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

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AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
JULY 2016	02 Sep 2016	July 2016 quality report Major update regarding quality assessment procedures and methods. Change of the operational team in charge of producing this quality report.
AUGUST 2016	02 Sep 2016	August 2016 quality report
SEPTEMBER 2016	03 Oct 2016	September 2016 quality report
OCTOBER 2016	03 NOV 2016	October 2016 quality report
NOVEMBER 2016	02 DEC 2016 (internal issue)	November 2016 quality report
NOVEMBER 2016	09 Jan 2017	Update of November 2016 quality report with L1T products
DECEMBER 2016	27 Jan 2017	December 2016 quality report
JANUARY 2017	02 Mar 2017	January 2017 quality report
FEBRUARY 2017	03 May 2017	February 2017 quality report

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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.

B2B	Band-to-Band
ESA	European Space Agency
IDEAS+	Instrument Data Evaluation and Analysis Service
LDCM	Landsat Data Continuity Mission
NIR	Near Infra-Red
NRT	Near Real Time
OLI	Operational Land Imager
RMS	Root Mean Square
ROI	Region Of Interest
SWIR	Short Wave Infra-Red
TIRS	Thermal Infra-Red Sensor
TOA	Top of Atmosphere
USGS	United State Geological Survey

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

Validation Item	Tests Performed / Results Expected
Radiometric Accuracy: 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	1) Interband registration assessment has not been conducted during this reporting period as there is insufficient cloud-free data for the La Crau site. The results in this section of the report relate to the previous reporting period (January) and will be updated during the March report.

Note: The USGS Landsat pages have been updated here 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. 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

TIRS image quality issues have been detected on one product observed this month. Vertical strips as residual of relative calibration are shown in both the TIRS band 10 image and the TIRS band 11 image. Investigations are on-going.

Some data available from the ESA service has been processed to L1Gt processing level, meaning that registration to a common reference map is not performed. Nominally, the L1Gt processing is an option which is applied when the ground control points set is not appropriate for geometric model refinement (number of points, spatial distribution). It is mainly due to the cloud cover content of the scene. Recently it has been observed that some scenes were unexpectedly processed as L1Gt.

This has now been corrected and the issue is closed, however it is still recommended, when selecting a Level 1 scene in the portal, to check the processing level metadata, as shown in Figure 1 below.

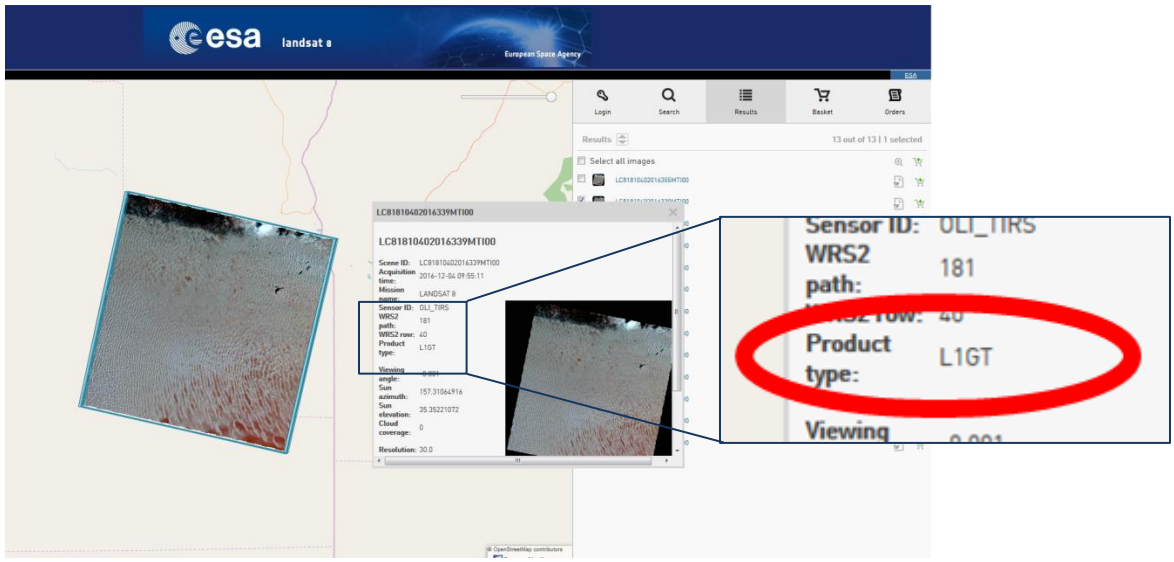


Figure 1 Screenshot of ESA Landsat 8 Web Portal, highlighting processing level under Product Type information

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 2 Landsat 8, OLI / TIRS spectral bandwidth definition and spatial resolution. Note that the bands in bold are the bands considered in this analysis (1-7 & 9)

Band Id	Band Label	Central Wavelength	Bandwidth (µm)	Spatial resolution (m)
1	**Coastal Aerosol**	**0.4426**	**0.43 - 0.45**	**30**
2	**Blue**	**0.4837**	**0.45 - 0.51**	**30**
3	**Green**	**0.5616**	**0.53 - 0.59**	**30**
4	**Red**	**0.6545**	**0.64 – 0.67**	**30**
5	**Near Infrared (NIR)**	**0.8641**	**0.85 – 0.88**	**30**

[1] *CEOS / Q4EO - USGS Test site catalog:* *http://calval.cr.usgs.gov/sites_catalog_template.php?site=lib4*

Band Id	Band Label	Central Wavelength	Bandwidth (µm)	Spatial resolution (m)
6	**Shortwave Infrared 1 (SWIR 1)**	**1.6097**	**1.57 – 1.65**	**30**
7	**Shortwave Infrared 2 (SWIR 2)**	**2.2036**	**2.11 – 2.29**	**30**
8	Panchromatic	0.5987	0.50 – 0.68	15
9	**Cirrus**	**1.373**	**1.36 – 1.38**	**30**
10	TIRS 1	-	10.60 – 11.19	100 * (30)
11	TIRS 2	-	11.50 – 12.51	100 * (30)

The relative spectral response curves of spectral bands considered in this analysis are shown in Figure 2 below.

