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LANDSAT 4-7
SURFACE REFLECTANCE (LEDAPS)
PRODUCT GUIDE

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USGS
science for a changing world

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SURFACE REFLECTANCE (LEDAPS)
PRODUCT GUIDE

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Executive Summary

This document describes relevant characteristics of the Landsat 4-5 and Landsat 7 Surface Reflectance (SR), Top of Atmosphere (TOA) Reflectance, and TOA Brightness Temperature (BT) Science Products to facilitate their use in the land remote sensing community.

SR, TOA Reflectance, and TOA BT are derived from Landsat 4, 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data using Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS).

Information about Surface Reflectance processing of Landsat 8 data can be found in the Landsat 8 Surface Reflectance Code (LaSRC) Product Guide.

Other processing options, such as spectral indices, format conversion, spatial subset, and/or coordinate system reprojection are described in other product guides and web pages.

Document History

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Section 1 Introduction

1.1 Background

Landsat satellite data have been produced, archived, and distributed by the U.S. Geological Survey (USGS) since 1972. Users rely upon these data for conducting historical studies of land surface change but have shouldered the burden of post-production processing to create applications-ready data sets. To alleviate this burden on the user, and in compliance with guidelines established through the Global Climate Observing System, USGS has initiated an effort to produce a collection of Landsat Science Products to support land surface change studies. These products include terrestrial variables such as Surface Reflectance (SR), Provisional Surface Temperature (ST), Dynamic Surface Water Extent (DSWE), Burned Area (BA), and Fractional Snow Covered Area (fSCA) that are suitable for monitoring, assessing, and predicting land surface change over time.

Landsat 4-7 SR data products are 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). LEDAPS applies atmospheric correction routines to Landsat 4-5 Thematic Mapper (TM) or Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level 1 data, similar to routines derived from Moderate Resolution Imaging Spectroradiometer (MODIS). LEDAPS generates Top of Atmosphere (TOA) Reflectance and TOA Brightness Temperature (BT) using the calibration parameters from the metadata. Auxiliary data such as water vapor, ozone, geopotential height, Aerosol Optical Thickness (AOT), and digital elevation are then input with Landsat TOA Reflectance and TOA BT to Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer model to generate Surface Reflectance. The result is delivered as the Landsat Surface Reflectance data product.

Visit the LEDAPS Release Notes for more information pertaining to algorithm updates.

Figure 1-1. Example of LEDAPS Atmospheric Correction: Left, Top of Atmosphere Reflectance Image; Right, Surface Reflectance Image

Figure 1-1 shows a comparison of a TOA Reflectance composite (bands 3,2,1), and a Surface Reflectance composite image of the San Francisco Bay, using data acquired by Landsat 7 ETM+ (Path 44 Row 34) on July 7, 1999. Both images are linearly scaled from $\rho = 0.0$ to 0.15.

The LEDAPS algorithm is distinctly different from the algorithm used by USGS to process Landsat 8 Level-1 products to Surface Reflectance, known as the Landsat 8 Surface Reflectance Code (LaSRC). Details of these differences are described in Table 1-1.

Parameter	Landsat 4–5, 7 (LEDAPS)	Landsat 8 (LaSRC)
(Original) research grant	NASA GSFC, MEaSUREs (Masek)	NASA GSFC
Global coverage	Yes	Yes
TOA Reflectance	Visible (Bands 1–5,7)	Visible (Bands 1–7, 9)
TOA Brightness Temperature	Thermal (Band 6)	Thermal (Bands 10 & 11 TIRS)
SR	Visible (1–5, 7) bands	Visible (Bands 1–7) (OLI only)
Thermal bands used in SR processing?	Yes (Brightness temperature Band 6 is used in cloud estimation)	No
Radiative transfer model	6S	Internal algorithm
Thermal correction level	TOA only	TOA only
Thermal band units	Kelvin	Kelvin
Pressure	NCEP Grid	Surface pressure is calculated internally based on the elevation
Water vapor	NCEP Grid	MODIS CMA
Air temperature	NCEP Grid	MODIS CMA
DEM	GTOPO5	GTOPO5
Ozone	OMI/TOMS	MODIS CMG Coarse resolution ozone
AOT	Correlation between chlorophyll absorption and bound water absorption of scene	MODIS CMA
Sun angle	Scene center from input metadata	Scene center from input metadata
View zenith angle	From input metadata	Hard-coded to 0
Undesirable zenith angle correction	SR not processed when solar zenith angle > 76 degrees	SR not processed when solar zenith angle > 76 degrees
Pan band processed?	No	No
XML metadata?	Yes	Yes
Brightness temperature calculated	Yes (Band 6 TM/ETM+)	Yes (Bands 10 & 11 TIRS)
Cloud mask	Internal algorithm; CFmask	Internal algorithm; CFmask
Data format	INT16	INT16
Fill values	-9999	-9999
QA bands	Cloud Adjacent cloud Cloud shadow DDV Fill Land water Snow Atmospheric opacity	Cloud Adjacent cloud Cloud shadow Aerosols Cirrus Aerosol Interpolation Flag

