Landsat 8, Level 1 Product Performance
Cyclic Report – October 2017

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Amy Beaton (IDEAS+, Telespazio VEGA)
The Amendment Record Sheet below records the history and issue status of this document.

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>DATE</th>
<th>REASON</th>
</tr>
</thead>
<tbody>
<tr>
<td>JULY 2016</td>
<td>02 Sep 2016</td>
<td>July 2016 quality report</td>
</tr>
<tr>
<td></td>
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<td>Major update regarding quality assessment procedures and methods.</td>
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<td>Change of the operational team in charge of producing this quality report.</td>
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<td>AUGUST 2016</td>
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<td>August 2016 quality report</td>
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<td>SEPTEMBER 2016</td>
<td>03 Oct 2016</td>
<td>September 2016 quality report</td>
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<td>OCTOBER 2016</td>
<td>03 NOV 2016</td>
<td>October 2016 quality report</td>
</tr>
<tr>
<td>NOVEMBER 2016</td>
<td>02 DEC 2016 (internal issue)</td>
<td>November 2016 quality report</td>
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<tr>
<td>NOVEMBER 2016</td>
<td>09 Jan 2017</td>
<td>Update of November 2016 quality report with L1T products</td>
</tr>
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<td>DECEMBER 2016</td>
<td>27 Jan 2017</td>
<td>December 2016 quality report</td>
</tr>
<tr>
<td>JANUARY 2017</td>
<td>02 Mar 2017</td>
<td>January 2017 quality report</td>
</tr>
<tr>
<td>FEBRUARY 2017</td>
<td>03 Apr 2017</td>
<td>February 2017 quality report</td>
</tr>
<tr>
<td>MARCH 2017</td>
<td>13 Jun 2017</td>
<td>March 2017 quality report</td>
</tr>
<tr>
<td>APRIL 2017</td>
<td>19 Sep 2017</td>
<td>April 2017 quality report</td>
</tr>
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<td>JUNE 2017</td>
<td>21 Dec 2017</td>
<td>June 2017 quality report</td>
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<tr>
<td>JULY 2017</td>
<td>21 Dec 2017</td>
<td>July 2017 quality report</td>
</tr>
<tr>
<td>AUGUST 2017</td>
<td>21 Dec 2017</td>
<td>August 2017 quality report</td>
</tr>
<tr>
<td>SEPTEMBER 2017</td>
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<td>September 2017 quality report</td>
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<td>OCTOBER 2017</td>
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1. INTRODUCTION

On May 30, 2013, data from the Landsat 8 satellite (launched as the Landsat Data Continuity Mission (LDCM) on February 11, 2013) became available. The European Space Agency (ESA) distributes Landsat 8 Level 1C products as a Near Real Time (NRT) service. Products are processed at the ESA facility with the same processing baseline as the United State Geological Survey (USGS).

Please refer to https://landsat8portal.eo.esa.int/portal or https://earth.esa.int/web/sppa/mission-performance/esa-3rd-party-missions/landsat-8 for more information about the service.

1.1 Scope

The scope of this document is to report the results on the monitoring of the Landsat 8 Level 1 product performance. The report includes comparison with USGS processed products in order to ensure full agreement between both product sources for the community. It is also foreseen to include data comparisons from other similar missions, such as Sentinel-2, in the future.

The main quality items addressed relate to radiometric calibration, geometric calibration and image quality. Hence, every month, the operational team select products acquired over specific validation test sites and perform accuracy analysis.

Note that, an insight on methods is given in RD-1 and the test data set used for this analysis is detailed in RD-2 and is regularly updated.

For any questions regarding the methods and results not covered in this report, please contact the Instrument Data Evaluation and Analysis Service (IDEAS+) through EOHelp: eohelp@esa.int

1.2 Report Structure

This report is organized as follows:

1 INTRODUCTION

This introduction.

2 EXECUTIVE SUMMARY

The main findings of the month are summarized in a dedicated table, any observed changes, and degradations are mentioned.

3 ON GOING QC ISSUES

Any quality issues detected during the reporting period are documented in this section. Also, results from specific ad hoc analysis are given: product format, visual inspection including QA bands and image quality.

4 RADIOMETRIC ACCURACY STABILITY MONITORING

Multi temporal stability results with methodologies based on Pseudo Invariant test sites are presented. Statistics on the overall accuracy and figures are given.

5 GEOMETRIC ACCURACY STABILITY

Multi temporal geolocation results with methodologies based on several geometric test sites in Europe are presented. Aggregated and site-dependant statistics derived from correlation grid analysis are presented.
6 INTERBAND REGISTRATION ACCURACY

Interband registration results with methodologies based on specific interband sites are presented. Inter registration accuracy and intra (OLI/TIRS images) registration accuracy are analysed and results are given.

7 TEST SITE DESCRIPTION

The list of test sites, reference equipment and details on input data are reported in this section.

