# Technical Note on Quality Assessment for Landsat 1-7


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# AMENDMENT RECORD SHEET

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

| ISSUE | DATE | REASON |
|---|---|---|
| 0.1 | 25/11/2020 | Draft version for ESA review |
| 1.0 | 14/03/2022 | Final version |

# TABLE OF CONTENTS

# 1. EXECUTIVE SUMMARY

The primary purpose of the activity performed with Landsat 1-7 data has been to ensure that the product format and content of the ESA-reprocessed Multispectral Scanner (**MSS**), Thematic Mapper (**TM**) and Enhanced Thematic Mapper Plus (**ETM+**) Landsat products generated as part of the Quality Assurance for Earth Observation (**QA4EO**) (formally IDEAS+) 2019-2020 reprocessing campaign, are of suitable quality. The assessment focused on the product details provided, the geolocation accuracies and the radiometric calibration. For more information on the ESA products used within this assessment, see Section 5.2.

The Report is divided into two sections. In the first section, the results are summarised following the EDAP guidelines documents [RD-1] and [RD-2]. The second section contains the detailed assessment performed and summarised in the first section.

# 2. INTRODUCTION

This document is the Technical Note (**TN**) on Quality Assessment report for the Landsat 1-7 missions.

The quality assessment provides a series of checks on the product format and metadata; checks on the geometric and radiometric validation were performed on a limited number of products.

Please note that at the time of writing this document, the assessment provided herein has been performed on the most recently reprocessed ESA Landsat products (rather than USGS products), see Section 5.2 for more details.

The quality assessment performed here is in line with the assessment guidelines provided in the EARTHNET Data Assessment Pilot (**EDAP**) project [RD-1] and the guidelines tailored for optical missions [RD-2].

## 2.1 Reference Documents

The following is a list of reference documents with a direct bearing on the content of this proposal. Where referenced in the text, these are identified as [RD-n], where 'n' is the number in the list below:

RD-1. EDAP.REP.001 Generic EDAP Best Practice Guidelines,1.1 23 May 2019

RD-2. EDAP.REP.002 Optical Mission Quality Assessment Guidelines, v1.0, 16 October 2019.

RD-3. IDEAS-VEG-SRV-REP-1320 IDEAS Landsat Product Description Document, v6.0 2015 https://earth.esa.int/documents/10174/679851/LANDSAT_Products_Description_Document.pdf

RD-4. IDEAS+-VEG-OQC-REP-2648 Landsat MSS QA Band Technical Note, v3.0, 9 November 2018

RD-5. EDAP.MEM.017 EDAP Landsat 1-7 Test Dataset v1.0, 25 November 2020

RD-6. Global Land Survey (GLS) data sets: https://www.usgs.gov/core-science-systems/nli/landsat/global-land-survey-gls?qt-science_support_page_related_con=0#qt-science_support_page_related_con

## 2.2 Glossary

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

| | |
|---|---|
| BQA | Quality Assurance Band |
| CCI | Climate Change Initiative |

| | |
|---|---|
| CE90 | the Circular Error at the 90th percentile |
| EDAP | EARTHNET Data Assessment Pilot |
| ETM+ | Enhanced Thematic Mapper Plus |
| GCPs | Ground Control Points |
| GLS | Global Land Survey |
| IGS | International Ground Station |
| MSS | Multispectral Scanner |
| NASA | National Aeronautics and Space Administration |
| NIR | Near InfraRed |
| NPL | National Physical Laboratory |
| OLI | Operational Land Imager |
| PICS | Pseudo Invariant Calibration Sites |
| QA4EO | Quality Assurance for Earth Observation |
| S2 | Sentinel 2 |
| S2A | Sentinel-2A |
| S2B | Sentinel-2B |
| SOM | Space Oblique Mercator |
| TM | Thematic Mapper |
| TN | Technical Note |
| TOA | Top of Atmosphere |
| USGS | United States Geological Survey |
| ZNCC | Zero-mean Normalised Cross-Correlation |

# 3. EDAP QUALITY ASSESSMENT

## 3.1 EDAP Maturity Matrix

The preliminary assessment was performed following the EDAP quality assessment guidelines written by the National Physical Laboratory (**NPL**) [RD-1], with the summary reported in Table 3-1 below and detailed analysis within Section 4.

This assessment has been performed for the ESA IPF/products rather than those generated by USGS. However, the ESA IPF processor has been developed from USGS documents alongside the knowledge of the ESA team – where the assessment primarily related to USGS documentation; this has been indicated with '[USGS]'. Also, it is considered as a 'preliminary assessment' as it was prepared using a limited number of products over specific calibration sites and the documentation is still being updated as, at the time of issue of this document, the TM/ETM reprocessing is in the final stages of being completed.

**Table 3-1: Landsat 1-7 Quality Maturity Matrix**

| Product Information | Product Generation | Ancillary Information | Uncertainty Characterisation | Validation |
|---|---|---|---|---|
| Product Details | Sensor Calibration & Characterisation Pre-Flight [USGS] | Product Flags | Uncertainty Characterisation Method | Reference Data Representativeness |
| Product Availability & Accessibility | Sensor Calibration & Characterisation Post-Launch [USGS] | Ancillary Data – not all documents publicly available | Uncertainty Sources Included | Reference Data Quality |
| Product Format | Retrieval Algorithm Method | If target mission data product is Level 2 | Uncertainty Values Provided | Validation Method |
| User Documentation – not all publicly available | Retrieval Algorithm Tuning | | Geolocation Uncertainty | Validation Results |
| Metrological Traceability Documentation | Additional Processing | | | |

| Key |
|---|
| Not Assessed |
| Not Assessable |
| Basic |
| Intermediate |
| Good |
| Excellent |

Information not public

## 3.2 Summary of Quality Assessment

The summary of the activities performed for Landsat 1-7 products listed in RD-5 is shown in Table 3-2.

**Table 3-2: Executive Summary**

| Assessment | Results |
|---|---|
| **Product details and visual assessment** | The images assessed within this study were without artefacts or anomalies. Although Landsat products, as a whole, are well documented to have artefacts and anomalies these are known and accounted for within the Quality Band.<br><br>The existing documentation, regarding the Quality mask band can be considered mature across each of the Landsat Missions and is typically consistent when identifying anomalies, artefacts and implementation of the cloud and water masks.<br><br>Where inconsistencies occur within the Quality band, they are attributed to the supplementary data used in its production, e.g. the Water mask is derived from the Climate Change Initiative (**CCI**) land-cover classification. The minor inconsistencies relate to either the temporal restrictions of the classification or false positives of the 'Water Bodies' class used within Landsat's Quality band. |
| **Geometric accuracy** | As expected, the geometric assessment performed on the medium resolution Landsat imagery showed that earlier missions have a lower accuracy than LS08 and Sentinel-2A (**S2A**) and Sentinel-2B (**S2B**).<br><br>Results from the matching process showed some MSS LS01 to LS05 scenes contain pixel displacement higher than 5, whereas LS08 are very accurate and precision is below 0.25 pixels.<br><br>In comparison, S2A & S2B sensors are highly accurate and precise.<br><br>When compared with other data layers, i.e. GLS or Sentinel 2 (**S2**), Landsat missions are observed to have a displacement in the easting direction. |
| **Radiometric accuracy** | In line with expectations regarding geometric accuracy, LS07 had the highest radiometric accuracy in reference to S2 data, as well as most consistent across the time-series analysed.<br><br>Surprisingly, it was observed that LS04 and LS05 (MSS) products had the lowest radiometric accuracy with reference products compared to LS01-3 (MSS) and LS05 (TM).<br><br>Within Landsat mission's individual time-series, the results show a strong linear consistency within LS02 (MSS), LS05 (MSS), LS05 (TM) and LS07 (ETM+). However, in comparison to the Sentinel-2 reference data, the radiometric accuracy is somewhat removed. |

# 4. DETAILED EDAP QUALITY ASSESSMENT

## 4.1 Product Information

| Product Details | |
|---|---|
| Product Name | *Precision Ortho-Corrected* |
| Sensor Name | *Landsat 1-7* |
| Sensor Type | *MSS (LS1-5), TM (LT5) and ETM (L07)* |
| Product Version Number | *L1T* |
| Processor Name / Version | *<Landsat/Sensor/Satellite>_<Path/Row>_<Year/Julian Day>_<Ground Station Identifier/Archive Version number>*<br>*Example:* LM12010431975113FUI00<br>*Full list in APPENDIX A* |
| Product ID | *Level 1* |
| Processing level of product | *Radiance / Top of Atmosphere Reflectance* |
| Measured Quantity Name | $W\ sr^{-1}\ m^{-2}\ \mu m^{-1}$ |
| Measured Quantity Units | *Unavailable* |
| Stated Measurement Quality | *60 m (LS1-5)/ 30 m (LS7)* |
| Spatial Resolution | *180 km x 180 km Tiles* |
| Spatial Coverage | *16-day global repeat acquisitions are provided by each satellite within the Landsat constellation.* |
| Temporal Resolution | *Variable* |
| Temporal Coverage | *Precision Ortho-Corrected* |
| Point of Contact | *ESA* |
| Product locator (DOI/URL) | *None* |
| Conditions for access and use | *None* |
| Limitations on public access | *None* |
| Product Abstract | *Full product description available at:*<br>LANDSAT_Products_Description_Document.pdf |

| Availability & Accessibility | |
|---|---|
| Compliant with FAIR principles | *Yes* |
| Data Management Plan | *Not available to users* |
| Availability Status | *Available for download* |

| Product Format | |
|---|---|
| Product File Format | *ESA data encoding is standard GeoTIFF with .XML and .TXT metadata files.* |

| | |
|---|---|
| Metadata Conventions | *ESA Metadata Schema located at* https://earth.esa.int/documents/700255/1834061/ngEO+Tailoring+for+Landsat.pdf |
| Analysis Ready Data? | • *No for ESA – geometric information missing from metadata, geolocation accuracy non-compliant with CARD4L standards*<br>• *USGS does have an ARD product for conterminous United States (CONUS), Alaska and Hawaii:* *https://www.usgs.gov/core-science-systems/nli/landsat/us-landsat-analysis-ready-data* |

| User Documentation | | |
|---|---|---|
| *Document* | *Reference* | *QA4ECV Compliant* |
| Product User Guide | • *ESA product specification document available online:* LANDSAT_Products_Description_Document.pdf<br>• *USGS documents available at* *https://www.usgs.gov/core-science-systems/nli/landsat/product-information* | *ESA document partially – user cases and validation missing. Also, needs updating for the latest TM and ETM results.* |
| ATBD | • ESA IPF ATBD currently only available internally<br>• Several USGS documents have been used as inputs to the ESA IPF, and they are listed in the ESA IPF ATBD | |

| Metrological Traceability Documentation | |
|---|---|
| Document Reference | *N/A* |
| Traceability Chain / Uncertainty Tree Diagram Available | *Traceability / Uncertainty analysis not conducted for ESA IPF* |

## 4.2 Product Generation

| Sensor Calibration & Characterisation – Pre-Flight | |
|---|---|
| Summary | • *Described in detail by USGS on the Landsat specific website, in addition the approach is published in technical notes and numerous peer-reviewed papers.*<br>• *ESA MSS products that were saturating have an adapted calibration applied – will be described in the next update of the ESA product specification document* |
| References | • https://www.usgs.gov/core-science-systems/nli/landsat |

| Sensor Calibration & Characterisation – Post-Launch | |
|---|---|
| Summary | The Landsat Science Team (including USGS, NASA and external scientists) are tasked with providing scientific and technical evaluations. Also, there are on-going activities in the broader worldwide scientific community. |

| | |
|---|---|
| References | • Full list of Science Team publications at https://www.usgs.gov/core-science-systems/nli/landsat/landsat-science-team-publications |

| Additional Processing | |
|---|---|
| *Additional Processing 1* | |
| Description | *N/A* |
| Reference | *N/A* |