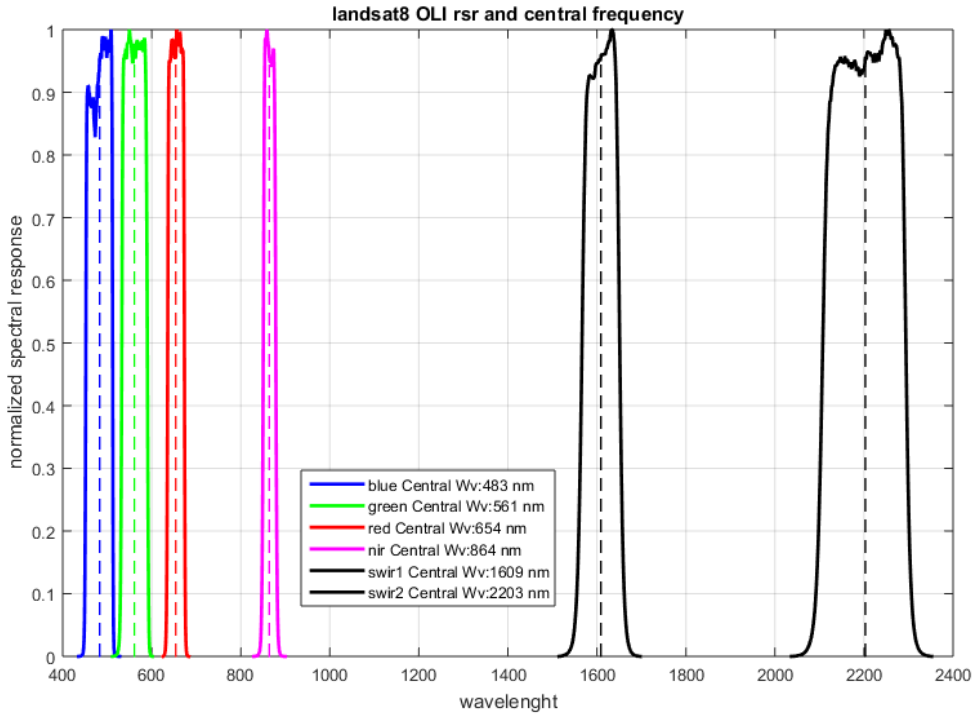


Figure 2 Relative Spectral Response

4.3 Results and Discussions

The statistics listed in both tables below are computed based on a dataset of 59 L1T products (from 02/05/2013 to 22/02/2017).

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[2]. 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).

Band Label	Mean Reflectance TOA	Std Reflectance TOA	Temporal Uncertainty (100 * Std / Mean)
Coastal Aerosol	0.217	0.002	1.120
Blue	0.241	0.002	0.945
Green	0.331	0.003	1.000
Red	0.450	0.005	1.165
Near Infrared (NIR)	0.574	0.007	1.290
Shortwave Infrared 1 (SWIR 1)	0.658	0.014	2.059
Shortwave Infrared 2 (SWIR 2)	0.601	0.0015	2.420

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

Band Label	Mean Reflectance TOA	Std Reflectance TOA	Temporal Uncertainty (100 * Std / Mean)
Coastal Aerosol	0.218	0.002	1.064
Blue	0.242	0.002	0.894
Green	0.330	0.003	1.008
Red	0.447	0.005	1.198
Near Infrared (NIR)	0.571	0.007	1.328
Shortwave Infrared 1 (SWIR 1)	0.656	0.014	2.081
Shortwave Infrared 2 (SWIR 2)	0.599	0.015	2.430

[2] *Nischal Mishra and Al, Absolute Calibration Of Optical Satellite Sensors using Libya 4 Pseudo Invariant Calibration Site, Remote Sens. 2014, 6, 1327-1346; doi:10.3390/rs6021327.*

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.