1.3 Reference Documents

The following is a list of reference documents applicable to this report. Where referenced in the text, these are identified as [RD.n], where ‘n’ is the number in the list below:

RD-1. IDEAS+-TN-02-L8_DataValidation.docx, Landsat 8 Data Validation, 08 April 2015, Issue 1.
RD-2. TDS_L8_cyclic.xlsx, Landsat 8 Validation Data Details

1.4 Glossary

The following acronyms and abbreviations have been used in this Report.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2B</td>
<td>Band-to-Band</td>
</tr>
<tr>
<td>CCD</td>
<td>Charge-Coupled Device</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>IDEAS+</td>
<td>Instrument Data Evaluation and Analysis Service</td>
</tr>
<tr>
<td>LDCM</td>
<td>Landsat Data Continuity Mission</td>
</tr>
<tr>
<td>NIR</td>
<td>Near Infra-Red</td>
</tr>
<tr>
<td>NRT</td>
<td>Near Real Time</td>
</tr>
<tr>
<td>RMS</td>
<td>Root Mean Square</td>
</tr>
<tr>
<td>ROI</td>
<td>Region Of Interest</td>
</tr>
<tr>
<td>SWIR</td>
<td>Short Wave Infra-Red</td>
</tr>
<tr>
<td>TIRS</td>
<td>Thermal Infra-Red Sensor</td>
</tr>
<tr>
<td>TOA</td>
<td>Top of Atmosphere</td>
</tr>
<tr>
<td>USGS</td>
<td>United State Geological Survey</td>
</tr>
</tbody>
</table>
2. EXECUTIVE SUMMARY

The purpose of the Landsat 8 data validation is to assess the continuity of data accuracy of the Landsat Project. The following table summarises the items validated each month and the expected results.

Table 1 Executive Summary

<table>
<thead>
<tr>
<th>Validation Item</th>
<th>Tests Performed / Results Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometric Accuracy:</td>
<td></td>
</tr>
</tbody>
</table>
| Calibration Stability Monitoring     | 1) Temporal stability is correct (Top of Atmosphere (TOA) reflectance standard deviation is less than 0.7 for blue, green, red and Near Infra-Red (NIR) bands and less than 1.6 for Short Wave Infra-Red (SWIR) 1 and SWIR2 bands).  
2) The radiometric calibration of the ESA products and the USGS products are fully in agreement.  
Note: A small degradation is observed in the early life of the sensor with no major impact for current products.                                                                 |
| Geolocation Accuracy:                |                                                                                                                                                                                                                                     |
| Multi temporal Registration Stability | 1) Relative location results show a correct matching between Landsat 8 products (Root Mean Square (RMS) values are less than 5m in both directions).  
2) The radial error is within 2 m.  
3) The multi temporal stability is correct (standard deviation errors are less than 5m in both directions)  
4) Accuracy remains stable (dependant on the season and the test site).                                                                                                                                 |
| Interband Registration               | The process has been updated to better manage the outliers caused by sea and cloud. However, the influence of shadow and vegetation can negatively impact the accuracy. It has been shown that the two sites, La Crau and Grenada, are evolving differently with time and the interband registration accuracy methods are very sensitive to scene content. |

Note: The USGS Landsat pages have been updated here [https://landsat.usgs.gov/landsat-8](https://landsat.usgs.gov/landsat-8) and include information on the products specifications:

- 12 meter circular error, 90% confidence global accuracy for OLI
- 41 meter circular error, 90% confidence global accuracy for TIRS

The Landsat Science Team meeting was held in Boston (January 10-12, 2017) and the Landsat GCP improvement to improve L8/S2 registration is discussed in [https://landsat.usgs.gov/sites/default/files/documents/landsat_science_team/2017-Jan_Day1_Morfitt_Geometry.pdf](https://landsat.usgs.gov/sites/default/files/documents/landsat_science_team/2017-Jan_Day1_Morfitt_Geometry.pdf). As per USGS results, the measured OLI to MSI registration is estimated to be 22.3 m (2 sigma), assessed over 255 test sites.
3. **ON GOING QC ISSUES**

3.1.1 **TIRS Anomaly**

As discussed in previous cyclic reports, and detailed on the ESA SPPA Landsat 8 Product Anomalies webpages [https://earth.esa.int/web/sppa/mission-performance/esa-3rd-party-missions/landsat-8/oli-tirs/products-anomalies](https://earth.esa.int/web/sppa/mission-performance/esa-3rd-party-missions/landsat-8/oli-tirs/products-anomalies), image quality issues have been detected on the ESA Landsat 8 TIRS products which systematically contaminate the Band 10 and Band 11 TIRS data (the OLI data remains unaffected).

The thermal bands are now calibrated by using adjusted parameters based on the characterization data collection during the on orbit data checkout. All ESA products acquired after April 11 2017 are processed with the new parameters which remove the striping effects observed in TIRS imagery. Discussions are ongoing with the view to reprocess data acquired prior to April 11.

Concerning the banding effect mainly due to stray light, a correction has already been implemented and is operational on the USGS side [RD-3]. However, this correction is not currently operational on the ESA side. Discussions are ongoing with the view to reprocess the ESA Landsat 8 data with the latest software and supporting data in order to recover the affected products.
4. RADIOMETRIC ACCURACY STABILITY MONITORING

4.1 Objectives

The objective is to assess the radiometric stability of Landsat 8 data and to detect any anomalies between data processed by ESA and USGS.