## 4.3 Ancillary Information

| Product Flags | |
|---|---|
| Product Flag Documentation | *The ESA products have a quality assessment band (BQA), based on but differing from the USGS products – will be described in the next update of the* LANDSAT_Products_Description_Document.pdf |
| Comprehensiveness of Flags | *Flags are available for: clouds, water, saturation, and several anomalies*<br>*The cloud flagging is limited when compared with the USGS approach, but the ESA product flags sticky bits (and corrects for MSS) that the USGS product doesn't include* |

| Ancillary Data | |
|---|---|
| Ancillary Data Documentation | *Described in the ESA IPF ATBD and* LANDSAT_Products_Description_Document.pdf |
| Comprehensiveness of Data | • *Publicly available: USGS Calibration Parameter File (CPF), DEM from the GLS2000 dataset (http://glcf.umd.edu/data/glsdem/) and BQA water mask is derived from the CCI land-cover classification*<br>• *Not available to users, but available within ESA: State Vector Files and GCP database* |
| Uncertainty Quantified | *Not performed* |

## 4.4 Uncertainty Characterisation

| Uncertainty Characterisation Method | |
|---|---|
| Summary | *Radiometric Uncertainty Characterisation not performed for the ESA products* |
| Reference | *N/A* |

| Uncertainty Sources Included | |
|---|---|
| Summary | *N/A* |
| Reference | *N/A* |

| Uncertainty Values Provided | |
|---|---|
| Summary | *N/A* |
| Reference | *N/A* |

| | |
|---|---|
| Analysis Ready Data? | *N/A* |

| Geolocation Uncertainty | |
|---|---|
| Summary | *Described within this technical note, and earlier versions of the analysis have been presented at conferences, e.g. see references below* |
| Reference | • *Saunier et al. 2017 European Space Agency (ESA) Landsat MSS/TM/ETM+/OLI archive: 42 years of our history, DOI: 10.1109/Multi-Temp.2017.8035252*<br>• *Saunier et al. 2019 Evaluation of the geometric accuracy across the European Space Agency (ESA) Landsat historical archive, DOI: 10.1117/12.2533198* |

## 4.5 Validation

| Reference Data Representativeness | |
|---|---|
| Summary | *Geolocation and radiometric accuracy were tested on limited number of locations.* |
| Reference | *This Report* |

| Reference Data Quality & Suitability | |
|---|---|
| Summary | *Sentinel-2A and Landsat-8 are typically missions used as a reference as their accuracy is high and well documented* |
| Reference | • https://sentinel.esa.int/documents/247904/685211/Sentinel-2_User_Handbook<br>• https://www.usgs.gov/land-resources/nli/landsat/landsat-8-data-users-handbook |

| Validation Method | |
|---|---|
| Summary | *Relative and absolute geolocation and radiometric accuracy* |
| Reference | *See Sections 5.5 and 5.6* |

| Validation Results | |
|---|---|
| Summary | *Described within the listed sections of this Report* |
| Reference | *See Sections 5.5 and 5.6* |

# 5. DETAILED LANDSAT 1-7 QUALITY ASSESSMENT

## 5.1 Goals

This TN proposes accuracy results regarding the following validation aspects:

- Geometric Calibration Quality
- Radiometric Calibration Quality
- Image Quality

## 5.2 Mission Description and Product Documentation

Running since 1972, the Landsat program is a joint United States Geological Survey (**USGS**) and National Aeronautics and Space Administration (**NASA**) led enterprise for Earth Observation. As technological capabilities improved, instruments on board consecutive missions changed and subsequently, four 'families' of Landsat satellites have been distinguished based on sensor and platform characteristics: LS01 – LS05 (MSS), LS05 (TM), LS07 (ETM+) and LS08 (Operational Land Imager (**OLI**)).

ESA, part of the Landsat International Ground Station (**IGS**) Network, operating ground stations within Europe as well as repatriating Landsat data from stations in the US, Brazil and Canada, in parallel with the USGS activities, developed and operates their own processing system / archiving system / receiving station for Landsat which allows users to access an important collection of historical products.

The main objective of the reprocessing within the QA4EO programme is to generate as many accurate Level 1T (ortho-corrected) products as possible. In addition, the ESA products include a dedicated Quality Assurance Band (**BQA**) for each product whereas the USGS products do not; see [RD-4] for more information on the BQA.

Refer to RD-3 for further descriptions and details of the ESA reprocessed Landsat products.

## 5.3 Product Format Evaluation

The product format of the ESA Landsat 1-7 products is detailed in the IDEAS Landsat Products Description Document [RD-3] and BQA Technical Note [RD-4].

## 5.4 Image Quality

### 5.4.1 Activity Description Sheet

| **Visual inspection** |
|---|
| *Inputs* |
| Sets of Level 1 Landsat 1-7 data observed over 4 Pseudo Invariant Calibration Sites (**PICS**) sites were used for the visual inspection of products |
| *Description* |
| Check image quick look generated from the input products<br>Check colour composite of full resolution images<br>Check content of the mask included in the standard products |

| Visual inspection |
| --- |
| *Outputs* |
| Qualitative assessment of the image data information, including quality assurance information. |

### 5.4.2 Introduction

The visual inspection of LS01-7 products aims to simply assess the qualitative consistency of Landsat data and accompanying supplementary information that supports it e.g. the Quality Band. Within the assessment, quick-looks, full resolution colour composites and data masks are assessed for consistency and anomalous artefacts.

### 5.4.3 Methods and Tools

Visual checks of image quick-looks, full resolution colour composites for saturation, striping and geometric consistency with Sentinel-2 reference data, as well as checks on mask band continuity, have been completed.

### 5.4.4 Results

Through this visual inspection of LS01-7, no major anomalies were observed in the data sample and the cloud mask within the Quality band remained consistent. Despite the positive analysis of data from the PICS sites, the LS01-7 legacy is well documented to have anomalies and artefacts. However, the accompanying Quality band and metadata are mature enough to enforce user's confidence, enable users to make informed decisions and simple modifications to their datasets to facilitate best practices regarding data exploitation.

Below is an example of the inconsistencies observed within the water mask of the BQA band and the 'Christmas Tree' anomaly that can be experienced in some Landsat products.

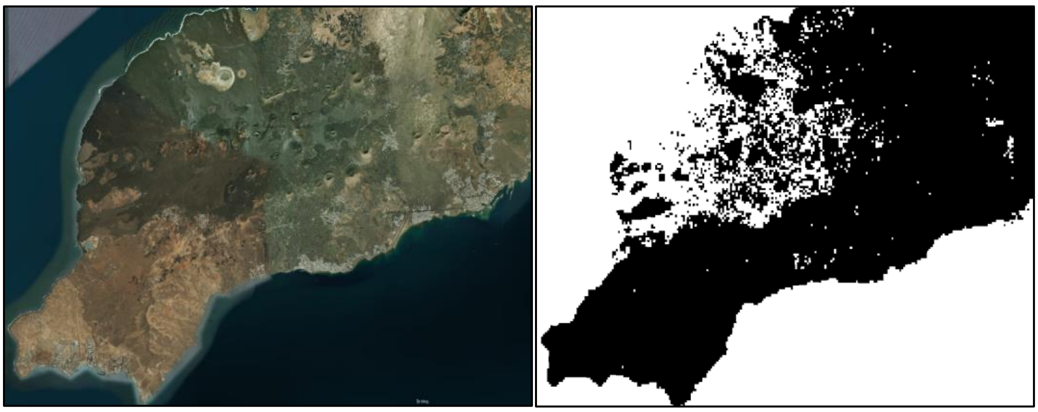


**Figure 5-1: Landsat 7 ETM+ image acquired 2002/02/13 path/row 205/40. Left, true colour composite showing Lava Flows across Los Volcanoes Natural Park, Lanzarote. Right, Misclassification of Lava Flows presented within the BQA Band as No Data.**

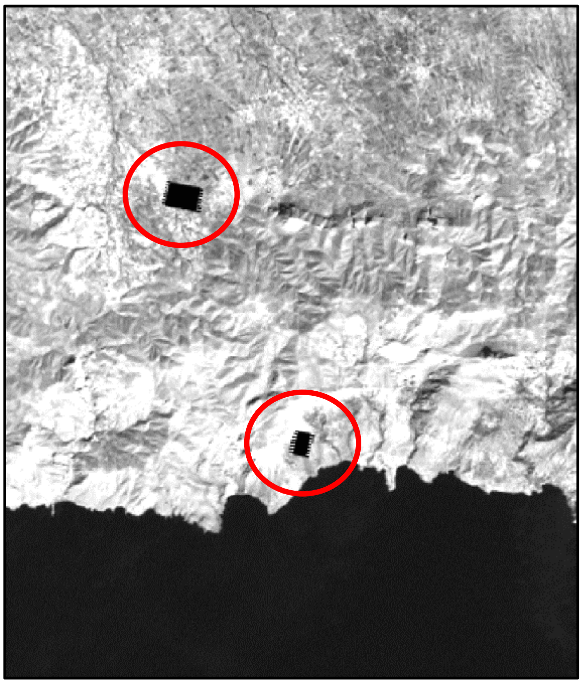


**Figure 5-2: Landsat 7 ETM+ Band 4, image acquired 2001/09/30 path/row 181/36 showing 'Christmas Tree' anomaly (in red).**

## 5.5 Geometric Calibration / Validation

### 5.5.1 Activity Description Sheet

| **Geometric Accuracy Validation: Absolute / Multitemporal / Interband registration** |
|---|
| *Inputs* |
| L1 Landsat 1-7 MSS/TM/ETM+ over Libya 1 & 4, Algeria 3 & 5. |
| *Description* |
| 1. Input products are ingested and multispectral images rescaled to 8 bit, and radiometric equalisation performed depending on the location in the orbit track.<br>2. Input L1C images in UTM cartographic projection are warped into Space Oblique Mercator (**SOM**) projection, so that the input pixel spacing is preserved and dedicated geometric resampling applied.<br>3. Depending on the comparison to be performed, the scenes are stitched together and the geometric grid rescaled to the target map resolution, one composite image per orbit is created.<br>4. The two-orbit image grids are compared with image matching techniques.<br>5. The output matching images (displacement map images, confidence map images) are filtered, analysed, and the accuracy statistics reported. |
| *Outputs* |
| Geometric accuracy metrics |

### 5.5.2 Introduction

The objective of this assessment was to develop a dedicated geometric validation methodology to assess the accuracy of an entire product orbit.

The technique, based on dense matching techniques Zero-mean Normalised Cross-Correlation (**ZNCC**), employs the comparison of two image grids expressed into the SOM map projection. The method of assessing geolocation accuracy compares the results from different sensor pairs. In addition, as the product sample is small, the routinely used intensity-based matching method is also shown as an alternative method that is based on key point matching.

### 5.5.3 Image Matching Geolocation Accuracy

#### 5.5.3.1 Methods

The input L1 images are in the UTM cartographic map projection. The 'scene-based' approach has some practical limitations:

- The geographical extent of two scenes from two different satellites / two different systems will always be different, and so is the overlapping (smaller) area that is selected for matching;
- Because of image orientation (True North), the comparison of two UTM images does not provide a straightforward characterisation of the geometric anomaly;
- It is more difficult to separate statistical / dynamic errors, systematic / non-systematic errors.

The general method relies on the following subsequent stages:

1. Input products are ingested and multispectral images rescaled to 8-bit, and radiometric equalisation performed depending on location in the orbit track.
2. Input L1C images in UTM cartographic projection are warped into SOM projection so input pixel spacing is preserved and dedicated geometric resampling applied.
3. Depending on the comparison to be performed, scenes are stitched together and the geometric grid rescaled to the target map resolution, one composite image per orbit is created.
4. The two-orbit image grids are compared with image matching techniques.
5. The output matching images (displacement map images, confidence map images) are filtered, analysed, and the accuracy statistics reported.

