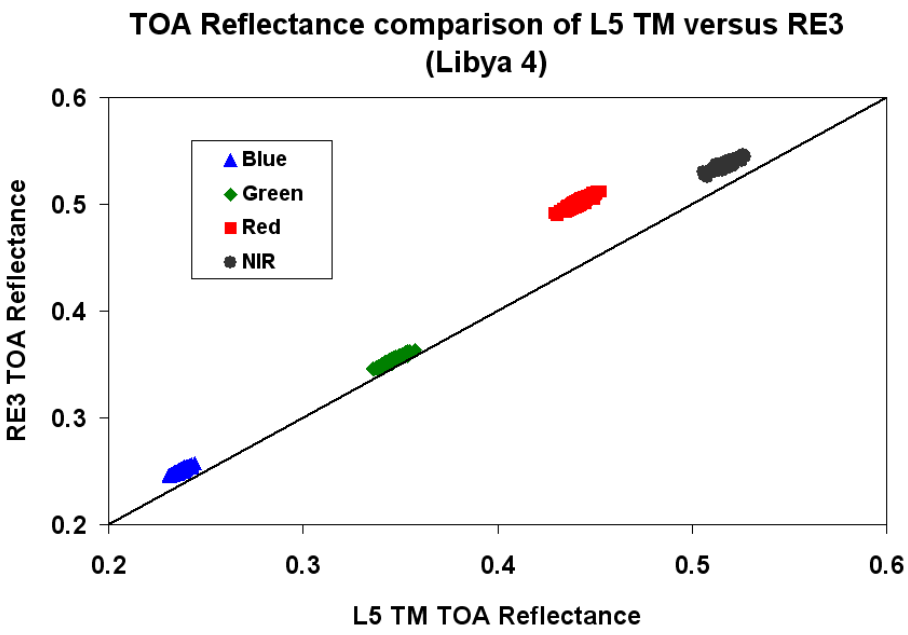
Landsat to RE Comparison Methodology

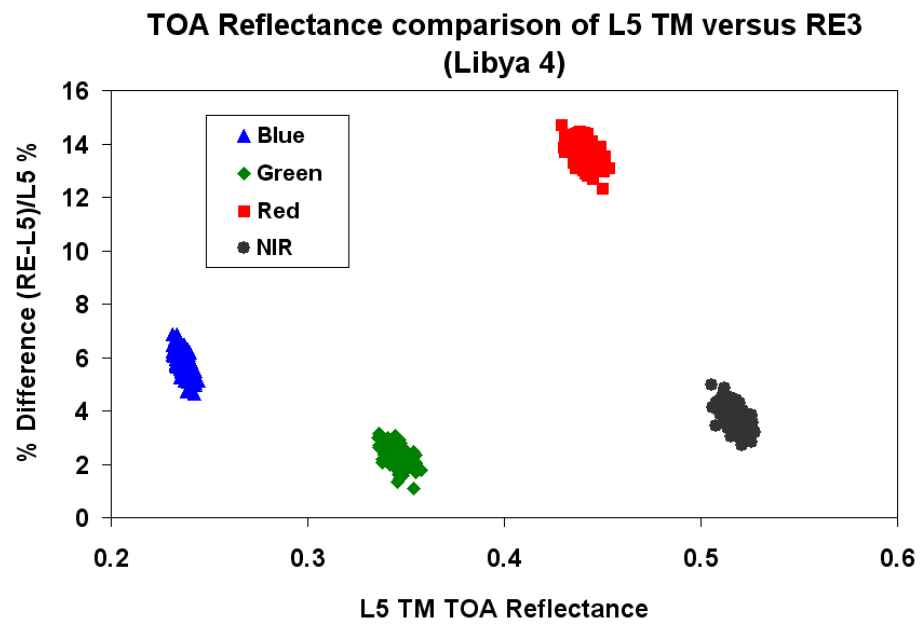
- Processing level:
  - RapidEye ortho (3As)-radiometric, sensor and geometric corrections
  - Landsat TM/ETM+ L1T-radiometric, geometric, precision and terrain correction

- Near-simultaneous same day acquired scenes by Landsat and RE were used
  - 256 ROIs,1500 m X 1500 m each, were selected
  - Mean TOA reflectance from each ROI were calculated
  - Gap pixels due to SLC were excluded from L7 calculations
  - Percent difference of TOA reflectance between the sensors over all ROIs were calculated for Blue, Green, Red & NIR bands
  - Spectral differences and BRDF effects were not accounted for due to lack of hyperspectral and ground measurements