4.2 Methods

The method consists in monitoring the TOA reflectance acquired on a bright site referred to as “Libya4”, known as spatially uniform (as seen with L8/OLI spatial resolution) and spectrally stable in time\(^1\).

For input images, a Region Of Interest (ROI) corresponding to an area of one square degree centred on the geographical coordinates of the site, is extracted. TOA measurement retrieved and then temporal statistics computed. The Libyan site “Libya4” centre is 28.55N / 23.39E, the mean altitude of the site, over the WGS84 ellipsoid is 118m.

For completeness, data in a second window called the “half degree” window is also retrieved and used for comparison.

It is expected that the temporal evolution of TOA measurements over the mission’s lifetime is stable. The results are also computed in radiance units but are not reported in this document.

Landsat 8 OLI and Thermal Infra-Red Sensor (TIRS) images consist respectively of nine and two spectral bands. The OLI spatial resolution is 30 metres for multi spectral bands, and 15 metres for panchromatic bands. As an additional feature compared to previous Landsat missions, there is a new band 1 (ultra-blue) which is useful for coastal and aerosol studies and a new band 9 which is useful for cirrus cloud detection. Regarding TIRS, there are two thermal bands 10 and 11, sampling earth surface at 100 metre intervals. TIRS data are useful for providing more accurate surface temperatures. Note that the pixel spacing of Level 1C products is 30 meters, oversampling is applied. This validation considers multi spectral bands, as indicated in bold in the table below.

<table>
<thead>
<tr>
<th>Band Id</th>
<th>Band Label</th>
<th>Central Wavelength</th>
<th>Bandwidth (µm)</th>
<th>Spatial resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coastal Aerosol</td>
<td>0.4426</td>
<td>0.43 – 0.45</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Blue</td>
<td>0.4837</td>
<td>0.45 – 0.51</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Green</td>
<td>0.5616</td>
<td>0.53 – 0.59</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>0.6545</td>
<td>0.64 – 0.67</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Near Infrared (NIR)</td>
<td>0.8641</td>
<td>0.85 – 0.88</td>
<td>30</td>
</tr>
</tbody>
</table>

\(^1\) CEOS / Q4EO - USGS Test site catalog: http://calval.cr.usgs.gov/sites_catalog_template.php?site=lib4
### Results and Discussions

The relative spectral response curves of spectral bands considered in this analysis are shown in Figure 1 below.

![Relative Spectral Response](image)

**Figure 1 Relative Spectral Response**

4.3 **Results and Discussions**

The statistics listed in both tables below are computed based on a dataset of 66 L1T products (from 02/05/2013 to 31/10/2017). Note, products acquired over Libya-4 during April have not been used during this analysis.

The processing software version is not the same in all cases, since the archive has not been reprocessed. L1Gt products are not taken into account in these statistics. TOA reflectance values are averaged over square zones. Two regions, both centred on site coordinates, are considered. Despite different geographical coverage (50 km x 50 km) against (100 km x 100 km), statistical results agree together.
This cloud free image data stack is used to compute the temporal uncertainty of OLI bands defined as a coefficient of variation (standard deviation divided by mean).

As shown in Table 3, the temporal uncertainty is within 1.5 % for all Visible and NIR bands. Greater uncertainty affects SWIR bands, up to 2.5 %, which is mainly due to atmospheric effects.

Mishra proposes a comparison of ETM+ TOA measurements sensed over pseudo invariant test sites, Libya 4 site included. The results obtained herein are in the same order, even better concerning the SWIR bands.

Table 3 Landsat 8, OLI statistics on temporal stability (half square degree).

<table>
<thead>
<tr>
<th>Band Label</th>
<th>Mean Reflectance TOA</th>
<th>Std Reflectance TOA</th>
<th>Temporal Uncertainty (100 * Std / Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Aerosol</td>
<td>0.216</td>
<td>0.002</td>
<td>1.110</td>
</tr>
<tr>
<td>Blue</td>
<td>0.241</td>
<td>0.002</td>
<td>0.873</td>
</tr>
<tr>
<td>Green</td>
<td>0.330</td>
<td>0.003</td>
<td>0.858</td>
</tr>
<tr>
<td>Red</td>
<td>0.449</td>
<td>0.005</td>
<td>1.080</td>
</tr>
<tr>
<td>Near Infrared (NIR)</td>
<td>0.574</td>
<td>0.007</td>
<td>1.202</td>
</tr>
<tr>
<td>Shortwave Infrared 1 (SWIR 1)</td>
<td>0.658</td>
<td>0.013</td>
<td>1.954</td>
</tr>
<tr>
<td>Shortwave Infrared 2 (SWIR 2)</td>
<td>0.601</td>
<td>0.014</td>
<td>2.359</td>
</tr>
</tbody>
</table>

Table 4 Landsat 8, OLI statistics on temporal stability (one square degree).