The main output of this method is information on the co-registration between orbits from different satellites. The following L1 Near InfraRed (**NIR**) sensors twins have been considered:

- S2A and S2B
- S2A, S2B, LS08), LS07, LS05 (MSS), LS05 TM and Global Land Survey (GLS) datasets.
- S2A, S2B and LS08

#### 5.5.3.2 Results

Table 5-1 shows the summary statistics with Figure 5-3 showing the Circular Error at the 90th percentile (**CE90**) plots for a selection of the sensor twins. It should be noted that the quality matching depends on the observation dates, and data should be acquired during the same season so that features appear the same within the sensor pairs. Also, the Landsat IPF processed the L1 data with the GLS as the reference source for the Ground

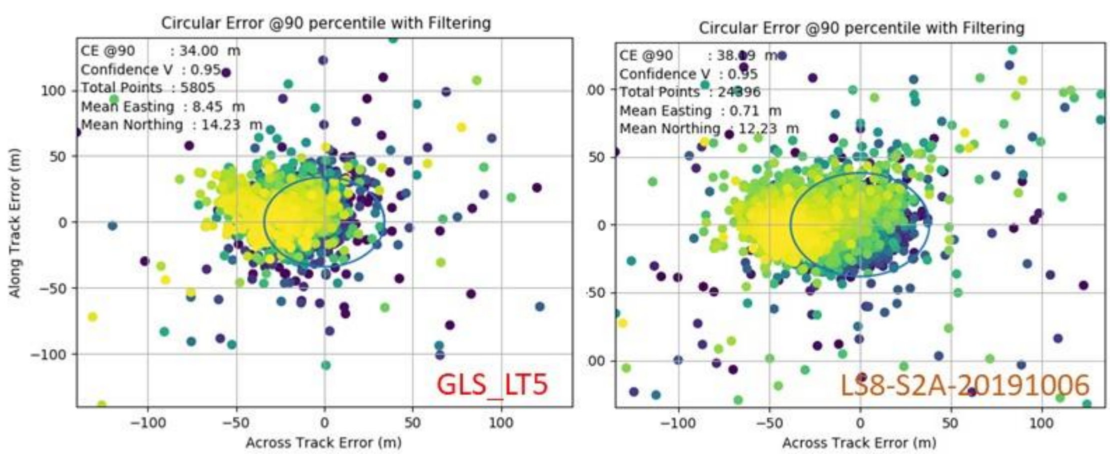
Control Points (**GCPs**). The GLS datasets provide a consistent, terrain corrected, coordinated collection of data [RD-6].

In terms of the statistics:

- The Landsat missions' registration against GLS improves as the missions become more recent – reflecting the improved instrument technology. For example, the geometric processing of the LS08 L1 data is very accurate with a precision (standard deviation, std) that equates to less than one quarter of a pixel (Yellow, Table 5-1)
- The co-registration between S2A/S2B is also very accurate and precise, although the comparison between S2B and GLS does not provide good results (Yellow, Table 5-1).
- The LS08/S2 errors are most pronounced in the easting direction, with the error budget (Green, Table 5-1) confirming that the results are consistent.

**Table 5-1: Statistical results**

| Image Matching Results, orbit configuration , (confidence : 0.95), unit : meter, AL :Along Track, AC : ACross Track | | | | | | | |
|---|---|---|---|---|---|---|---|
| Twin | total valid pixel | median AL | mean AL | std AL | median AC | mean AC | std AC |
| GLS_LM5 | 927 | -7,97 | -7,04 | 31,32 | 4,22 | 4,22 | 77,72 |
| GLS_LT5 | 7455 | -0,70 | -0,70 | 14,00 | -1,17 | -0,73 | 17,11 |
| GLS_LS7 | 6080 | -1,41 | -1,41 | 10,41 | -2,58 | -2,14 | 12,51 |
| GLS_LS8 (20141024) | 22966 | 0,47 | 0,61 | 6,71 | -1,88 | -1,81 | 7,76 |
| | | | | | | | |
| GLS_S2B (20191001) | 5759 | 8,67 | 8,44 | 11,63 | -13,83 | -14,27 | 13,18 |
| LS8-S2A (20191006) | 24241 | 0,94 | 0,62 | 9,69 | -9,14 | -12,31 | 14,94 |
| LS8-S2A (20180802) | 6011 | 18,52 | 12,26 | 30,08 | -4,69 | -6,90 | 18,01 |
| LS8-S2B (20191001) | 15031 | 5,63 | 4,98 | 11,05 | -9,14 | -10,30 | 11,32 |
| LS8-S2B (20191011) | 7562 | 7,03 | 8,47 | 11,86 | -19,69 | -22,50 | 17,45 |
| S2A (20191006) S2B (20191001) | 61232 | 4,22 | 4,00 | 2,34 | -2,11 | -1,61 | 3,06 |



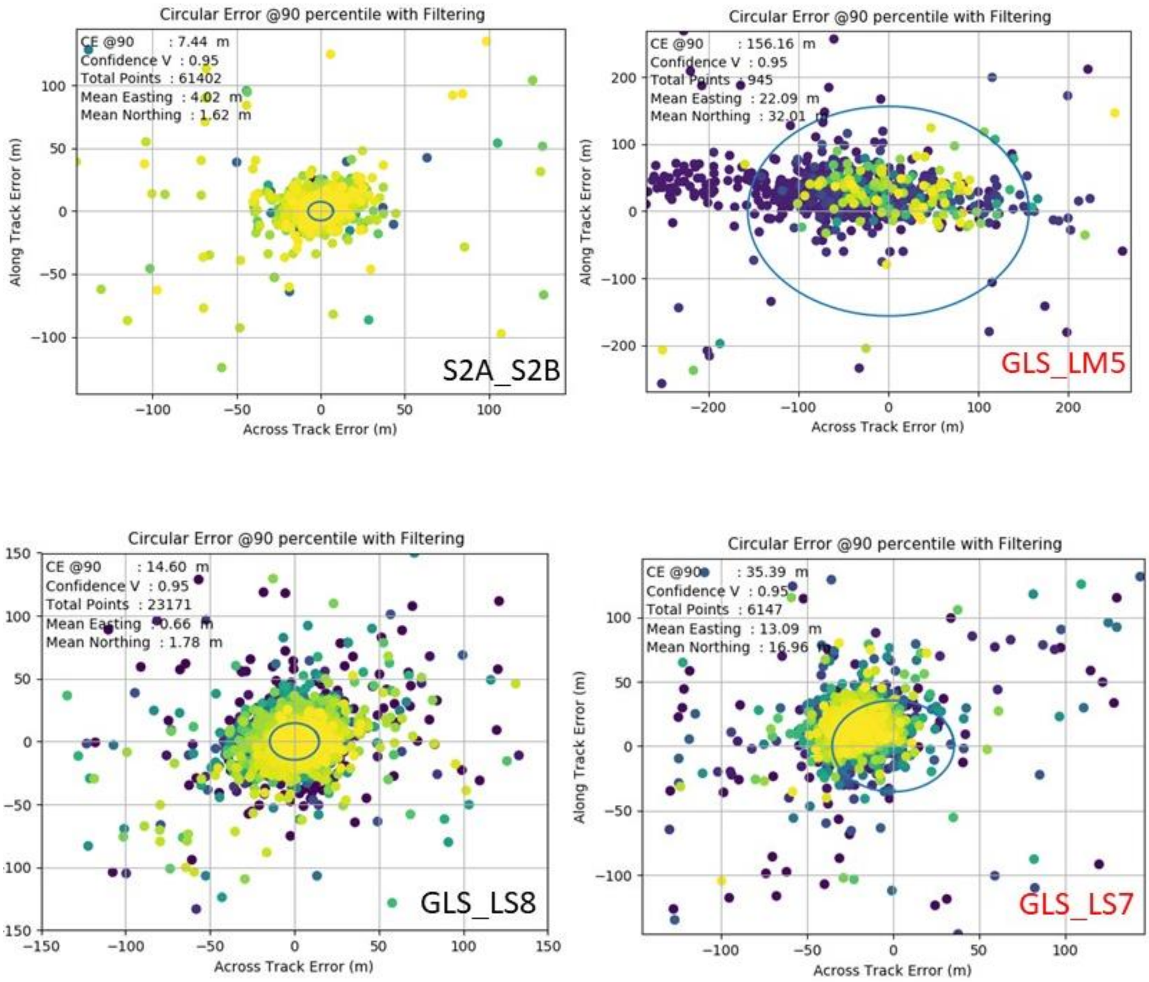



**Figure 5-3: Circular Error plots for a selection of the sensor twins.**

The visual analysis (Figure 5-4) shows that:

- **GLS/LM5:** The across-track displacement image shows the panoramic effects for LS05 MSS data, which is due to missing mirror scan telemetry data.
- **GLS/LT5:** The across-track displacement image shows that the elevation information is correctly managed by the ESA IPF. However, it also shows that internally the images are distorted, in particular, because of swath and line misalignment.
- **GLS/S2:** The comparison between GLS & S2 shows that the Digital Elevation Model (DEM) affects mainly the co-registration, probably more than the missing geometric reference for refinement in the case of S2.
- **S2A/S2B:** Even if very small, variation in the S2 orbit exists. It seems that errors increase towards the equator.
- **LS8/S2:** No systematic error is observed, but there is an anomaly due to the difference in the DEM used.

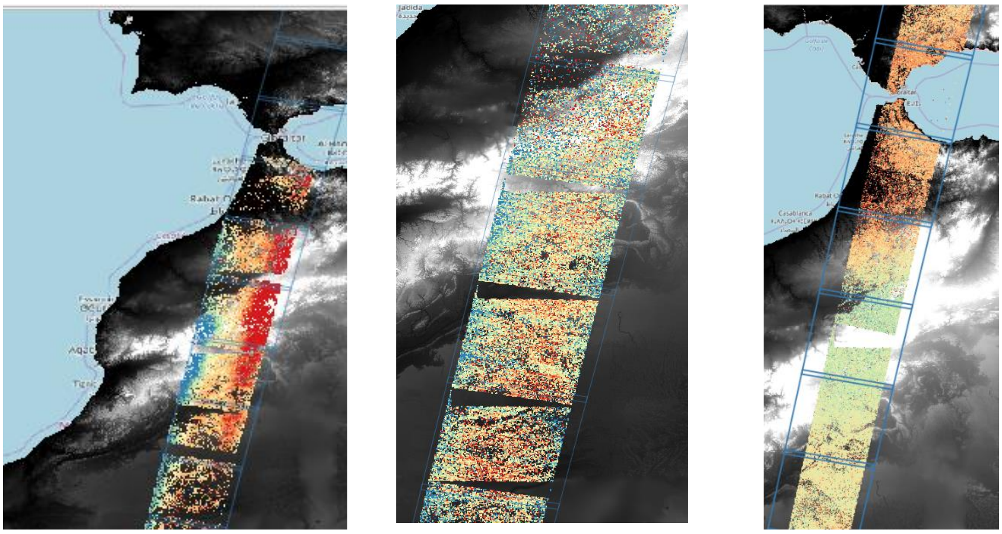


**Figure 5-4: Visual analysis for a selection of the sensor twins as the GLS/LM5 across track (left), GLS/LT5 across track (middle) and LS8/S2 across track (right); scale -2.5 pixels red to +2.5 blue pixels @30m.**

**Cross Validation – Alternative Matching Method**

Due to the small product sample used for the ZNCC analysis, an alternative matching method was also tested. It is a combination of an edge detector, feature-matching technique, and outlier filtering. This method was applied to tiles of 4096x2096 pixel in order to get a sufficient density of key points.

As within the LS08/S2 comparison shown for the ZNCC analysis, there is no systematic error evident. The differences are of the order of ±2.5 Landsat (30 m spatial resolution) pixels.