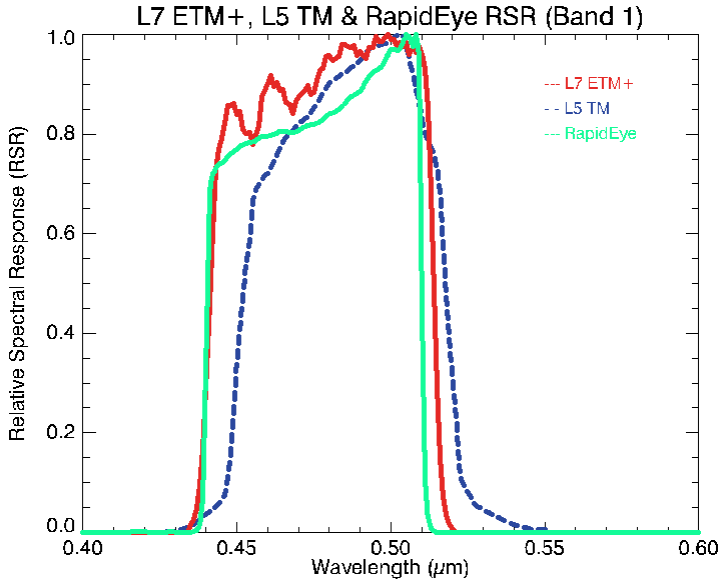

TOA Reflectance comparison of L7 ETM+ versus RE5
(Libya 4)
Blue
Green
Red
NIR
RE5 TOA Reflectance
L7 ETM+ TOA Reflectance
0.2
0.3
0.4
0.5
0.6

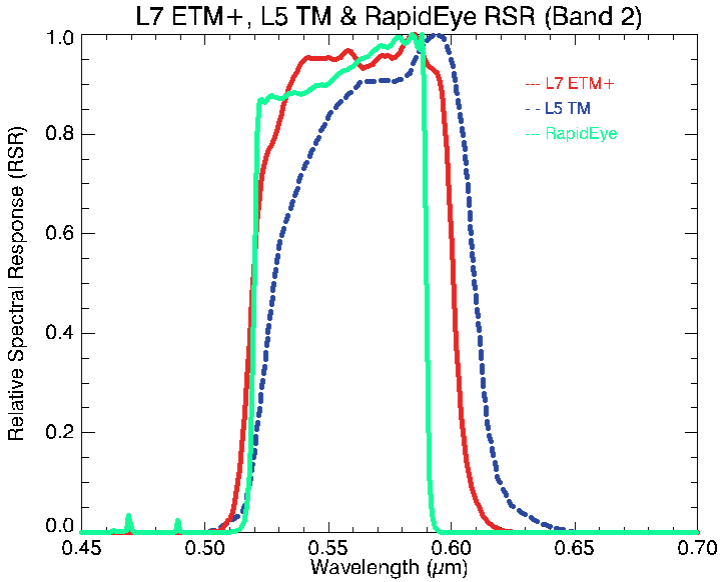

TOA Reflectance comparison of L7 ETM+ versus RE5
(Libya 4)
Blue
Green
Red
NIR
% Difference (RE-L7)/L7%
L7 ETM+ TOA Reflectance
0
2
4
6
8
10
12
0.2
0.3
0.4
0.5
0.6