6S = Second Simulation of a Satellite Signal in the Solar Spectrum, AOT = Aerosol Optical Thickness, CFMask = C Version of Function Of Mask, CMA = Climate Modeling Grid - Aerosol, CMG = Climate Modeling Grid, DDV = Dark Dense Vegetation, DEM = Digital Elevation Model, ETM+ = Enhanced Thematic Mapper Plus, GSFC = Goddard Space Flight Center, INT = Integer, LaSRC = Landsat Surface Reflectance Code, LEDAPS = Landsat Ecosystem Disturbance Adaptive Processing System, MEaSUREs = Making Earth Science Data Records for Use in Research Environments, MODIS = Moderate Resolution Imaging Spectroradiometer, NA = Not Applicable, NASA = National Aeronautics and Space Administration, NCEP = National Centers for Environmental Prediction, OLI = Operational Land Imager, OMI = Ozone Monitoring Instrument, QA = Quality Assessment, SR = Surface Reflectance, TIRS = Thermal Infrared Sensor, TM = Thematic Mapper, TOA = Top of Atmosphere Reflectance, TOMS = Total Ozone Mapping Spectrometer, XML = Extensible Markup Language

Table 1-1. Differences Between Landsat 4–7 and Landsat 8 Surface Reflectance Algorithms

1.2 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 provides an explanation of caveats and constraints
- Section 3 provides details on product access
- Section 4 provides details on product packaging
- Section 5 provides an explanation of product characteristics
- Section 6 provides details on detecting product uncertainty
- Section 7 provides auxiliary data
- Section 8 provides document citation information
- Section 9 provides document acknowledgements
- Section 10 provides User Services contact information
- Appendix A provides glossary terms and definitions
- Appendix B provides a list of metadata fields
- Appendix C provides a list of acronyms
- The References section contains a list of reference documents

Section 2 Caveats and Constraints

1. Surface Reflectance can be processed on Landsat scenes within 3-5 days of acquisition.
2. The following date ranges apply to the availability of the Landsat archive for Surface Reflectance processing, with the exceptions noted in #3 below:
   - 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. Landsat 4-5 TM data cannot be processed to Surface Reflectance between specific dates because some auxiliary data required for Surface Reflectance processing are missing. See Section 7 for more information. The most up-to-date information regarding data gaps is in the “Caveats and Constraints” section of https://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance.
4. 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 Level 1 Metadata (MTL) file was used. This will impact the 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.
5. Landsat 7 ETM+ Real-Time (RT) Collection 1 data can be processed to Surface Reflectance once the auxiliary 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. 26 days after acquisition) will likely be different than the Real-Time data. See https://www.usgs.gov/land-resources/nli/landsat/landsat-collection-1 for more information on the differences between RT and T1/T2 data sets.
6. Landsat 7 ETM+ inputs are not gap-filled in Surface Reflectance production, and gapped areas are not processed for Surface Reflectance. See https://www.usgs.gov/land-resources/nli/landsat/landsat-7 for information on Landsat 7 Scan Line Corrector (SLC)-off data products.
7. SR is not run on scenes with a solar zenith angle of greater than 76º. The primary physical issues with retrieving SR from high solar zenith angles (low sun angle) include:

- Solar elevation varies more near the poles [1], especially when relying upon sun-synchronous observations.