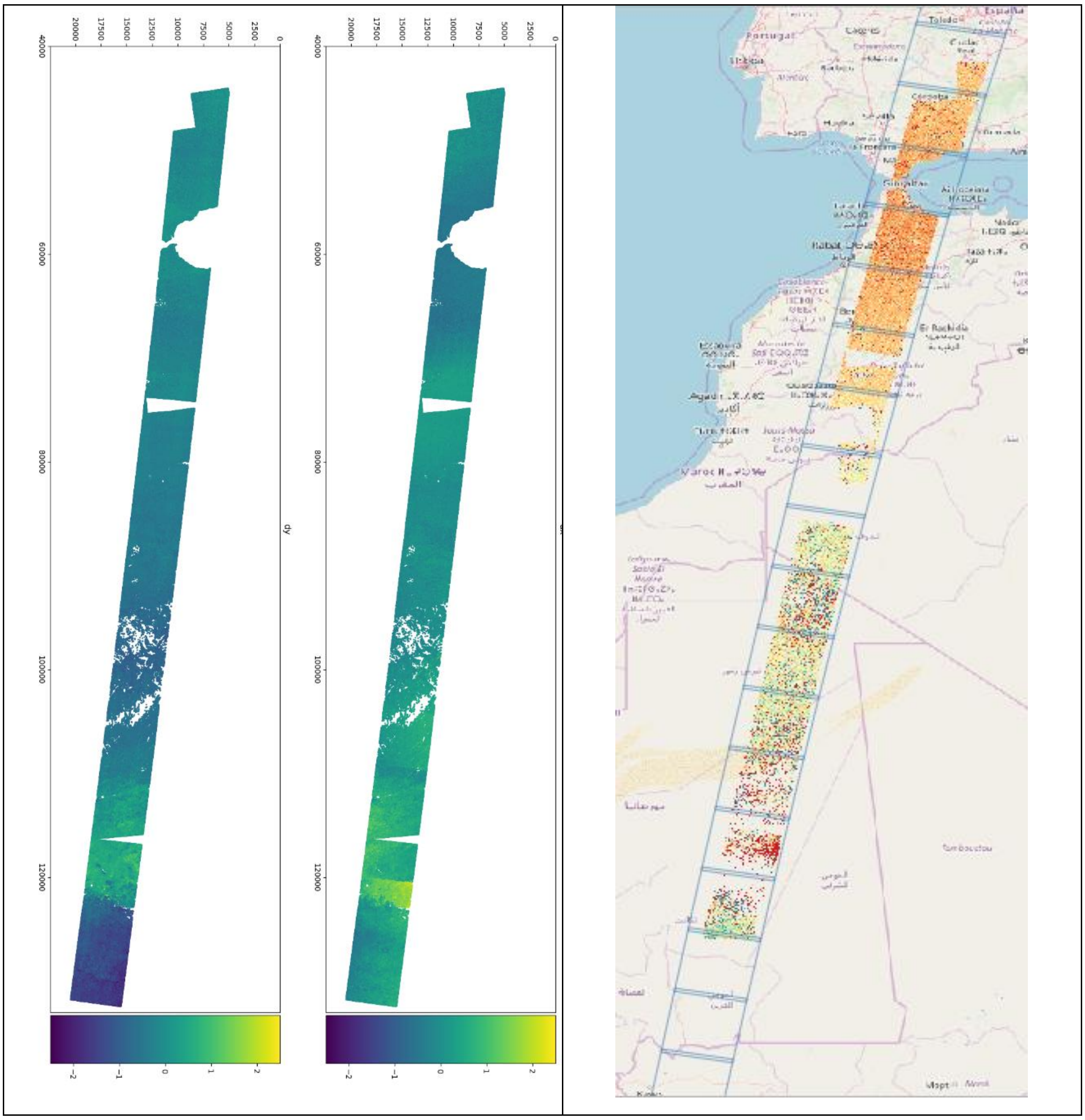


**Figure 5-5*:* S2/LS08, across (left) and along track (middle) displacements (scale: +/- 2.5 pixels @30m) with the location shown (right) as S2A/B across track differences (scale -2.5 pixels red to +2.5 blue pixels @30m).**

## 5.6 Radiometric Calibration / Validation: Absolute calibration of Landsat 1-7 by using Sentinel-2 Products

### 5.6.1 Activity Description Sheet

| Radiometric Accuracy Validation |
|---|
| *Inputs* |
| Set of Level 1 S2 / MSI |

| |
|---|
| Set of Level 1 Landsat 1-5 data<br><br>Half degree polygon ROI |
| *Description* |
| The scope is to assess the radiometric consistency, absolute calibration and cross-comparison of Landsat 1-7 products using Sentinel-2 products as reference. PICS sites Libya1, Libya4, Algeria3 and Algeria5 are used with a smaller half-degree ROI within sites for the assessment as they exhibit low radiometric variance. |
| *Outputs* |
| Radiometric consistency, absolute radiometric calibration and cross comparison across the Landsat 1-7 sensors. |

### 5.6.2 Introduction

The radiometric assessment of Landsat 1-7 products will assess the radiometric accuracy and consistency across time-series of products from ESA's Landsat repository using Sentinel-2 Copernicus data as a reference. The radiometric assessment techniques are implemented across 4 PICS sites with low seasonal variability as a good average for results.

### 5.6.3 Methods and Tools

The method used for this exercise consists of different processing stages summarised as follows:

- Extract multispectral Top of Atmosphere (**TOA**) measurements from Landsat products over the four PICS sites. The measurement is spatially integrated over a window size of half a degree.
- Retrieve L1C Sentinel-2 from the Copernicus Data Portal and extract TOA measurements over the four PICS sites. Where it was not possible to acquire data on the exact observation date/time for all Landsat 1-7 products, the Julian day of each product was alternatively used to observe seasonal variations and same-day comparisons.
- Compute temporal consistency for each Landsat 1-7 band as follows:

$$\text{Temporal Consistency } = \left(\frac{Mean}{Standard\ Deviation}\right)$$

- Compute the calibration ratio across Blue, Green, Red and NIR bands for Landsat 1-7 using Mean TOA (over ROI) and Sentinel-2 TOA computing the percent difference as follows:

$$\%Difference = \frac{100 * (TOA\_Measure - TOA\_Reference)}{TOA\_Reference}$$

Where *TOA_Measure* is the measurement processed from the Landsat products and *TOA_Reference* is the measurement extracted from Sentinel-2 reference data.

Note that this method is also used with Sentinel-2B data, for which viewing angle is greater. As the calibration accuracy for Sentinel-2B is well known, it allows validation of the proposed process.

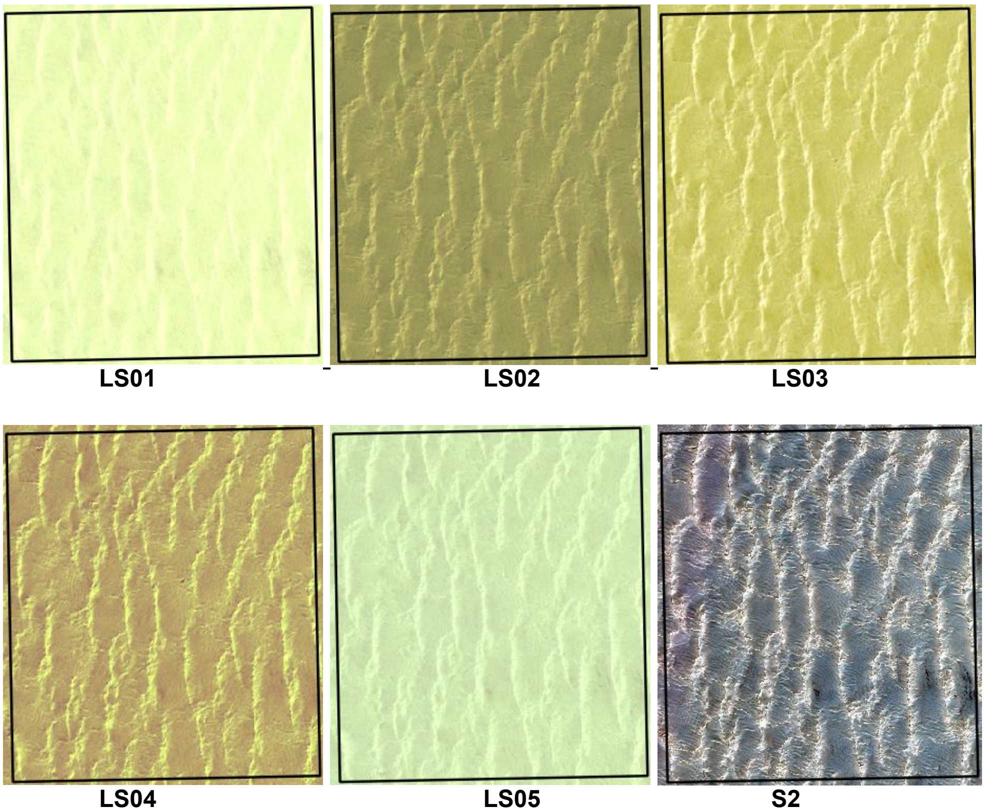



**Figure 5-6: Example Landsat 1-7 and Sentinel-2 products ordered top left to right (Libya4).**

### 5.6.4 Region of interest


**Figure 5-7: Spatial distribution of PICS used for the radiometric assessment, each Region of Interest half a degree in height and width.**

### 5.6.5 Data

#### 5.6.5.1 Landsat Data

**Table 5-2: Landsat products used for radiometric assessments.**

| PICS | # LS01-07 Products | Date Range |
|---|---|---|
| **Libya1** | 236 | 23/04/1975 – 27/01/1992 |
| **Libya4** | 249 | 05/05/1975 - 19/11/1993 |
| **Algeria3** | 418 | 25/10/1975 - 18/12/1993 |
| **Algeria5** | 303 | 02/05/1975 – 14/12/1993 |

#### 5.6.5.2 Sentinel 2 Data

**Table 5-3: Sentinel-2 reference products used for radiometric assessments.**

| PICS | # S2A & S2B Products | Date Range |
|---|---|---|
| **Libya1** | 39 | 02/10/2019 – 01/10/20 |
| **Libya4** | 48 | 30/09/2019 – 29/09/20 |
| **Algeria3** | 40 | 01/10/2019 – 30/09/20 |
| **Algeria5** | 28 | 27/10/2019 – 16/09/20 |

### 5.6.6 Results

PICS site Libya4 results are presented within this section, with the results for the other three study sites presented within APPENDIX A.

Across the radiometric assessment of Landsat products, LS07 had the highest average radiometric accuracy and consistency across the time-series when compared with the S2 reference data, displaying greater consistency than S2 (Table 5-5).

In contrast, LS03 and LS05 (MSS) are on average found to be the least accurate (percent difference) in terms of absolute radiometric calibration compared with the S2 reference data, and least consistent across the observed time-series (Table 5-4). However, Figure 5-8 to Figure 5-11 that display the temporal consistency of each mission and band, we observe a more defined linear temporal progression within LS02, LS05 (TM) and LS07.

Considering the ESA Landsat 1-7 products were recalibrated with PICS site Libya4, we observed higher temporal consistencies for LS01, LS03 and LS04 missions at Libya1, Algeria3 and Algeria 5. In contrast, lower temporal consistencies are seen for LS02 and LS05 at Libya1, Algeria3 and Algeria 5. In terms of the difference to Sentinel-2 reference data, lower radiometric accuracies are observed for all Landsat missions at the three comparison PICS sites, except for LS02 that experiences a higher radiometric accuracy in comparison to Libya4, the recalibration site.

