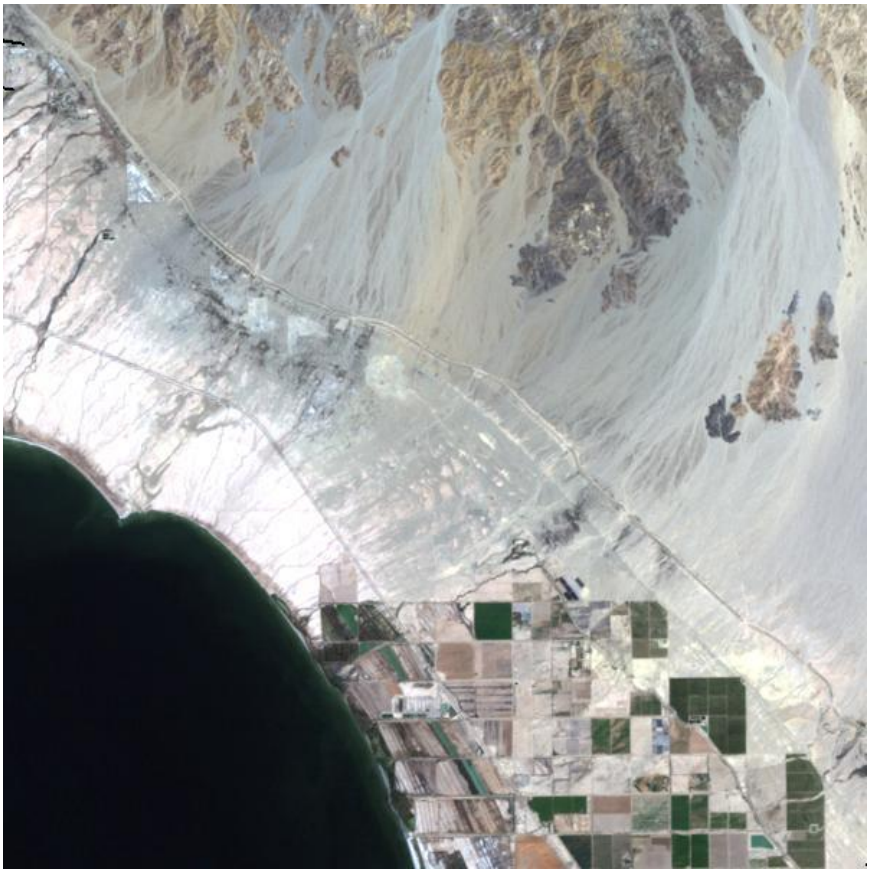
Department of the Interior
U.S. Geological Survey

PRODUCT GUIDE

LANDSAT 4-7 CLIMATE DATA RECORD (CDR) SURFACE REFLECTANCE



Version 7.1

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USGS
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Executive Summary

This document describes relevant characteristics of the Landsat Surface Reflectance Climate Data Record to facilitate its use in the land remote sensing community.

Please note that this document describes only the original Surface Reflectance files as derived for Landsat 4, 5 and 7. Other versions of the data which have been further processed to spectral indices, or altered by conversion, subset, and/or reprojection services, are described respectively in the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) Spectral Indices Product Guide and the ESPA On Demand Interface User Guide. Information about the Landsat 8 Surface Reflectance product can be found in the Provisional Landsat 8 Surface Reflectance Code (LaSRC) Product Guide.

Document History

Document Version	Publication Date	Change Description
Version 1.0	10/17/2012	Initial Draft
Version1.1	10/24/2012	Revision after Peer Review
Version1.2	11/07/2012	Revision after Bureau Review
Version 1.3	12/06/2012	Updated for LEDAPS 1.1.1
Version 1.4	12/11/2012	Updated with Fill and B6 details
Version 1.5	01/02/2013	Updated for LEDAPS 1.1.2
Version 1.6	01/16/2013	Corrected typos, added saturation value for Band 6, updated NLAPS processing protocol, revised product package description
Version 2.0	03/27/2013	Updated for LEDAPS 1.2.0 and new product options
Version 3.0	05/07/2013	Updated for LEDAPS 1.2.1, final version for FY13
Version 3.1	07/15/2013	Added information on LEDAPS 1.2.2 capability to process Landsat 4 Thematic Mapper scenes and output a C version of the Function of Mask (CFmask)
Version 3.2	09/09/2013	Included specific product information for CFmask, and reformatted to add appendices
Version 3.3	09/28/2013	Updated metadata fields in Appendix B
Version 3.4	12/01/2013	Moved spectral indices information to a new Product Guide. Added caveat against production using Landsat 7 data acquired on May 31, 2003. Added caveat against CFmask known issue. Removed Browse from product options
Version 3.5	01/06/2014	Updated bulk download and manipulation tool information
Version 4.0	03/28/2014	Revised to accommodate new file format options
Version 4.1	06/26/2014	Rearranged product option listing in Section 3 to match document content
Version 5.0	07/24/2014	Updated nomenclature to align with ESPA version 2.4.0.
Version 5.1	08/04/2014	Updated sections to recognize Brightness Temperature as a separate product.
Version 5.2	08/25/2014	Changed file names from ‘fmask’ to ‘cfmask’.
Version 5.3	11/04/2014	Changed Brightness Temperature section to indicate TOA BT units are in Kelvin. Corrected appendix reference typo. Added

