Radiometric & Geometric Assessment of Data from RapidEye Constellation of Satellites

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Introduction

RapidEye consists of a constellation of five Earth Observation satellites. The satellites capture data at a spatial resolution of 5 m. The objective of this study is to compare the radiometric sensor response and the geometric accuracy among the RapidEye member satellites.

Table 1. RapidEye sensor characteristics

Platform	RapidEye
Sensor	MSI
Launch Date	29-Aug-08
Number of Bands	5
Spatial Resolution (m)	5
Swath (km)	77
Spectral Coverage (µm)	0.4~0.85
Pixel Quantization (bits)	12
Orbit Type	Sun synchronous
Equatorial Crossing Time	Approximately 11.00 AM
Altitude (km)	630

Study area

The radiometric analysis was conducted over the Libya 4 test site. The site is a high reflectance site, consisting of sand dunes and devoid of vegetation.

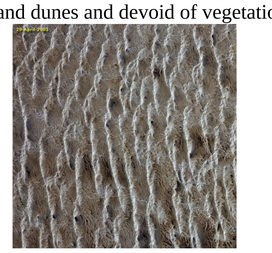

Figure 1. Libya 4 test site. The site is located in Libya, Africa, at 28.55º latitude and 23.39º longitude. Its usable area is approximately 75km X 75 km

The geometric assessment of the data was carried out over two of the USGS National Test ranges (NTR), located at Sioux Falls, SD and Pueblo, CO. The USGS NTRs are high accuracy geometric test sites for assessing the geometric accuracy of remotely sensed data

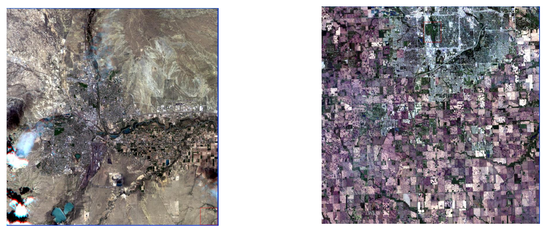

Figure 2. RapidEye data over (a) Pueblo NTR, and (b) the Sioux Falls NTR .

Radiometric and Geometric methods of analysis

Radiometric methods

The at-sensor radiance is calculated from the calibrated Digital Numbers using Eq. 1

$$L_\lambda = \frac{Q_{cal}}{100} \qquad (1)$$

To reduce the scene-to-scene variability, it is converted to exoatmospheric reflectance, using Eq. 2. The ESUN values for Eq. 2 are obtained from Table 2.

$$\rho = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos\theta_s} \qquad (2)$$

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/(m² sr µm)]
d = Earth-Sun distance [astronomical units]
$ESUN_\lambda$ = Mean exoatmospheric solar irradiance [W/(m² µm)]
θ_s = Solar zenith angle [degrees]

Table 2. The ESUN values of RapidEye bands using various models.

Band	RE 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

Analysis

RapidEye ortho (3As) products acquired during the years 2009 and 2010 were used for analysis.

- Analysis was performed over the Pseudo-invariant Libya 4 site
- 81 ROIs, 500 X 500 pixels in dimensions, were selected and registered using cross-correlation
- Mean TOA reflectance & standard deviation from each ROI were calculated
- Overall means 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 (Figures 3(a) and 3 (b))

Table 3. Mean TOA reflectance for 2009 acquisitions

2009 acquisitions	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

Table 4. Mean TOA reflectance for 2010 acquisitions

2010 acquisitions	RE1	RE2	RE3	RE4	RE5
Acquisition Date	9/17/2010	9/13/2010	9/19/2010	9/15/2010	9/16/2010
Illumination Azimuth Angle	176.52	173.03	176.66	173.12	174.52
Azimuth Angle	99.75	99.27	99.74	99.43	99.60
Illumination Elevation Angle	63.61	65.04	62.84	64.27	63.94
Radiometric Scale Factor	0.01	0.01	0.01	0.01	0.01
Incidence Angle	20.22	11.72	24.11	15.96	19.58
Earth Sun Distance (d)	1.0050	1.0060	1.0045	1.0056	1.0053