**Table 5-4: Algeria5 TOA % difference between Landsat and known absolute radiometric Sentinel-2 reference data.**

| Comparison | LS % Difference to Sentinel-2 | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS V S2** | -28.55 | -5.95 | -27.90 | -26.18 |
| **LS02 MSS V S2** | -27.70 | -8.52 | -25.31 | -30.75 |
| **LS03 MSS V S2** | -43.70 | -19.95 | -32.62 | -39.06 |
| **LS04 MSS V S2** | -23.45 | -4.96 | -21.83 | -37.94 |
| **LS05 MSS V S2** | -50.59 | -41.28 | -51.11 | -57.63 |
| **LS05 TM V S2** | 147.84 | 159.24 | 167.80 | 181.29 |
| **LS07 ETM+ V S2** | 113.16 | 36.67 | -27.59 | -53.26 |

**Table 5-5: Algeria5 temporal consistency comparison between Landsat and Sentinel-2.**

| Sensor | Temporal Consistency | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS** | 15.58 | 15.99 | 13.61 | 12.91 |
| **LS02 MSS** | 17.81 | 28.13 | 24.97 | 21.68 |
| **LS03 MSS** | 6.86 | 6.22 | 6.28 | 6.99 |
| **LS04 MSS** | 6.15 | 5.65 | 5.25 | 4.81 |
| **LS05 MSS** | 6.92 | 7.04 | 6.71 | 7.40 |
| **LS05 TM** | 1.14 | 1.20 | 1.25 | 1.25 |
| **LS07 ETM+** | 6.92 | 7.04 | 6.71 | 7.40 |
| **S2** | 90.29 | 56.78 | 47.73 | 39.46 |

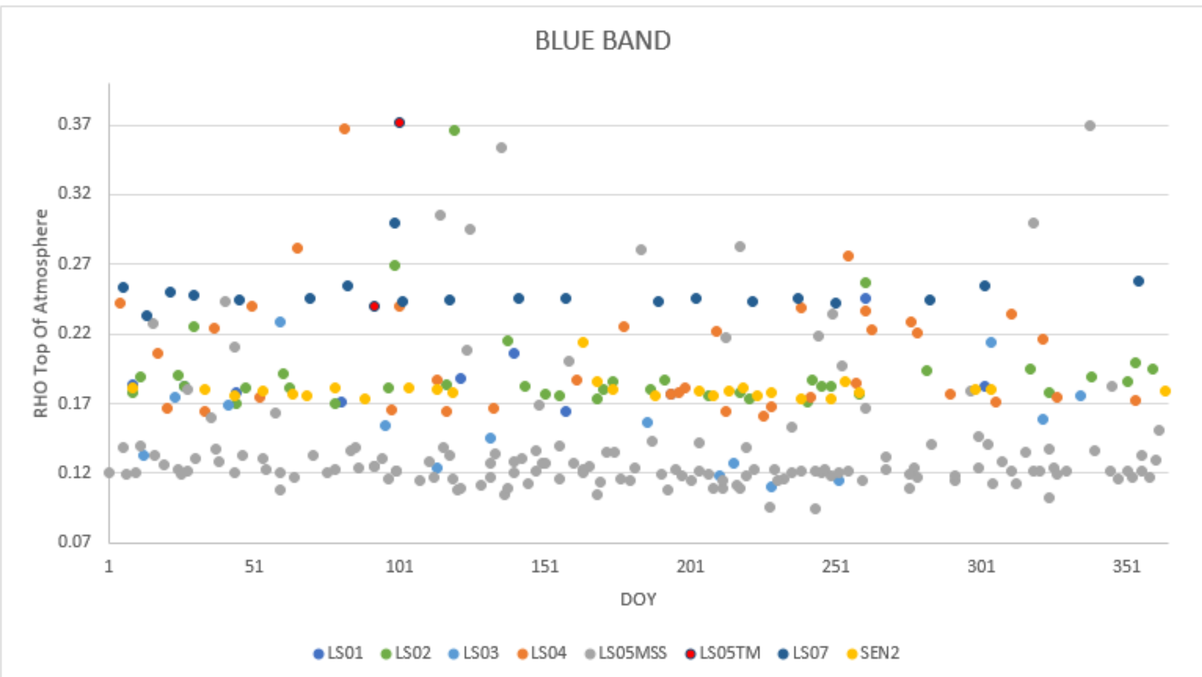


**Figure 5-8: Algeria5 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Blue Band.**

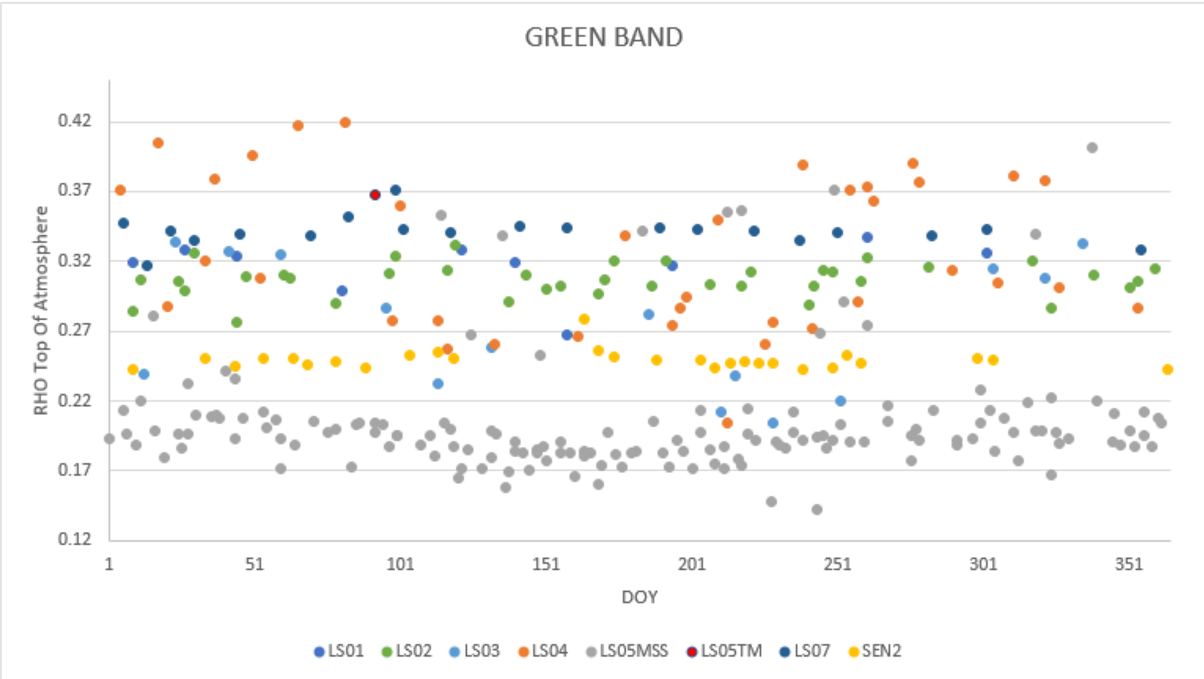



**Figure 5-9: Algeria5 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Green Band.**

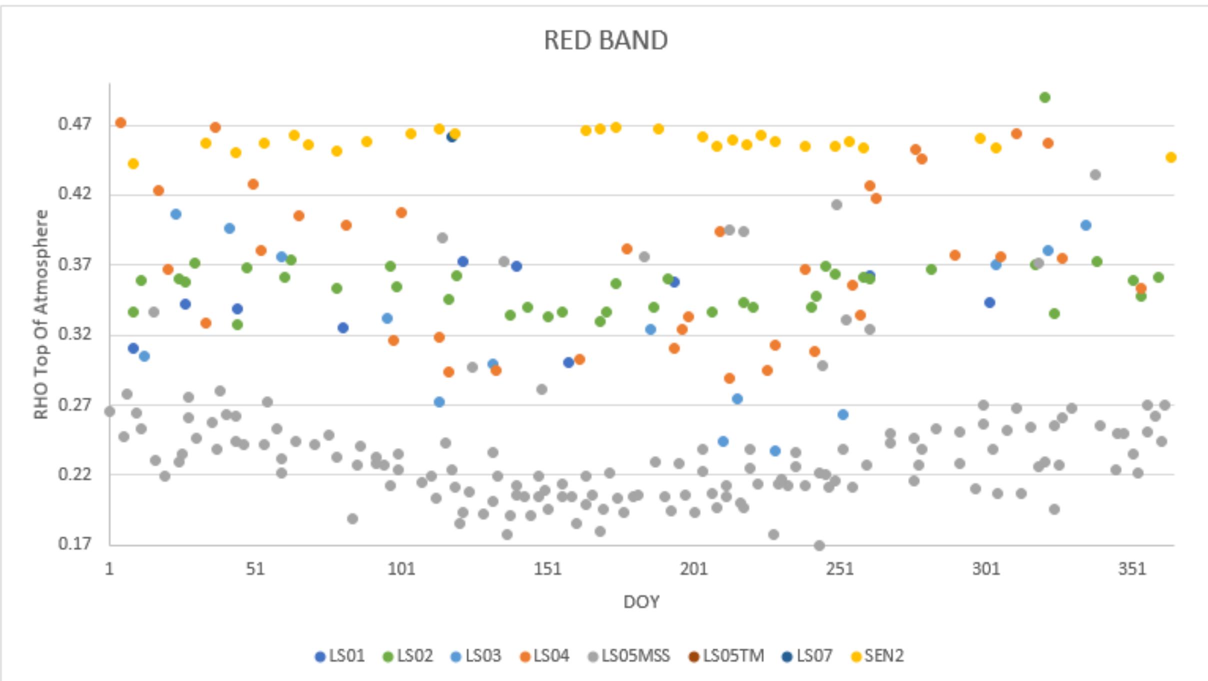



**Figure 5-10: Algeria5 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Red Band.**

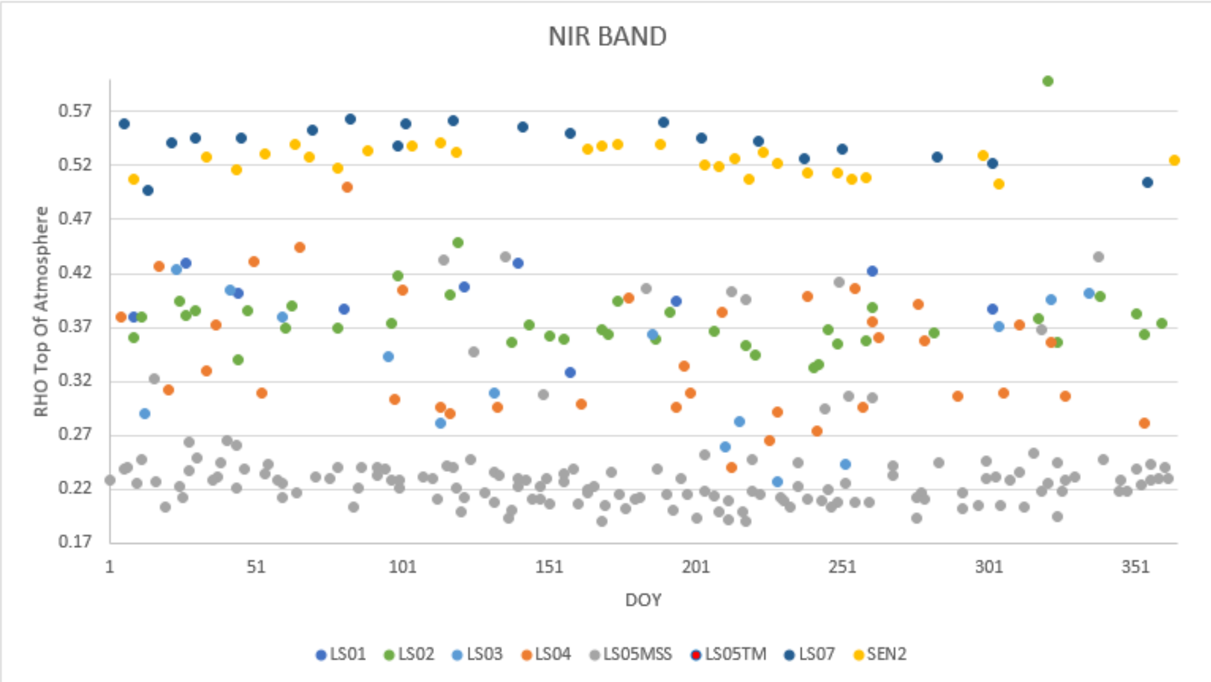



**Figure 5-11: Algeria5 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, NIR Band.**

# 6. CONCLUSIONS

## 6.1 General and visual assessment

- The metadata and product information for each Landsat mission is well documented (both for the ESA and USGS processing), clear and publicly available, although the ESA Landsat ATBD's are not, so are considered intermediate.
- Across the validation dataset there were no anomalies or artefacts, with the Quality band mask aligning to what is observed within the image.
- Outside of the test dataset, the Landsat legacy's known artefacts and anomalies are well documented.
- Through visual inspection and general assessment of metadata data, documentation and quality band mask, the concluding mark for this aspect of ESA's LS01-7 products is excellent.

## 6.2 Geometric calibration

- As expected, the geometric assessment performed on the medium resolution Landsat imagery showed that the earlier missions had a lower accuracy than LS08 and S2A & S2B. Overall, the S2A & S2B sensors are highly accurate and precise.
- Results from the matching process showed some LS01 to LS05 scenes contain pixel displacements higher than 5 m, whereas LS08 are very accurate and precision is below a quarter of a pixel.
- When compared with other missions / data layers, i.e. GLS or S2, Landsat missions are observed to have a displacement in the easting direction.
- In summary, the overall accuracy of LS01 to LS05 can be considered intermediate, whereas LS07 is deemed to be good, and LS08 excellent when cross compared with the GLS or S2 reference data.