		CFmask footprint caveat. Added actual XML file examples to Appendix B.
Version 5.4	12/23/2014	Updated table descriptions. Added links to Prototype Landsat 8 Surface Reflectance product guide.
Version 5.5	01/16/2015	Update to nomenclature of the QA values.
Version 5.6	03/09/2015	Update to band designations in Tables 6-1, 6-3 and 6-4.
Version 5.7	05/14/2015	Addition of provisional CFmask cloud confidence band.
Version 5.8	06/08/2015	Clarification of Bands 10-11 Brightness Temperature output.
Version 5.9	6/26/2015	Corrected URLS in Executive Summary.
Version 6.0	09/02/2015	Removed incorrect "_bt" file naming convention from Brightness Temperature description.
Version 6.1	12/01/2015	Added "Intial Characterization of Product Uncertainty" section. Corrected minor typos and revised the formatting of citations. Updated "User Services" section with correct information.
Version 6.2	02/10/2016	Edited instances where "shadow" should be "cloud shadow" (in reference to CFmask).
Version 6.3	03/01/2016	Data generation constraint added: cannot generate SR for products with scene center solar zenith angle > 76 degrees. Updated source code links to Github pages.
Version 6.4	05/27/2016	Added details about use of Atmospheric Opacity band. Updated CFmask cloud confidence description.
Version 6.5	07/01/2016	Updated reference and links to Landsat 8 Surface Reflectance Code (LaSRC) algorithm product and product guide.
Version 6.6	07/26/2016	Added "known issues" to CFmask section.
Version 6.7	08/23/2016	Removed SLC-off gap files from output product lists (no longer provided).
Version 6.8	09/07/2016	Added missing dates of auxiliary data in "Caveats and Constraints" section. Changed cloud confidence bits to actual representation – "low", "medium" and "high".
Version 6.9	09/30/2016	Fixed bad reference.
Version 7.0	10/11/2016	Added NetCDF file format.

Version 7.1	12/06/2016	Replaced links to Landsat Missions Website

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Section 1 Introduction

Landsat satellite data have been produced, archived, and distributed by the U.S. Geological Survey (USGS) since 1972. Users rely on these data for historical study of land surface change, but shoulder the burden of post-production processing to create applications-ready data sets. In compliance with guidelines established through the Global Climate Observing System, USGS has embarked on production of higher-level Landsat data products to support land surface change studies. Terrestrial variables such as surface reflectance and land surface temperature will be offered as Climate Data Records (CDR). Global 30-meter land cover, burned area extent, snow covered area, and surface water extent will represent Essential Climate Variables (ECV). These CDRs and ECVs will offer a framework for producing long-term Landsat science data collections suited for monitoring, assessing, and predicting land surface change over time.

The Surface Reflectance CDR is generated from specialized software called Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). LEDAPS was originally developed through a National Aeronautics and Space Administration (NASA) Making Earth System Data Records for Use in Research Environments (MEaSUREs) grant by NASA Goddard Space Flight Center (GSFC) and the University of Maryland (Masek et al., 2006). The software applies Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric correction routines to Level-1 Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) data. Water vapor, ozone, geopotential height, aerosol optical thickness, and digital elevation are input with Landsat data to Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer models to generate Top of Atmosphere (TOA) Reflectance, Surface Reflectance, Brightness Temperature, and masks for clouds, cloud shadows, adjacent clouds, land, and water. The result is delivered as the Landsat Surface Reflectance CDR.