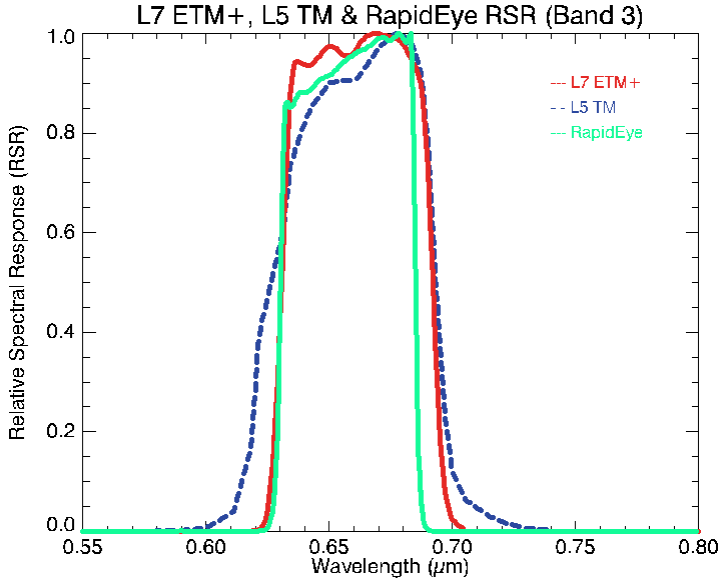

TOA Reflectance comparison of L5 TM versus RE3
(Libya 4)
Blue
Green
Red
NIR
RE3 TOA Reflectance
L5 TM TOA Reflectance
0.2
0.3
0.4
0.5
0.6

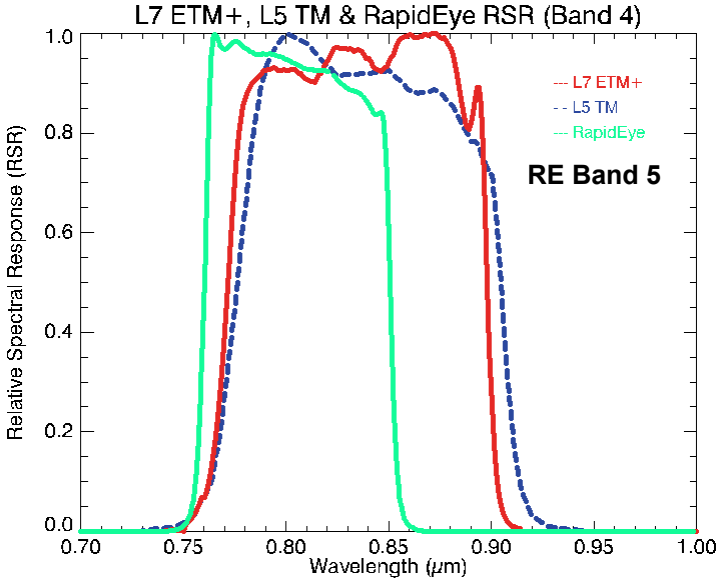

TOA Reflectance comparison of L5 TM versus RE3
(Libya 4)
Blue
Green
Red
NIR
% Difference (RE-L5)/L5 %
L5 TM TOA Reflectance
0
2
4
6
8
10
12
14
16
0.2
0.3
0.4
0.5
0.6

RapidEye and Landsat RSR Comparison









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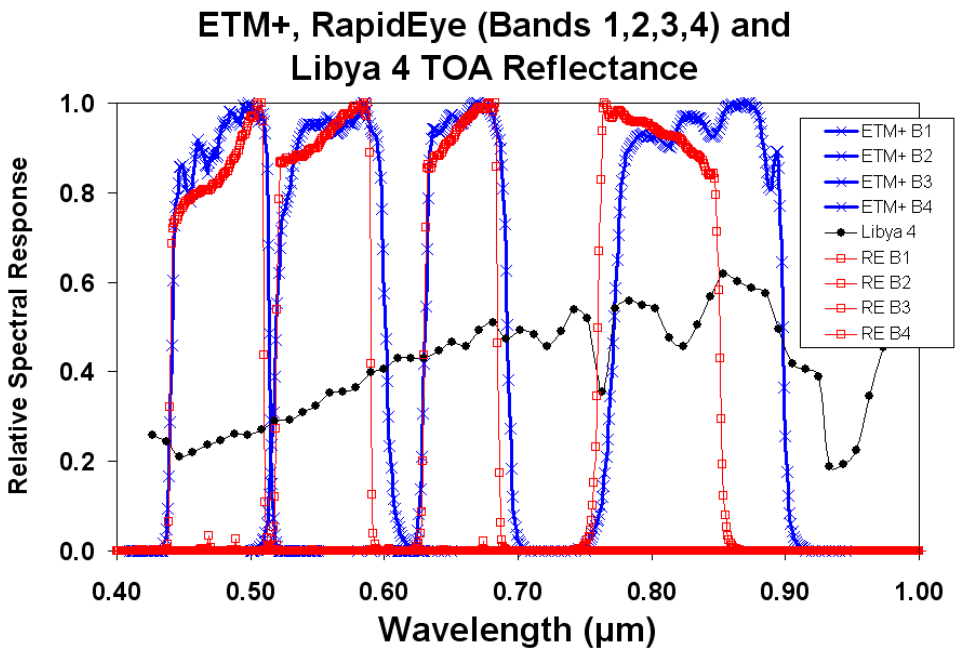
Spectral Band Adjustment Factor (SBAF)