## 6.3 Radiometric assessment

- In line with expectations factoring geometric accuracy, LS07 had the highest radiometric accuracy in reference to S2 data, as well as most consistent across the time-series analysed (Table 5-5 and Figure 5-8 to Figure 5-11).
- Surprisingly, it was observed that LS04 and LS05 MSS products had the lowest radiometric accuracy with reference products compared to LS01-03.
- Within Landsat mission's individual time-series, there is a strong linear consistency within LS02, LS05 and LS07. However, in comparison to the S2 reference data, the radiometric accuracy is somewhat removed.
- It should be noted that the availability of products for LS01-04, for each PICS site, was limited to less than 20 products per mission (1-4) and in some cases less than 10.
- Higher temporal consistency is observed for LS01, LS03 and LS04, whereas lower temporal consistency is seen for LS02 and LS05 when comparing the Libya4 recalibration site with the other three PICS sites.
- Lower radiometric accuracies are highlighted between the S2 reference data and for LS01, LS03, LS04 and LS05. Higher accuracies are observed for LS02 when we compare findings between the recalibration site Libya4 and the other three PICS sites.

# APPENDIX A RADIOMETRIC RESULTS

**Table 6-1: Libya 1 TOA % difference between Landsat and known absolute radiometric Sentinel-2 reference data.**

| Comparison | LS % Difference to Sentinel-2 | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS V S2** | 39.75 | 37.67 | -3.28 | -4.45 |
| **LS02 MSS V S2** | 32.21 | 39.09 | -5.45 | -10.00 |
| **LS03 MSS V S2** | 3.00 | 8.54 | -23.91 | -29.52 |
| **LS04 MSS V S2** | 46.98 | 48.23 | 2.86 | -19.43 |
| **LS05 MSS V S2** | 52.10 | 40.88 | -6.67 | -17.28 |
| **LS05 TM V S2** | 6.81 | 9.53 | -5.68 | -1.86 |

**Table 6-2: Libya 1 temporal consistency comparison between Landsat and Sentinel-2.**

| Sensor | Temporal Consistency | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS** | 7.21 | 11.57 | 9.81 | 8.78 |
| **LS02 MSS** | 14.35 | 22.50 | 21.16 | 16.09 |
| **LS03 MSS** | 2.53 | 2.91 | 2.93 | 2.85 |
| **LS04 MSS** | 7.44 | 7.27 | 12.23 | 8.57 |
| **LS05 MSS** | 6.15 | 9.73 | 8.26 | 7.99 |
| **LS05 TM** | 5.59 | 7.40 | 10.40 | 10.70 |
| **LS07 ETM+** | 32.34 | 36.08 | 45.38 | 42.74 |

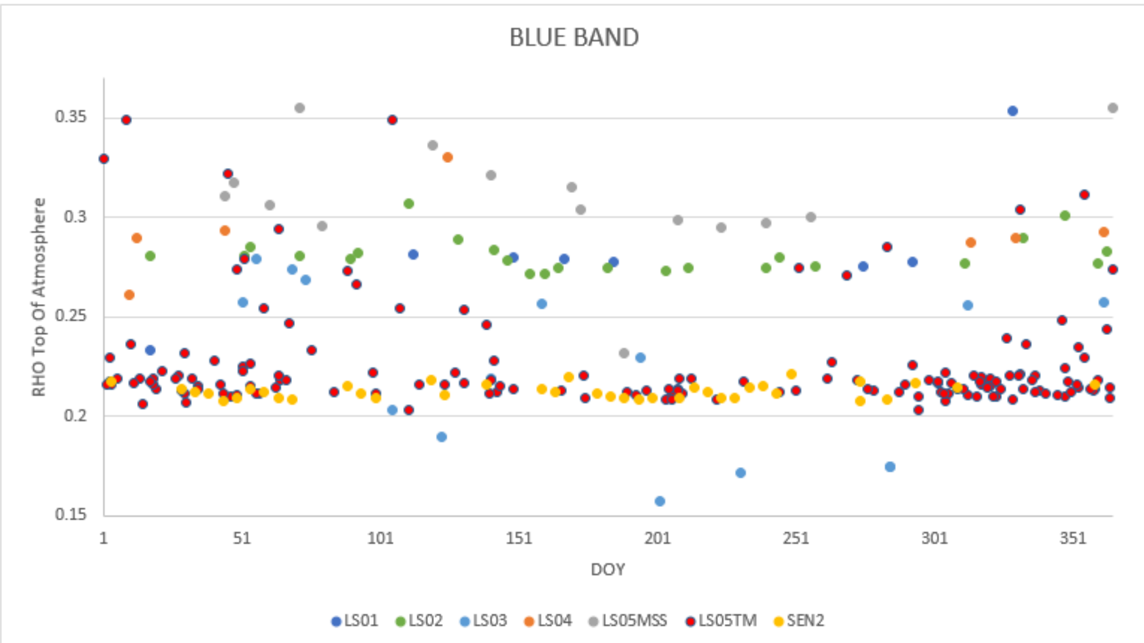


**Figure 6-1: Libya1 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Blue Band.**

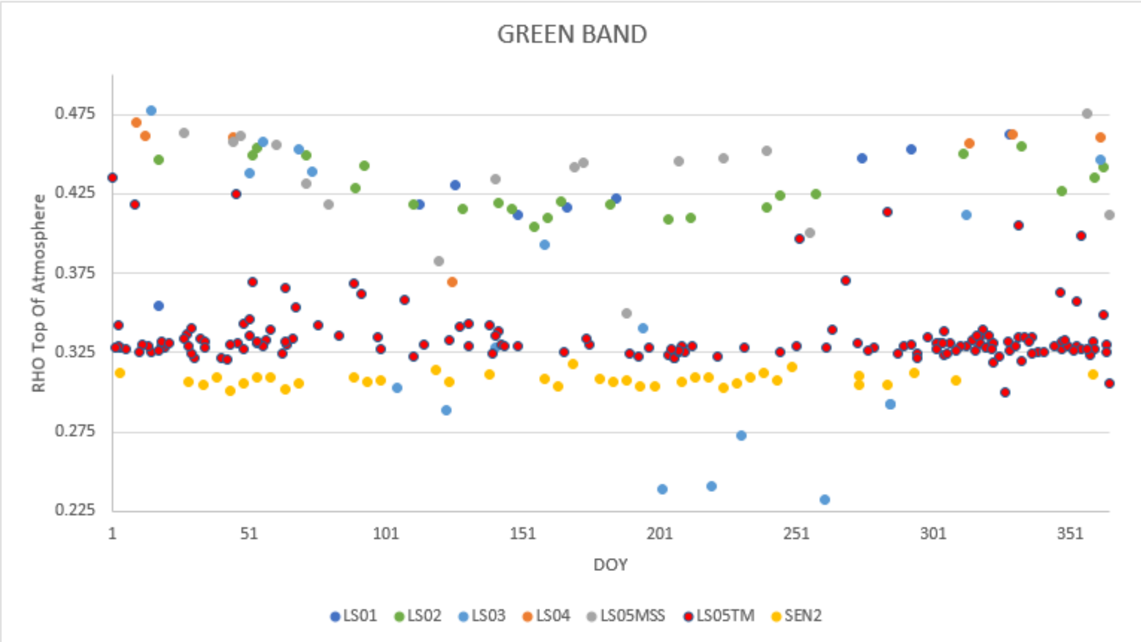



**Figure 6-2: Libya1 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Green Band.**

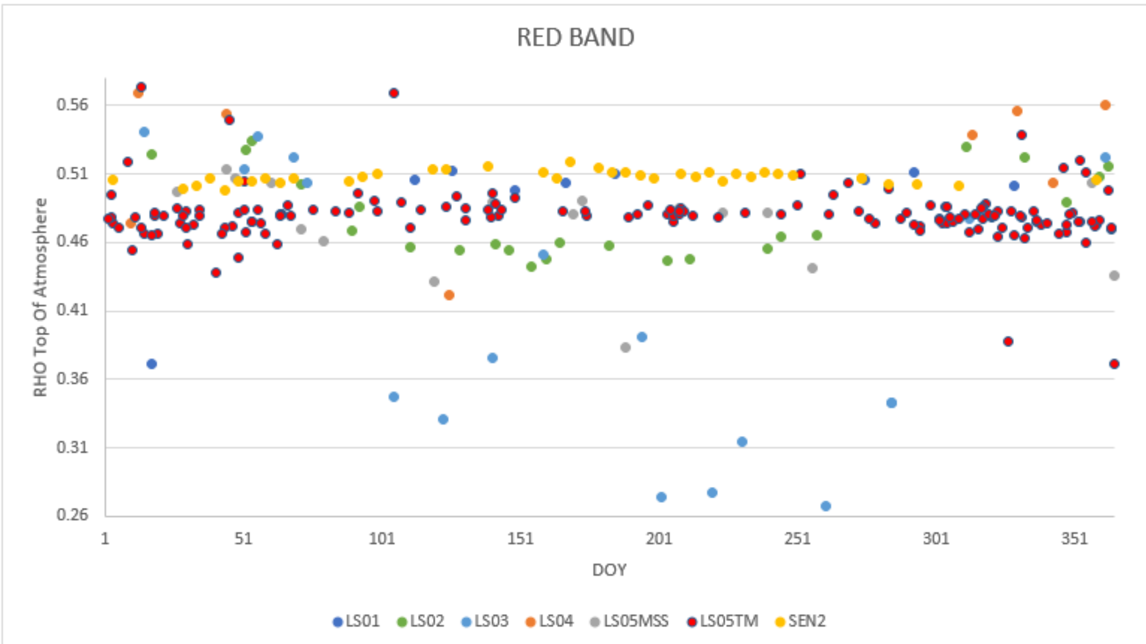



**Figure 6-3: Libya1 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, Red Band.**

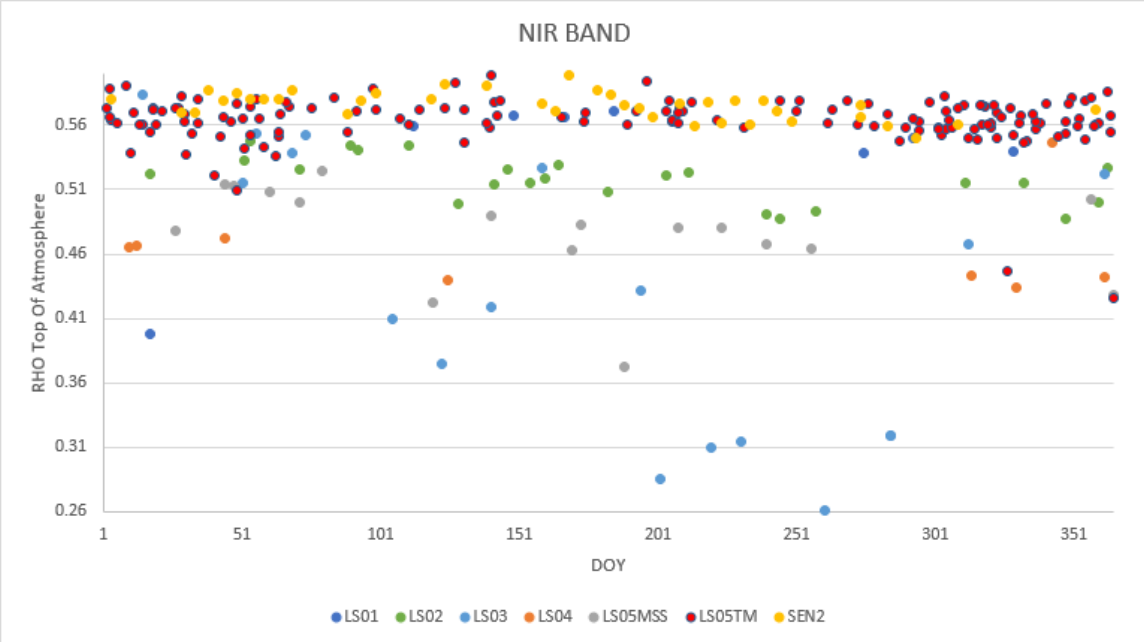



**Figure 6-4: Libya1 Landsat 1-5 time-series consistency comparison with Sentinel-2 reference data, NIR Band.**

**Table 6-3: Libya 4 TOA % difference between Landsat and known absolute radiometric Sentinel-2 reference data.**

| Comparison | LS % Difference to Sentinel-2 | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS V S2** | 20.95 | 24.12 | -3.31 | -5.21 |
| **LS02 MSS V S2** | 20.95 | 22.51 | -2.40 | -11.99 |
| **LS03 MSS V S2** | 3.90 | 17.17 | -3.22 | -14.48 |
| **LS04 MSS V S2** | 20.04 | 25.83 | 1.17 | -20.44 |
| **LS05 MSS V S2** | 58.77 | 32.37 | 1.64 | -11.21 |
| **LS05 TM V S2** | 3.49 | 4.87 | -5.00 | -1.36 |