<table>
<thead>
<tr>
<th>Band Label</th>
<th>Mean Reflectance TOA</th>
<th>Std Reflectance TOA</th>
<th>Temporal Uncertainty (100 * Std / Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Aerosol</td>
<td>0.218</td>
<td>0.002</td>
<td>1.045</td>
</tr>
<tr>
<td>Blue</td>
<td>0.241</td>
<td>0.002</td>
<td>0.806</td>
</tr>
<tr>
<td>Green</td>
<td>0.329</td>
<td>0.003</td>
<td>0.835</td>
</tr>
<tr>
<td>Red</td>
<td>0.446</td>
<td>0.005</td>
<td>1.076</td>
</tr>
<tr>
<td>Near Infrared (NIR)</td>
<td>0.570</td>
<td>0.007</td>
<td>1.209</td>
</tr>
<tr>
<td>Shortwave Infrared 1 (SWIR 1)</td>
<td>0.656</td>
<td>0.013</td>
<td>1.966</td>
</tr>
<tr>
<td>Shortwave Infrared 2 (SWIR 2)</td>
<td>0.599</td>
<td>0.014</td>
<td>2.348</td>
</tr>
</tbody>
</table>

---

Rebuilding coarse TOA spectrum of Libya 4 site based on ‘half square degree’ results, grouping together all observations, gives an approximate idea on the dispersion around each centre band wavelength. The dispersion arising on SWIR1 and SWIR2 measurements would be smaller in the bottom of atmosphere.

![TOA Reflectance against band center wavelength (Libya4)](image)

**Figure 2 Reflectance profile as indicator of uncertainty.**

The figures in Table 5 below show the temporal evolution of TOA measurements over a period of three years. Measurements taken in the early life of the mission have been kept (USGS data) for statistics. For all bands, a very small linear drift of the sensor is observed; it does not affect the correctness of the physical measurement because change mainly occurs at the beginning of the series. If one considers a smaller period, the results are totally stable.

In addition, series have been built up based on USGS and ESA products. For common observation dates, statistical comparison has been done; in all cases both data are the same and confirm results obtained during USGS certification exercises³.

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³ “Landsat Data Continuity Mission (LDCM) International Ground Station (IGS) Data Validation and Exchange (DV&E) and Certification Plan LS IC - 12 Version 2.0”
Table 5 Landsat 8, OLI statistics on Temporal Stability of radiometric calibration.

<table>
<thead>
<tr>
<th>Plot 1</th>
<th>Plot 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Plot 1" /></td>
<td><img src="image2.png" alt="Plot 2" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Plot 3" /></td>
<td><img src="image4.png" alt="Plot 4" /></td>
</tr>
<tr>
<td><img src="image5.png" alt="Plot 5" /></td>
<td><img src="image6.png" alt="Plot 6" /></td>
</tr>
</tbody>
</table>

Days since 11/02/2013 (Launch)
5. GEOMETRIC ACCURACY STABILITY

5.1 Objectives

The objective is to assess geometric stability of Landsat 8 data. According to the USGS certification document\(^4\), the standard deviation of the difference in the line and sample components between L1T reference product band and each L1T corresponding product band should be less than 12m.

5.2 Methods

The input panchromatic image (band 8), included in L1T products (image resampled to pixel size of 15m), is validated against a ‘reference’ panchromatic image originating from Landsat 8 OLI. The comparison is therefore relative. These results complement the interband registration results and registration of multi spectral bands against the panchromatic band is analysed.

The method is based on the following generic processing stages:

1. Dense matching processing between reference image and input image from the working data stack;
2. Filtering and analysis of image matching results (correlation grid);
3. Accuracy analysis based on filtered data.

Different geodetic accuracy metrics are proposed for the analysis; for instance, the root mean square and the circular error. It is important to distinguish between ‘product’ and ‘multi temporal’ metrics, therefore:

- A ‘product’ circular error at 90 percentile considers sample data of results obtained at pixel level
- A ‘multi temporal’ circular error at 90 percentile considers sample data of results obtained at product level

The results on each product are analysed and are aggregated in order to produce multi temporal accuracy presented herein.

In some sites, different regions exist, and therefore, results from different regions of the same scene are statistically compared. For details regarding reference products used for each test site please refer to section 7.

5.3 Results and Discussions

The geometry of 76 panchromatic band images observed over the different test sites has been checked: the multi temporal statistics have been computed over a period from the beginning of the year 2015 up to now. The sample data has been filtered, selecting cloud free data, and also removing those for which anomalies have been found (anomalies are discussed above).

As detailed below, the input data sample includes data from different test sites and also different regions. All the results have been merged together for the purpose of this report.

\(^4\) “Landsat Data Continuity Mission (LDCM) International Ground Station (IGS) Data Validation and Exchange (DV&E) and Certification Plan LS IC - 12 Version 2.0”
Differences exist depending on test site location and observation date. For all given test sites the results are mostly stable.

