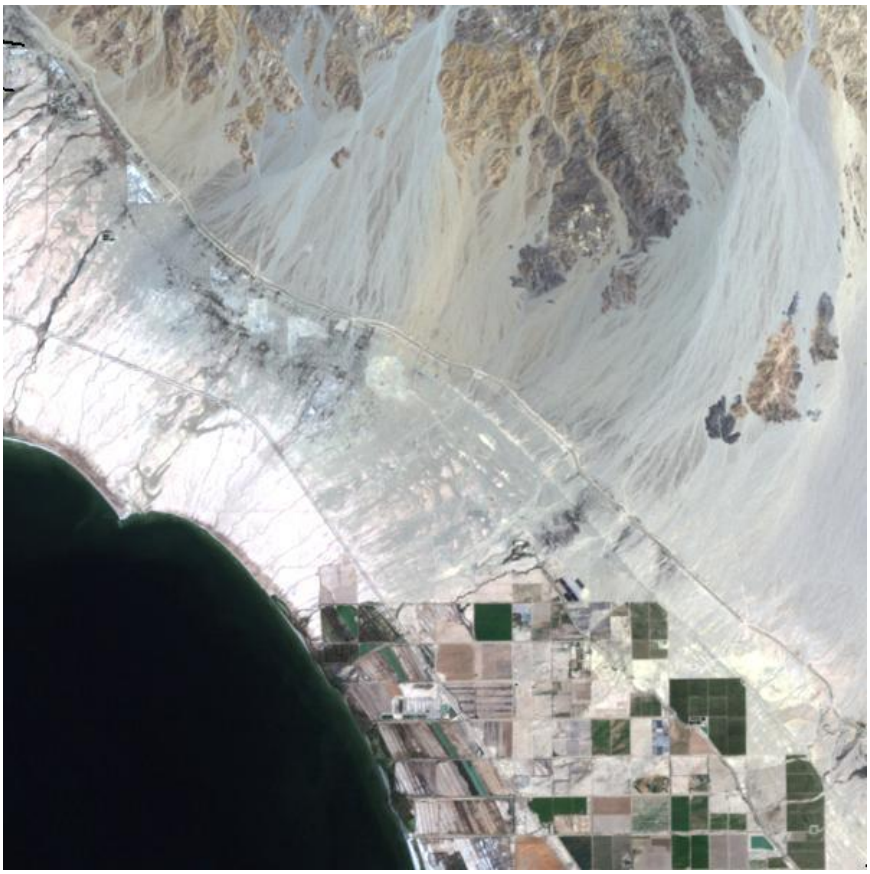
Department of the Interior
U.S. Geological Survey

PRODUCT GUIDE

LANDSAT 4-7 SURFACE REFLECTANCE (LEDAPS) PRODUCT



Version 7.8

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USGS
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Executive Summary

This document describes relevant characteristics of the Landsat Surface Reflectance data product 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 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
Version 7.2	01/11/2017	Updated “Input Products” and “Input Metadata” options description. Added ancillary data product table and description. Added ANG file to L1 metadata references (C1 only). Edited “Product Options”, “Product Access”, “Product Packaging”, “Product Characteristics” sections to reflect Landsat C1 addition. Notably, LEDAPS QA is now a single bit-packed for C1 data. Cloud QA bit is no longer corrected by LEDAPS (i.e., left in raw form). CFMask bands are no longer included by default in C1 SR data. Added band6_qa table. Added information about C1 RT data sets in “Caveats and Constraints”.
Version 7.3	03/10/2017	Edited for new quality assurance (QA) band information in Collection 1 (cfmask, cfmask_conf replaced by pixel_qa.) L1 quality band (bqa) removed from standard output. Per-pixel sensor/solar angle bands (derived from band 4) now provided with each product. toa_qa replaced by radsat_qa.
Version 7.4	03/31/2017	Removal of “Provisional” status for all C1 datasets. Updated angle band zenith valid range to 0-9000; angle band azimuth valid range -18000 – 18000; all angle band nodata to -32768. Addition of missing OMI dates (Section 8 Ancillary Data.)
Version 7.5	04/06/2017	Removal of Pre-Collection Landsat information.
Version 7.6	05/09/2017	Updated pixel_qa description, added detailed tables with pixel_qa values. Changed footer from “Landsat Surface Reflectance CDR” to “LEDAPS Product Guide”. Altered title of guide to be similar to footer. Added CFMask bands’ discontinuation date (02 June 2017).
Version 7.7	06/02/2017	Added interpretation table for sr_cloud_qa band. Removed TOA QA and BT QA; replaced with radsat_qa information. Updated table names.
Version 7.8	06/07/2017	Corrected typographical errors.

