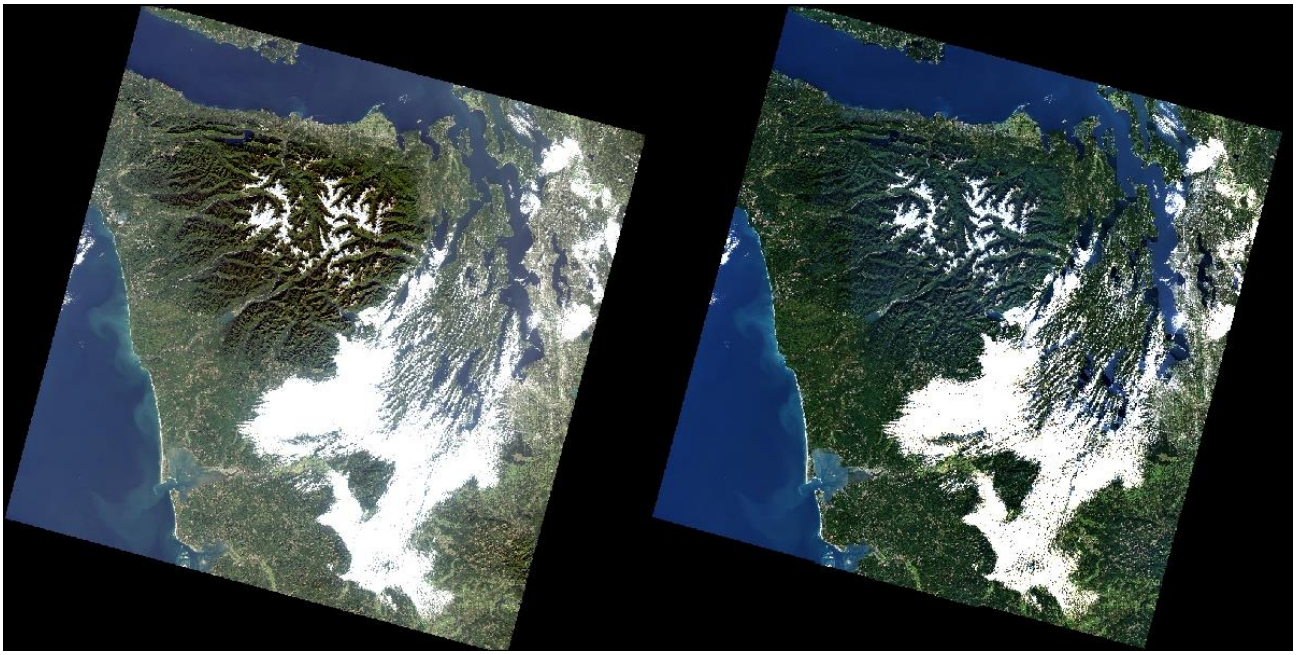
Department of the Interior
U.S. Geological Survey

PRODUCT GUIDE

PROVISIONAL LANDSAT 8 SURFACE REFLECTANCE CODE (LASRC) PRODUCT



Version 3.5

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USGS
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Executive Summary

This document describes relevant characteristics of the Provisional Landsat 8 Surface Reflectance Code (LaSRC) Climate Data Record to facilitate its use in the land remote sensing community.

This document describes Top of Atmosphere Reflectance and Brightness Temperature derived from Landsat 8 Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), respectively. Surface Reflectance can be derived only for OLI data. Other processing options, such as spectral indices, format conversion, spatial subset, and/or coordinate system reprojection are described in other product guides.