- Lower solar elevations at high latitudes results in longer atmospheric paths (i.e., more scattering) [1].
- The degree of uncertainty in SR retrieval greatly increases, from being negligible to highly inaccurate, at solar zenith angle > 76 degrees.

  References: [1] Campbell, J. W., & Aarup, T. (1989). Photosynthetically available radiation at high latitudes. Limnology and Oceanography, 34(8), 1490-1499. http://dx.doi.org/10.4319/lo.1989.34.8.1490.

8. For reasons mentioned above, users are cautioned against processing data acquired over high latitudes (> 65º) to Surface Reflectance.
9. There are additional adverse conditions that can affect the efficacy of Landsat SR retrievals, such as:
   - 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
10. Refer to the Quality Assessment (QA) bands for pixel-level condition and validity flags. For cloud masking, users are advised to use the cloud bits populated in the Level-1 QA Band.
11. 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.
12. Landsat 7 Band 8 (panchromatic band) is not processed to Top of Atmosphere or Surface Reflectance.

Section 3 Product Access

Processing requests for Landsat 4-5 and Landsat 7 Surface Reflectance data products can be submitted through EarthExplorer, under the “Data Sets” tab > “Landsat” > “Landsat Collection 1 Level-2 (On-Demand)”, then “Landsat 7 ETM+ C1 Level-2” and “Landsat 4-5 TM C1 Level-2”.

The USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) On-demand interface (https://espa.cr.usgs.gov/) offers Landsat 4-5 TM, and Landsat 7 ETM+ Surface Reflectance, in addition to Input Level 1 Products and Metadata, TOA Reflectance, TOA Brightness Temperature, NDVI, NDMI, NBR, NBR2, SAVI, MSAVI, and EVI data products. Services such as reprojection, spatial subsetting, and pixel resizing are also available. Additional information about ESPA’s spectral indices and service processing options for Landsat 4–8 can be found on the Landsat Surface Reflectance Spectral Indices web page and in the ESPA On-Demand Interface User Guide.

Section 4 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 Level 1 product identifier (productID) appended with the suffix "_sr_" followed by a band designation to denote the Surface Reflectance transformation.

Following are the components of a typical Collection 1 file:

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 Level 1 processing
mm	Month of Level 1 processing
dd	Day of Level 1 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 5 Product Characteristics

The Landsat Level 1 Products are described on https://www.usgs.gov/land-resources/nli/landsat/landsat-level-1-processing-details. The characteristics of Level 2 science products such as TOA Reflectance, TOA Brightness Temperature, and Surface Reflectance are detailed in the following sections.

5.1 Surface Reflectance Specifications

The Landsat Surface Reflectance 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), Network Common Data Form (.NetCDF) or Exelis Visual Information Solutions (ENVI) binary (.img) 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 are delivered in files named with the original productID and appended with "_sr_" followed by a band designation. All packages include Extensible Markup Language (xml)-based metadata.

The Surface Reflectance bands are delivered in separate condition-specific files, with the exception of the Cloud QA band (sr_cloud_qa), which is delivered in a single bit-packed layer. Table 5-1 lists the specifications for the bands included in a Surface Reflectance data file. Table 5-2 describes the bit assignments within the sr_cloud_qa band. The sr_cloud_qa bit values are given in Table 5-3, and shown in greater detail in Table 5-4. Table 5-5 describes the bit assignments for the pixel_qa band. The pixel_qa bit values are given in Table 5-6, and shown in greater detail in Table 5-7.