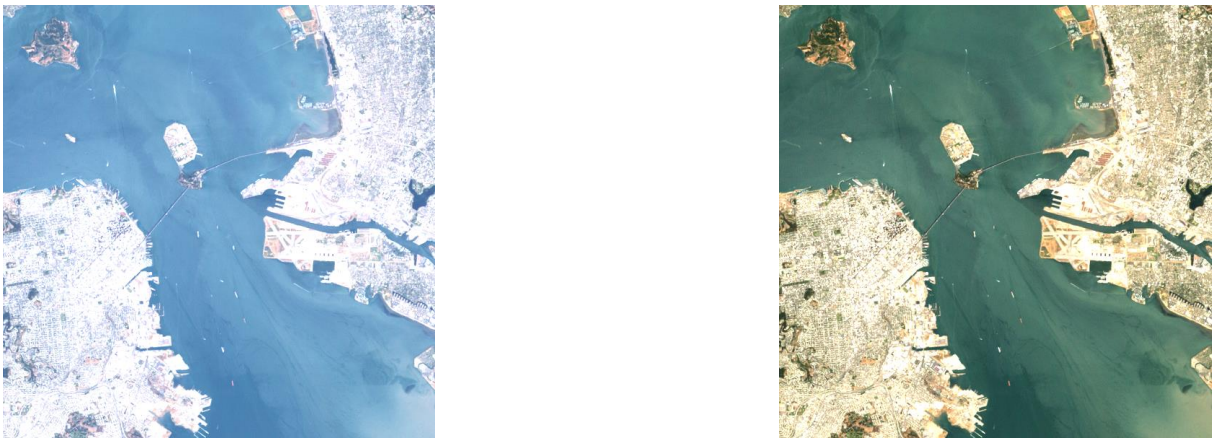

Figure 1-1 Example of LEDAPS atmospheric correction. Left, Top of Atmosphere (TOA) Reflectance composite (Bands 3,2,1) for Landsat-7 ETM+ image of San Francisco Bay (July 7, 1999); Right, Surface Reflectance composite. Both images are linearly scaled from p = 0.0 to 0.15.

Section 2 Caveats and Constraints

1. The Landsat Surface Reflectance CDRs are considered provisional.
2. The following date ranges and products cannot be processed to Surface Reflectance:
    - Landsat 4-5 TM processed through the National Landsat Archive Processing System (NLAPS), as they are formatted and calibrated differently than those processed through the Level-1 Product Generation System (LPGS). A list of known NLAPS scenes can be found online: https://landsat.usgs.gov/sites/default/files/documents/L4-5TM_NLAPS.xlsx
        1. NLAPS-based scenes will be automatically removed from user orders. The order status will be updated with this action and the remaining scenes will continue processing.
    - Landsat 7 ETM+ data collected between 2016-151 (May 30, 2016) and 2016-164 (June 12, 2016) due to missing auxiliary ozone information.
3. The following date ranges apply to the availability of the Landsat archive for Surface Reflectance processing, with the exceptions noted above:
    - Landsat 4 TM: July 1982 to December 1993
    - Landsat 5 TM: March 1984 to May 2012
    - Landsat 7 ETM+: April 1999 to within one week of present.
4. Landsat 7 ETM+ inputs are not gap-filled in Surface Reflectance production, and gapped areas are not processed for Surface Reflectance. See https://landsat.usgs.gov/using-landsat-7-data for information on Landsat 7 SLC-off data products.
5. Efficacy of the Surface Reflectance correction is likely to be reduced in areas where atmospheric correction is affected by adverse conditions:
    - Hyper-arid or snow-covered regions.
    - Low sun angle conditions.
    - Coastal regions where land area is small relative to adjacent water.
    - Areas with extensive cloud contamination.
6. Users are cautioned against correcting data acquired over high latitudes (> 65º).
7. Refer to the quality assurance (QA) bands for pixel-level condition and validity flags.
8. The cloud and cloud shadow indicators in the Surface Reflectance CDR are known to report erroneous conditions in areas where temperature differentials are either too large or too small. For example, a warm cloud over extremely cold ground may not calculate enough difference in temperature to identify the cloud. Conversely, residual ice surrounded by unusually warm ground can potentially be identified as cloud.

9. The panchromatic band (ETM+ Band 8) is not processed to Top of Atmosphere or Surface Reflectance.

Section 3 Product Options

This product guide is specific only to the products listed below. Options for processing beyond Surface Reflectance are covered in separate product guides.

1. Original Input Products
2. Original Input Metadata
3. Top of Atmosphere Reflectance
4. Surface Reflectance (all bands, including Band 6 Brightness Temperature)
5. Brightness Temperature

These products may be requested for any Landsat 7 ETM+, Landsat 5 TM, and Landsat 4 TM data available in the USGS archive, with the exceptions noted in Section 2 Caveats and Constraints.

3.1 Original Input Products

Selection of this option will deliver the original unaltered Landsat Level-1 scene.

Landsat 7 ETM+ Original Input Products output will contain:

- Level-1 data files (Band 1, 2, 3, 4, 5, 6 low gain, 6 high gain, 7, and 8)
- Read me file
- Filenames utilize the original scene identifier (sceneID), as exemplified by "LE70390372008210EDC00_*"

Landsat 4 and 5 TM Original Input Products output will contain:

- Level-1 data files (Band 1, 2, 3, 4, 5, 6, and 7)
- Readme file
- Filenames utilize the original scene identifier (sceneID), as exemplified by "LT50310181990192PAC00_*"

3.2 Original Input Metadata

Only the metadata associated with the Original Input Landsat scene is distributed when this option is requested.

Landsat 7 ETM+ Original Input Metadata output will contain:

- Ground Control Point text file
- Metadata text file
- Filenames begin as exemplified by "LE70390372008210EDC00_"

Landsat 4 and 5 TM Original Input Metadata output will contain:

- Ground Control Point text file
- Metadata text file
- Verify Image JPEG file
- Geometric Verify Report text file
- Filenames begin as exemplified by “LT50290302010281PAC01_”

3.3 Top of Atmosphere Reflectance

For users interested in TOA Reflectance calculated from the Original Input Landsat scene, the “Top of Atmosphere Reflectance” option may be selected. Further details are given in “**Section 6 Product Characteristics**.”