Document History

Document Version	Publication Date	Change Description
Version 1.0	12/18/2014	Initial Draft
Version 1.1	01/09/2015	Addition of “Known Issues” section.
Version 1.2	03/04/2015	Update to “Known Issues” section with additional information concerning improvements to aerosol retrieval. Update to aerosol bit value descriptions in Table 7-C. Corrected error in Bands 10-11 Brightness Temperature table.
Version 1.3	05/13/2015	Update to “Known Issues” section with additional information concerning improvements to land/water masking. Addition of provisional CFmask cloud confidence band.
Version 1.4	06/08/2015	Clarification of Bands 10-11 Brightness Temperature output.
Version 1.5	07/16/2015	Fixed broken reference.
Version 1.6	09/02/2015	Removed incorrect “_bt” file naming convention from Brightness Temperature description.
Version 1.7	9/21/2015	Added details to caveat describing high latitudes.
Version 1.8	12/01/2015	Added details about TIRS zero-fill data. Added changes to location of SR products on EE. Corrected minor typos and revised the formatting of citations.
Version 1.9	02/10/2016	Edited instances where “shadow” should be “cloud shadow” (in reference to CFmask).
Version 2.0	03/01/2016	Fixed broken L8 QA Band hyperlink. Updated source code links to Github pages.
Version 2.1	05/10/2016	Updates to “Known Issues” and “Caveats and Constraints” sections. Added citation for manuscript describing L8SR’s algorithm creation and initial analysis.
Version 3.0	07/01/2016	Changed name from “L8SR” to “LaSRC”. Fixed nearly all “blockiness” by interpolating missing aerosol data points. A new aerosol interpolation QA band (sr_ipflag) is now provided to show where aerosols have been interpolated versus actual observations. Reflectance is now retrieved over all pixels except those contaminated with cirrus. Added date restriction caveat for when MODIS Terra was in safe mode.
Version 3.1	08/23/2016	Added missing auxiliary data gaps dates.
Version 3.2	09/08/2016	Changed cloud confidence bits to actual representation – “low”, “medium” and “high”.

Version 3.3	10/11/2016	Added specifics on Known Issues, added NetCDF file format.
Version 3.4	12/07/2016	Replaced links to Landsat Missions Website
Version 3.5	03/10/2017	Some level of aerosol retrieval is now attempted for all pixels, and a special routine is used for water pixels (“Known Issues”; “Caveats & Constraints".) Addition of Collection 1 products. Addition of ancillary data chart. “sr_ipflag” and “sr_cloud” have now been replaced with “sr_aerosol_qa” for Pre-Collection and C1. For C1: addition of radiometric saturation (radsat_qa) and pixel quality (pixel_qa) band; removal of cfmask and cfmask_conf bands, unless ordered manually in ESPA. Added caveat stating that TIRS-only (LT8 or LT08) data cannot be processed to Brightness Temperature.

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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 upon these data for historical study of land surface change but shoulder the burden of post-production processing to create applications-ready data sets. To alleviate this burden, 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, 30-meter land cover, burned area extent, snow covered area, and surface water extent will be offered as high-level products. These products will offer a framework for producing long-term Landsat science data collections suited for monitoring, assessing, and predicting land surface change over time.

The product described here, the Provisional Landsat 8 Surface Reflectance Code (LaSRC) is distinctly different from the algorithm used by USGS to process Landsat 4–5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level-1 products to Surface Reflectance, known as the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). Details of these differences are described below in **Table 1-A**. Please remember that LaSRC is provisional software, and the values are subject to change.

LaSRC's original development and preliminary characterization is documented in the peer-reviewed manuscript published by Vermote et al., 2016. Please see **Section 12 References** for more details.

Table 1-A Differences between Landsat 4–7 and Landsat 8 Surface Reflectance algorithms

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, N/A Not Applicable, NASA National Aeronautics and Space Administration, NCEP National Centers for Environmental Prediction, OLI Operational Land Imager, OMI Ozone Monitoring Instrument, QA Quality Assurance, SR Surface Reflectance, TIRS Thermal Infrared Sensor, TM Thematic Mapper, TOA Top of Atmosphere Reflectance, TOMS Total Ozone Mapping Spectrometer, XML Extensible Markup Language

Parameter	Landsat 4–5, 7 (LEDAPS)	Landsat 8 OLI (LaSRC)
(Original) research grant	NASA GSFC, MEaSUREs (Masek)	NASA GSFC
Global coverage	Yes	Yes
TOA	Visible (1–5,7) + Brightness temp (6) bands	Visible (1–7, 9) +Thermal (10–11) bands
SR	Visible (1–5, 7) bands	Visible (1–7) bands (OLI/TIRS only)
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	Global Climate Model DEM	Global Climate Model DEM
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

Section 2 Known Issues

2.1 Surface Reflectance Artifacts

The artifacts present in Surface Reflectance data products obtained before July 1, 2016 product have been largely eliminated. The artifacts, or “blockiness” was largely caused by the Global Climate Modeling (GCM) grid’s aerosol values not being correctly interpolated to the Landsat grid, causing grid-shaped artifacts. To prevent this, LaSRC now interpolates missing aerosol grid values to fit continuously within the Landsat grid cells. While making the resulting data product appear more consistent, interpolated values are not direct measurements, therefore a QA band (sr_aerosol_qa) is now provided with the Surface Reflectance data product (**Section 7.1.3**).