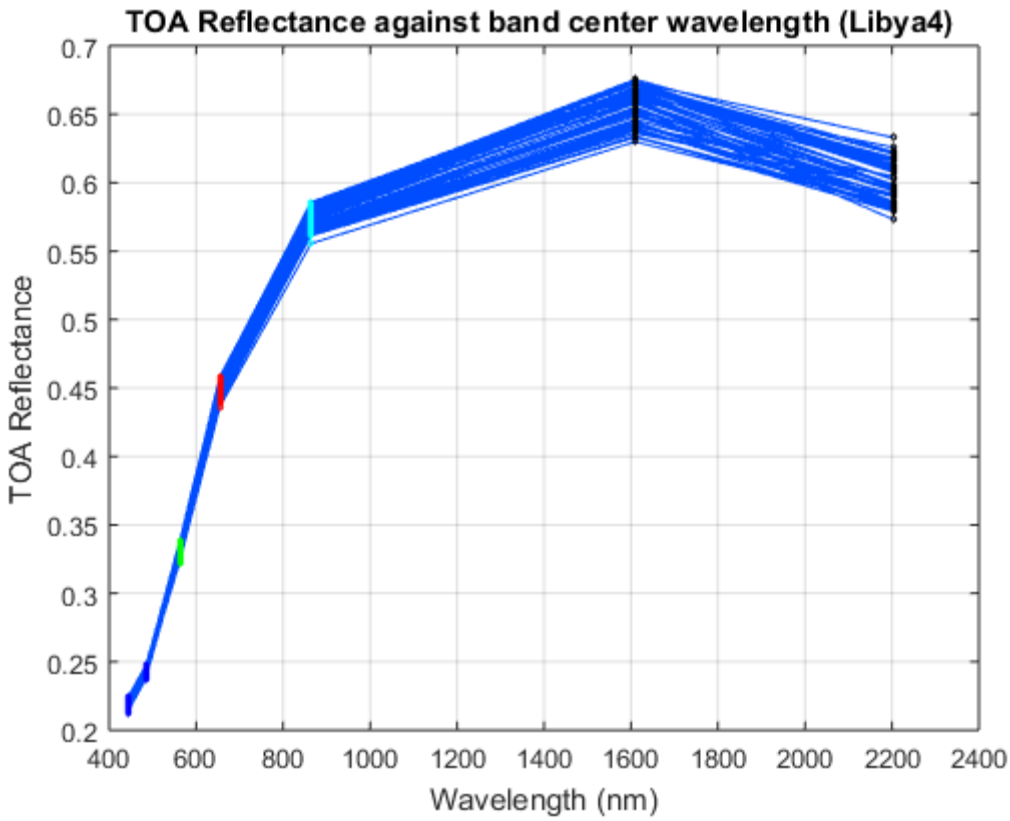


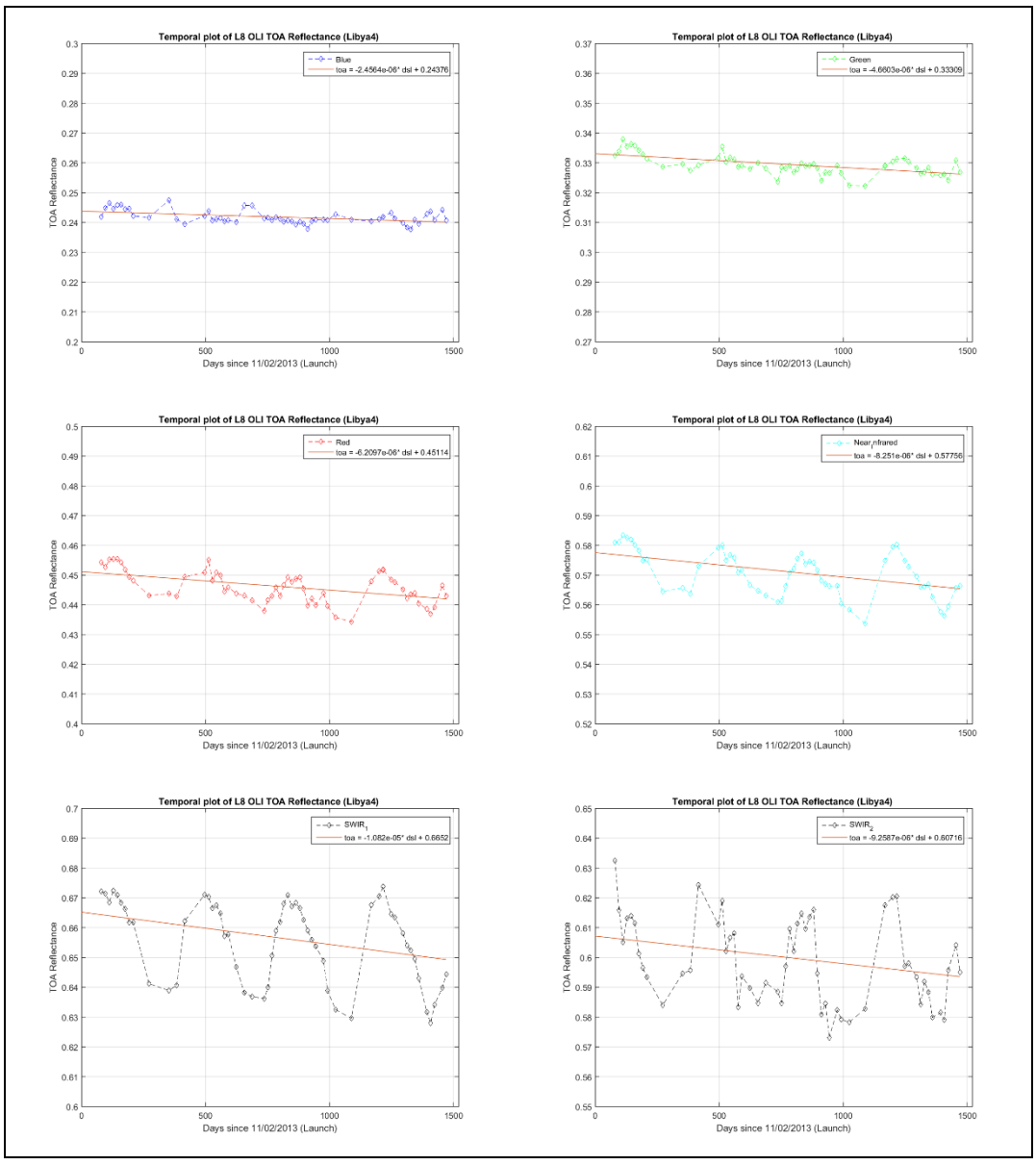
Figure 3 Reflectance profile as indicator of uncertainty.

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 exercises[3].

[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.



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

Starting from 71 L1T products, the geometry of 55 panchromatic band images have 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 2.34 m.

There are no results for data observed over La Crau, therefore degradation probably due to artefact, is not confirmed (see previous report for January 2017).

This month, results obtained over the Grenada site are very good since 45 % of the correlation measurement sample has been considered as confident. For this product, LC82000342017058MTI00, the mean error in both directions is below 1.3 m, leading to an overall RMS accuracy of 5 m. The centring in the North-South direction is more than correct (below 0.5 m). There is a small shift in the East-West direction due to the CCD margin footprint that is visible at a very fine scale.

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

Accuracy Parameter	Value	Comment
Mean Error Easting Direction (MeanX)	-0.25	Error between -2 m and 1.57 m
Mean Error Northing Direction (MeanY)	-0.32	Error between -2.4 m and 2.0 m
Standard Deviation Error Easting Direction (Std X)	0.77	Standard deviation of the mean errors. The standard deviation of each product is varying from 2m up to 9 m.
Standard Deviation Error Northing Direction (Std Y)	1.53	Standard deviation of the mean errors. The standard deviation of each product is varying from 2m up to 11 m.
Root Mean Square Easting Direction (RMS X)	0.81	-
Root Mean Square Northing Direction (RMSY)	1.56	-
Empirical Circular Error 90th Percentile (CE90)	1.81	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 classic circular error (2.34) because data distribution is not normal.

Figure 4 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 2.34 m.

Also, in the graphic below, the theoretical 1-sigma ellipse is also shown. It is used to assess 2D normal distribution of population (temporal mean errors on each point). In case of normality, the percentage of points should be about 68.3 %. For this experiment, this figure is 47 %.

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.

