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

JACIE Meeting
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U.S. Department of the Interior
U.S. Geological Survey
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
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.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Landsat 5</th>
<th>Landsat 7</th>
<th>Terra</th>
<th>IRS-P6</th>
<th>RapidEye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>TM</td>
<td>ETM+</td>
<td>MODIS</td>
<td>AWIFS</td>
<td>MSI</td>
</tr>
<tr>
<td>Number of Bands</td>
<td>7</td>
<td>8</td>
<td>36</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Spatial Resolution (m)</td>
<td>30, 120</td>
<td>15, 30, 60</td>
<td>250, 500, 1 km</td>
<td>56 (nadir), 70</td>
<td>5</td>
</tr>
<tr>
<td>Swath (km)</td>
<td>183</td>
<td>183</td>
<td>2330</td>
<td>740</td>
<td>77</td>
</tr>
<tr>
<td>Spectral Coverage (µm)</td>
<td>0.4~12.5</td>
<td>0.4~12.5</td>
<td>0.4~14</td>
<td>0.52~1.7</td>
<td>0.4~0.85</td>
</tr>
<tr>
<td>Pixel Quantization (bits)</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Launch Date</td>
<td>1-Mar-84</td>
<td>15-Apr-99</td>
<td>18-Dec-99</td>
<td>17-Oct-03</td>
<td>29-Aug-08</td>
</tr>
<tr>
<td>Orbit Type</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
</tr>
<tr>
<td>Equatorial Crossing Time</td>
<td>10:00 AM</td>
<td>10:00 AM</td>
<td>10:30 AM</td>
<td>10:30 AM</td>
<td>11:00 AM</td>
</tr>
<tr>
<td>Altitude (km)</td>
<td>705</td>
<td>705</td>
<td>705</td>
<td>817</td>
<td>630</td>
</tr>
</tbody>
</table>
Conversion to at-sensor spectral radiance ($Q_{cal}$-to- $L_{\lambda}$)

- **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 radiances:

- 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 ($L_\lambda$-to- $\rho_P$)

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

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

Where:

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

<table>
<thead>
<tr>
<th>Band</th>
<th>CHKUR</th>
<th>Thuillier</th>
<th>SIRS</th>
<th>WRC</th>
<th>Kurucz</th>
<th>New Kurucz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (Green)</td>
<td>1815</td>
<td>1824</td>
<td>1848</td>
<td>1853</td>
<td>1816</td>
<td>1863</td>
</tr>
<tr>
<td>3 (Red)</td>
<td>1566</td>
<td>1541</td>
<td>1531</td>
<td>1562</td>
<td>1573</td>
<td>1560</td>
</tr>
<tr>
<td>4 (Red Edge)</td>
<td>1352</td>
<td>1399</td>
<td>1362</td>
<td>1387</td>
<td>1392</td>
<td>1395</td>
</tr>
<tr>
<td>5 (NIR)</td>
<td>1121</td>
<td>1117</td>
<td>1100</td>
<td>1127</td>
<td>1121</td>
<td>1124</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESUN$_\lambda$ (Thuillier Model)</th>
<th>L7 ETM+</th>
<th>L5 TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>1997</td>
<td>1983</td>
</tr>
<tr>
<td>Band 2</td>
<td>1812</td>
<td>1796</td>
</tr>
<tr>
<td>Band 3</td>
<td>1533</td>
<td>1536</td>
</tr>
<tr>
<td>Band 4</td>
<td>1039</td>
<td>1031</td>
</tr>
<tr>
<td>Band 5</td>
<td>230.8</td>
<td>220.0</td>
</tr>
<tr>
<td>Band 7</td>
<td>84.90</td>
<td>83.44</td>
</tr>
<tr>
<td>PAN</td>
<td>1362</td>
<td></td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th></th>
<th>RE1</th>
<th>RE2</th>
<th>RE3</th>
<th>RE4</th>
<th>RE5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illumination Azimuth Angle</td>
<td>155.75</td>
<td>154.70</td>
<td>150.36</td>
<td>151.32</td>
<td>162.55</td>
</tr>
<tr>
<td>Azimuth Angle</td>
<td>99.43</td>
<td>278.40</td>
<td>100.25</td>
<td>99.70</td>
<td>99.20</td>
</tr>
<tr>
<td>Illumination Elevation Angle</td>
<td>73.45</td>
<td>69.69</td>
<td>73.81</td>
<td>73.59</td>
<td>67.61</td>
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<tr>
<td>radiometricScaleFactor</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Across Track Incidence Angle</td>
<td>11.29</td>
<td>8.87</td>
<td>-7.16</td>
<td>-9.19</td>
<td>8.75</td>
</tr>
<tr>
<td>Earth Sun Distance (d)</td>
<td>1.0124</td>
<td>1.0103</td>
<td>1.0129</td>
<td>1.0127</td>
<td>1.0084</td>
</tr>
</tbody>
</table>
**RE to RE Comparison Methodology**

