# Landsat Products, Algorithms and Processing (MSS, TM & ETM+)

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# 1. INTRODUCTION

## 1.1 Purpose and Scope

This document describes the algorithms, radiometric and geometric processing of the European Space Agency (**ESA**) Landsat Multispectral Scanner (**MSS**), Thematic Mapper (**TM**) and Enhanced Thematic Mapper Plus (ETM**+**) products. It is intended to point towards useful resources for more information rather than provide full descriptions of the specific algorithms used during the processing.

## 1.2 Structure of the Document

After this introduction, the document is divided into the following sections that are briefly described below:

**2 PRODUCTS AND ALGORITHMS**

An overview of the MSS / TM / ETM+ products, algorithms, radiometric and geometric processing.

**3 GLOSSARY**

The Glossary contains definitions of acronyms, abbreviations and terms used throughout the document.

## 1.3 Referenced Documents

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

RD.1 Biasutti R., et al., Bulk-processing of ESA’s Unique Landsat Archive (2014), Presentation at the Sentinel 2 for Science Workshop, ESA

RD.2 Gascon F., et al., European Space Agency (ESA) Landsat MSS/TM/ETM+ Archive Bulk-processing: Processor Improvements and Data Quality (2014), SPIE Proceedings, Vol 9218

RD.3 ACS, Transcribed Data Format on DLT (2009), Multi-Satellite Data Processing Systems, Version 6.8

RD.4 Goddard Space Flight Center, Landsat to Ground Station Interface Document (1986), Rev 9

RD.5 Lockheed Martin, Landsat 7 System Data Format Control Book Volume IV – Wideband Data (1999), Revision L

RD.6 USGS, Landsat Multispectral Scanner (MSS) Level 1 (L1) Data Format Control Book (DFCB) (2013), LSDS-286, Version 6.0

RD.7 USGS, Landsat Thematic Mapper (TM) Level 1 (L1) Data Format Control Book (DFCB) (2013), LS-DFCB-20, Version 5.0

RD.8 USGS, Landsat Enhanced Thematic Mapper Plus (ETM+) Level 1 (L1) Data Format Control Book (DFCB) (2013), LSDS-272, Version 18.0

RD.9 IDEAS+, Landsat Products Description Document (2015), IDEAS-VEG-SRV-REP-1320, version 6.0

RD.10 ESA, ngEO Tailoring for Landsat (2013), GMES-GSEG-EOPG-TN-12-0068, Issue 1.1

RD.11 Magellium, ngEO Browse Report File Generic Interface Document (BRGICD) (2014), ngEO-13-ICD-MFR-059, Issue 1.5

RD.12 GAEL, AMALFI 2.1 User Manual (2011), GAEL-AMALFI-SUM-001-03-04, Version 3.4

RD.13 GAEL, AMALFI Add-on User Manual (2014), GAEL-P255-SUM-002-01-04

RD.14 Magellium, Tool Description and Validation – State Vector Testing (2015), Dsi-TN-024-MAG, Version 1

RD.15 Rengarajan R., et al., Validation of Geometric Accuracy of Global Land survey (GLS) 2000 Data (2015), Photogrammetric Engineering & Remote Sensing, Vol 81, No. 2

RD.16 Goddard Space Flight Center, MSS Standard Interface Document (1978), GE-BO-78-034

RD.17 Goddard Space Flight Center, Landsat 4 Multispectral Scanner (MSS) Subsystem Radiometric Characterisation (1983)

RD.18 Goddard Space Flight Center, Generation and Physical Characteristics of the ERTS MSS System Corrected Computer Compatible Tapes (1973), X-563-73-206

RD.19 USGS, Landsat 1-5 Multispectral Scanner (MSS) Image Assessment System (IAS) Radiometric Algorithm Description Document (ADD) (2012), LS-IAS-07, Version 1.0

RD.20 Helder D. L., et al., Radiometric Calibration of the Landsat MSS Sensor Series (2012), IEEE Transactions on Geoscience and Remote Sensing, Vol 50, No 6

RD.21 Horn B. K. P., et al., Destriping Landsat MSS Images by Histogram Modification (1979), Computer Graphics and Image Processing, Volume 10

RD.22 USGS, Landsat 7 Image Assessment System (IAS) Geometric Algorithm Theoretical Basis Document (ATBD) (2006), LS_IAS-01, Version 1.0

RD.23 Tucker C. J., et al., NASA's Global Orthorectified Landsat Data Set (2004), Photogrammetric Engineering & Remote Sensing, Vol 70, No. 3