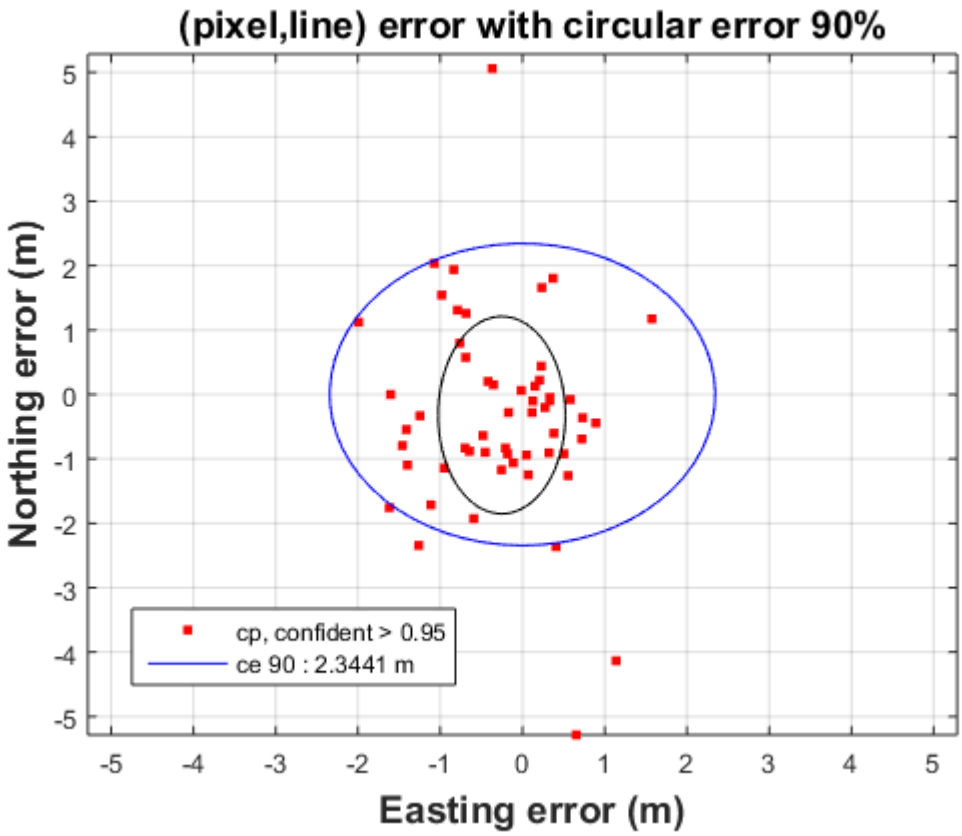


Figure 4 Circular Error and Radial Error Distribution, all products / all sites.

Figure 5 below shows the evolution of the mean error in both Easting and Northing directions for all selected products. The last measurement deviated significantly (4 m error in the Northing direction).

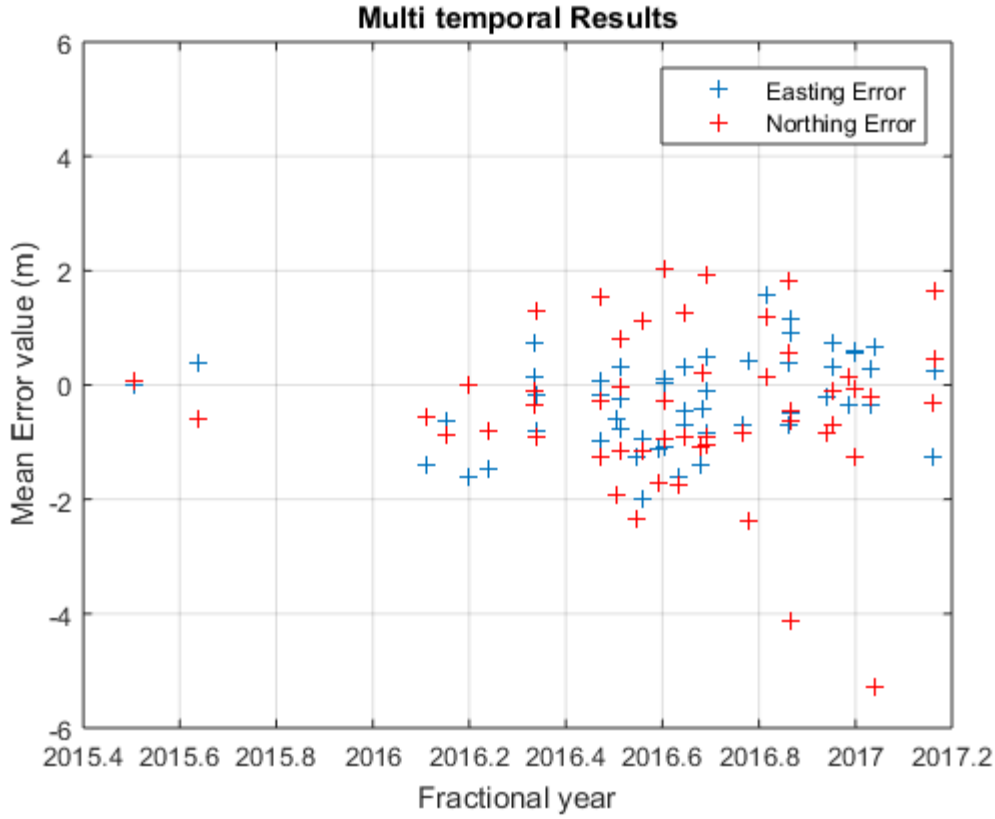


Figure 5 Multi Temporal Evolution of Mean Errors, all products / all sites.

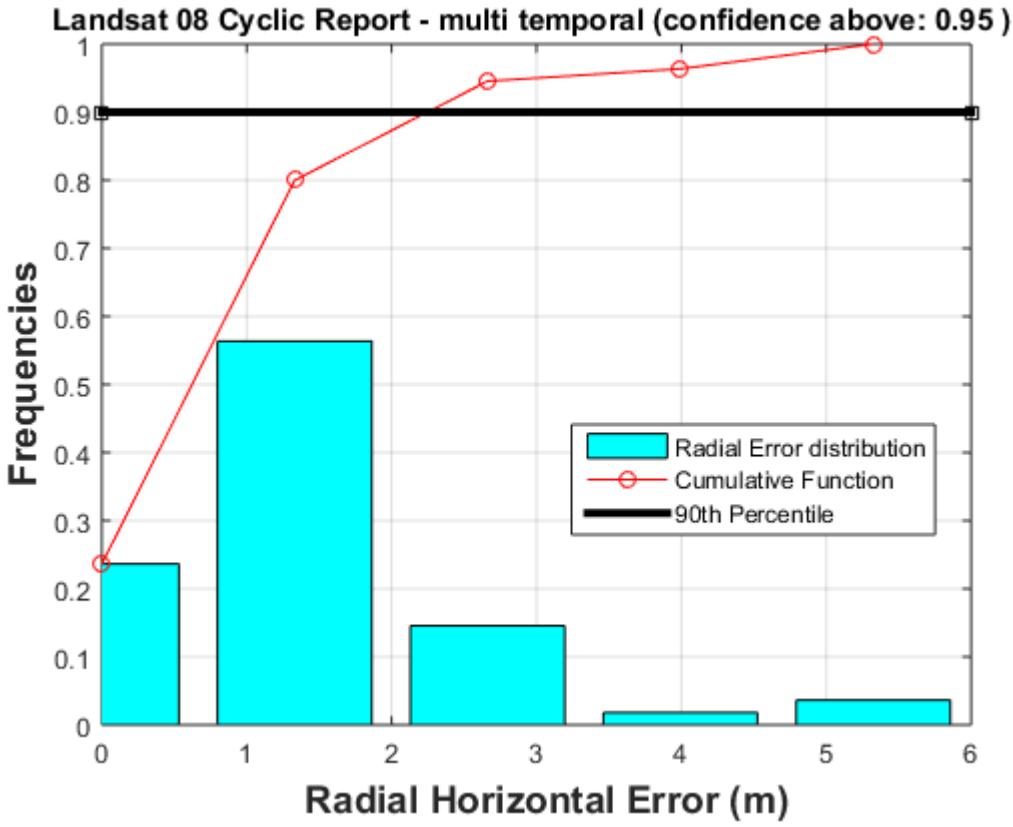


Figure 6 Distribution of radial errors, all products / all sites

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. As the number of products does not exceed 4, ce90 values are given for indication only.