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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 data product 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 data product.

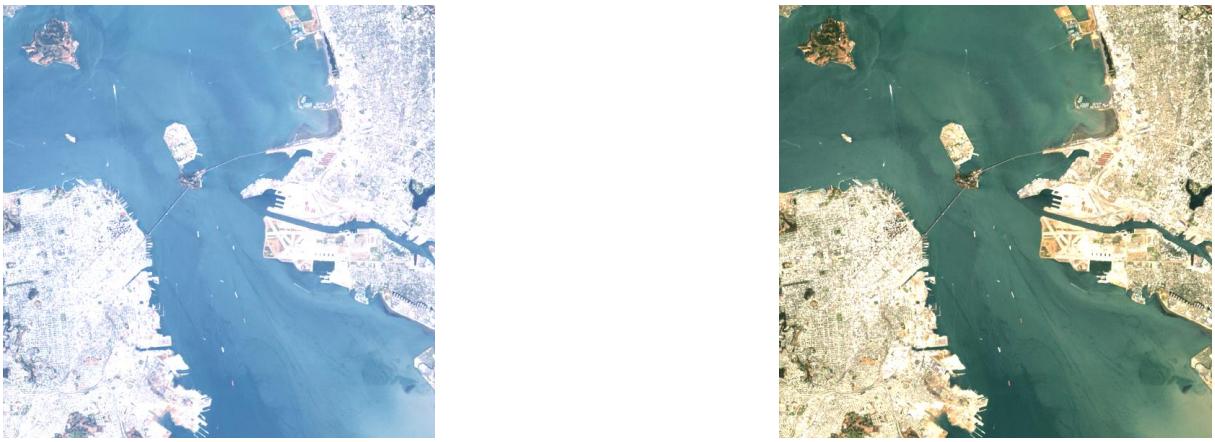

Figure 1-1 Example of LEDAPS atmospheric correction. Left, Top of Atmosphere (TOA) Reflectance composite (Bands 3,2,1) for Landsat-7 ETM+ image of San Francisco Bay (July 7, 1999); Right, Surface Reflectance composite. Both images are linearly scaled from p = 0.0 to 0.15.

Section 2 Caveats and Constraints

1. The 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.
    - Some auxiliary data are missing, which are required to process data to Surface Reflectance. See **Section 8 Ancillary Data** for more information. The most up-to-date information regarding data gaps is in the "Caveats and Constraints" section of https://landsat.usgs.gov/landsat-surface-reflectance-high-level-data-products.
2. 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.
3. Top of Atmosphere (TOA) Reflectance data are derived using per-pixel solar illumination angles generated from the angle coefficient file. Previously, the scene center solar illumination angle from the MTL file was used. This will impact the Surface Reflectance (SR) data products, as they are derived from TOA Reflectance.
    - This should ideally improve the accuracy of the TOA Reflectance and subsequent SR corrections.
    - Scene center solar illumination and sensor view angles (i.e., not per-pixel) are still used in the SR processing, as the Lookup Table routines are called on a grid that is spatially coarser than the resolution of the Landsat data, therefore not necessitating per-pixel angle information.
4. Real-Time (RT) Collection 1 data can be processed to Surface Reflectance once the ancillary data become available. Note that RT data will not have finalized geometric or radiometric processing, so the follow-on processing to place the data in Tier 1 (T1) or Tier 2 (T2) categories (approx. 2 weeks after acquisition) will likely be different than the Real Time data. See https://landsat.usgs.gov/landsat-collections for more information on the differences between RT and T1/T2 data sets.
5. 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/landsat-7 for information on Landsat 7 SLC-off data products.