**Table 6-4: Libya 4 temporal consistency comparison between Landsat and Sentinel-2.**

| Sensor | Temporal Consistency | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| **LS01 MSS** | 45.74 | 41.44 | 19.95 | 25.75 |
| **LS02 MSS** | 14.38 | 25.31 | 22.73 | 23.01 |
| **LS03 MSS** | 15.29 | 17.93 | 16.82 | 12.43 |
| **LS04 MSS** | 18.86 | 21.61 | 15.14 | 14.18 |
| **LS05 MSS** | 4.92 | 10.87 | 13.70 | 9.90 |
| **LS05 TM** | 6.53 | 10.53 | 16.55 | 20.01 |
| **LS07 ETM+** | 90.29 | 56.78 | 47.73 | 39.46 |

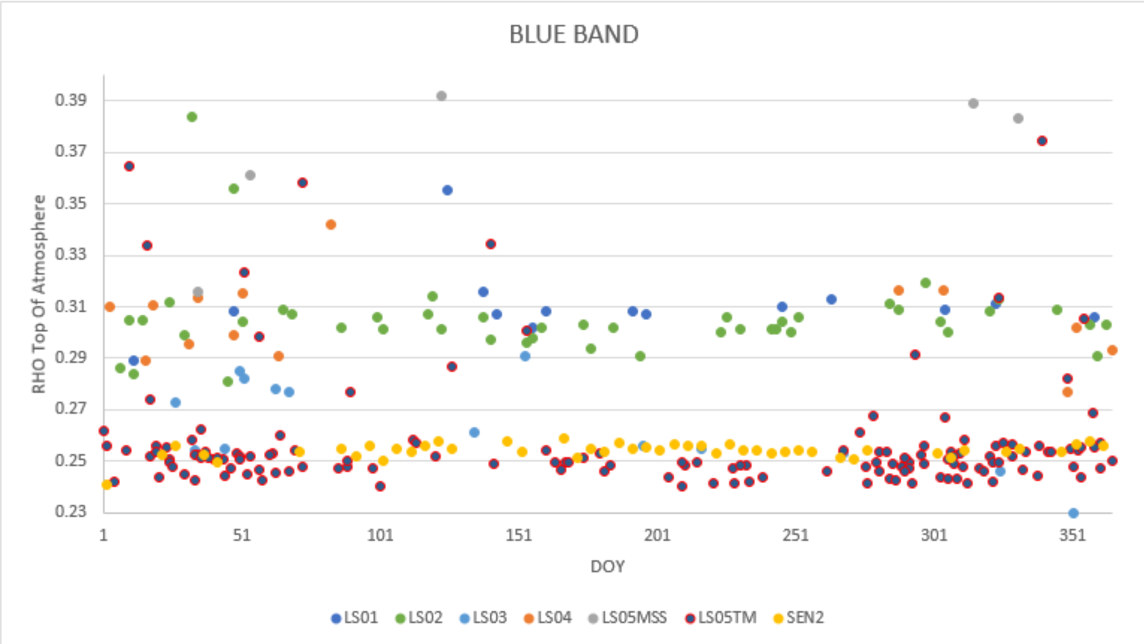



**Figure 6-5: Libya4 Landsat 1-7 time-series consistency comparison with Sentinel-2 reference data, Blue Band.**

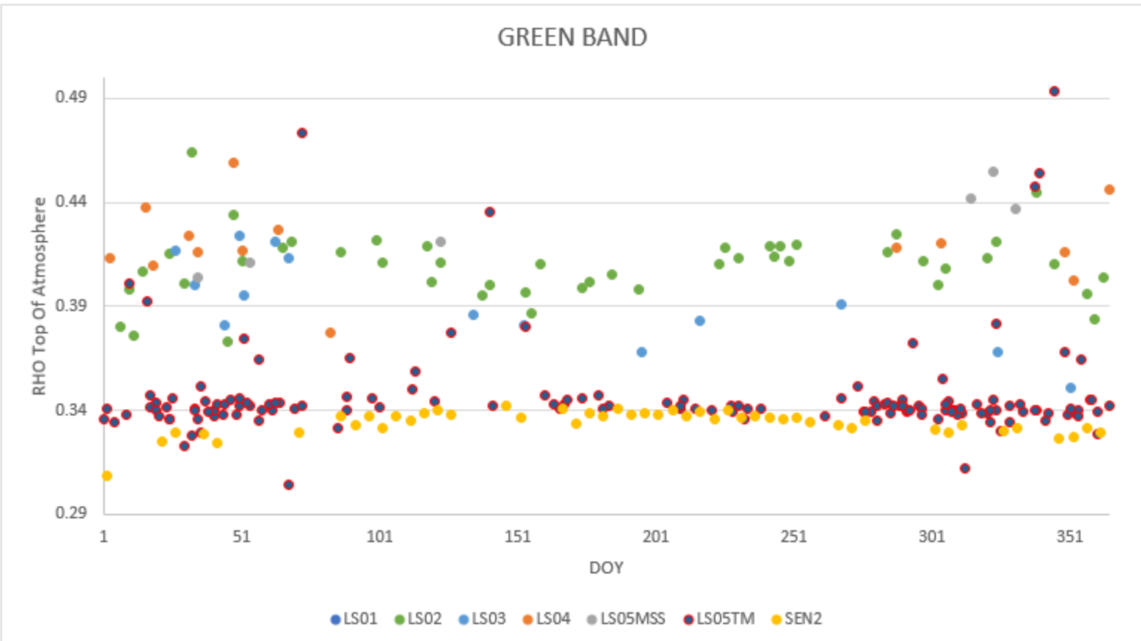



**Figure 6-6: Libya4 Landsat 1-7 time-series consistency comparison with Sentinel-2 reference data, Green Band.**

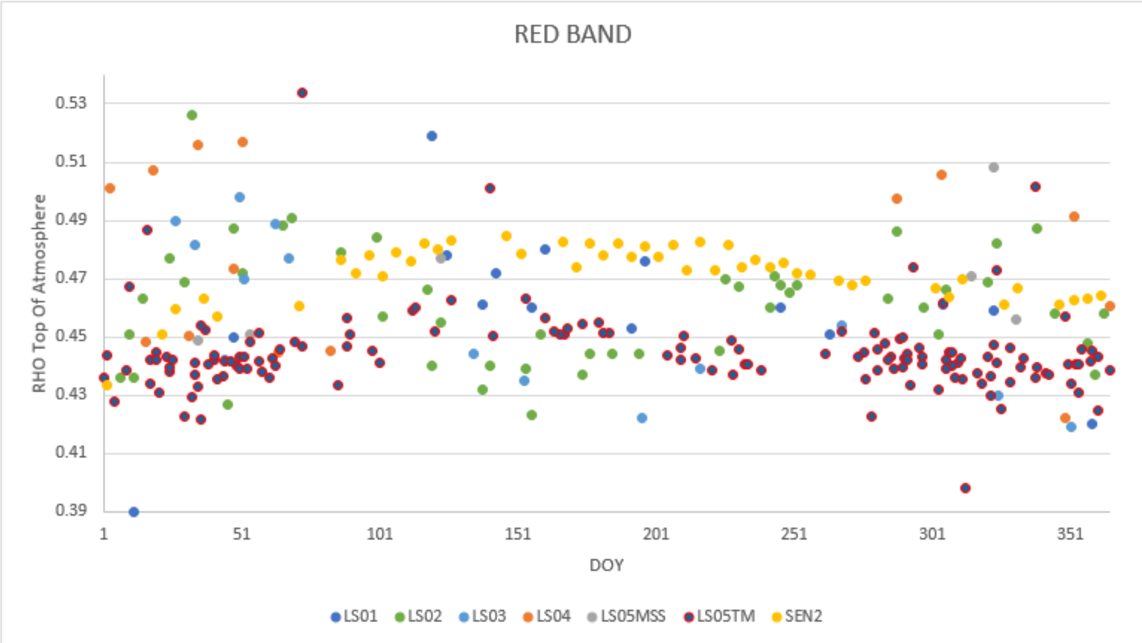



**Figure 6-7: Libya4 Landsat 1-7 time-series consistency comparison with Sentinel-2 reference data, Red Band.**

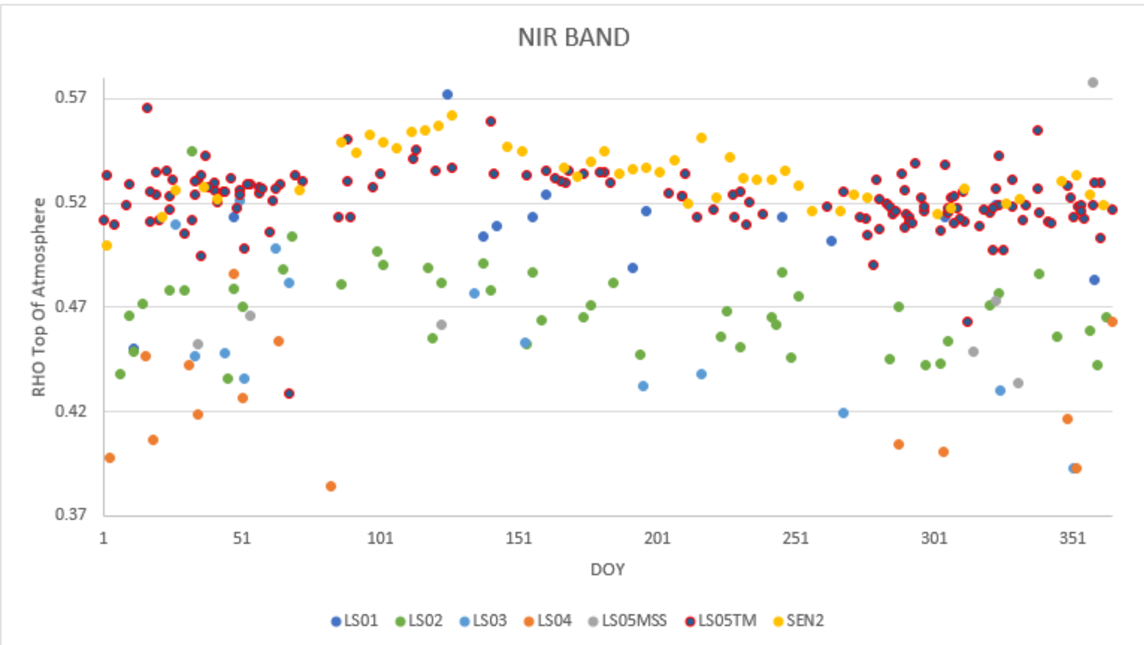



**Figure 6-8: Libya4 Landsat 1-7 time-series consistency comparison with Sentinel-2 reference data, NIR Band.**

**Table 6-5: Algeria3 TOA % difference between Landsat and known absolute radiometric Sentinel-2 reference data.**

| Comparison | LS % Difference to Sentinel-2 | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| LS01 MSS V S2 | -66.46 | -61.71 | -86.54 | -78.67 |
| LS02 MSS V S2 | -3.94 | 11.91 | -34.19 | -56.49 |
| LS03 MSS V S2 | -88.19 | -92.75 | -96.34 | -93.74 |
| LS04 MSS V S2 | -81.22 | -89.09 | -93.90 | -89.30 |
| LS05 MSS V S2 | -23.49 | -44.60 | -72.72 | -57.57 |
| LS05 TM V S2 | -87.71 | -91.33 | -90.70 | -79.02 |