These results show that the mission operational goal is met: For each product, the magnitude of the mis-registration remains mainly below 1 m and the variability is within half the pixel. The temporal variability of the mean errors is also within 1 m, leading to a temporal circular error of 2.33 m.

The degradation seen during the winter months is no longer observed here, and it is therefore confirmed that the errors seen are due to season or more precisely seasonal differences between the reference and the input image.

Table 6 Landsat 8, OLI Panchromatic band – statistics on multi temporal geolocation accuracy (m).

<table>
<thead>
<tr>
<th>Accuracy Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Error Easting Direction (MeanX)</td>
<td>-0.20</td>
<td>Error between -2 m and 1.57 m</td>
</tr>
<tr>
<td>Mean Error Northing Direction (MeanY)</td>
<td>-0.31</td>
<td>Error between -5.28 m and 5.0 m</td>
</tr>
<tr>
<td>Standard Deviation Error Easting Direction (Std X)</td>
<td>0.69</td>
<td>Standard deviation of the mean errors. The standard deviation of each product varies from 1.6 m up to 12 m</td>
</tr>
<tr>
<td>Standard Deviation Error Northing Direction (Std Y)</td>
<td>1.40</td>
<td>Standard deviation of the mean errors. The standard deviation of each product varies from 1.3 m up to 12 m</td>
</tr>
<tr>
<td>Root Mean Square Easting Direction (RMS X)</td>
<td>0.72</td>
<td>The RMSX of each product varies from 1.65 m up to 12.48 m</td>
</tr>
<tr>
<td>Root Mean Square Northing Direction (RMSY)</td>
<td>1.44</td>
<td>The standard deviation of each product varies from 1.31 m up to 13.62 m</td>
</tr>
<tr>
<td>Empirical Circular Error 90th Percentile (CE90)</td>
<td>1.60</td>
<td>The empirical circular error is computed based on RM2D value supposed to be estimated at 1 sigma value. The linear relationship between CE and RMS2D CE90 = RMS2D x 1.575. This value is below the circular error (2.33) because estimated mean error sample does not follow a normal distribution.</td>
</tr>
</tbody>
</table>

Figure 3 below shows a multi temporal circular error plot, where one point depicts one product and the point coordinates is the easting displacement errors (meters) and northing displacement errors (meters). For 90% of the points, the radial error is within 2.33 m (better than 1 / 6 of map spacing – 15 m).
Note that, the results are relative to the quality of the Landsat 8 reference data, which is observed in some cases in a different year and in a different period of the year.

**Figure 3 Circular Error and Radial Error Distribution, all products / all sites.**

Figure 4 below shows the evolution of the mean error in both Easting and Northing directions for all selected products. The last measurements are within 2 m in terms of mean errors. Measurements above 4 m (absolute values) are most likely due to seasonal differences between the input images and the reference images.
Figure 4 Multi Temporal Evolution of Mean Errors, all products / all sites.

Figure 5 Distribution of radial errors, all products / all sites
For each test site, the mean errors of multi temporal registration are nearly below 1 metre which is considered excellent. The multi temporal variation of errors (‘Std’) is mainly due to the test site itself; natural variability of the terrain, agreement with the reference data etc.

The ‘multi temporal’ circular error below is computed based on the input data stack; the more products provided as input, the more relevant results are. The number of products is given to better assess reliability of circular error value.

Compared to the previous reporting period, the “France La Crau (196 / 30)”, “Spain Grenada (200 / 34)”, “Spain Balears (196 / 32)” and “Spain Ibiza (198 / 33)” results have been updated and are given below in Table 7.

The accuracy (CE90) of products observed over the different sites of Spain is approximately in the same order of magnitude. In case of La Crau (France), the results looks degraded, due to the bad results coming from the two products observed in the winter period, mean Error value in Northing direction is above 4.0 m (absolute value). For the rest of products, the La Crau results are conformed to the other ones.

Table 7 Landsat 8, OLI Panchromatic band – statistics on multi temporal geolocation accuracy (meter), per sites where X,Y samples are defined as vector of mean error in each direction for each product.

<table>
<thead>
<tr>
<th>Site (WRS2 Path/Row)</th>
<th>Products/ROI</th>
<th>Mean X</th>
<th>Mean Y</th>
<th>Std X</th>
<th>Std Y</th>
<th>RMS X</th>
<th>RMS Y</th>
<th>RMS 2D</th>
<th>CE90</th>
</tr>
</thead>
<tbody>
<tr>
<td>France La Crau (196 / 30)</td>
<td>20/ 1</td>
<td>0.28</td>
<td>-1.34</td>
<td>0.31</td>
<td>1.44</td>
<td>0.42</td>
<td>1.96</td>
<td>0.59</td>
<td>3.53</td>
</tr>
<tr>
<td>Spain Balears (196 / 32)</td>
<td>21 / 2</td>
<td>-0.36</td>
<td>0.16</td>
<td>0.61</td>
<td>1.27</td>
<td>0.71</td>
<td>1.28</td>
<td>1.00</td>
<td>2.14</td>
</tr>
<tr>
<td>Spain Ibiza (198 / 33)</td>
<td>14 / 2</td>
<td>0.27</td>
<td>0.45</td>
<td>0.51</td>
<td>1.08</td>
<td>0.58</td>
<td>1.16</td>
<td>0.82</td>
<td>1.61</td>
</tr>
<tr>
<td>Spain Grenada (200 / 34)</td>
<td>21 / 1</td>
<td>-0.92</td>
<td>-1.29</td>
<td>0.52</td>
<td>0.83</td>
<td>1.06</td>
<td>1.54</td>
<td>1.49</td>
<td>2.38</td>
</tr>
</tbody>
</table>
6. INTERBAND REGISTRATION ACCURACY