Landsat Top of Atmosphere Reflectance output from Landsat 7 ETM+, Landsat 5 TM, and Landsat 4 TM will contain:

- TOA Reflectance data files (Bands 1-5, 7)
- TOA Reflectance quality files
- TOA Reflectance metadata files
- Readme file
- Filenames utilize the original sceneID followed by “_toa_,” as exemplified by “LT50290302010281PAC01_toa_*”

3.4 Surface Reflectance

This option delivers only the Surface Reflectance product, without the TOA Reflectance, Brightness Temperature, and original input files. “**Section 6 Product Characteristics**” describes the product in full detail, but the general contents are listed below.

Landsat Surface Reflectance output from Landsat 7 ETM+, Landsat 5 TM, and Landsat 4 TM will contain:

- Surface Reflectance data files (Bands 1-5, 7)
- Cloud mask (CFmask) band (see **Section 6.2** for more details)
- CFmask cloud confidence band (see **Section 6.2.1** for more details)
- Surface Reflectance quality files
- Surface Reflectance metadata files
- Readme file
- Filenames utilize the original sceneID followed by “_sr_,” as exemplified by “LT40230281982346XXX04_sr_*”

3.5 Band 6 Brightness Temperature

Brightness Temperature for thermal Band 6 can be ordered as a separate product through the ESPA interface, but is included with all original products. Brightness Temperature output from Landsat 7 ETM+, Landsat 5 TM, and Landsat 4 TM will contain:

- Brightness Temperature data file (Band 6)
- Brightness Temperature quality file (Band 6)
- Brightness Temperature header file

- Filenames utilize the original sceneID followed by "_toa_band6_," as exemplified by "LT40230281982346XXX04_toa_band6_*".

Note that only the low gain thermal band (Band 6-1) is processed to Brightness Temperature for ETM+ products.

3.6 Spectral Indices

Surface Reflectance is also used to derive several spectral indices products, as listed below. Their characteristics are described in a separate product guide (see ESPA Spectral Indices Product Guide).

- Normalized Difference Vegetation Index (NDVI)
- Enhanced Vegetation Index (EVI)
- Soil Adjusted Vegetation Index (SAVI)
- Modified Soil Adjusted Vegetation Index (MSAVI)
- Normalized Difference Moisture Index (NDMI)
- Normalized Burn Ratio (NBR)
- Normalized Burn Ratio 2 (NBR2)

Section 4 Product Access

Landsat 4-7 Surface Reflectance data products are available through EarthExplorer, under the “Data Sets” > “Landsat Archive” tabs as “Landsat Surface Reflectance – L7 ETM+” and “Landsat Surface Reflectance – L4-5 TM”.

An on-demand interface called ESPA (U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)) offers Landsat 8 Surface Reflectance in addition to Original Input Products and Metadata, TOA Reflectance, NDVI, NDMI, NBR, NBR2, SAVI, MSAVI, and EVI data products. ESPA is accessible at http://espa.cr.usgs.gov/. Services such as reprojection, spatial subsetting, and pixel resizing are also available through ESPA. Additional information about ESPA’s spectral indices and service processing options for Landsat 4–8 can be found in the Spectral Indices Product Guide and ESPA On-Demand Interface User Guide, respectively.

Section 5 Product Packaging

Surface Reflectance products are supplied in a gzip file (“.tar.gz”). Unzipping this file produces a tarball (“.tar”), which will “untar” to a Georeferenced Tagged Image File Format (GeoTIFF; .tif) file. The filenames are structured as the original scene ID appended with the suffix “_sr_” followed by a band designation to denote the Surface Reflectance transformation. An example breaking down the components of a typical file is:

LXXPPPRRRYYYYDDDSTNVR_prod_band.ext
(e.g., LE70390372008210MOR00_sr_band1.tif)

LXX	LE7 for Landsat 7 Enhanced Thematic Mapper Plus
LXX	LT5 for Landsat 5 Thematic Mapper
LXX	LT4 for Landsat 4 Thematic Mapper
PPP	Path
RRR	Row
YYYY	Year of Acquisition
DDD	Julian Date of Acquisition
STN	Receiving Station
VR	Version Number
prod	Product, such as “toa” or “sr”
band	Band, such as “band<1-7>,” “qa,” or spectral index.
ext	File format extension, such as “tif,” “tfw,” “xml,” “hdf,” “hdr,” “nc,” or “img”

Section 6 Product Characteristics

The original input product options now available from ESPA, such as the original Landsat scene and metadata, are amply described in existing documentation (https://landsat.usgs.gov/landsat-processing-details). The characteristics of higher-level data sets such as TOA Reflectance, Brightness Temperature, and Surface Reflectance are detailed in the following sections.