6. 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.
7. Users are cautioned against correcting data acquired over high latitudes (> 65º).
8. Refer to the quality assurance (QA) bands for pixel-level condition and validity flags.
   - Before Collection 1 was implemented, a post-processing step was used to clean up the bit(s) flagged as cloud after reflectance retrieval. For Collection 1, this step is no longer performed in order to reflect the exact QA information that is used during reflectance retrieval. For cloud masking, users are advised to use the cloud bits populated in the Level-1 QA Band.
9. The cloud and cloud shadow indicators in the Surface Reflectance data product 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.
10. 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 and associated QA
4. Brightness Temperature and associated QA
5. Surface Reflectance and associated QA.

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 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)
- Level-1 metadata files
- Level-1 Quality Assurance band
- XML metadata
- Filenames utilize the product identifier (productID), as exemplified by "LE07_L1TP_039037_20080728_20160918_01_T1_*".

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

- Level-1 data files (Band 1, 2, 3, 4, 5, 6, and 7)
- Level-1 metadata files
- Level-1 Quality Assurance band
- XML metadata
- Filenames utilize the product identifier (productID), as exemplified by "LT05_L1TP_031018_19900710_20160918_01_T1_*".

3.2 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
- Angle Band Coefficients file
- Quality Assurance band
- XML metadata

- Filenames begin as exemplified by "LE07_L1TP_039037_20080728_20160918_01_T1_*".

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
- Angle Band Coefficients file
- Quality Assurance band
- XML metadata
- Filenames begin as exemplified by "LT05_L1TP_029030_20100805_20160831_01_T1_*".

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)
  - Note: files are created using per-pixel solar illumination angles generated from the angle coefficient file. Previously, the scene center solar illumination angle from the MTL file was used.
- TOA Reflectance metadata files
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa)
- Radiometric Saturation Quality Assurance band (radsat_qa)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- XML metadata
- Filenames utilize the productID followed by "_toa_," as exemplified by "LT05_L1TP_029030_20100805_20160831_01_T1_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)
- Surface Reflectance quality files (sr_cloud_qa, sr_atmos_opacity)
- Surface Reflectance metadata files
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa)
- Radiometric Saturation Quality Assurance band (radsat_qa)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- XML metadata
- Filenames utilize the productID followed by "_sr_," as exemplified by "LT04_L1TP_023028_19821212_20161004_01_T1_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 header file
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa)
- Radiometric Saturation Quality Assurance band (radsat_qa)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- XML metadata
- Filenames utilize the productID followed by "_bt_band6," as exemplified by "LT04_L1TP_023028_19821212_20161004_01_T1_bt_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 for “Collection 1 Higher-Level” 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 4-5 TM, Landsat 7 ETM+ and Landsat 8 OLI 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 Landsat 8 Surface Reflectance Code (LaSRC) Product Guide, Spectral Indices Product Guide and ESPA On-Demand Interface User Guide.

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 Collection 1 product is:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX_prod_band.ext
(e.g., LE07_L1TP_039037_20080728_20160918_01_T1_sr_band1.tif)

L	Landsat
X	Sensor ("E" = ETM+; "T" = TM)
SS	Satellite ("07" = Landsat 7; "05" = Landsat 5; "04" = Landsat 4)
LLLL	Processing correction level ("L1TP" = Precision Terrain; "L1GT" = Systematic Terrain; "L1GS" = Systematic)
PPP	Path
RRR	Row
YYYY	Year of acquisition
MM	Month of acquisition
DD	Day of acquisition
yyyy	Year of processing
mm	Month of processing
dd	Day of processing
CX	Collection number ("01", "02", etc.)
TX	Collection category ("RT" = Real-Time; "T1" = Tier 1; "T2" = Tier 2)
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 data product 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 product ID 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, and the QA band (sr_cloud_qa) is delivered in a single bit-packed layer. **Table 6-1** lists the specifications for the bands included in a Surface Reflectance data file. **Table 6-2** describes the bit assignments within the sr_cloud_qa band. The sr_cloud_qa bit values are given in **Table 6-3**, and shown in greater detail in **Table 6-4. Table 6-5** describes the bit assignments for the pixel_qa band. The pixel_qa bit values are given in **Table 6-6**, and shown in greater detail in **Table 6-7**.