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
ProductID_sr_band1	Band 1	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band2	Band 2	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band3	Band 3	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band4	Band 4	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band5	Band 5	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band7	Band 7	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_atmos_opacity[1]	Atmospheric Opacity	INT16	Unitless	-2000 – 16000	0 - 10000	-9999	NA	0.0010
ProductID_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1- 32768	1- 32768	1 (bit 0)	NA	NA
ProductID_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 –255	0 –255	1 (bit 0)	NA	NA
ProductID_sr_cloud_qa	Surface Reflectance Cloud QA	UINT8	Bit index	0 - 255	0 - 63	NA	NA	NA
ProductID_MTL.txt	Level-1 Metadata file	NA	NA	NA	NA	NA	NA	NA
ProductID_ANG.txt	Level-1 Angle Coefficient file	NA	NA	NA	NA	NA	NA	NA

INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, QA = Quality Assessment, DDV = Dark Dense Vegetation, CFMask = C version of Function of Mask, NA = not applicable

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

Table 5-1. Surface Reflectance 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 5-2. Surface Reflectance Cloud Quality Assessment (sr_cloud_qa) Bit Index

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 5-3. Surface Reflectance Cloud Quality Assessment (sr_cloud_qa) 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 5-4. Surface Reflectance Cloud Quality Assessment (sr_cloud_qa) Value Interpretations

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

Bit	Bit Value	Cumulative Sum	Attribute
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	32768	65535	Unused

Table 5-5. Landsat 4-7 Pixel Quality Assessment (pixel_qa) Bit Index

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 5-6. Landsat 4-7 Pixel Quality Assessment (pixel_qa) 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

Table 5-7. Landsat 4-7 Pixel Quality Assessment (pixel_qa) Value Interpretations*

*The QA band is validated against the confidence levels, not the clear/cloud bits, the confidence level bits are a truer measure of the cloud extent in the imagery. It is recommended to either use the clear/cloud bits OR the confidence levels, but not both.

**96 (cloud + low confidence cloud) is an artifact of the dilation process: after marking high confidence clouds, the clouds are then dilated by a few pixels and all of the pixels at the edge of the clouds are marked as cloud, however the confidence values are not changed, meaning it is possible to get low confidence pixels at the edge of a cloud which are marked as cloudy by the dilation.

5.1.1 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. Table 5-8 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 5-8 describes the bit assignments for the radsat_qa band.

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
LSB = Least Significant Bit, MSB = Most Significant Bit			

Table 5-8. Landsat 4-7 Radiometric Saturation Quality Assessment (radsat_qa) Bit Index

5.1.2 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 Appendix A.

5.1.3 Angle Coefficient Files

Each Surface Reflectance product contains an angle coefficient file ("_ANG.txt"). This file consists of angle coefficients that can be used as input into a set of tools to generate per-pixel solar and sensor azimuth and zenith angle values. For more details on Angle Coefficient Files see https://www.usgs.gov/land-resources/nli/landsat/solar-illumination-and-sensor-viewing-angle-coefficient-files.

5.1.4 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.

5.2 Cloud and Cloud Shadow Specifications

The Level 2 Pixel Quality Assessment band (pixel_qa; Table 5-5) is populated using information from the Level 1 Quality Assessment 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 science products using Level 2 as input, certain QA values are generated or recalculated (water, cloud, snow), specifically to include cloud dilation.

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).

5.2.1 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 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 chance of being omitted by CFMask.

5.3 Top of Atmosphere Reflectance (TOA) & TOA Brightness Temperature Specifications

5.3.1 Top of Atmosphere Reflectance – Bands 1-5, 7 Specifications

Calibration coefficients are 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 TOA Brightness Temperature (Section 5.3.2).

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

Table 5-9 lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Reflectance product bands.

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
ProductID_toa_band1	Band 1 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_toa_band2	Band 2 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_toa_band3	Band 3 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_toa_band4	Band 4 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_toa_band5	Band 5 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_toa_band7	Band 7 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
ProductID_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 –255	0 –255	1 (bit 0)	NA	NA
ProductID_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1- 32768	1- 32768	1 (bit 0)	NA	NA
ProductID_solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
ProductID_solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	0 – 9000	-32768	NA	0.0100
ProductID_sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	0 - 9000	-32768	NA	0.0100
ProductID_sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, TOA = top of atmosphere, QA = quality Assessment, NA = not applicable								

Table 5-9. Top of Atmosphere Reflectance – Bands 1-5, 7 Specifications

5.3.2 Top of Atmosphere Brightness Temperature – Band 6 Specifications

Band 6 TOA Brightness Temperature is derived from TOA radiance and two thermal constants, as described on https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product. 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 TOA Reflectance, but it is specific to TOA Brightness Temperature processing.