RD.24 USGS, Landsat 4/5 Thematic Mapper (TM) Image Assessment System IAS) Radiometric Algorithm theoretical Basis Document (ATBD) (2012), LS-IAS-03, Version 3

RD.25 Chander G., et al., Revised Landsat-5 Thematic Mapper Radiometric Calibration (2007), IEEE Geoscience and Remote Sensing Letters, Vol 4, No 3

RD.26 USGS, Landsat 5 Thematic Mapper (TM) Lookup Table (LUT) Release Version Description document (VDD) (2004), IAS-223.3, Version 3

RD.27 Barsi J. A., et al., Landsat-5 Thematic Mapper Thermal Band Calibration Update (2007), IEEE Geoscience and Remote Sensing Letters, Vol 4, No 4

RD.28 Arvidson T., et al., Landsat and Thermal Infrared Imaging

RD.29 USGS, Landsat 7 Image Assessment System (IAS) Geometric Algorithm Theoretical Basis Document (ATBD) (2006), LS_IAS-01, Version 1.0

RD.30 USGS, Thematic Mapper/Enhanced Thematic Mapper Plus Bumper Mode Scan Mirror Correction Algorithm Theoretical Basis (2006), Version 3.0

RD.31 USGS, Landsat 7 Image Assessment System (IAS) Radiometric Algorithm Theoretical Basis Document (ATBD) (2003), LS-IAS-02, Version 1.0

## 1.4 Definitions of Terms

The following terms have been used in this report with the meanings shown.

| Term | Definition |
|---|---|
| SLAP | Systematic Landsat Archive Processing; This project covers the MSS, TM and ETM+ products from Landsat 1-7, and is the first systematic reprocessing project of the ESA Landsat archive. |

# 2. PRODUCTS AND ALGORITHMS

The Landsat MSS products are being reprocessed as part of the Systematic Landsat Archive Processing (**SLAP**) project, and will be released to the users progressively during 2015.

## 2.1 Product Information

ESA has acquired Landsat data over Europe through the ESA ground stations during the last 40 years, in co-operation with the United States Geological Survey (**USGS**) and the National Aeronautics and Space Administration (**NASA**). Lately, the product generation system of ESA has been significantly improved for supporting the Landsat MSS, TM and ETM+ archive reprocessing [RD.1] and aligning historical Landsat data to Landsat 8 and Sentinel 2.

In terms of products and algorithms, the approach of ESA and the USGS is now similar and ESA algorithms are mostly based on the USGS ones (even if the software is different). Developments of the ESA software include the following improvements, and are discussed in detail in [RD.2]

- Multi-scene refinement processing;
- Extension of the Terrain Corrected Processor above 60° North;
- MSS geometric and radiometric improvements;
- MSS cloud cover assessments.

The content herein is intended to point the reader towards useful resources for more information on the following topics, rather than provide a full description of the specific algorithms used.

- Input data format
- Level 1 product format
- Supporting data description: state vector, calibration parameter; reference data
- MSS radiometric / geometric processing
- TM radiometric / geometric processing
- ETM+ radiometric / geometric processing

### 2.1.1 Input Data Format

The ESA Landsat processor ingests raw data provided in the ACS WILMA format. The WILMA format is fully described in [RD.3]. The format of the MSS and TM telemetry are described in [RD.4] and ETM+ in [RD.5].

Note that there is a single and harmonized processing system, including specific functionalities depending on the input mission.

Note that with the reprocessing of the Landsat Level 1 archives, the opportunity to quality check all the RAW Level 0 data was seized and the reports are now available in an online database (https://web.magellium.fr/ideasl0db/).

### 2.1.2 Level 1 Product Format

The format of Landsat MSS / TM / ETM+ Level 1 products is compliant with the USGS Data Format Control Book (**DFCB**) [RD.6, RD.7 & RD.8, respectively]. The content of the format and the image itself differ depending on the Level 1 processing levels (Level 1G, Level 1Gt and Level 1T). These differences are well explained in the Landsat Product Description Document (**PDD**) [RD.9].

It is important to note that the product Metadata and Quick Look are compliant to the Next Generation User Services for Earth Observation (**ngEO**) requirements, whose objective it is to provide online user services; primarily access to operational and non-operational data, for both Copernicus and non-Copernicus missions. For more information on the ngEO concepts, how the service is tailored to satisfy Landsat products, products metadata and browse format information, please see the ngEO Tailoring for Landsat and Browse Report File Generic Interface documents [RD.10 & RD.11].

The Level 1 product also includes a quality control report. The definition of the inspections applied and criteria are given in the AMALFI Software User Manual & Add-on Manual [RD.12 & RD.13].