Table 6-1 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_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1-32768	1-32768	1 (bit 0)	NA	NA
sceneid_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 –255	0 –255	1 (bit 0)	NA	NA
sceneid_sr_cloud_qa	sr_cloud_qa	UINT8	Bit index	0 - 255	0 - 63	NA	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	0 – 9000	-32768	NA	0.0100
sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	0 - 9000	-32768	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100

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

Table 6-2 Sr_cloud_qa Band Specifications

Bit	Attribute
0	Dark Dense Vegetation (DDV)
1	Cloud
2	Cloud shadow
3	Adjacent to cloud
4	Snow
5	Water
6	Unused
7	Unused

Table 6-3 Sr_cloud_qa Values

Attribute	Pixel Value
DDV	1, 9
Cloud	2, 34
Cloud shadow	4, 12, 20, 36, 52
Adjacent to cloud	8, 12, 24, 40, 56
Snow	16, 20, 24, 48, 52, 56
Water	32, 34, 36, 40, 48, 52, 56

Table 6-4 Sr_cloud_qa Bit Values

Pixel Value	DDV	Cloud	Cloud shadow	Adjacent to cloud	Snow	Water	Pixel Description
0	No	No	No	No	No	No	None
1	Yes	No	No	No	No	No	DDV
2	No	Yes	No	No	No	No	Cloud
4	No	No	Yes	No	No	No	Cloud shadow
8	No	No	No	Yes	No	No	Adjacent to cloud

9	Yes	No	No	Yes	No	No	DDV, adjacent to cloud
12	No	No	Yes	Yes	No	No	Adjacent to cloud, cloud shadow
16	No	No	No	No	Yes	No	Snow
20	No	No	Yes	No	Yes	No	Cloud shadow, snow
24	No	No	No	Yes	Yes	No	Adjacent to cloud, snow
32	No	No	No	No	No	Yes	Water
34	No	Yes	No	No	No	Yes	Cloud, water
36	No	No	Yes	No	No	Yes	Cloud shadow, water
40	No	No	No	Yes	No	Yes	Adjacent to cloud, water
48	No	No	No	No	Yes	Yes	Snow, water
52	No	No	Yes	No	Yes	Yes	Cloud shadow, snow, water
56	No	No	No	Yes	Yes	Yes	Adjacent to cloud, snow, water

Table 6-5 Landsat 4-7 Pixel Quality Attributes (pixel_qa) Bit Index

Bit	Bit Value	Cumulative Sum	Attribute
0	1	1	Fill
1	2	3	Clear
2	4	7	Water
3	8	15	Cloud shadow
4	16	31	Snow
5	32	63	Cloud
6	64	127	Cloud Confidence 00 = None 01 = Low 10 = Medium 11 = High
7	128	255	
8	256	511	Unused
9	512	1023	Unused
10	1024	2047	Unused
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65553	Unused

Table 6-6 Landsat 4-7 Pixel Quality Attributes (pixel_qa) Values

Attribute	Pixel Value
Fill	1
Clear	66, 130
Water	68, 132
Cloud shadow	72, 136

Snow/ice	80, 112, 144, 176
Cloud	96, 112, 160, 176, 224
Low confidence cloud	66, 68, 72, 80, 96, 112
Medium confidence cloud	130, 132, 136, 144, 160, 176
High confidence cloud	224