Previous interpolation issues along coastal water bodies led us to implement a land/water mask to better identify coastal waters, since aerosols were not being retrieved over coastal waters and this resulted in significant blockiness along the coastal areas. Given the change in the new version of LaSRC to attempt aerosol retrieval over all pixels, the coastal water mask has been removed from the processing stream.

Additionally, aerosols are now retrieved from pixels identified as water, but uses a different routine than over land.

Please see https://landsat.usgs.gov/sites/default/files/documents/lasrc_release_notes.pdf for more information pertaining to the algorithm updates.

Section 3 Caveats and Constraints

1. The LaSRC algorithm has not been completely validated; the algorithm and its subsequent output products are considered provisional.
2. Corrections from OLI Bands 1 and 2 (coastal aerosol and blue bands, respectively) should not be used for analysis, as they are already used within the algorithm to perform aerosol inversion tests, making them potentially unreliable.
3. Landsat 8 data cannot be processed to Surface Reflectance between specific dates. More information pertaining to the ancillary data characteristics and availability is shown in **Section 8 Ancillary Data**. 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
4. Aerosol retrieval is attempted over all pixels, though a separate routine is used for pixels flagged by LaSRC as water. These conditions are detailed in the Aerosol QA band (**Section 7.1.3 Aerosol QA Band**).
5. Surface Reflectance cannot be run on Landsat 8 Pre-Worldwide Reference System (WRS)-2 scenes. More information about Pre-WRS-2 scenes can be found at https://landsat.usgs.gov/what-landsat-8-olitirs-pre-wrs-2-data.
6. Although Surface Reflectance can be processed only from the Operational Land Imager (OLI) bands, SR requires combined OLI/Thermal Infrared Sensor (TIRS) product (LC8) input in order to generate the accompanying cloud mask. Therefore, OLI only (LO8), and TIRS only (LT8) data products cannot be calculated to SR.
7. TIRS-only data (LT8 for Pre-Collection; LT08 for Collection 1) cannot currently be processed to Brightness Temperature.
8. 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 or above a 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.
9. For reasons mentioned above, users are cautioned against processing data acquired over high latitudes (> 65º) to Surface Reflectance.
10. Users are cautioned against using pixels flagged as high aerosol content. See **Section 7.1.3** for details.

11. There are additional adverse conditions that can affect the efficacy of L8SR 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.
12. OLI Band 8 (panchromatic band) is not processed to Top of Atmosphere or Surface Reflectance.

Section 4 Product Options

This product guide is specific only to the products listed below. Options for processing other Landsat data are covered in separate product guides.

1. Original Input Products
2. Original Input Metadata
3. Top of Atmosphere (TOA) Reflectance (all bands except Panchromatic Band 8).
4. Brightness Temperature (calculated from at-sensor radiances to calculate the corresponding TOA Brightness Temperature, or simply referred to as “Brightness Temperature”. These are separate products generated for Bands 10 and 11).
5. Surface Reflectance (all bands except Panchromatic Band 8, Cirrus Band 9, and Thermal Bands 10 and 11).

These products are available for any Landsat 8 data product available in the USGS archive, with the exceptions noted in **Section 3 Caveats and Constraints.**

4.1 Original Input Products

Selection of this option delivers the original unaltered Landsat 8 Level-1 data product.

4.1.1 Pre-Collection

Landsat 8 OLI/TIRS Original Input Products output will contain:

- Level-1 data files (Bands 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11)
- Quality Assessment (QA) Band file https://landsat.usgs.gov/qualityband
- Angle Band Coefficients file
- Metadata text file (MTL.txt)

Filenames utilize the original scene identifier (sceneID), for example, “LC80270332014310LGN00_*.” Product details are found at https://landsat.usgs.gov/landsat-8.