### 2.1.3 Supporting Data

Supporting data are involved in the operational processing of MSS products. From a generic point of view, whatever the Landsat mission, they are divided into the following categories and are discussed in more detail below:

- State Vector (**SV**) Files
- Calibration Parameter File (**CPF**)
- Reference data

#### 2.1.3.1 State vector Files

No on board navigation system (e.g. Global Positioning System (**GPS**)) is carried on Landsat 1 – 7 to provide real time position and velocity information. Instead, the Landsat flight operation team computed, on a daily basis, predicted ephemeris for supporting spacecraft operation. In return, this data are included in the payload control data stream. The flight operation team was integrating data from the Tracking and Data Relay Satellite (**TDRS**) simultaneously to the Landsat ground station to provide consolidated estimates of satellite position and velocity. This data are most commonly known as Definitive ephemeris and are available, for Landsat 5 (TM) and Landsat 7 (ETM+), from the USGS portal (https://landsat.usgs.gov/science_DE.php). The totality of this data has been repatriated at ESA to guarantee the most accurate geometric processing in particular for L1G / L1Gt products.

**SPPA Activities**

An ephemeris data gap has been identified for the processing of MSS data. In this case, and to overcome this problem, work has been conducted to regenerate the data using a new method. The drawback of this approach is that the geolocation accuracy of MSS Level 1G products is unfortunately not guaranteed [RD.14]. For instance, the geolocation accuracy of Landsat 1 MSS Level 1G products may reach 18 km Root Mean Square (**RMS**) error with the existing information on orbital information; it is difficult to achieve a better accuracy. Having said this, the accuracy of the corresponding Level 1T products is **not** degraded; indeed the operational goal of 2 pixels accuracy has been reached.

#### 2.1.3.2 Calibration Parameter Files (CPF)

The CPF is distributed by the USGS, and the ESA processor is fully interfaced with this file. The CPF parameters are involved in the geometric, absolute and relative calibration processing algorithms. The most up to date version of CPF is used by the ESA processor. Consequently, as the processing algorithm has been implemented on the ESA side, the calibration accuracy of the ESA product is always aligned with the USGS products.

CPF files are available from the USGS for the MSS (http://landsat.usgs.gov/science_L12345MSS_cpf.php), TM (https://landsat.usgs.gov/science_L5_cpf.php) and ETM+ (https://landsat.usgs.gov/science_L7_cpf.php) datasets.

#### 2.1.3.3 Reference data

As supporting information, the reference data are used for geometric corrections, in particular for the co-registration of any input images to a reference map (Raster reference) and for accounting for distortions due to terrain relief (Digital Elevation Model (**DEM**)).

The NASA Global Landsat Survey Image Database (http://glcf.umd.edu/data/gls/) has been selected as the raster reference for any Landsat mission. The raster reference is used as a reference source for building a Ground Control Point (**GCP**) database associated to each Landsat WRS scene. The accuracy of the GLS2000 dataset is better than 25 m (RMS) for most of the constituent scenes [RD.15].

The Global Land Survey Digital Elevation Model (**GLSDEM**) (version 4.0) (http://www.glcf.umd.edu/data/glsdem/) has been selected as the elevation data. The GLSDEM collection includes the National Elevation Dataset (**NED**) of the USA, the Canadian Digital Elevation Dataset (**CDED**) of Canada and the Shuttle Radar Topography Mission (**SRTM**) covering most of the globe: 83° North – 56° South. The GLSDEM product is of 3 arc second (90 m) resolution and in geographic coordinates with a WGS-84 datum. The usage of the GLSDEM allows an easy extension of the GTC production over 60° North, which is the main limitation of using the SRTM DEM only. The elevation accuracy of GLSDEM strongly depends on the geographic location, because its accuracy depends on the typology of the relief. Mostly, an elevation accuracy of 30 m (RMS) is expected.

### 2.1.4 MSS Radiometric Processing

Relatively complete documentation of the pre-launch and post-launch calibration procedures is provided in [RD.16] for Landsat 1-3 and [RD.17] for Landsat 4.

The ground radiometric processing procedures used for Landsat 1 - 3 are also documented in [RD.18] and the radiometric calibration processing of MSS data is mostly based on algorithms proposed in the MSS Image Assessment Radiometric Algorithm Description Document [RD.19].