Table 6-7 Landsat 4-7 Pixel Quality Attributes (pixel_qa) Bit Values

Pixel Value	Fill	Clear	Water	Cloud Shadow	Snow	Cloud	Cloud Confidence	Pixel Description
1	Yes	No	No	No	No	No	None	Fill pixel
66	No	Yes	No	No	No	No	Low	Clear, low-confidence cloud
68	No	No	Yes	No	No	No	Low	Water, low-confidence cloud
72	No	No	No	Yes	No	No	Low	Cloud shadow, low-confidence cloud
80	No	No	No	No	Yes	No	Low	Snow/ice, low-confidence cloud
96	No	No	No	No	No	Yes	Low	Cloud, low-confidence cloud
112	No	No	No	No	Yes	Yes	Low	Snow/ice, cloud, low-confidence cloud
130	No	Yes	No	No	No	No	Medium	Clear, medium-confidence cloud
132	No	No	Yes	No	No	No	Medium	Water, medium-confidence cloud
136	No	No	No	Yes	No	No	Medium	Cloud shadow, medium-confidence cloud
144	No	No	No	No	Yes	No	Medium	Snow/ice, medium-confidence cloud
160	No	No	No	No	No	Yes	Medium	Cloud, medium-confidence cloud
176	No	No	No	No	Yes	Yes	Medium	Snow/ice, cloud, medium-confidence cloud
224	No	No	No	No	No	Yes	High	High confidence cloud

6.1.1 Radiometric Saturation Band

The Radiometric Saturation Quality (radsat_qa) band is a bit packed representation of which sensor bands were saturated during data capture, yielding unusable data. The table below displays the interpretation of possible pixel values expected in the radsat_qa band after its bits are unpacked. For example, a pixel value of 8 indicates that Band 3 is saturated. **Table 6-8** describes the bit assignments for the radsat_qa band.

Table 6-8 Landsat 4-7 Radiometric Saturation Quality Attributes (radsat_qa) Bit Index

Bit	Bit Value	Cumulative Sum	Description
Bits are numbered from right to left (bit 1 = LSB, bit 7 = MSB)			
0	1	1	Data Fill Flag (0 valid data, 1 invalid data)
1	2	3	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	4	7	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	8	15	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	16	31	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	32	63	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	64	127	Band 6 Data Saturation Flag (0 valid data, 1 saturated data)
7	128	255	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)
8	N/A	N/A	Not used

6.1.2 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 **Table 12-0-1 Default File Characteristics.**

6.1.3 Surface Reflectance Special Notes

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 Level-2 Pixel Quality Assurance band (pixel_qa; **Table 6-5**) is populated using information from the Level-1 Quality Assurance band, specifically Cloud Confidence, Cloud Shadow and Snow/Ice flags derived from the CFMask algorithm. Unlike the legacy CFMask band, the Clouds are not dilated, and there is no water information provided. In order to support higher-level products using Level-2 as input, certain QA values are generated or recalculated (Water, Cloud, Snow), specifically to include cloud dilation.

Note: the legacy CFMask and CFMask confidence bands are still orderable through the ESPA interface as a separate option (discontinued **02 June 2017**), though the same information is available in the default pixel_qa band.

The information with the pixel_qa band is likely to present more accurate results than the QA bands provided with Surface Reflectance (sr_cloud_qa). The algorithm underlying bqa and pixel_qa bands, CFMask, 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).

6.2.1 CFMask Algorithm Known Issues

1. The cloud indicators in the sr_cloud_qa and CFMask algorithms 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 per-pixel solar angles derived from band 4 (closest to center of focal plane.) 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**).

The pixel_qa and radsat_qa bands are delivered with all TOA Reflectance products.

Table 6-9 lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Reflectance product bands.

Table 6-9 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_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 –255	0 –255	1 (bit 0)	NA	NA

sceneid_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1-32768	1-32768	1 (bit 0)	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	0 – 9000	-32768	NA	0.0100
sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	0 - 9000	-32768	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100

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 6-10 lists the data type, units, value range, fill value, saturation value, and scale factor for the Brightness Temperature product bands.

Table 6-10 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_bt_band6	Band 6 Reflectance	INT16	Brightness Temperature (Kelvin)	-100 – 16000	0 – 10000	-9999	20000	0.1
sceneid_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 – 255	0 – 255	1 (bit 0)	NA	NA
sceneid_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1-32768	1-32768	1 (bit 0)	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	0 – 9000	-32768	NA	0.0100
sensor_zenith_band4	Sensor Azimuth	INT16	Degrees	-32768 - 32767	0 - 9000	-32768	NA	0.0100

	Angles Band 4							
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100

6.3.3 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 Radiometric Saturation quality band "_radsat_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/landsat-surface-reflectance-high-level-data-products.