Compared to the previous reporting period, "France La Crau (196 / 30)" and "Spain Ibiza (198 / 33)" results have been updated below in Table 7. The accuracy (CE90) of products observed over Spain is in the same order of magnitude. However, these results are different from France La Crau ones.

Table 7 Landsat 8, OLI Panchromatic band – statics on multi temporal geolocation accuracy (meter), per sites.

Site (WRS2 Path/Row)	Products/ ROI	Mean X	Mean Y	Std X	Std Y	RMS X	RMS Y	RMS 2D	CE90
France La Crau (196 / 30)	10 / 1	0.33	-1.45	0.36	1.81	0.51	2.37	1.15	4.28
Spain Balears (196 / 32)	10 / 2	-0.32	-0.03	0.72	1.17	0.79	1.17	1.12	2.11
Spain Ibiza (198 / 33)	6 / 2	0.20	0.88	0.58	1.49	0.61	1.73	0.86	1.93
Spain Grenada (200 / 34)	13 / 1	-1.04	-0.99	0.48	0.75	1.15	1.24	1.63	*2.28*

5.3.1 General Comments

Spain 4 – "Grenada / Almeria" (200 / 34):

Collected products show that this site is particularly well suited for the geolocation accuracy assessment. For this site, it is common to get more than 50 % of image pixels that are successfully (in term of confidence) matched with the reference baseline map.

Figure 7 below shows the matching results of the last product received this month. At the left part of the image, a 'vertical' brighter line is observed and within this location, the errors in pixel direction are a little bit higher (0.25 pixel ⇔ 3.75 m).

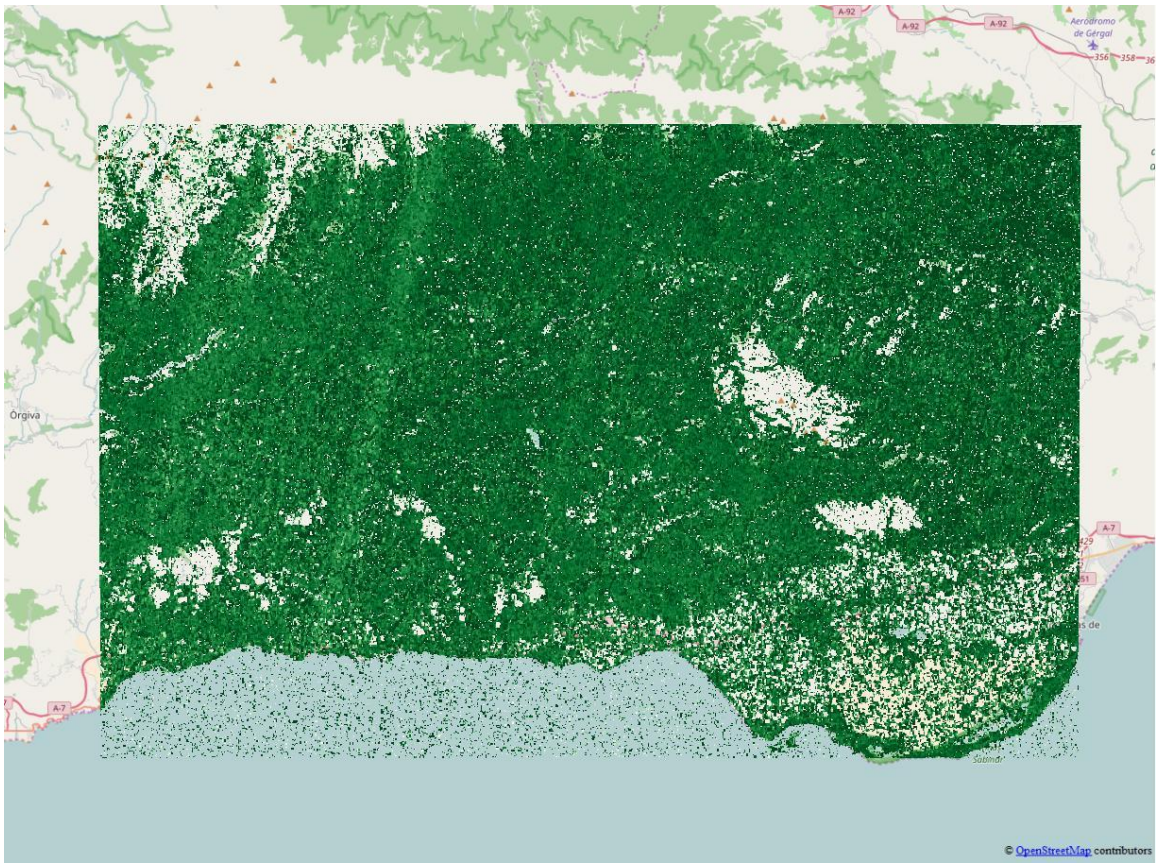


Figure 7 Image of pixel direction displacements (LC82000342017058MTI00)

This geometric problem is also observed in the histogram of error displacement images. The histogram of pixel direction error is shifted, not centred around '0' as seen for Line displacement errors (see Figure 8 and Figure 9 below).