Substantial differences, of up to 16%, existed between the MSS instruments on board Landsat 1 – 5. A methodology was set up by the USGS / NASA calibration / validation team to align the radiometric calibration of MSS sensors to within 5%, and also provide the Landsat 5 MSS sensor with an absolute radiometric scale using the Landsat 5 TM sensor. The uncertainties associated with this calibration approach are considered to be less than 5% [RD.20]. Consistent calibration of the Landsat MSS archive, back to 1972, has been achieved.

During development, a striping anomaly has been observed within Landsat 1 MSS Band 6 and Band 7 images. To eliminate this problem, an additional post processing has been implemented [RD.21]. The histogram equalization is applied to correct residual striping after radiometric calibration.

### 2.1.5 MSS Geometric Processing

The notion of the geometric stability and internal geometry coherence are fundamental for an appropriate use of measurement over time. In addition, the residual errors estimated at each stage of the geometric processing validation should be carefully reported for traceability purposes. The latter assertion is reinforced in the case of the MSS data archive, for which long term records of the Earth's evolution are available but the data quality is degraded and past technology was not designed to achieve sub pixel accuracy.

Consequently in the context of the Landsat archive reprocessing, major improvements have been conducted regarding the MSS geometric processing. The product generation system of MSS has been aligned to the TM and ETM+ ones; hence algorithms are very close to those exposed in the Landsat 7 ETM+ Image Assessment System Geometric ATBD [RD.22]: the geometric correction grid is built over the scan geometry as the input image grid. Subsequently, a grid cell polynomial mapping between ground geometry (output image grid) and input image grid is applied.

The MSS telemetry is generally affected by missing and corrupted data, mainly because of mission ageing and archive degradation, resulting in a poor quality geometric model. The orbit, attitude and data from the Payload Control Data (**PCD**) stream are generally used to compute the geometric model.

To overcome corrupted data issues, satellite position bias and attitude angle corrections are estimated as part of the geometric model refinement process. The refinement is performed by using a GCP set extracted from a dedicated database with images originating from the NASA GLS2000 dataset (http://glcf.umd.edu/data/gls/) for which the geolocation accuracy is estimated to be 25 m (RMSE). The physical model parameters are estimated by using least square adjustment methods over a set of linearized collinearity equations. A better accuracy is achieved by using this approach compared with the use of warping functions as for TM and ETM+. The geometric model is calibrated by using information obtained over the satellite and not a single WRS scene. Hence, block adjustment techniques have been implemented to estimate an accurate georeferencing model and in order to perform subsequent ortho-rectification. The approach is very similar to the approach adopted in the context of image data mosaicking [RD.23].

Note that MSS geometric processing uses the most up to date calibration parameters written into the CPF, released by the USGS.

### 2.1.6 TM Radiometric Processing

The radiometric calibration processing of TM data is mostly based on algorithms proposed in the Landsat 4 – 5 TM Image Assessment System Radiometric ATBD [RD.24]. In particular, it is worth highlighting that several corrections have been set up to improve the image quality: Residual striping correction; Memory Effect (**ME**) corrections and Scan Correlated Shift (**SCS**) corrections.

In addition, it is important to note that the operational calibration procedure of TM reflective bands has changed during the mission lifetime. From a user point of view, it is therefore essential to ensure that the latest version of radiometric calibration algorithms have been applied as several existing papers, still available on the web today, may include outdated information.

As recommended by the USGS team, the radiometric calibration processing on the ESA side is now a Look-up-table (**LUT**) based calibration procedure approach. It is an evolution compared to the Pre Flight, Internal Calibrator (**IC**) procedures used in the past. The lifetime radiometric calibration curve is derived from the instrument response to pseudo invariant desert sites and from cross calibration with Landsat 7 ETM+ [RD.25]. As opposed to historical calibration methods, the new calibration procedure significantly improves the radiometric fidelity of the instrument: when comparing with the ETM+, the percentage mean difference in reflectance is estimated to be less than 3%. A more consistent calibration over the mission lifetime is therefore achieved. More information on the LUTs generated for Landsat 5 is available in [RD.26].

For information, the LUT gains can be accessed online through the USGS Landsat Project Website. The LUT file is ASCII with 11 (3+6+2) columns. The first three columns are time related. The next six columns list the Band average time-dependent gain coefficients generated from the lifetime gain equations. The last two columns provide Band average icing-corrected gain coefficients for Bands 5 and 7.

The calibration procedure of the emissive band (Band 6) is based on in-flight data as recorded by the IC device: pulse values given on a per-scan basis are used in determining scene-based gains and scan-based offsets for each detector. The algorithms are clearly detailed in [RD.27 & RD.28].