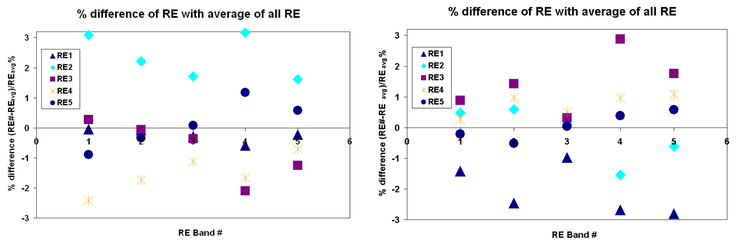

Figure 3. Plot of percentage difference of reflectance compared to average TOA reflectances for (a) (left) 2009 and (b) (right) 2010 acquisitions

- RE2 shows improved agreement with the constellation average in 2010. In 2009 data RE2 showed the highest percent difference from the average for all bands and varied from 1.624% to 3.05% .
- RE1 showed the least difference from the average among the sensors in 2009, however, the difference from the average has increased in 2010 acquisitions
- In general Red and RedEdge bands show the least and highest percent differences from the constellation averages among all bands
- Among the satellites' sensors RE5 agrees the most with the constellation average and shows the least percentage difference for all bands (2010 data).

Geometric methods of analysis

The Image Assessment System (IAS) which was developed for the Landsat program was used for geometric analysis.

Band to Band (B2B) methods

- 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) methods

- 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

Analysis

All bands in both the 2009 an d 2010 acquisitions were found to be registered to within 0.25 pixels of each other.

I2I analysis was conducted against reference ortho imagery data.

- The Sioux Falls reference data has a native resolution of 0.30 m, with an accuracy of 0.45 m (in UTM)
- The Pueblo reference data has a native resolution of 0.30 m over the urban regions and 0.6 m over rural regions, with an accuracy of 0.6 m and 1.2 m respectively (in State Plane Coordinate System)
- Both the reference datasets were resampled (and in Pueblo's case, reprojected) to 5 m to match the resolution of the RapidEye data

Table 4. I2I analysis results for 2009 acquisitions

2009	Pixels		Meters	
	Line	Sample	Line	Sample
RE #1 scene (SIOUX FALLS)				
Mean	-0.09	-0.38	-0.4	-1.9
Standard Deviation	0.41	0.40	2.0	1.9
RMSE	0.42	0.55	2.1	2.7
RE #2 scene (SIOUX FALLS)				
Mean	-1.10	-0.46	-5.5	-2.3
Standard Deviation	0.37	0.24	1.8	1.2
RMSE	1.16	0.52	5.8	2.6
RE #3 scene (SIOUX FALLS)				
Mean	-0.47	-0.55	-2.3	-2.75
Standard Deviation	0.36	0.38	1.8	1.9
RMSE	0.59	0.67	5.8	2.6
RE #4 scene (SIOUX FALLS)				
Mean	-2.24	0.33	-5.5	-2.3
Standard Deviation	0.37	0.28	1.84	1.38
RMSE	2.27	0.43	11.3	2.2
RE #5 scene (SIOUX FALLS)				
Mean	-11.0	0.58	-55.1	2.9
Standard Deviation	0.17	0.39	0.85	1.95
RMSE	11.0	0.70	55.1	3.5

Table 5. I2I analysis results for 2010 acquisitions

2010	Pixels		Meters	
	Line	Sample	Line	Sample
RE #1 scene (SIOUX FALLS)				
Mean	-0.09	-0.38	-0.4	-1.9
Standard deviation	0.41	0.40	2.0	1.9
RMSE	0.42	0.55	2.1	2.7
RE #2 scene (Pueblo)				
Mean	-0.06	-0.14	-0.3	-0.7
Standard deviation	0.14	0.135	0.7	0.67
RMSE	0.15	0.2	0.75	1
RE #3 scene (Pueblo)				
Mean	-0.51	0.71	-2.57	3.55
Standard Deviation	0.15	0.16	0.76	0.82
RMSE	0.53	0.72	2.68	3.64
RE #4 scene (Sioux Falls)				
Mean	-0.33	0.27	-1.66	1.36
Standard Deviation	0.199	0.26	0.99	1.33
RMSE	0.38	0.38	1.94	1.9
RE #5 scene (Sioux Falls)				
Mean	-0.55	-0.18	-2.76	-0.93
Standard Deviation	0.18	0.31	0.94	1.55
RMSE	0.58	0.36	2.91	1.81

Summary

- The TOA reflectance average percent difference between the RE sensors agree within 3% for both the 2009 and 2010 acquisitions over Libya 4 site
- The B2B characterization results show that the bands are registered to each other to within 0.25 pixels.
- The I2I characterization results show that the RE data were typically registered to within one pixel (5 m), with the exception of RE5 data set in 2009