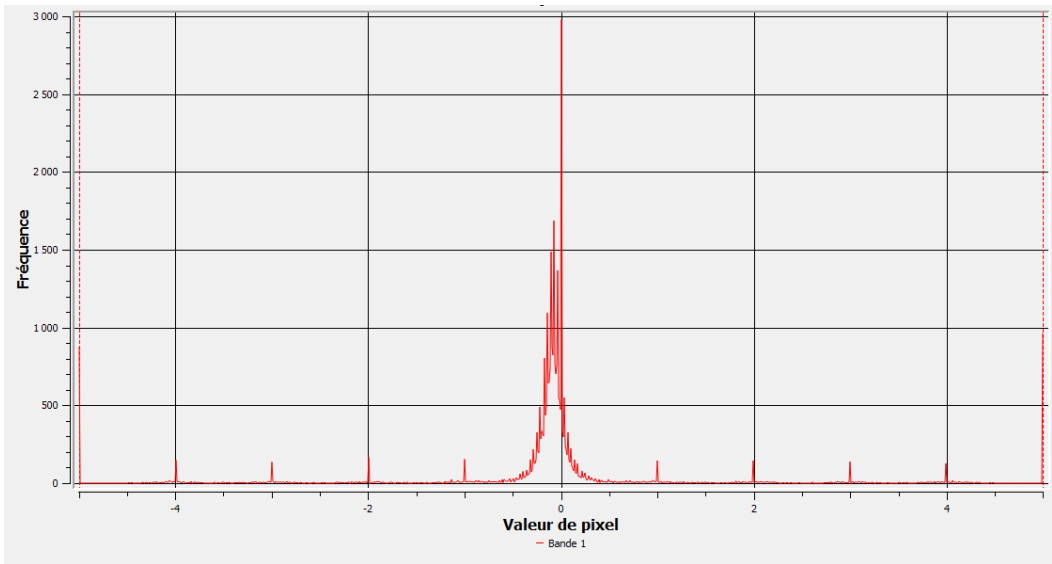


Figure 8 Histogram of geometric errors (pixel unit), pixel direction displacements (LC82000342017058MTI00)

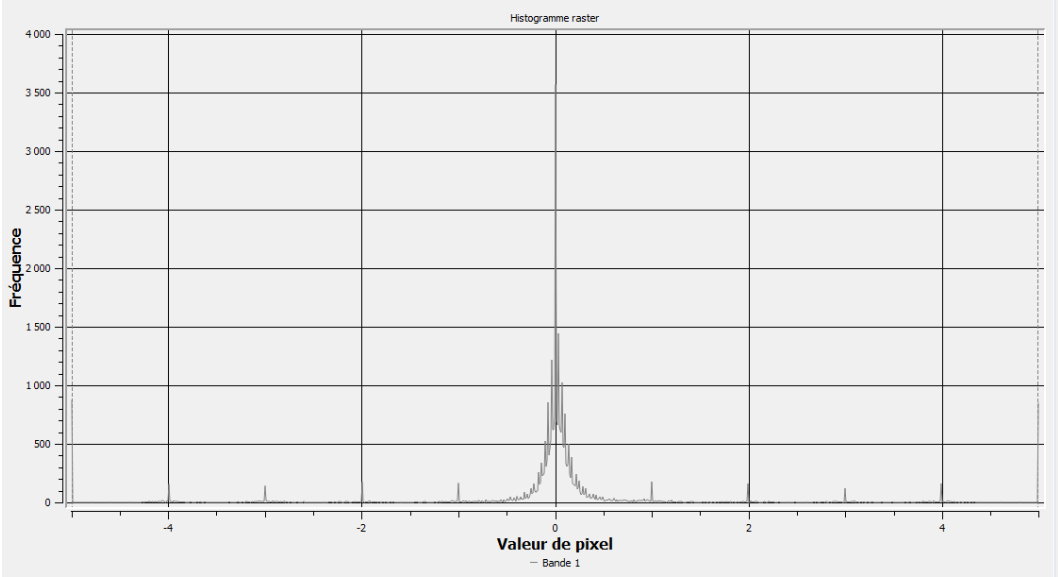


Figure 9 Histogram of geometric errors (pixel unit), line direction displacements (LC82000342017058MTI00)

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 interband registration accuracy is assessed with the analysis of image matching results based on image pixels for which the correlation confident is above 0.95. The image twins as input of image matching are the following ones:

- 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 and the transitivity of results is checked in order to evaluate the error budget. With this approach, it might happen that the number of pixels is too small to provide consistent results; therefore the selection of test site becomes critical.

The registration accuracy is also evaluated from a multi temporal point of view. The two sites considered are mostly the La Crau site (France) and the Grenada site (Spain).

6.3 Results and Discussions

These results and discussion relate to the products acquired in the January period as there was insufficient cloud-free data for the La Crau site during February. The results will be updated during the next (March) report.

6.3.1 OLI Multi spectral

One product observed over La Crau, France, has been considered as input to this analysis, the matching quality depends on the image twin with 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] remain accurate but not as precise as we might expect. Regarding mean errors, the transitivity test indicates a deviation of 0.21 m in the easting direction and 0.50 m in the northing directions which is, to a certain extent, still within the error budget of the method, compared to 30 m pixel resolution.

[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"*

Table 8 below summarizes geometric registration accuracy results for band twins; [2,3], [3,4], [4,5], [5,6], [6,2] for the France La Crau product LC81960302017014MTI00 (Results obtained on product LC81960302015153MTI00 are also indicated in '()').

Compared to previous results, the accuracy is stable, except for band [5,6] for which there is date to date variability, as shown in the figures below. Results are within the USGS specifications for band twins [2,3] and [3,4]. The results in the table below are averaged over all possible band combinations. Information on absolute value is given in the comment column.

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

Accuracy Parameter	Value	Comment
Mean Error Easting Direction (MeanX)	-0.04/(-0.08)	Error between -0.20 m and -0.39 m
Mean Error Northing Direction (MeanY)	-0.10/(-0.03)	Error between -0.97 m and -0.14 m
Standard Deviation Error Easting Direction (Std X)	0.30/(0.15)	Standard deviation values are higher for band twin [4,5], between 1.71 m and 17 m.
Standard Deviation Error Northing Direction (Std Y)	0.51/(0.19)	Standard deviation values are higher for band twin [4,5], between 2.4 m and 17 m.
Root Mean Square Easting Direction (RMS X)	0.30/(0.17)	For band twin [4,5], [5,6] and [6,2], the RMS results exceed 9.8 m. This is due to the accuracy of the method.
Root Mean Square Northing Direction (RMSY)	0.52/(0.20)	For band twin [4,5], [5,6] and [6,2], the RMS results exceed 8.8 m. This is due to the accuracy of the method.
Empirical Circular Error 90th Percentile (CE90)	0.68/(0.24)	For band twin [4,5], [5,6] and [6,2], the RMS results exceed 13 m. This is due to the accuracy of the method.