6.1 Surface Reflectance Specifications

The Landsat Surface Reflectance CDR is generated at 30-meter spatial resolution on a Universal Transverse Mercator (UTM) or Polar Stereographic (PS) mapping grid. The default file format is GeoTIFF, but options for delivery in Hierarchical Data Format – Earth Observing System – 2 (HDF-EOS-2; .hdf), NetCDF (.nc) or ENVI binary (.img), which are available through the ESPA Ordering Interface. More information on output formats can be found in the ESPA On Demand Interface User Guide.

Surface Reflectance is delivered in files named with the original sceneID and appended with "_sr_" followed by a band designation. All packages include files for Surface Reflectance, quality, headers (if applicable), and Extensible Markup Language (xml)-based metadata.

The Surface Reflectance bands are defined much like MODIS, with the notable exception that the QA is delivered in separate, condition-specific bands rather than as a single bit-packed layer. **Table 6-A** lists the specifications for the bands included in a Surface Reflectance data file.

Table 6-A Surface Reflectance Specifications

INT16 16-bit signed integer, UINT8 8-bit unsigned integer, QA quality assurance, DDV dark dense vegetation, CFmask C version of Function of Mask, NA not applicable

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
sceneid_sr_band1	Band 1	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_band2	Band 2	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_band3	Band 3	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_band4	Band 4	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_band5	Band 5	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_band7	Band 7	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sceneid_sr_atmos_opacity[1]	Atmospheric Opacity	INT16	Unitless	-2000 – 16000	0 - 10000	-9999	NA	0.0010
sceneid_sr_fill_qa	Fill QA	UINT8	Flag	0 not fill 255 fill	0 not fill 255 fill	NA	NA	NA
sceneid_sr_ddv_qa	DDV QA	UINT8	Flag	0 not DDV 255 DDV	0 not DDV 255 DDV	NA	NA	NA
sceneid_sr_cloud_qa	Cloud QA	UINT8	Flag	0 not cloud 255 cloud	0 not cloud 255 cloud	NA	NA	NA
sceneid_sr_cloud_shadow_qa	Cloud Shadow QA	UINT8	Flag	0 not cloud shadow 255 cloud shadow	0 not cloud shadow 255 cloud shadow	NA	NA	NA
sceneid_sr_snow_qa	Snow QA	UINT8	Flag	0 not snow 255 snow	0 not snow 255 snow	NA	NA	NA
sceneid_sr_land_water_qa	Land Water QA	UINT8	Flag	0 land 255 water	0 land 255 water	NA	NA	NA
sceneid_sr_adjacent_cloud_qa	Adjacent Cloud QA	UINT8	Flag	0 not adjacent cloud 255 adjacent cloud	0 not adjacent cloud 255 adjacent cloud	NA	NA	NA
sceneid_sr_cfmask	CFmask	UINT8	Flag	0 clear 1 water 2 cloud shadow 3 snow 4 cloud	0 clear 1 water 2 cloud shadow 3 snow 4 cloud	255	NA	NA
sceneid_sr_cfmask_conf	CFmask Cloud Confidence	UINT8	Flag	0 none 1 low confidence 2 medium confidence 3 high confidence	0 none 1 low confidence 2 medium confidence 3 high confidence	255	NA	NA

1 General interpretation for atmospheric opacity: < 0.1 = clear; 0.1 – 0.3 = average; > 0.3 = hazy.

6.1.1 Surface Reflectance Metadata

Each Surface Reflectance file is accompanied by an XML-based metadata file. Examples of the metadata included in the XML are listed in **Appendix B Metadata Fields**.

6.1.2 Surface Reflectance Special Notes

1. Regarding the "sr_fill_qa" band, a pixel is marked as fill if any of the reflectance bands holds a fill value for that pixel.

2. Metadata is included to help define the orientation of Polar Stereographic scenes acquired in ascending orbit over Antarctica. Whether on a descending or ascending orbit path, the first pixels acquired in a Landsat scene comprise the upper portion of an image. As Landsat crosses the Southern polar region, it views the southern latitudes first and progresses North. This places pixels in southern latitudes in the upper part of the image so that it appears to the user that South is 'up' and North is 'down.' The <corner> field in the metadata xml clarifies the upper left and lower right corners of the scene.

6.2 Cloud and Cloud Shadow Specifications

The Surface Reflectance product includes an alternative to cloud, cloud shadow, snow, and water identification, and is likely to present more accurate results than its companion bands (cloud_qa and cloud_shadow_qa). The "cfmask" band was originally developed at Boston University in a Matrix Laboratory (MATLAB) environment to automate cloud, cloud shadow, and snow masking for Landsat TM and ETM+ images. The MATLAB Function of Mask (Fmask) was subsequently translated into open source C code at the USGS EROS Center, where it is implemented as the C version of Fmask, or CFmask (https://github.com/USGS-EROS/espa-cloud-masking).

CFmask designates whether clouds, cloud shadows, snow, or water were identified in each pixel in the Surface Reflectance product, as described in **Table 6-B**.