- **Processing level:**
  - RapidEye ortho (3As): radiometric, sensor and geometric corrections
  - Radiance product: radiometricScaleFactor: 1/100: (W/m² 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**
TOA Reflectance comparison of RE1 versus RE2

TOA Reflectance comparison of RE1 versus RE3

TOA Reflectance comparison of RE1 versus RE4

TOA Reflectance comparison of RE1 versus RE5

G. Chander (gchander@usgs.gov) JACIE Meeting (March 16-18, 2010)
Landsat TM/ETM+ to RapidEye

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

<table>
<thead>
<tr>
<th>Libya 4</th>
<th>RE5</th>
<th>L7 ETM+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illumination Azimuth Angle</td>
<td>162.55</td>
<td>128.41</td>
</tr>
<tr>
<td>Illumination Elevation Angle</td>
<td>67.61</td>
<td>58.17</td>
</tr>
<tr>
<td>Across Track Incidence Angle</td>
<td>8.75</td>
<td>nadir</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Libya 4</th>
<th>RE3</th>
<th>L5 TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition Date</td>
<td>8/14/2009</td>
<td>8/27/2009</td>
</tr>
<tr>
<td>Illumination Azimuth Angle</td>
<td>150.36</td>
<td>123.36</td>
</tr>
<tr>
<td>Illumination Elevation Angle</td>
<td>73.81</td>
<td>59.62</td>
</tr>
<tr>
<td>Across Track Incidence Angle</td>
<td>-7.16</td>
<td>nadir</td>
</tr>
</tbody>
</table>
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)

- L7 ETM+ TOA Reflectance
- RE5 TOA Reflectance

TOA Reflectance comparison of L5 TM versus RE3 (Libya 4)

- L5 TM TOA Reflectance
- RE3 TOA Reflectance

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RapidEye and Landsat RSR Comparison

L7 ETM+, L5 TM & RapidEye RSR (Band 1)

L7 ETM+, L5 TM & RapidEye RSR (Band 2)

L7 ETM+, L5 TM & RapidEye RSR (Band 3)

L7 ETM+, L5 TM & RapidEye RSR (Band 4)

RE Band 5
Spectral Band Adjustment Factor (SBAF)

- 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:

\[
SBAF = \frac{\rho_{\text{ETM}+}}{\rho_{\text{RE}}} = \left( \frac{\int \rho_\lambda \cdot RSR_{\lambda(\text{ETM}+)} d\lambda}{\int \rho_\lambda \cdot RSR_{\lambda(\text{RE})} d\lambda} \right) / \left( \int RSR_{\lambda(\text{ETM}+)} d\lambda \right) / \left( \int RSR_{\lambda(\text{RE})} d\lambda \right)
\]

\[
\rho^*_{\text{ETM}+} = \frac{\rho_{\text{ETM}+}}{SBAF}
\]

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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
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.
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**

<table>
<thead>
<tr>
<th>375 points used to calculate statistics for mosaic scene</th>
<th>Pixels</th>
<th>Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line</td>
<td>Sample</td>
</tr>
<tr>
<td>Mean</td>
<td>0.76</td>
<td>0.02</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.89</td>
<td>0.37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Line</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>2.35</td>
<td>1.5</td>
</tr>
<tr>
<td>RMSE</td>
<td>4.45</td>
<td>1.85</td>
</tr>
</tbody>
</table>

The Level 3A (precision & terrain corrected) RE product shows less than one pixel (5 m) RMSE in comparison with DOQ.
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).
RapidEye  R2 (I2I) – Sioux Falls
Vector scale 1:500

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

<table>
<thead>
<tr>
<th>Band</th>
<th>L7 vs. RE5</th>
<th>L5 vs. RE3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Blue)</td>
<td>2.99</td>
<td>5.81</td>
</tr>
<tr>
<td>2 (Green)</td>
<td>3.52</td>
<td>2.33</td>
</tr>
<tr>
<td>3 (Red)</td>
<td>9.09</td>
<td>13.67</td>
</tr>
<tr>
<td>5 (NIR)</td>
<td>2.07</td>
<td>3.79</td>
</tr>
</tbody>
</table>

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