6.1 Objectives

The objective is to validate band registration accuracy by performing a Band-to-Band (B2B) alignment analysis upon validated products. According to the USGS certification document\(^5\), the RMSE-line and RMSE-sample error threshold for B2B, averaged for all within-band comparisons is:

- 0.15 pixels (4.5m) for OLI
- 0.18 pixels (18m) for TIRS
- 0.3 pixels (30m) for OLI/TIRS comparisons

6.2 Methods

The L1T band to band registration accuracy is assessed by analysing image matching results based on image pixels for which the correlation confidence is above 0.95. The image twins as input of image matching are as follows:

- OLI Band Twin: [2, 3], [3, 4], [4, 5], [5, 6], [6, 2]
- TIRS Band Twin: [10, 11]
- OLI/TIRS comparisons: [5, 10]

The registration between the NIR band and panchromatic band is evaluated separately.

In case of OLI bands, the same pixel candidates are considered for all image twins. With this approach, it might happen that the number of pixels is too small to provide consistent results and product is discarded. The properties of the selected test site is an important aspect.

In order to evaluate our error budget, a “transitivity check” is performed: displacement errors for band twins [2, 3], [3, 4], [4, 5], [5, 6] are summed up and then compared to results of [2, 6].

The error budget is the driver of this method. When several products are analysed, it is always the results of the one with the lowest error budget that is kept.

The registration accuracy is also evaluated from a multi temporal point of view. The temporal evolution of radial error is analysed, with results from different sites merged together. This output should be carefully analysed because interband results are test site dependant.

The two sites considered are mostly the La Crau site (France) and the Grenada site (Spain).

6.3 Results and Discussions

6.3.1 OLI Multi spectral

This month, the selected product has been observed over La Crau (France).

\(^5\) “Landsat Data Continuity Mission (LDCM) International Ground Station (IGS) Data Validation and Exchange (DV&E) and Certification Plan LS IC - 12 Version 2.0”
As usual, the matching quality depends on the image twin and spectral bands involved. The influence of the atmosphere is significant in the NIR and the SWIR bands which introduce spectral variability between two bands, as well as noise.

Consequently, with less confident pixels, results for band twins [4, 5] and [5, 6], [6, 2] remain accurate but not as precise as we might expect. Regarding mean errors, the transitivity test, for all band twins, indicates a deviation of 0.05 m in the easting direction and 0.38 m in the northing directions: Results given are reliable.

Table 8 below summarizes geometric registration accuracy results for band twins; [2,3], [3,4], [4,5], [5,6], [6,2] for the product LC8196030302MTI00 (La Crau). Accuracy statistics are computed based on mean displacement results of each twin.

Table 8 Landsat 8, OLI MS bands – statistics on band to band registration accuracy (m)

<table>
<thead>
<tr>
<th>Band Twin</th>
<th>Confident Pixels Percentage</th>
<th>MeanX (m)</th>
<th>MeanY (m)</th>
<th>StdX (m)</th>
<th>StdY (m)</th>
<th>RMSX (m)</th>
<th>RMSY (m)</th>
<th>RMS (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2, 3]</td>
<td>39.64</td>
<td>-0.15</td>
<td>0.36</td>
<td>1.44</td>
<td>1.74</td>
<td>1.44</td>
<td>1.78</td>
<td>2.29</td>
</tr>
<tr>
<td>[3, 4]</td>
<td>50.96</td>
<td>0.13</td>
<td>-0.19</td>
<td>1.15</td>
<td>1.28</td>
<td>1.16</td>
<td>1.30</td>
<td>1.74</td>
</tr>
<tr>
<td>[4, 5]</td>
<td>5.54</td>
<td>-0.04</td>
<td>0.37</td>
<td>2.03</td>
<td>2.69</td>
<td>2.03</td>
<td>2.72</td>
<td>3.39</td>
</tr>
<tr>
<td>[5, 6]</td>
<td>4.13</td>
<td>0.14</td>
<td>-0.38</td>
<td>3.07</td>
<td>3.67</td>
<td>3.07</td>
<td>3.69</td>
<td>4.80</td>
</tr>
<tr>
<td>[6, 2]</td>
<td>8.11</td>
<td>-0.13</td>
<td>-0.54</td>
<td>2.78</td>
<td>3.26</td>
<td>2.78</td>
<td>3.31</td>
<td>4.32</td>
</tr>
</tbody>
</table>

The temporal evolution of radial errors in both directions is shown in the figure below. Results of two different sites are merged together (La Crau, Grenada).