Table 6-B CFmask Pixel Values

Pixel Value	Interpretation
255	Fill
0	Clear
1	Water
2	Cloud Shadow
3	Snow
4	Cloud

6.2.1 CFmask Cloud Confidence Band

A confidence band for the cloud detection portion of CFmask is provided with the Landsat 4-7 Surface Reflectance product. The output of this band are considered

provisional, as the confidence thresholds are subject to change. **Table 6-C** describes each value within the CFmask Cloud Confidence Band.

Table 6-C CFmask Cloud Confidence Band Values

Pixel Value	Interpretation
255	Fill
0	None
1	Low cloud confidence
2	Medium cloud confidence
3	High cloud confidence

6.2.2 CFmask Known Issues

1. The cloud indicators in the sr_cloud_qa and CFmask are known to report erroneous cloud conditions when temperature differentials are either too large or too small. For example, a warm cloud over extremely cold ground may not calculate enough difference in temperature to identify the cloud. Conversely, residual ice surrounded by unusually warm ground can potentially be identified as cloud.
2. CFmask may have issues over-including bright targets such as building tops, beaches, snow/ice, sand dunes and/or salt lakes.
3. Optically thin clouds will always be challenging to identify, and have a change of being omitted by CFmask.
4. The CFmask product does not align identically with the South and West edges of bands 1-5, 7 due to sharing a grid with band 6.

6.3 Top of Atmosphere Reflectance Specifications

6.3.1 Top of Atmosphere Reflectance - Bands 1-5, 7 Specifications

Calibration is applied to Landsat digital numbers to derive the TOA Reflectance component, using scene center solar angles in the computation. The "_toa_" packages contain TOA Reflectance and bit-packed quality information for Landsat Bands 1, 2, 3, 4, 5, and 7. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but it is specific to TOA Reflectance processing. Specifications for TOA Reflectance bands are similar to those for Surface Reflectance, but with a higher minimum value. Note: TOA Reflectance is not processed for thermal Band 6, but can be ordered separately as Brightness Temperature (**Section 6.3.2**).

Table 6-D lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Reflectance product bands.

Table 6-D Top of Atmosphere Reflectance – Bands 1-5, 7 Specifications

INT16 16-bit signed integer, UINT8 8-bit unsigned integer, TOA top of atmosphere, QA quality assurance, NA not applicable

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
sceneid_toa_band1	Band 1 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_band2	Band 2 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_band3	Band 3 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_band4	Band 4 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_band5	Band 5 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_band7	Band 7 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
sceneid_toa_qa	TOA QA	UINT8	Bit Index	0 – 255	0 – 255	1	NA	NA

6.3.2 Band 6 Brightness Temperature Specifications

Band 6 Brightness Temperature is derived from TOA radiance and two thermal constants. A QA band is also provided with this output product. The associated header files, metadata files, and specifications are the same kind of information as described for Top of Atmosphere Reflectance, but it is specific to Brightness Temperature processing.

Table 6-E lists the data type, units, value range, fill value, saturation value, and scale factor for the Brightness Temperature product bands.

Table 6-E Band 6 Brightness Temperature Specifications

INT16 16-bit signed integer, UINT8 8-bit unsigned integer, TOA top of atmosphere, QA quality assurance, NA not applicable

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
sceneid_toa_band6	Band 6 Reflectance	INT16	Brightness Temperature (Kelvin)	-100 – 16000	0 – 10000	-9999	20000	0.1
sceneid_toa_band6_qa	Band 6 TOA QA	UINT8	Bit Index	0 - 255	0 – 255	1	NA	NA

6.3.3 Top of Atmosphere QA Band

Shown in **Table 6-F**, TOA Reflectance uses a generic 8-bit QA derivation to simply express the saturation state of all input bands.

Table 6-F Top of Atmosphere Reflectance QA Bit Map Index

LSB least significant bit, MSB most significant bit, QA quality assurance

QA Bit	Description
Bits are numbered from right to left (bit 0 = LSB, bit 7 = MSB)	
0	Data Fill Flag (0 valid data, 1 invalid data)
1	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	Band 6 Data Saturation Flag (not set)
7	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)

6.3.4 TOA Reflectance Special Notes

1. Only the low gain thermal band (Band 6-1) is used when processing ETM+ data to Brightness Temperature.

2. Metadata is included to help define the orientation of Polar Stereographic scenes acquired in ascending orbit over Antarctica. Whether on a descending or ascending orbit path, the first pixels acquired in a Landsat scene comprise the upper portion of an image. As Landsat crosses the Southern polar region, it views the southern latitudes first and progresses North. This places pixels in southern latitudes in the upper part of the image so that it appears to the user that South is ‘up’ and North is ‘down.’ The <corner> field in the metadata xml clarifies the upper left and lower right corners of the scene.

3. The bit packed TOA Reflectance quality band “_toa_qa” can be unpacked using the Landsat Land Data Operational Product Evaluation (L-LDOPE) Toolbelt. Information and tool download are available at https://landsat.usgs.gov/data-manipulation-tools.