SBAF over Libya 4 (RapidEye)		
Landsat Bands	L7 ETM+	L5 TM
1 (Blue)	1.009	1.036
2 (Green)	1.026	1.069
3 (Red)	1.003	0.999
4 (NIR)	1.054	1.043

- In this study, a SBAF were derived using hyperspectral EO-1 Hyperion measurements
- To understand the impact of the sensor spectral response differences on TOA reflectance measurements over Libya-4 site, the following equations were used

$$\overline{\rho_\lambda} = \frac{\int \rho_\lambda \, RSR_\lambda \, d\lambda}{\int RSR_\lambda \, d\lambda}$$

$$SBAF = \frac{\rho_{ETM+}}{\rho_{RE}} = \frac{\left(\int \rho_\lambda \, RSR_{\lambda(ETM+)} d\lambda\right) / \left(\int RSR_{\lambda(ETM+)} d\lambda\right)}{\left(\int \rho_\lambda \, RSR_{\lambda(RE)} d\lambda\right) / \left(\int RSR_{\lambda(RE)} d\lambda\right)}$$

$$\rho^*_{ETM+} = \frac{\rho_{ETM+}}{SBAF}$$

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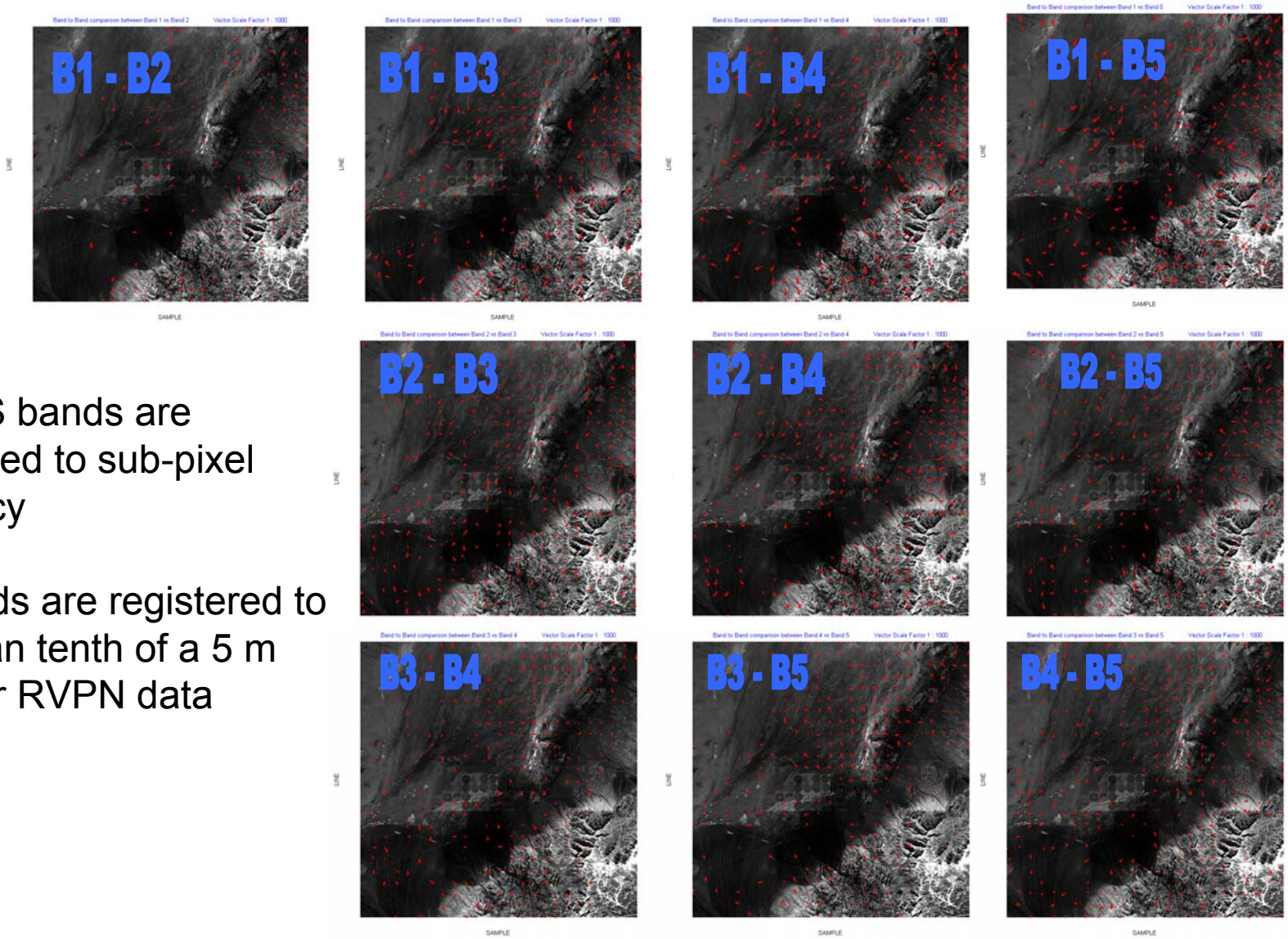
Geometric Assessment