4.1.2 Collection 1

Landsat 8 OLI/TIRS Original Input Products output will contain:

- Level-1 data files (Bands 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11)
- Quality Assessment (QA) Band file https://landsat.usgs.gov/collectionqualityband
- Angle Band Coefficients file
- Metadata text file (MTL.txt)

Filenames utilize the product identifier (productID), for example, “LC08_L1TP_220071_20170207_20170216_01_T1”. Product details are found at https://landsat.usgs.gov/landsat-collections

4.2 Original Input Metadata

The Landsat 8 Level-1 metadata (MTL.txt) and angle band coefficients file (ANG.txt) will be distributed when this option is requested.

4.3 Top of Atmosphere Reflectance

This option calculates TOA Reflectance from the Original Input Landsat scene. Further details are given in **Section 7 Product Characteristics**.

4.3.1 Pre-Collection

Top of Atmosphere Reflectance output from Landsat 8 contains:

- LC8 data: TOA Reflectance data files (Bands 1–7, 9)
- LO8 data: TOA Reflectance data files (Bands 1–7, 9)
- TOA Reflectance header files
- TOA Reflectance metadata file (.xml)

Filenames utilize the original sceneID followed by "_toa_," for example, "LC80180602014247LGN00_toa_*."

4.3.2 Collection 1

Top of Atmosphere Reflectance output from Landsat 8 contains:

- LC8 data: TOA Reflectance data files (Bands 1–7, 9)
- LO8 data: TOA Reflectance data files (Bands 1–7, 9)
- TOA Reflectance header files
- Radiometric Saturation Quality Assurance file (radsat_qa)
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- TOA Reflectance metadata file (.xml)

Filenames utilize the productID followed by "_toa_," for example, "LC08_L1TP_018060_20140904_20160101_01_T1_toa_*."

4.4 Brightness Temperature

This option delivers the Top of Atmosphere Brightness Temperature product (Bands 10 and 11), which are converted to Kelvin.

4.4.1 Pre-Collection

Brightness Temperature output from Landsat 8 contains:

- LC8 data: Brightness Temperature data files (Bands 10–11)
- Brightness Temperature header files
- Brightness Temperature metadata file (.xml)

Filenames utilize the original sceneID followed by "_toa_," for example, "LC81710612014183LGN00_toa_*."

4.4.2 Collection 1

Brightness Temperature output from Landsat 8 contains:

- LC8 data: Brightness Temperature data files (Bands 10–11)
- Brightness Temperature header files
- Radiometric Saturation Quality Assurance file (radsat_qa)
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- Brightness Temperature metadata file (.xml)

Filenames utilize the productID followed by "_bt_," for example, "LC08_L1TP_171061_20140702_2016010_01_T1_bt_*."

4.5 Surface Reflectance

This option delivers the Surface Reflectance product, without the TOA Reflectance or the original input files. **Section 7 Product Characteristics** describes the product in full detail. General contents are listed below.

4.5.1 Pre-Collection

Landsat Surface Reflectance output from Landsat 8 contains:

- Surface Reflectance data files (Bands 1–7)
- Aerosol QA band (see **Section 7.1.3** for more details)
- Cloud mask (CFmask) band (see **Section** 7.2 for more details)
- CFmask cloud confidence band (see **Section 7.2.1.1** for more details)
- Surface Reflectance metadata file (.xml)

Filenames utilize the original sceneID followed by "_sr_," for example, "LC82330132014265LGN00_sr_*."

4.5.2 Collection 1

Landsat Surface Reflectance output from Landsat 8 contains:

- Surface Reflectance data files (Bands 1–7)
- Surface Reflectance Aerosol QA band (see **Section 7.1.3** for more details)
- Radiometric Saturation QA band (radsat_qa; see **Section 7.1.2.1** for more details)
- Level-1 metadata files
- Level-2 Pixel Quality Assurance band (pixel_qa; see **Section 7.1.2** for more details)
- Per-pixel solar zenith, solar azimuth, sensor zenith and sensor azimuth bands (band 4 only)
- Surface Reflectance metadata file (.xml)

Filenames utilize the productID followed by "_sr_," for example, "LC08_L1TP_233013_2014265LGN00_sr_*."

4.6 Spectral Indices

Landsat 8 Surface Reflectance can be used to derive several spectral index products, as listed below. Their characteristics are described in a separate product guide for Landsat 4–8 (see Landsat Spectral Indices Product Guide) and currently include:

- 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 5 Product Access

Provisional Landsat 8 Surface Reflectance data products are available through EarthExplorer, under the “Data Sets” > “Landsat Archive” tabs as “Landsat Surface Reflectance – L8 OLI/TIRS”.