**Table 6-6: Algeria3 temporal consistency comparison between Landsat and Sentinel-2.**

| Sensor | Temporal Consistency | | | |
|---|---|---|---|---|
| | BLUE | GREEN | RED | NIR |
| LS01 MSS | 8.60 | 17.36 | 12.34 | 10.38 |
| LS02 MSS | 24.61 | 50.74 | 60.32 | 21.17 |
| LS03 MSS | 3.03 | 3.29 | 3.36 | 3.05 |
| LS04 MSS | 4.81 | 4.95 | 5.59 | 5.21 |
| LS05 MSS | 19.61 | 25.12 | 25.01 | 20.65 |
| LS05 TM | 3.15 | 3.93 | 8.52 | 10.21 |
| LS07 ETM+ | 25.62 | 45.34 | 91.65 | 48.67 |

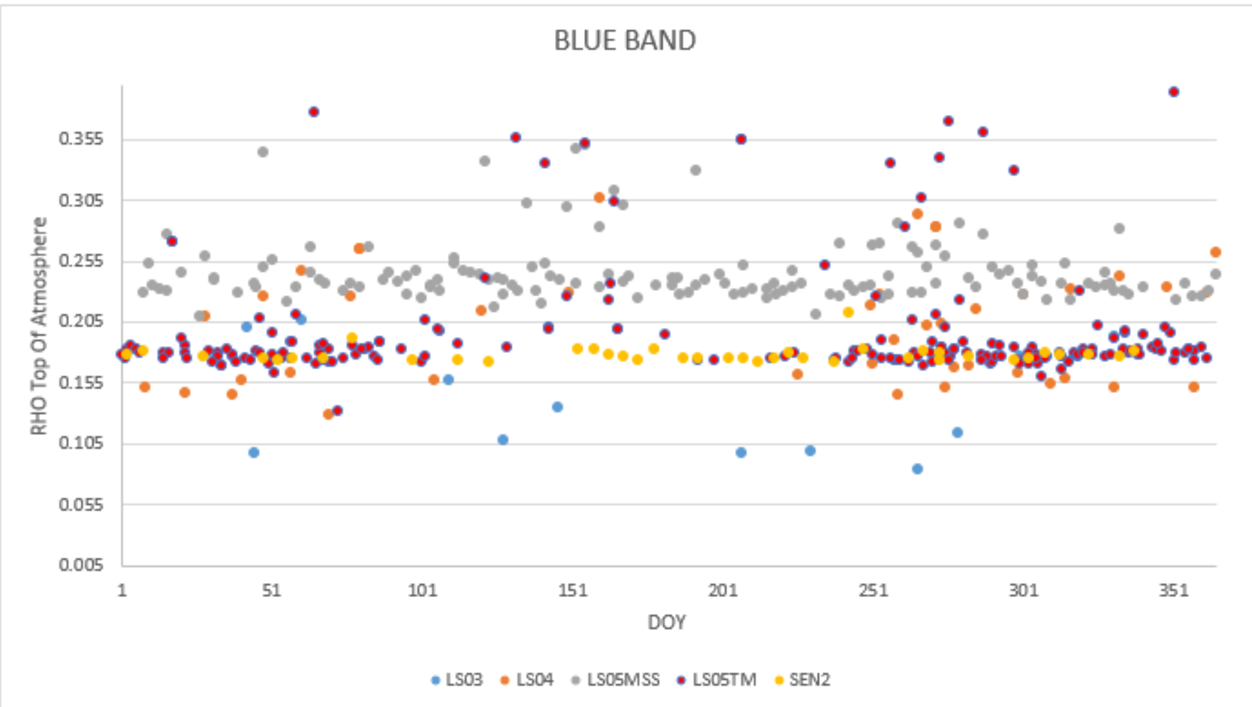



**Figure 6-9: Algeria3 Landsat 3-5 time-series consistency comparison with Sentinel-2 reference data, Blue Band.**

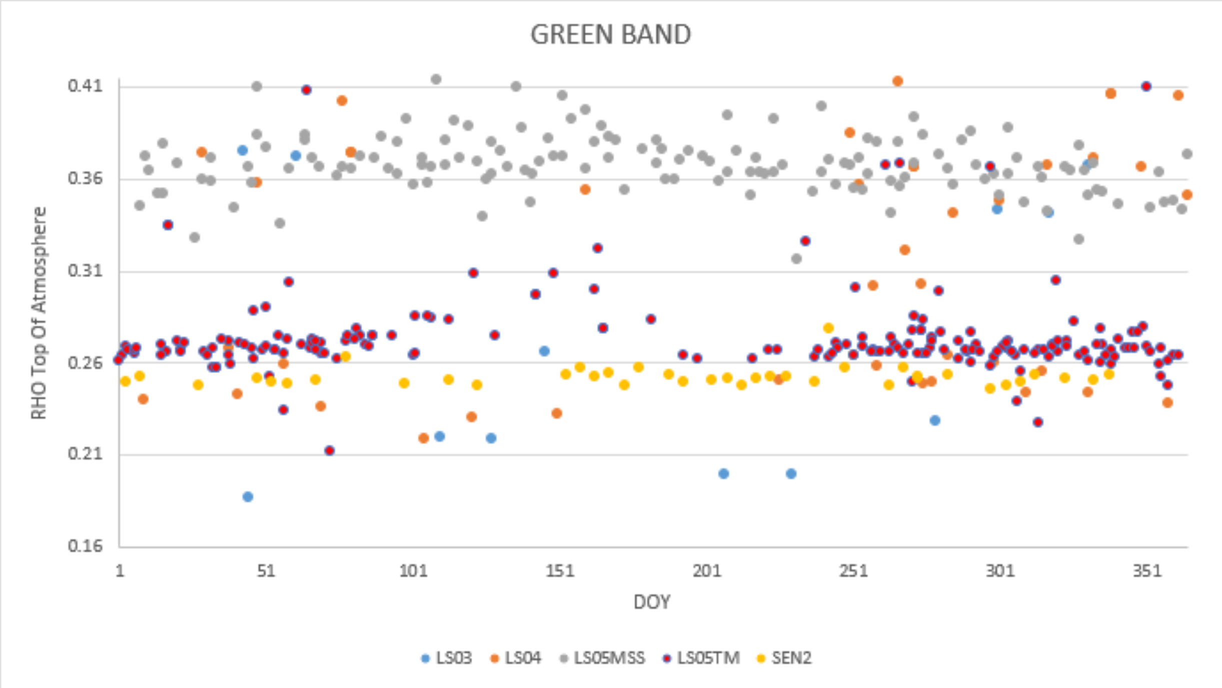



**Figure 6-10: Algeria3 Landsat 3-5 time-series consistency comparison with Sentinel-2 reference data, Green Band.**

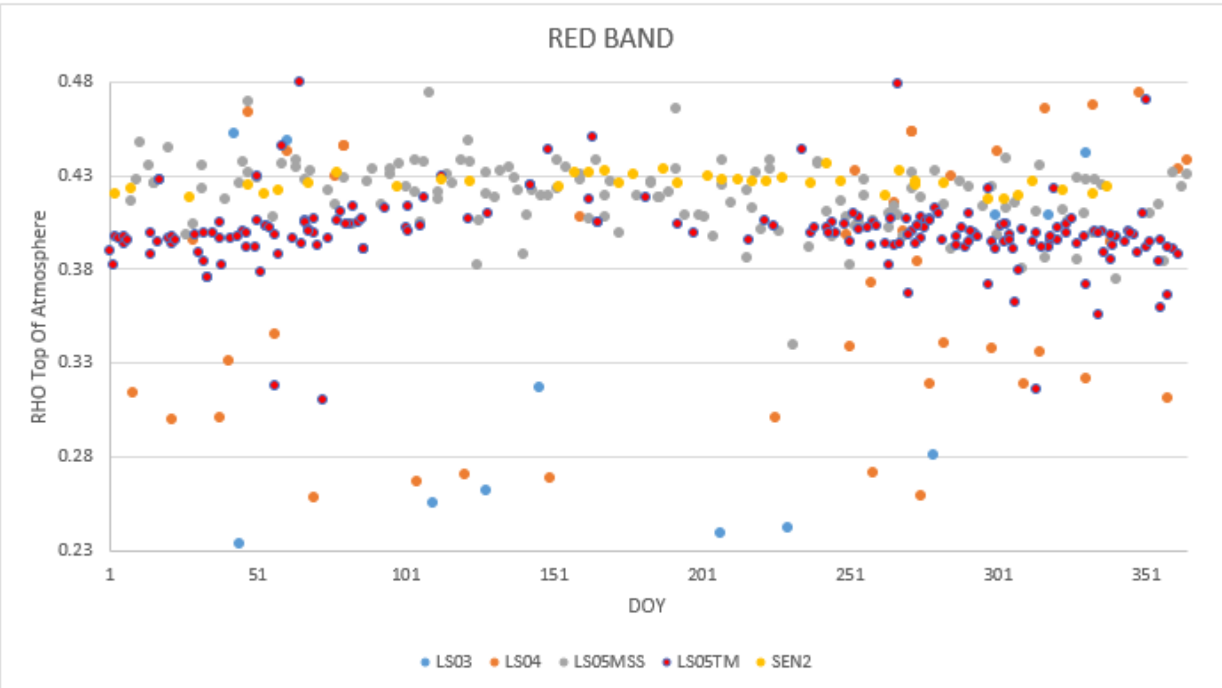



**Figure 6-11: Algeria3 Landsat 3-5 time-series consistency comparison with Sentinel-2 reference data, Red Band.**

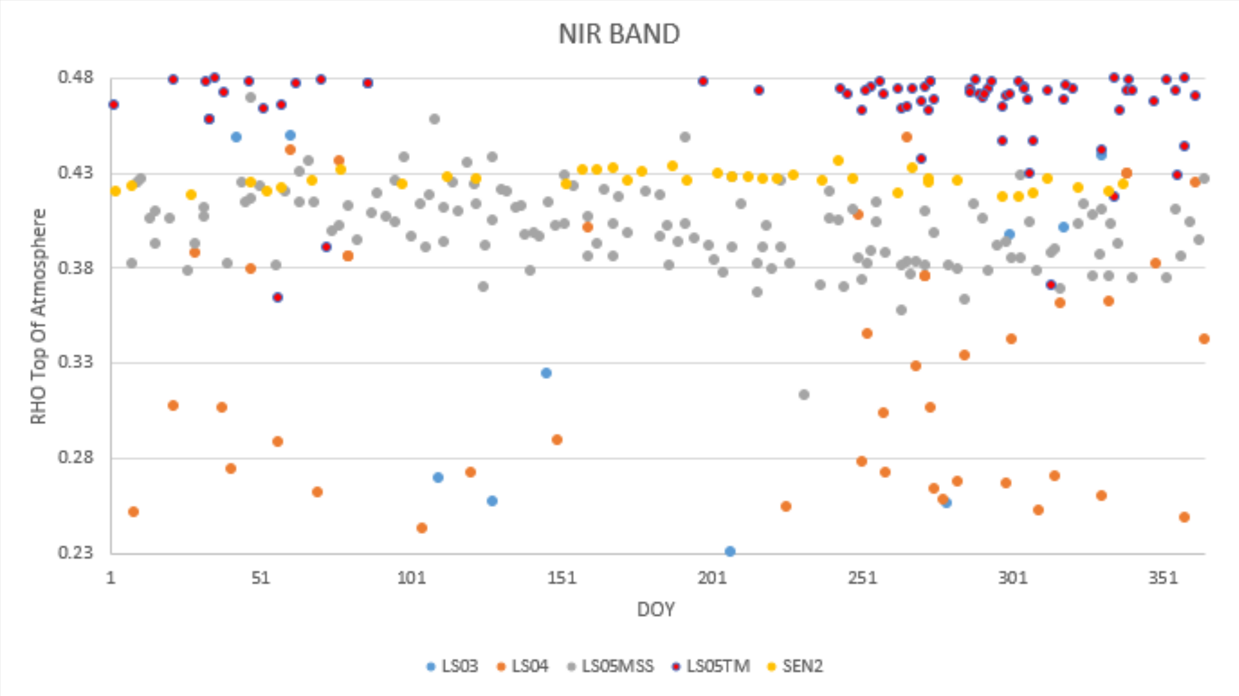



**Figure 6-12: Algeria3 Landsat 3-5 time-series consistency comparison with Sentinel-2 reference data, NIR Band.**

# APPENDIX B LANDSAT 1-7 TEST DATASET

Please refer to RD-5 for TDS product information.

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