- Completed using the Image Assessment System (IAS) which was developed for Radiometric and Geometric Characterization and Calibration for The Landsat program.

- Band to Band (B2B) registration assessment tool
  - B2B is performed to ensure that the proper band alignment parameters are provided
  - It is typically done by registering each band against every other band
  - A reference band is selected and all other bands are adjusted (offset determined) by least square adjustment of the registration solution

- Image to Image (I2I) registration assessment tool
  - I2I is usually performed to compare the relative accuracy between two images
  - One image is selected as reference and another as the search image
  - Image chips are selected from reference image and are correlated with search image
  - The co-registration results provide an insight to the relative accuracy of the search image with respect to the reference image
  - When the correlated points are plotted in the image, it also helps to detect any systematic bias in the image

RapidEye (B2B) – RVPN Vector Scale 1:1000



The MS bands are registered to sub-pixel accuracy

All bands are registered to less than tenth of a 5 m pixel for RVPN data

RapidEye (I2I) – RVPN & Sioux Falls

- The RVPN DOQ reference data has a native resolution of 1 m, with an accuracy of 6 m
  - I2I analysis performed on 12 precision terrain corrected RE scenes
  - The mosaic of 12 scenes (created in ENVI) was compared against DOQ
  - Individual scene results and the mosaic scene results were consistent

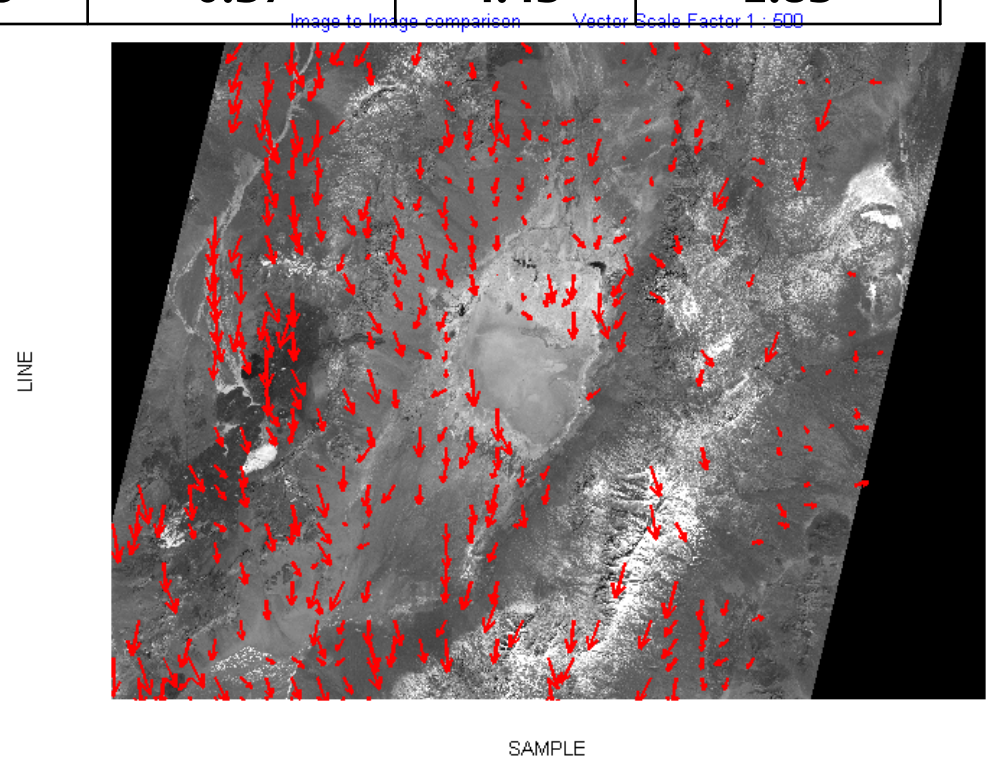
- The Sioux Falls reference data has a native resolution of 0.30 m, with an accuracy of 0.45 m
  - I2I analysis performed on one precision terrain corrected RE scene for each satellite of the RE constellation