As shown in the figure, accuracy derived from this validation is varying from month to month: it is mostly due to the atmospheric conditions, the season and the different properties of each test site. In any cases, the following observations are made.

- For “La Crau” site, the radial error never exceed 1 m (twin [5, 6]).
- For “Grenada” site, the radial error may reach 2 m (twin [5, 6]).

Also, one can note that the accuracy specification of the October product is in agreement with the past (previous) measurements.

![Figure 6 Temporal evolution of radial errors, MS band twins, (196/30 & 200/34)](image-url)
6.3.2 **TIRS Band Twin**

For “LC81960300302MTI00” the quality of band to band registration between the two TIRS bands (B10 and B11) has been assessed:

- The mean displacement remains with -1.07 m in the Easting direction and 4 m in the Northing direction.
- The standard deviation of errors in both directions reaches 8 m.

Results are improved compared to previous results, however Charge-Coupled Device (CCD) patterns still observed in the image. This checking of TIRS image is very accurate; more than 50% of the input image pixels have been used to compute these RMSE accuracy statistics.

6.3.3 **OLI / TIRS**

The method compares registration between the TIRS band 10 image and the OLI band 5 image. For this input dataset, results obtained are not reliable and cannot be used for reporting.

6.3.4 **OLI Panchromatic / Multi Spectral Bands**

The method compares registration between the panchromatic image rescaled to 30 m and selected multi spectral bands and thermal bands.

Results below are those obtained for “LC81960302017302MTI00”, the registration accuracy between the panchromatic image and multi spectral images has been assessed. All possible band combinations have been performed in the limit of the method (when matching cannot be performed or results are not reliable, the band combination is discarded).

Note that in general, the results for band twins [8, 5] and [8, 6] are statistically less significant because of image matching issues. All band twins results are aggregated together to provide synthetic results, as listed in Table 9 below, the results are fully compliant with the specification.

**Table 9 Landsat 8, OLI PAN/MS bands – statistics on band to band registration accuracy (m).**

<table>
<thead>
<tr>
<th>Band Twin</th>
<th>Confidence Pixels Percentage</th>
<th>MeanX (m)</th>
<th>MeanY (m)</th>
<th>StdX (m)</th>
<th>StdY (m)</th>
<th>RMSX (m)</th>
<th>RMSY (m)</th>
<th>RMS (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[8, 2]</td>
<td>11.45</td>
<td>-0.03</td>
<td>-0.10</td>
<td>0.83</td>
<td>0.89</td>
<td>0.89</td>
<td>0.89</td>
<td>1.22</td>
</tr>
<tr>
<td>[8, 3]</td>
<td>16.84</td>
<td>-0.04</td>
<td>0.05</td>
<td>0.68</td>
<td>0.74</td>
<td>0.68</td>
<td>0.74</td>
<td>1.00</td>
</tr>
<tr>
<td>[8, 4]</td>
<td>16.24</td>
<td>0.01</td>
<td>-0.07</td>
<td>0.68</td>
<td>0.71</td>
<td>0.68</td>
<td>0.72</td>
<td>0.99</td>
</tr>
<tr>
<td>[8, 5]</td>
<td>0.98</td>
<td>0.01</td>
<td>0.29</td>
<td>1.31</td>
<td>1.76</td>
<td>1.31</td>
<td>1.78</td>
<td>2.21</td>
</tr>
<tr>
<td>[8, 6]</td>
<td>3.38</td>
<td>0.07</td>
<td>0.22</td>
<td>1.27</td>
<td>1.27</td>
<td>1.27</td>
<td>1.29</td>
<td>1.81</td>
</tr>
</tbody>
</table>
7. TEST SITE DESCRIPTION

7.1 Geometric Test Sites

Seven geometric test sites have been defined, and four are currently used for the purpose of this analysis:

- France / La Crau and Spain / Balears sites belong to the same LS08 satellite path and we expect to analyse accuracy changes over a short term period. Geometric references exist in La Crau and other datasets are available for cross comparison.
- Spain / Ibiza site has been selected because two regions are located in opposite parts of the scene and results can therefore be statistically compared in order to analyse the stability in the scene.
- Spain / Grenada has been selected to maximize the number of cloud-free products acquired over a full year. The test field is centred on Sierra Nevada Park and the content of the site and terrain relief varies from north to south.