Table 5-10 lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Brightness Temperature product bands.

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
ProductID_bt_band6	Band 6 Reflectance	INT16	TOA Brightness Temperature (Kelvin)	-100 – 16000	0 – 10000	-9999	20000	0.1
ProductID_radsat_qa	Radiometric Saturation QA	UINT8	Bit Index	0 – 255	0 – 255	1 (bit 0)	NA	NA
ProductID_pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	1-32768	1-32768	1 (bit 0)	NA	NA
INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, TOA = top of atmosphere, QA = Quality Assessment, NA = not applicable								

Table 5-10. Top of Atmosphere Brightness Temperature – Band 6 Specifications

5.3.3 TOA Reflectance Special Notes

1. Only the low gain thermal band (Band 6-1) is used when processing ETM+ data to Top of Atmosphere 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 QA Tools. Information and tool download are available at https://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance.

Section 6 Initial Characterization of Product Uncertainty

Several studies have been performed in regard 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 Landsat TM and ETM+ data. Maiersperger et al. (2013) compared LEDAPS' Aerosol Optical Thickness (AOT) estimates with AERONET AOT, field spectrometer data, and the MODIS Surface Reflectance product over the conterminous United States. Claverie et al. (2015) used a similar methodology but added 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 expanded the spatial coverage to the entire world.

Claverie et al. (2015) performed 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, and
U = uncertainty, as the squared sum of the mean bias and standard deviation.

For the resulting APU metrics, Claverie et al. (2015) established 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 showed 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 was no significant inter-annual variation between Landsat sensors. Geographic uncertainty is greatest in high latitude areas and over tropical evergreen forests.

Section 7 Auxiliary 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 auxiliary data. For LEDAPS, auxiliary data are gathered either from other satellite-based observations or from an aggregation of ground and satellite data, known as reanalysis. Both spatial and temporal interpolations are performed to fit this auxiliary 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 7-1.

Note that LEDAPS does not use auxiliary data for aerosols, but instead uses the Dark Dense Vegetation (DDV) method using Landsat's multispectral information. Please see *Masek et al., 2006* (see 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://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance.

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	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
Surface Pressure												
Precipitable Water												

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

Table 7-1. Auxiliary Data for LEDAPS

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

Section 8 Citation Information

There are no restrictions on the use of these Landsat Science Products. It is not a requirement of data use, but the following citation may be used in publication or presentation materials 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.

Reprints or citations of papers or oral presentations based on USGS data are welcome to help the USGS stay informed of how data are being used. These can be sent to the User Services address included in this guide.

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 Science Products and associated interfaces are supported by User Services staff at the USGS EROS. Any questions or comments regarding Landsat Science Products or interfaces can be directed to USGS EROS Customer Services:

Email: custserv@usgs.gov

Phone: 1-605-594-6151
Phone (toll-free): 1-800-252-4547

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.

Appendix A Default File Characteristics

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 (Kbytes)	Example File Name
Source Level-1 Bands (9)	54,631	LE07_L1TP_039037_20080728_20170314_01_T1_b*.tif
Source Level-1 Panchromatic Band	218,381	LE07_L1TP_039037_20080728_20170314_01_T1_b8.tif
Source Level-1 Metadata	9	LE07_L1TP_039037_20080728_20170314_01_T1_MTL.txt
Level-1 QA Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_bqa.tif
Angle Band Coefficients	43	LE07_L1TP_039037_20080728_20170314_01_T1_ANG.txt
TOA Reflectance Bands (6)	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_toa_*.tif
TOA Brightness Temperature Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_bt_band6.tif
Surface Reflectance Bands (6)	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_sr_*.tif
Level-2 Pixel QA	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_pixel_qa.tif
Surface Reflectance Atmospheric Opacity Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_sr_atmos_opacity.tif
Surface Reflectance Cloud Quality Assessment Band	54,631	LE07_L1TP_039037_20080728_20170314_01_T1_sr_cloud_qa.tif
Sensor Azimuth Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_sensor_azimuth_band4.tif
Sensor Zenith Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_sensor_zenith_band4.tif
Solar Azimuth Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_solar_azimuth_band4.tif
Solar Zenith Band	109,206	LE07_L1TP_039037_20080728_20170314_01_T1_solar_zenith_band4.tif
Radiometric Saturation Band	54,631	LE07_L1TP_039037_20080728_20170314_01_T1_radsat_qa.tif
Level-2 Metadata	28	LE07_L1TP_039037_20080728_20170314_01_T1.xml