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

Section 6 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.

6.1 Pre-Collection

Following are the components of a typical pre-collection file:

LXXPPPRRRYYYYDDDSTNVR_prod_band.ext
(e.g., LC80120542014301LGN00_sr_band1.tif)

LXX	LC8 for Landsat 8 OLI and TIRS
PPP	Path
RRR	Row
YYYY	Year of Acquisition
DDD	Julian Date of Acquisition
STN	Receiving Station
VR	Version Number
prod	Product, such as "toa" or "sr"
band	Band, such as "band<1-8, 10-11>," "qa," or spectral index.
ext	File format extension, such as "tif," "tfw," "xml," "hdf," "hdr," or "img"

6.2 Collection 1

Following are the components of a typical Collection 1 file:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX_prod_band.ext
(e.g., LC08_L1TP_039037_20150728_20160918_01_T1_sr_band1.tif)

L	Landsat
X	Sensor ("O" = OLI; "T" = TIRS; "C" = OLI/TIRS)
SS	Satellite ("08" = Landsat 8)
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<1-11>,” “qa,” or spectral index.
ext	File format extension, such as “tif,” “tfw,” “xml,” “hdf,” “hdr,” “nc,” or “img”

Section 7 Product Characteristics

Original Input Products and Original Input Metadata are described on https://landsat.usgs.gov/landsat-processing-details. The characteristics of Surface Reflectance, TOA Reflectance, and Brightness Temperature are detailed in the following sections.

7.1 Surface Reflectance Specifications

The Landsat 8 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), NetCDF (.nc) or ENVI binary (.img) are available through the ESPA Ordering Interface. More information on output formats currently used for Landsat 4–8 can be found in the ESPA On Demand Interface User Guide.

7.1.1 Pre-Collection

Landsat 8 Surface Reflectance will be delivered in files named with the original sceneID 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 Aerosol QA Band, which is delivered in a single bit-packed layer. **Table 7-A** lists the specifications for the bands included in a Surface Reflectance data file.

Table 7-A Surface Reflectance Specifications

INT16 16-bit signed integer, UINT8 8-bit unsigned integer, QA quality assurance, 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
sr_band1	Band 1	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band2	Band 2	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band3	Band 3	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band4	Band 4	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band5	Band 5	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band6	Band 6	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band7	Band 7	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_aerosol_qa	Aerosol QA	UINT8	Bit Index	0 - 255	0 - 255	NA	NA	NA
sr_cfmask	CFmask	UNIT8	Value Flag	0-255	0-4	255	NA	NA
sr_cfmask_conf	CFmask Cloud Confidence	UINT8	Value Flag	0-255	0-4	255	NA	NA

7.1.2 Collection 1

Landsat 8 Surface Reflectance will be delivered in files named with the new product ID 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 Aerosol QA Band, which is delivered in a single bit-packed layer. **Table 7-B** lists the specifications for the bands included in a Surface Reflectance data file. **Table 7-C** describes the bit assignments for the pixel_qa band.

Table 7-B Surface Reflectance Specifications

INT16 16-bit signed integer, UINT8 8-bit unsigned integer, QA quality assurance, 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
sr_band1	Band 1	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band2	Band 2	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band3	Band 3	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band4	Band 4	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band5	Band 5	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band6	Band 6	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
sr_band7	Band 7	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	0-32768	0-32768	1 (bit 0)	NA	NA
sr_aerosol_qa	Aerosol QA	UINT8	Bit Index	0 - 255	0 - 255	NA	NA	NA
radsat_qa	Radiometric Saturation QA	UINT16	Bit Index	0-32768	0-3839	1 (bit 0)	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100

Table 7-C Landsat 8 Pixel Quality Attributes (pixel_qa) Bit Index

Bit	Value	Cumulative Sum	Interpretation
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	Cirrus Confidence 00 = Not set 01 = Low from OLI Band 9 reflectance 10 = Medium from OLI Band 9 reflectance 11 = High from OLI Band 9 reflectance
9	512	1023	
10	1024	2047	Unused
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65553	Unused

7.1.2.1 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 1024 indicates that TIRS Band 10 is saturated.