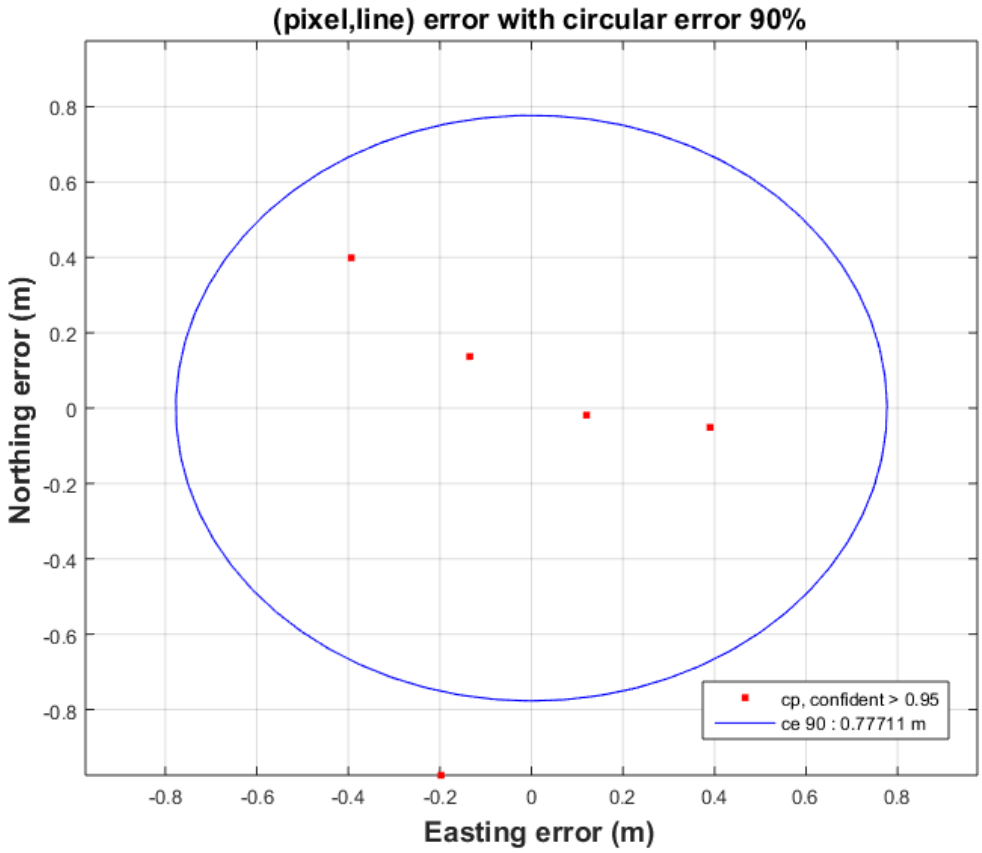


Figure 10 Circular Error and Radial Error Distribution, MS band twins, one product

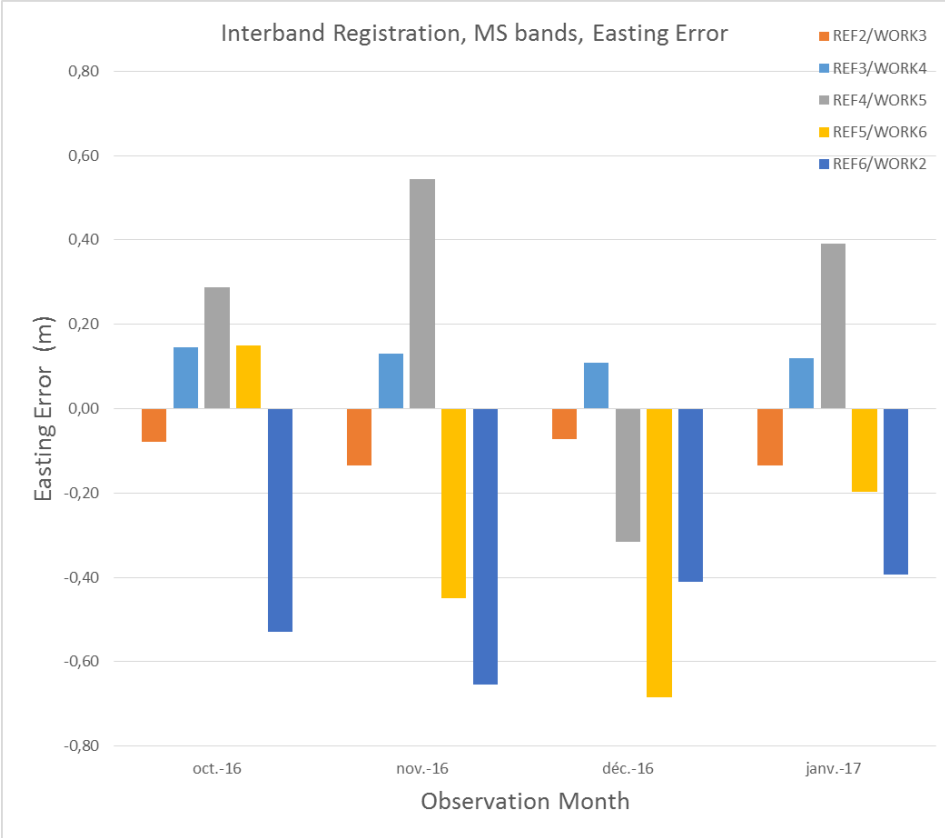


Figure 11 Temporal evolution of Easting direction errors, MS band twins, (196/30)