Section 7 Initial Characterization of Product Uncertainty

Several studies have been performed in regards to uncertainty of surface reflectance retrievals performed by the LEDAPS algorithm. Uncertainty is generally established through comparison of validated and reliable datasets which are independent of Landsats TM and ETM+. Maiersperger et al. (2013) compare LEDAPS' AOT estimates with AERONET AOT, field spectrometer data, and the MODIS Surface Reflectance product over the conterminous United States. Claverie et al. (2015) use a similar methodology, but add BRDF-corrected MODIS Terra/Aqua data, Landsat 5 TM and Landsat 7 ETM+ data corrected with AERONET AOT (Ju et al. (2012)), LEDAPS-corrected Landsat 5 TM data, and expands the spatial coverage to the entire world.

Claverie et al. (2015) perform their comparisons with the AERONET-derived reflectance, LEDAPS-derived reflectance, and MODIS reflectance using the metrics of accuracy, precision, and uncertainty, abbreviated as APU. APU was originally implemented by Vermote and Kotchenova (2008), where:

A = accuracy, as the mean bias of the satellite retrievals, versus the truth data,
P = precision, as the standard deviation of the satellite retrievals from the truth data and from the mean bias,
U = uncertainty, as the squared sum of the mean bias and standard deviation.

For the resulting APU metrics, Claverie et al. (2015) establish specification thresholds, or S, for the LEDAPS-AERONET comparisons and the LEDAPS-MODIS comparisons. The specifications are defined as:

$S_{LEDAPSxAERONET} = 0.05\rho + 0.005$, and
$S_{MODISxLEDAPS} = 0.071\rho + 0.0071$,

where ρ is the reflectance. The LEDAPS-AERONET specification (~5% error threshold) is identical to that of the MODIS APU specification. The specifications for the LEDAPS-MODIS comparison (~7.1% error threshold) are defined differently to account for the BRDF and spectral corrections applied to the MODIS surface reflectance.

The overall results show that most LEDAPS retrievals fell within the defined specification, with the highest error being in the blue band. There is not a significant difference in performance between Landsat 5 TM and Landsat 7 ETM+. Compared with MODIS surface reflectance, Landsat 7 ETM+ had better performance over Landsat 5 TM due to ETM+ and MODIS having similar sun-view geometry characteristics. There were no significant inter-annual variation between Landsat sensors. Geographic uncertainty is greatest in high latitude areas and over tropical evergreen forests.

Section 8 Citation Information

There are no restrictions on the use of these high-level Landsat products. It is not a requirement of data use, but please include the following citation in publication or presentation materials based on these products to acknowledge the USGS as a data source, and to credit the original research.

Landsat Surface Reflectance products courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center.

Masek, J.G., Vermote, E.F., Saleous N.E., Wolfe, R., Hall, F.G., Huemmrich, K.F., Gao, F., Kutler, J., and Lim, T-K. (2006). A Landsat surface reflectance dataset for North America, 1990–2000. IEEE Geoscience and Remote Sensing Letters 3(1):68-72. http://dx.doi.org/10.1109/LGRS.2005.857030.

If possible, reprints or citations of papers or oral presentations based on USGS data are welcome at the User Services addresses included in this guide. Such cooperation will help USGS stay informed of how the data are being used.

Section 9 Acknowledgments

The original LEDAPS software was developed by Eric Vermote, Nazmi Saleous, Jonathan Kutler, and Robert Wolfe with support from the NASA Terrestrial Ecology program (Principal Investigator: Jeff Masek). Subsequent versions were adapted by Dr. Feng Gao (GSFC/ERT Corp.) with support from the NASA Advancing Collaborative Connections for Earth System Science (ACCESS) and the USGS Landsat Programs.

The original CFmask software, Fmask, was developed by Zhe Zhu and Curtis E. Woodcock at the Center for Remote Sensing in the Department of Earth and Environment at Boston University, and is available from https://github.com/prs021/fmask.

Section 10 User Services

Landsat high-level products and associated interfaces are supported by User Services staff at USGS EROS. Any questions or comments regarding data products or interfaces are welcomed through the Landsat “Contact Us” online correspondence form: https://landsat.usgs.gov/contact. E-mail can also be sent to the customer service address included below, with the same indication of topic.

USGS User Services
http://landsat.usgs.gov/contact
custserv@usgs.gov

User support is available Monday through Friday from 8:00 a.m. – 4:00 p.m. Central Time. Inquiries received outside of these hours will be addressed during the next business day.

Section 11 References

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Appendix A Default File Characteristics

Table A-1 Default File Characteristics

DIR directory, tif GeoTIFF file format, VCID Virtual Channel Identifier, AUX auxillary, XML Extensible Markup Language, QA quality assurance, BT brightness temperature, TOA Top of Atmosphere, SR Surface Reflectance

NOTE: A Landsat 7 ETM+ sceneID is used only as an example. Landsat 4 and 5 TM files have similar characteristics.