### 2.1.7 TM Geometric Processing

The product generation system of TM is mostly based on algorithms proposed in the Landsat 7 ETM+ Image Assessment System Geometric ATBD [RD.29]. It implements algorithms that use the instrument and spacecraft support data, provided in the Landsat data stream, to construct a model of the geometric relationship between the acquired image data and an Earth Fixed ground reference system.

This support data includes on board measurements of instrument timing, spacecraft attitude (orientation) and jitter, and estimates of spacecraft velocity derived from ground tracking data. A rigorous model of the sensor imaging geometry is constructed using this instrument and spacecraft data in conjunction with a set of geometric calibration parameters derived, maintained by the Image Assessment System (**IAS**), [STOREY 1999] and distributed to ICs in the form of CPF.

As for ETM+ products, an additional processing is dedicated to the refinement of the product geolocation with the usage of a GCP set, selected from the Landsat GLS dataset (http://glcf.umd.edu/data/gls/).

Unlike MSS, the ortho-rectification approach is based on a warping approach: correcting for distortion corresponds to repositioning pixels from their original locations to their correct locations by using bilinear polynomial mapping coordinates in the original image to coordinates in the corrected image (8 parameters). In case the GCP set is missing, the ortho-rectification is applied, but the resulting image is not registered to a common reference map.

Note that following the loss of synchronization between the scan mirror and calibration shutter in early 2002 ("caterpillar tracks" on image), the ESA processor has been improved to process images observed in backup bumper mirror mode, following switching operated by the USGS. More information is available in the bumper mode scan mirror correction ATBD [RD.30].

### 2.1.8 ETM+ Radiometric Processing

Regarding radiometric processing, the product generation system of ETM+ data is mostly based on algorithms proposed in the Landsat 7 ETM+ Image Assessment System Radiometric ATBD [RD.31].

ESA has decided not to receive Landsat ETM+ data after the Scan Line Corrector (**SLC**) failure on May 31, 2013. Therefore, processing algorithms have not been modified accordingly.

### 2.1.9 ETM+ Geometric Processing

The product generation system of ETM+ is mostly based on algorithms proposed in the Landsat 7 ETM+ Image Assessment System Geometric ATBD [RD.29]. It implements algorithms that use the instrument and spacecraft support data, provided in the Landsat data stream, to construct a model of the geometric relationship between the acquired image data and an Earth Fixed ground reference system.

This support data includes on board measurements of instrument timing, spacecraft attitude (orientation) and jitter, and estimates of spacecraft velocity derived from ground tracking data. A rigorous model of the sensor imaging geometry is constructed using this instrument and spacecraft data in conjunction with a set of geometric calibration parameters derived, maintained by the IAS, [STOREY 1999] and distributed to ICs in the form of CPF.

As for MSS / TM products, an additional processing is dedicated to the refinement of the product geolocation with the usage of a GCP set, selected from the Landsat GLS dataset (http://glcf.umd.edu/data/gls/).

Unlike MSS, the ortho-rectification approach is based on a warping approach: correcting for distortion corresponds to repositioning pixels from their original locations to their correct locations by using bilinear polynomial mapping coordinates in the original image to coordinates in the corrected image (8 parameters). In case the GCP set is missing, the ortho-rectification is applied, but the resulting image is not registered to a common reference map.

Note that ESA has decided not to receive Landsat ETM+ data after the SLC failure on May 31, 2013. Therefore, processing algorithms have not been modified accordingly.

# 3. GLOSSARY

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

| | |
|---|---|
| CDED | Canadian Digital Elevation Dataset |
| CPF | Calibration Parameter File |
| DEM | Digital Elevation Model |
| DFCB | Data Format Control Book |
| ESA | European Space Agency |
| ETM+ | Enhanced Thematic Mapper Plus |
| GCP | Ground Control Point |
| GLSDEM | Global Land Survey Digital Elevation Model |
| GPS | Global Positioning System |
| IAS | Image Assessment System |
| IC | Internal Calibrator |
| LUT | Look-up-table |
| ME | Memory Effect |
| MSS | Multispectral Scanner |
| NASA | National Aeronautics and Space Administration |
| NED | National Elevation Dataset |
| ngEO | Next Generation User Services for Earth Observation |
| PCD | Payload Control Data |
| PDD | Product Description Document |
| RD | Reference Document |
| RMS | Root Mean Square |
| SCS | Scan Correlated Shift |
| SLAP | Systematic Landsat Archive Processing |
| SLC | Scan Line Corrector |
| SRTM | Shuttle Radar Topography Mission |
| SV | State Vector |
| TDRS | Tracking and Data Relay Satellite |
| TM | Thematic Mapper |
| USGS | United States Geological Survey |