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 Bidirectional Reflectance Distribution Function (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 Ancillary Data

The atmosphere between the satellite and the Earth's surface is composed of different gases that potentially absorb and/or scatter both incoming and reflected sunlight. These gases are primarily aerosols, water vapor and ozone, all of which are partially modulated by the local air temperature. The Landsat instruments do not contain on-board sensors to measure these conditions, so this information is obtained through other observations, known as ancillary data. For LEDAPS, ancillary data are gathered either from other satellite based observations, or an aggregation of ground and satellite data, known as reanalysis. Both spatial and temporal interpolations are performed to fit this ancillary data within the ground area imaged and time of the Landsat image acquisition. This information is derived from multiple data sources, which have their own unique properties, as described in **Table 8-1**.

Note that LEDAPS does not use ancillary data for aerosols, but instead uses the dark, dense vegetation (DDV) method using Landsat's multispectral information. Please see *Masek et al., 2006* (**Section 12 References**) for more information pertaining to DDV's use and relative performance in LEDAPS.

Missing data range(s) are periodically updated in this guide; the most up-to-date information regarding data gaps is in the "Caveats and Constraints" section of https://landsat.usgs.gov/landsat-surface-reflectance-high-level-data-products.

Table 8-1 Ancillary Data for LEDAPS

NCEP National Centers For Environmental Prediction, TOMS Total Ozone Mapping Spectrometer, NCAR National Center for Atmospheric Research, OMI Ozone Monitoring Instrument

Data	Product	Source	Version	Instrument	Grid Resolution	Date Begin	Date End	Backup	Backup Begin	Backup End	Missing Range(s)	Additional Missing Data & Date(s)
Ozone	TOMS	ftp://toms.gsfc.nasa.gov	N/A	NIMBUS	1.25° x 1.0°	1/1/1978	12/31/1990	N/A	N/A	N/A	N/A	N/A
				METEOR3		1/1/1991	11/24/1994	NIMBUS	1/1/1991	12/31/1993	11/25/1994 - 7/31/1996**	N/A
				EARTHPROBE		8/1/1996	12/31/2003	N/A	N/A	N/A		ftp://toms.gsfc.nasa.gov/pub/eptoms/earthprobe_data_coverage.txt **
				OMI	1.0° x 1.0°	1/1/2004	Present	EARTHPROBE	1/1/2004	12/31/2005	5/30/2016 - 6/12/2016*; 3/12/2017 – 3/17/2017*	N/A
Air Temperature Surface Pressure Precipitable Water	NCEP	ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis/surface	NCEP/NCAR Reanalysis 1	N/A	2.5° x 2.5°	1/1/1948	Present	N/A	N/A	N/A	N/A	N/A

* Indicates surface reflectance not processed for these date(s).
** Indicates missing data are interpolated by surface reflectance code.

Section 9 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 10 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 11 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 12 References

Chander, G., Markham, B.L., and Helder, D.L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sensing of Environment 113:893-903.http://dx.doi.org/10.1016/j.rse.2009.01.007.

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Appendix A Default File Characteristics