Description	Example File Size (bytes)	Example File Name
Source Bands (8)	55,941,118	LE70390372008210MOR00_B*.tif
Source Panchromatic Band	223,621,278	LE70390372008210MOR00_B8.tif
Source Ground Control Point	10,919	LE70390372008210MOR00_GCP.txt
Source Metadata	65,535	LE70390372008210MOR00_MTL.txt
TOA Reflectance Bands (7)	119,336,075	LE70390372008210MOR00_toa_*.tif
TOA Reflectance Quality Band	59,697,384	LE70390372008210MOR00_toa_qa.tif
TOA Brightness Temperature Quality Band	59,697,384	LE70390372008210MOR00_toa_band6_qa.tif
Surface Reflectance Bands (6)	119,336,075	LE70390372008210MOR00_sr_*.tif
Surface Reflectance Atmospheric Opacity Band	119,336,075	LE70390372008210MOR00_sr_atmos_opacity.tif
Surface Reflectance Quality Bands (7)	56,697,384	LE70390372008210MOR00_sr_*.tif
CFmask Band	59,697,386	LE70390372008210MOR00_sr_cfmask.tif
CFmask Cloud Confidence Band	59,697,386	LE70390372008210MOR00_sr_cfmask_conf.tif
Metadata	25,556	LE70390372008210MOR00.xml

Appendix B Metadata Fields

Example of global XML metadata:

```
<global_metadata>
      <data_provider>USGS/EROS</data_provider>
      <satellite>LANDSAT_4</satellite>
      <instrument>TM</instrument>
      <acquisition_date>1989-04-20</acquisition_date>
      <scene_center_time>16:51:34.138013Z</scene_center_time>
      <level1_production_date>2014-05-29T21:32:07Z</level1_production_date>
      <solar_angles zenith="37.693756" azimuth="135.410049" units="degrees"/>
      <wrs system="2" path="30" row="31"/>
      <lpgs_metadata_file>LT40300311989110XXX02_MTL.txt</lpgs_metadata_file>
      <corner location="UL" latitude="42.717320" longitude="-100.621850"/>
      <corner location="LR" latitude="40.784750" longitude="-97.761490"/>
      <bounding_coordinates>
         <west>-100.622035</west>
         <east>-97.723491</east>
         <north>42.728942</north>
         <south>40.780521</south>
      </bounding_coordinates>
      <projection_information projection="UTM" datum="WGS84" units="meters">
         <corner_point location="UL" x="367200.000000" y="4730700.000000"/>
         <corner_point location="LR" x="604500.000000" y="4515600.000000"/>
         <grid_origin>CENTER</grid_origin>
         <utm_proj_params>
            <zone_code>14</zone_code>
         </utm_proj_params>
      </projection_information>
      <orientation_angle>0.000000</orientation_angle>
   </global_metadata>
```

Example of per-band XML metadata:

```
   <bands>
      <band product="toa_refl" source="level1" name="toa_band1" category="image" data_type="INT16"
nlines="7171" nsamps="7911" fill_value="-9999" saturate_value="20000" scale_factor="0.000100"
add_offset="0.000000">
         <short_name>LT4REF</short_name>
         <long_name>band 1 TOA reflectance</long_name>
         <file_name>LT40300311989110XXX02_toa_band1.tif</file_name>
         <pixel_size x="30" y="30" units="meters"/>
         <data_units>reflectance</data_units>
         <valid_range min="-100" max="16000"/>
         <calibrated_nt>5.000000</calibrated_nt>
         <app_version>LEDAPS_2.1.0</app_version>
         <production_date>2014-10-31T14:34:45Z</production_date>
      </band>
```

Appendix C Acronyms

Acronym	Description
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
CDR	Climate Data Record
CFmask	C version of Function of Mask (USGS EROS)
DDV	Dark Dense Vegetation
DIR	Directory
ECV	Essential Climate Variable
ENVI	Exelis Visual Information Solutions
EROS	Earth Resources Observation and Science
ESPA	EROS Science Processing Architecture
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
Fmask	Function of Mask (Boston University)
GeoTIFF	Geographic Tagged Image File Format
GSFC	Goddard Space Flight Center
HDF-EOS2	Hierarchical Data Format – Earth Observing System (version 2)
HDR	Header
INT	Signed Integer
LDOPE	Land Data Operational Product Evaluation
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LPGS	Landsat Product Generation System
LSB	Least Significant Bit
MATLAB	Matrix Laboratory
m	meter
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MODIS	Moderate Resolution Imaging Spectroradiometer
MSAVI	Modified Soil Adjusted Vegetation Index
MSB	Most Significant Bit
NA	Not Applicable
NASA	National Aeronautic and Space Administration
NBR	Normalized Burn Ratio
NBR2	Normalized Burn Ratio 2
NC	NetCDF File Format
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NLAPS	National Landsat Archive Processing System
PS	Polar Stereographic
QA	Quality Assurance
SAVI	Soil Adjusted Vegetation Index
sceneID	Scene Identifier
SLC	Scan Line Corrector

SR	Surface Reflectance
TM	Thematic Mapper
TOA	Top of Atmosphere
UINT	Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
xml	Extensible Markup Language