- The Level 3A (precision & terrain corrected) RE product was used for analysis
  - RE 3A products have 25 x 25 km scene extent
  - The reference data is resampled to 5 m to match the resolution of RE data
  - Each scene was compared against the reference data
  - RE B5 data was used for I2I assessment with reference data

RapidEye 2 (I2I) – RVPN mosaic Vector scale 1:500

375 points used to calculate statistics for mosaic scene	Pixels		Meters	
	Line	Sample	Line	Sample
Mean	**0.76**	**0.02**	**3.8**	**0.1**
Standard Deviation	**0.47**	**0.30**	**2.35**	**1.5**
RMSE	**0.89**	**0.37**	**4.45**	**1.85**

The Level 3A (precision & terrain corrected) RE product shows less than one pixel (5 m) RMSEr in comparison with DOQ



RapidEye (I2I) – Sioux Falls

- The Level 3A (precision & terrain corrected) RE product was geometrically tested against reference data over Sioux Falls
  - The mean displacement (distance) between the reference data and RE varies between 0.4 (RE #1) pixels to 11.0 pixels (RE #5)
  - The low standard deviation values indicate that the products are internally very consistent

The standard deviation of the displacement across all the scenes are found to be between 0.42 pixels to 0.53 pixels

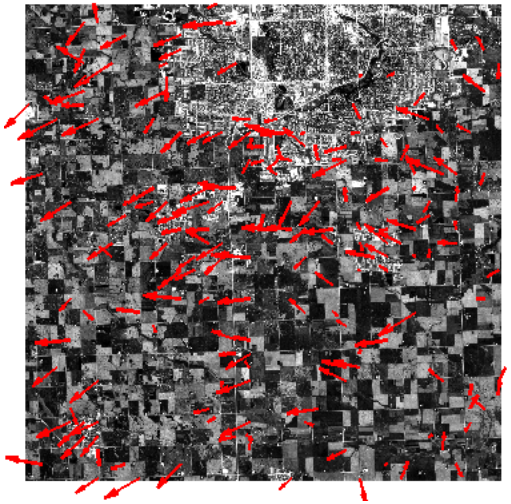
The RMSE of the displacement across all the scenes are found to be between 0.69 pixels to 11.02 pixels

The RE # 5 scene was found to be displaced in the North-South direction (The shift seems systematic, as standard deviation of the displacement is very small)

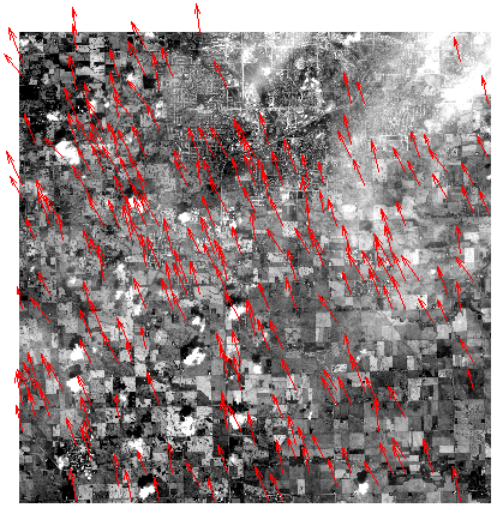
	Pixels		Meters	
	Line	Sample	Line	Sample
	RE 1 (519 points used)			
Mean	-0.09	-0.38	-0.40	-1.90
Standard Deviation	0.41	0.40	2.00	1.90
RMSE	0.42	0.55	2.10	2.70
	RE 2 (730 points used)			
Mean	-1.10	-0.46	-5.50	-2.30
Standard Deviation	0.37	0.24	1.80	1.20
RMSE	1.16	0.52	5.80	2.60
	RE 3 (784 points used)			
Mean	-0.47	-0.55	-2.30	-2.75
Standard Deviation	0.36	0.38	1.80	1.90
RMSE	0.59	0.67	5.80	2.60
	RE 4 (804 points used)			
Mean	-2.24	0.33	-5.50	-2.30
Standard Deviation	0.37	0.28	1.84	1.38
RMSE	2.27	0.43	11.30	2.20
	RE 5 (401 points used)			
Mean	-11.00	0.58	-55.10	2.90
Standard Deviation	0.17	0.39	0.85	1.95
RMSE	11.00	0.70	55.10	3.50