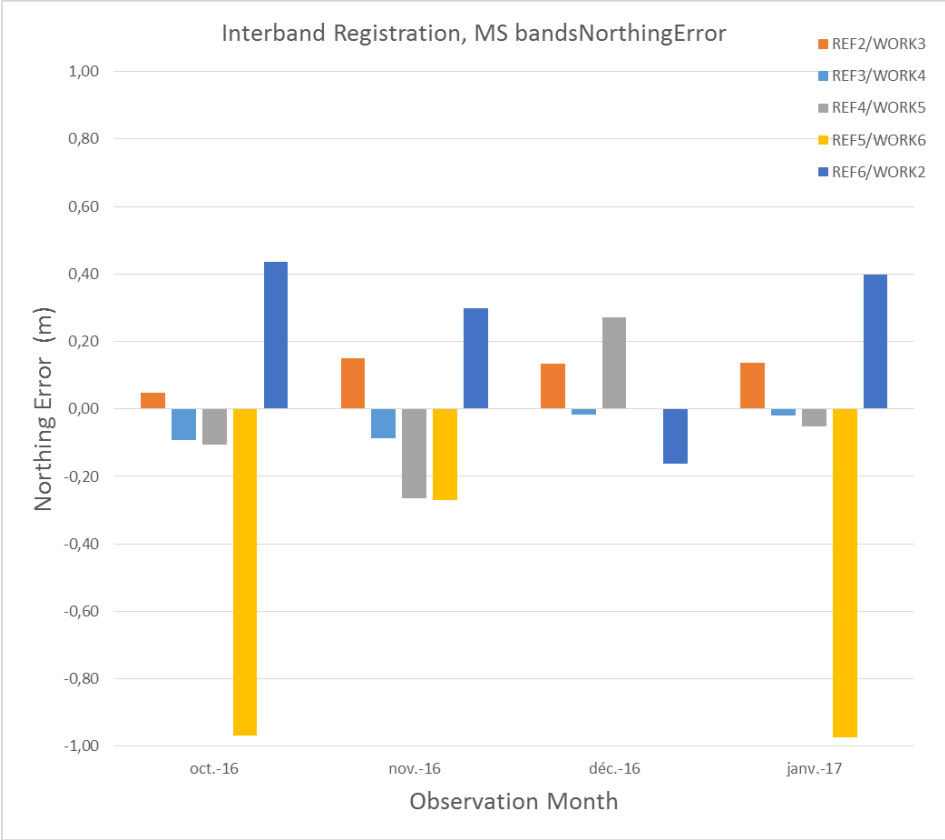


Figure 12 Temporal evolution of Northing direction errors, MS band twins, (196/30)

6.3.2 TIRS Band Twin

For "LC81960302017014MTI00", the quality of band to band registration between the two TIRS bands (B10 and B11) has been assessed. Due to an anomaly in Band 11, as shown in Figure 13, the results do not reach the operational goal: the RMS accuracy is about 50 m and the following outputs can be given:

- The mean displacement is still with 4 m in the Easting direction and 7 m in the Northing direction.
- The standard deviation of errors is the Northing direction reaches 53 m which is above L1T pixel size (30 m).

Results are very stable compared to those obtained in the December 2016 report.

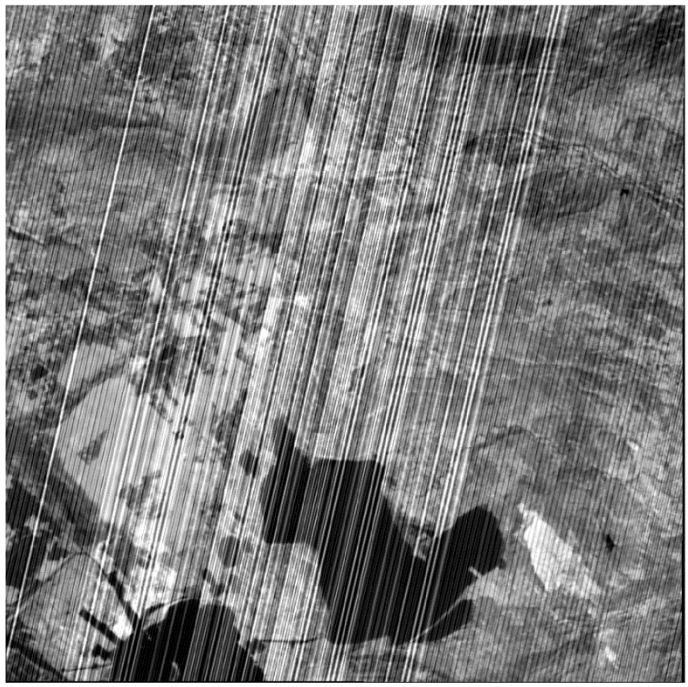


Figure 13 ROI image, TIRS Band 10.

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 "LC81960302017014MTI00", the registration accuracy between the panchromatic image and multi spectral images has been assessed. All possible band combinations have been performed.

In general, the results of following 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 – statics on band to band registration accuracy (m).

Accuracy Parameter	Value	Comment
Mean Error Easting Direction (MeanX)	0.06	Always negative values within 0.1 m, except [8,2] and [8,5] reaching 0.32 m.
Mean Error Northing Direction (MeanY)	-0.34	Always negative values within 0.1 m, , except [8,2] and [8,5] reaching 0.80 m.
Standard Deviation Error Easting Direction (Std X)	0.20	It is the mean of std of all band twins considered
Standard Deviation Error Northing Direction (Std Y)	0.43	It is the mean of std of all band twins considered. Large std values observed for twin [2,8]
Root Mean Square Easting Direction (RMS X)	0.21	It is the mean of RMS X of all band twins considered. Large std values observed for twin [2,8]
Root Mean Square Northing Direction (RMS Y)	0.55	It is the mean of RMS Y of all band twins considered. It remains below 5 m, 1/3 of geo coded pan chromatic pixel footprint

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 belongs 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 14 Geometric Test sites

Table 10 Geometric Test site details

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

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.

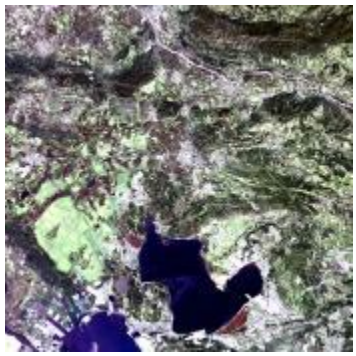


Figure 15 Geometric Test sites: France La Crau ROI

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 16 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)

- LC81960302015153MTI000 [REF]
- LC81960302015185MTI00
- LC81960302015233MTI00
- LC81960302015313MTI00
- LC81960302016012MTI00
- LC81960302016124MTI00
- LC81960302016172MTI00
- LC81960302016188MTI00
- LC81960302016220MTI00
- LC81960302016236MTI00
- LC81960302016248MTI00
- LC81960302016252MTI00
- LC81960302016284MTI00
- LC81960302016316MTI00
- LC81960302016348MTI00 (removed)
- LC81960302016364MTI00 (removed)
- LC819603020170314TI00
- LC81960302017030MTI00 (cloudy)

7.2.2 Spain / Balears (196 / 32)

- LC81960322016012MTI00 [REF]
- LC81960322016124MTI00
- LC81960322016172MTI00
- LC81960322016188MTI00
- LC81960322016204MTI00
- LC81960322016220MTI00
- LC81960322016236MTI00
- LC81960322016252MTI00
- LC81960322016316MTI00
- LC81960322016348MTI00
- LC81960322016364MTI00
- LC819603220170314TI00 (cloudy)
- LC81960322017030MTI00 (cloudy)

7.2.3 Spain / Ibiza (198 / 33)

- LC81980332016090MTI00 – [REF]

- LC81980332016154MTI00
- LC81980332016122MTI00
- LC81980332016250MTI00
- LC81980332016298MTI00
- LC81980332016314MTI00
- LC81980332016314MTI00
- LC81980332017028MTI00 (cloudy)
- LC81980332017012MTI00

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)
- LC82000342017010MTI00 (cloudy)