Figure 7 Geometric Test sites
Table 10 Geometric Test site details

<table>
<thead>
<tr>
<th>Country / Site Name</th>
<th>Landsat WRS2 Path/Row</th>
<th>Center Latitude (dd)/ Longitude (dd)</th>
<th>Number of ROIs</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>France / La Crau</td>
<td>196/30</td>
<td>43.85 / 5.18</td>
<td>1</td>
<td>HR Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GCP from GPS Test fields Campaign 'LC81960302015153MTI00'</td>
</tr>
<tr>
<td>Spain / Balears</td>
<td>196/32</td>
<td>39.71 / 3.62</td>
<td>2</td>
<td>'LC81960322016012MTI00'</td>
</tr>
<tr>
<td>Spain / Ibiza</td>
<td>198/33</td>
<td>38.80 / 0.59</td>
<td>2</td>
<td>'LC81980332016090MTI00'</td>
</tr>
<tr>
<td>Spain / Grenada</td>
<td>200/34</td>
<td>37.35 / -3.2</td>
<td>2</td>
<td>'LC82000342016008MTI00'</td>
</tr>
<tr>
<td>France / Toulouse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy / Rome</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy / Piemont</td>
<td></td>
<td></td>
<td></td>
<td>GCP from GPS Test fields Campaign</td>
</tr>
</tbody>
</table>

The three last rows of Table 10 above list sites not already used in the context of this work, but which are planned to be for future analysis.

Figure 8 Geometric Test sites: France La Crau ROI

For the purpose of the interband registration accuracy analysis, all the sites have been evaluated with the La Crau ROI offering the best results as it is largely spectrally stable and includes suitable features for matching (at the LS08 spatial scale).

7.2 Radiometric Test Sites

Regarding radiometric calibration, the Libya 4 test site is used (Path / Row 181 / 40). For more information on Libya 4 please refer to details in the document above.
Figure 9 Radiometric Test site, Libya 4
APPENDIX A GEOMETRIC SITE PRODUCT LIST

Listed below are all products used as input to our processing. For multi temporal geolocation accuracy, the reference data is part of the input dataset; these products are indicated with '[REF]'. The data used to update the statistical results (the new products acquired each month), are indicated in green. Also, the processing level of input data is mostly 'Level 1T'. In cases where the processing level is different i.e. L1Gt, this information is also reported. Note that 'L1Gt' products are used for the monitoring of radiometric stability and band to band registration. However, 'L1Gt' products are not used as input of the geometric accuracy stability assessment.

7.2.1 France / La Crau (196 / 30)

- LC81960302015153MTI00 [REF]
- LC81960302015185MTI00
- LC81960302015233MTI00
- LC81960302015313MTI00
- LC81960302016012MTI00
- LC81960302016124MTI00
- LC81960302016172MTI00
- LC81960302016188MTI00
- LC81960302016220MTI00
- LC81960302016236MTI00
- LC81960302016248MTI00
- LC81960302016252MTI00
- LC81960302016284MTI00
- LC81960302016316MTI00
- LC81960302016348MTI00 (removed)
- LC81960302016364MTI00 (removed)
- LC819603020170314TI00
- LC81960302017030MTI00 (cloudy – not used)
- LC81960302017062MTI00 (cloudy – not used)
- LC81960302017078MTI00
- LC81960302017094MTI00
- LC81960302017110MTI00
- LC81960302017142MTI00 (cloudy – not used)
- LC81960302017158MTI00
- LC81960302017206MTI00
- LC81960302017254MTI00
- LC81960302017270MTI00
- LC81960302017286MTI00
- LC81960302017302MTI00

7.2.2 Spain / Balears (196 / 32)

- LC81960322016012MTI00 [REF]
- LC81960322016124MTI00
- LC81960322016172MTI00
- LC81960322016188MTI00
- LC81960322016204MTI00
- LC81960322016220MTI00
- LC81960322016236MTI00
7.2.3 Spain / Ibiza (198 / 33)

- LC81980332016090MTI00 – [REF]
- LC81980332016154MTI00
- LC81980332016122MTI00
- LC81980332016250MTI00
- LC81980332016298MTI00
- LC81980332016314MTI00
- LC81980332016314MTI00
- LC81980332017028MTI00 (cloudy – not used)
- LC81980332017012MTI00
- LC81980332017060MTI00
- LC81980332017076MTI00 (cloudy – not used)
- LC81980332017092MTI00
- LC81980332017108MTI00
- LC81980332017124MTI00
- LC81980332017140MTI00
- LC81980332017172MTI00
- LC81980332017236MTI00
- LC81980332017252MTI00
- LC81980332017268MTI00
- LC81980332017284MTI00

7.2.4 Spain / Grenada (200 / 34)

- LC82000342016008MTI00 – [REF]
- LC82000342016056MTI00
- LC82000342016088MTI00
- LC82000342016200MTI00
- LC82000342016040MTI00
- LC82000342016072MTI00
- LC82000342016184MTI00
- LC82000342016216MTI00
- LC82000342016232MTI00
- LC82000342016248MTI00
- LC82000342016280MTI00
- LC82000342016312MTI00 (L1Gt, not processed)
- LC82000342016344MTI00
- LC82000342016360MTI00
- LC82000342017026MTI00 (cloudy – not used)
- LC82000342017010MTI00 (cloudy – not used)
- LC82000342017058MTI00
- LC82000342017074MTI00
- LC82000342017090MTI00 (cloudy – not used)
- LC82000342017106MTI00 (cloudy – not used)
- LC82000342017122MTI00
- LC82000342017138MTI00
- LC82000342017154MTI00
- LC82000342017170MTI00
- LC82000342017202MTI00
- LC82000342017234MTI00