Table A-1. Collection 1 Default File Characteristics

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

6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ACCESS	Advancing Collaborative Connections for Earth System Science
ANG	Angle Coefficients File
AOT	Aerosol Optical Thickness
BA	Burned Area
BRDF	Bidirectional Reflectance Distribution Function
BT	Brightness Temperature
C1	Landsat Collection 1
CDR	Climate Data Record
CFMask	C version of Function of Mask (USGS EROS)
CMA	Climate Modeling Grid - Aerosol
CMG	Climate Modeling Grid
DDV	Dark Dense Vegetation
DEM	Digital Elevation Model
DIR	Directory
DSWE	Dynamic Surface Water Extent
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
fSCA	Fractional Snow Covered Area
Fmask	Function of Mask (Boston University)
GeoTIFF	Geographic Tagged Image File Format
GSFC	Goddard Space Flight Center
HDF-EOS-2	Hierarchical Data Format – Earth Observing System (version 2)
HDR	Header
INT	Signed Integer
INT16	16-bit Signed Integer
L1GS	Level 1 Systemic
L1GT	Level 1 Systematic Terrain
L1TP	Level 1 Terrain Precision
LaSRC	Landsat 8 Surface Reflectance Code
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
MTL	Level 1 Metadata
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NBR2	Normalized Burn Ratio 2
NetCDF	Network Common Data Form
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
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
pixel_qa	Pixel Quality Assessment
PS	Polar Stereographic
QA	Quality Assessment
radsat_qa	Radiometric Saturation Quality
RT	Real-Time
SAVI	Soil Adjusted Vegetation Index
SLC	Scan Line Corrector
SR	Surface Reflectance
ST	Provisional Surface Temperature
T1	Tier 1
T2	Tier 2
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
UINT	Unsigned Integer
UINT8	8-bit Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
xml	Extensible Markup Language
WRS-2	Worldwide Reference System-2

Appendix D Document Change 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.

Document Version	Publication Date	Change Description
		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 "Initial 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.

Document Version	Publication Date	Change Description
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 assessment (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.

Document Version	Publication Date	Change Description
Version 7.8	06/07/2017	Corrected typographical errors.
Version 7.9	07/05/2017	Corrected typographical errors. Removed item #4 from “CFMask Algorithm Known Issues” since band clipping prevents this from occurring.
Version 8.0	10/05/2017	Replaced the terms high level and higher level products with science data products. Corrected various typographical errors.
Version 8.1	12/04/2017	Added “top of atmosphere” before “brightness temperature” to clarify that BT products are not atmospherically corrected.
Version 8.2	02/15/2018	Clarified use of MODIS routines in other ancillary data in Section 1.
Version 8.3	03/30/2018	Correct Product Characteristics table 6.1; remove Solar/Sensor Azimuth/Zenith band information; Add info/reference to L-1 ANG.txt and MTL.txt files that are delivered with SR product. Also added asterisks to Table 6.7 regarding cloud bits and confidence bits
Version 1.0 LSDS-1370	11/08/2018	Updated the Table A-1 for default file characteristics; Added/removed the products based on current ESPA outputs (e.g. removed solar/sensor angle bands form TOA BT outputs list, removed CFMask and GCP bands since they are not being delivered currently); Changed approximate latency of T1/T2 from 2 weeks to 26 days; Corrected bit value and cumulative sum for bit 15 in Table 6-5
Version 2.0 LSDS-1370	05/02/2019	Updated Landsat website URL references; Removed the Product Options section since it was mostly about ESPA interface; Corrected the source of DEM

References

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