G. Chander (gchander@usgs.gov) JACIE Meeting (March 16-18, 2010)

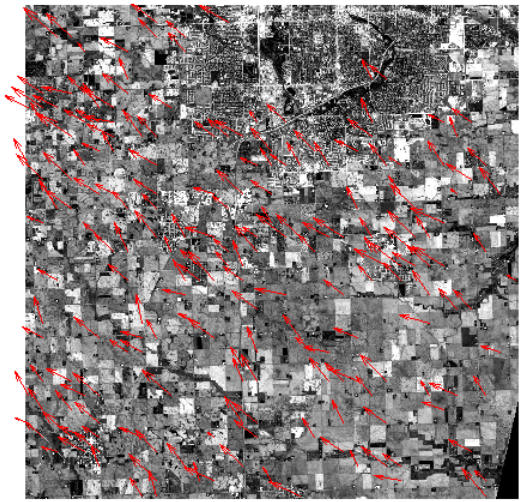
RapidEye R2 (I2I) – Sioux Falls Vector scale 1:500



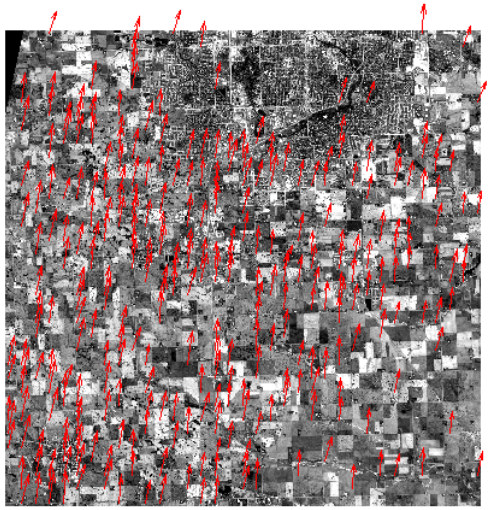
RE1 (6/30/2009)



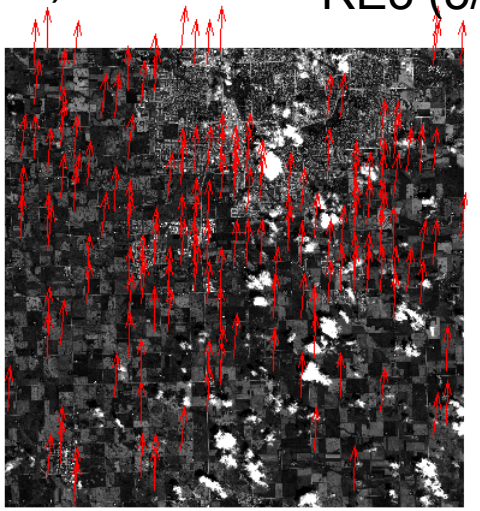
RE2 (5/10/2009)



RE3 (5/16/2009)



RE4 (4/23/2009)



RE5 (5/25/2009)

Summary

- The TOA reflectance average percent difference between
  - all the RE sensors agree within 3% (except RE2 RedEdge)
  - RE sensors show reasonably good agreement with the Landsat TM and ETM+ sensors (except the red band)
  - No compensation for the spectral responses, spatial, BRDF, atmosphere, etc. were incorporated in these preliminary results

Average Percent Difference		
Band	**L7 vs. RE5**	**L5 vs. RE3**
1 (Blue)	2.99	5.81
2 (Green)	3.52	2.33
3 (Red)	9.09	13.67
5 (NIR)	2.07	3.79

- The I2I and B2B characterization was performed and the results show that the RE data were *"typically"* registered to within one pixel (5 m)