Saturation in Landsat 8 is not common. When saturation does occur, it happens over volcanoes and wildland fires in the SWIR and thermal bands. Saturation can be found in two forms: one, saturated thermal and SWIR pixels can show as the maximum unsigned 16-bit value of 65535; or two, SWIR pixel values can "roll over" to the low end of the valid range (not necessarily just a value of 0), which is called oversaturation. Oversaturation will not occur with the TIRS thermal bands. The L8 radsat_qa band will flag only the saturation cases. **Table 7-D** describes the bit assignments for the radsat_qa band.

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

Bit	Value	Cumulative Sum	Description
Bits are numbered from right to left (bit 0 = 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
9	512	1023	Band 9 Data Saturation Flag (0 valid data, 1 saturated data)
10	1024	2047	Band 10 Data Saturation Flag (0 valid data, 1 saturated data)
11	2048	4095	Band 11 Data Saturation Flag (0 valid data, 1 saturated data)

7.1.3 Aerosol QA Band

Aerosol retrieval is a critical component in the atmospheric correction calculations used in generating Surface Reflectance for Landsat 8. The Internal Surface Reflectance Aerosol Quality (sr_aerosol_qa) band output with the Surface Reflectance product describes that parameter to provide low-level detail about the factors that may have influenced the final product result (**Table 7-E**).

Table 7-E Landsat 8 Internal Surface Reflectance Aerosol Quality (sr_aerosol_qa) Bit Index

Bit	Cumulative Sum	Value	Description
0	1	1	Fill Value
1	2	3	Aerosol Retrieval – Valid
2	4	7	Aerosol Retrieval – Interpolated
3	8	15	Water Pixel
4	16	31	Water Aerosol Retrieval Failed – Needs Interpolated (Internal Use Only)
5	32	63	Neighbor of Failed Aerosol Retrieval (Internal Use Only)
6	64	127	Aerosol Content 00 – Climatology 01 – Low 10 – Medium 11 – High
7	128	255	

Note that pixels classified as high aerosol content are not recommended for use.

7.1.4 Surface Reflectance Metadata

Each Landsat 8 Surface Reflectance order will be accompanied by an xml-based metadata file. The metadata fields included in the xml are listed in **Appendix B Metadata Field**.

7.1.5 Surface Reflectance Special Notes

Metadata are 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.

7.2 Cloud and Cloud Shadow Specifications

7.2.1 Pre-Collection

The Surface Reflectance product includes an alternative to cloud, cloud shadow, snow, and water identification, and is likely to present more accurate results than its

companion bands (cloud_qa and cloud_shadow_qa). The CFMask algorithm was originally developed at Boston University in a Matrix Laboratory (MATLAB) environment to automate cloud, cloud shadow, and snow masking for Landsat TM and ETM+ images. The MATLAB Function of Mask (Fmask) was subsequently translated into open source C code at the USGS EROS Center, where it is implemented as the C version of Fmask, or CFMask (https://github.com/USGS-EROS/espa-cloud-masking).

CFMask designates whether clouds, cloud shadows, snow, or water were identified in each pixel in the Surface Reflectance product, as described in **Table 7-F**.

Table 7-F CFMask Pixel Values

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

7.2.1.1 CFMask Cloud Confidence Band

A confidence band for the cloud detection portion of CFMask is provided with the Landsat 4-7 Surface Reflectance product (by default with pre-collection data, optionally with Collection 1 data.) The output of this band are considered provisional, as the confidence thresholds are subject to change. **Table 7-G** describes each value within the CFMask Cloud Confidence Band.

Table 7-G CFMask Cloud Confidence Band Values

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

7.2.2 Collection 1

The Level-2 Pixel Quality Assurance band (pixel_qa; **Table 7-C**) 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 (**Table 7-F**) and CFMask confidence (**Table 7-G**) bands are still orderable through the ESPA interface as a separate option, though the same information is available in the default pixel_qa band.

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).

7.2.3 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.