Table 12-0-1 Default File Characteristics

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

NOTE: A Landsat 7 ETM+ product ID 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	LE07_L1TP_039037_20080728_20161028_01_T1_B*.tif
Source Panchromatic Band	223,621,278	LE07_L1TP_039037_20080728_20161028_01_T1_B8.tif
Source Ground Control Point	10,919	LE07_L1TP_039037_20080728_20161028_01_T1_GCP.txt
Source Metadata	65,535	LE07_L1TP_039037_20080728_20161028_01_T1_MTL.txt
TOA Reflectance Bands (7)	119,336,075	LE07_L1TP_039037_20080728_20161028_01_T1_toa_*.tif
TOA Reflectance Quality Band	59,697,384	LE07_L1TP_039037_20080728_20161028_01_T1_toa_qa.tif
TOA Brightness Temperature Quality Band	59,697,384	LE07_L1TP_039037_20080728_20161028_01_T1_toa_band6_qa.tif
Surface Reflectance Bands (6)	119,336,075	LE07_L1TP_039037_20080728_20161028_01_T1_sr_*.tif
Surface Reflectance Atmospheric Opacity Band	119,336,075	LE07_L1TP_039037_20080728_20161028_01_T1_sr_atmos_opacity.tif
Surface Reflectance Quality Bands (7)	56,697,384	LE07_L1TP_039037_20080728_20161028_01_T1_sr_*.tif
CFMask Band	59,697,386	LE07_L1TP_039037_20080728_20161028_01_T1_sr_cfmask.tif
CFMask Cloud Confidence Band	59,697,386	LE07_L1TP_039037_20080728_20161028_01_T1_sr_cfmask_conf.tif
Metadata	25,556	LE07_L1TP_039037_20080728_20161028_01_T1.xml

Appendix B Metadata Fields

Example of global XML metadata:

```
< global_metadata>
        <data_provider>USGS/EROS</data_provider>
        <satellite>LANDSAT_5</satellite>
        <instrument>TM</instrument>
        <acquisition_date>2011-09-29</acquisition_date>
        <scene_center_time>18:12:35.0510690Z</scene_center_time>
        <level1_production_date>2016-10-28T17:03:51Z</level1_production_date>
        <solar_angles units="degrees" azimuth="157.466019" zenith="53.676094"/>
        <earth_sun_distance>1.001729</earth_sun_distance>
        <wrs row="26" path="41" system="2"/>
        <product_id>LT05_L1TP_041026_20110929_20161028_01_T1</product_id>
        <lpgs_metadata_file>LT05_L1TP_041026_20110929_20161028_01_T1_MTL.txt</lpgs_metadat
        a_file>
        <corner longitude="-115.345280" latitude="49.823780" location="UL"/>
        <corner longitude="-111.849170" latitude="47.872700" location="LR"/>
        <bounding_coordinates>
                <west>-115.345498</west>
                <east>-111.848971</east>
                <north>49.902051</north>
                <south>47.799768</south>
        </bounding_coordinates>
        <projection_information units="meters" datum="WGS84" projection="UTM">
                <corner_point location="UL" y="5528100.000000" x="187500.000000"/>
                <corner_point location="LR" y="5302500.000000" x="436500.000000"/>
                <grid_origin>CENTER</grid_origin>
                <utm_proj_params>
                        <zone_code>12</zone_code>
                </utm_proj_params>
        </projection_information>
        <orientation_angle>0.000000</orientation_angle>
</global_metadata>
```

Example of per-band XML metadata:

```
   <bands>
      <band fill_value="-9999" nsamps="7971" nlines="7011" data_type="INT16" category="image"
name="toa_band1" product="toa_refl" add_offset="0.000000" scale_factor="0.000100"
saturate_value="20000" source="level1">
        <short_name>LE7REF</short_name>
        <long_name>band 1 TOA reflectance</long_name>
        <file_name>LE07_L1TP_039037_20080728_20161028_01_T1_toa_band1.tif</file_name>
        <pixel_size units="meters" y="30" x="30"/>
        <resample_method>none</resample_method>
        <data_units>reflectance</data_units>
        <valid_range max="16000.000000" min="-100.000000"/>
        <app_version>LEDAPS_3.1.0</app_version>
        <production_date>2017-02-01T17:01:40Z</production_date>
</band>
```

Appendix C Acronyms

Acronym	Description
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ANG	Angle Coefficients File
BRDF	Bidirectional Reflectance Distribution Function
C1	Landsat Collection 1
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 Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NBR2	Normalized Burn Ratio 2
NC	NetCDF File Format
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NLAPS	National Landsat Archive Processing System

OMI	Ozone Monitoring Instrument
PS	Polar Stereographic
QA	Quality Assurance
RT	Real-Time
SAVI	Soil Adjusted Vegetation Index
SLC	Scan Line Corrector
SR	Surface Reflectance
T1	Tier 1
T2	Tier 2
TM	Thematic Mapper
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
UINT	Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
xml	Extensible Markup Language