7.3 Top of Atmosphere Reflectance & Brightness Temperature Specifications

7.3.1 Pre-Collection

7.3.1.1 Top of Atmosphere Reflectance - Bands 1–7, 9 Specifications

Calibration coefficients are applied to Landsat digital numbers to derive the TOA Reflectance component, using scene center solar angles in the computation. All files appended with "_toa_" are related to TOA Reflectance. The "_toa_" packages contain TOA Reflectance and bit-packed quality information for Landsat Bands 1, 2, 3, 4, 5, 6, 7, and 9. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but these are specific to TOA Reflectance processing. Valid data ranges 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 Bands 10 and 11, but can be ordered separately as Brightness Temperature (**Section 7.3.1.2**).

Table 7-H lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Reflectance product bands.

Table 7-H Top of Atmosphere Reflectance – Bands 1-7, 9 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
toa_band1	Band 1 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band2	Band 2 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band3	Band 3 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band4	Band 4 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band5	Band 5 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band6	Band 6 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band7	Band 7 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band9	Band 9 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001

7.3.1.2 Brightness Temperature - Bands 10–11 Specifications

Bands 10–11 Brightness Temperature is derived from TOA radiance and two thermal constants, as described at https://landsat.usgs.gov/using-usgs-landsat-8-product. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but they are specific to Brightness Temperature processing. Specifications for Brightness Temperature bands are similar to those for Surface Reflectance, but with a higher minimum value. **Table 7-I** lists the data type, units, value range, fill value, saturation value, and scale factor for the Brightness Temperature product bands.

Table 7-I Top of Atmosphere Brightness Temperature – Bands 10–11 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
toa_band10	Band 10 Brightness Temperature	INT16	Brightness Temperature (Kelvin)	-100 - 16000	0- 10000	-9999	20000	0.1
toa_band11	Band 11 Brightness Temperature	INT16	Brightness Temperature (Kelvin)	-100 - 16000	0- 10000	-9999	20000	0.1

7.3.2 Collection 1

7.3.2.1 Top of Atmosphere Reflectance - Bands 1–7, 9 Specifications

Calibration coefficients are applied to Landsat digital numbers to derive the TOA Reflectance component, using scene center solar angles in the computation. All files appended with "_toa_" are related to TOA Reflectance. The "_toa_" packages contain TOA Reflectance and bit-packed quality information for Landsat Bands 1, 2, 3, 4, 5, 6, 7, and 9. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but these are specific to TOA Reflectance processing. Valid data ranges 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 Bands 10 and 11, but can be ordered separately as Brightness Temperature (**Section 7.3.1.2**).

Table 7-J lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Reflectance product bands.

Table 7-J Top of Atmosphere Reflectance – Bands 1-7, 9 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
toa_band1	Band 1 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band2	Band 2 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band3	Band 3 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band4	Band 4 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band5	Band 5 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band6	Band 6 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band7	Band 7 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
toa_band9	Band 9 Reflectance	INT16	Reflectance	-100 – 16000	0 – 10000	-9999	20000	0.0001
pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	0-32768	0-32768	1 (bit 0)	NA	NA
radsat_qa	Radiometric Saturation Band	UINT16	Bit Index	0-32768	0-3839	1 (bit 0)	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
solar_zenith_band4	Solar Zenith	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100

	Angles Band 4							
sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100

7.3.2.2 Brightness Temperature - Bands 10–11 Specifications

Bands 10–11 Brightness Temperature is derived from TOA radiance and two thermal constants, as described at https://landsat.usgs.gov/using-usgs-landsat-8-product. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but they are specific to Brightness Temperature processing. Specifications for Brightness Temperature bands are similar to those for Surface Reflectance, but with a higher minimum value. **Table 7-K** lists the data type, units, value range, fill value, saturation value, and scale factor for the Brightness Temperature product bands.

Table 7-K Top of Atmosphere Brightness Temperature – Bands 10–11 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
bt_band10	Band 10 Brightness Temperature	INT16	Brightness Temperature (Kelvin)	-100 - 16000	0-10000	-9999	20000	0.1
bt_band11	Band 11 Brightness Temperature	INT16	Brightness Temperature (Kelvin)	-100 - 16000	0-10000	-9999	20000	0.1
pixel_qa	Level-2 Pixel Quality Band	UINT16	Bit Index	0-32768	0-32768	1 (bit 0)	NA	NA
radsat_qa	Radiometric Saturation Band	UINT16	Bit Index	0-32768	0-3839	1 (bit 0)	NA	NA
solar_azimuth_band4	Solar Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-32768 - 32767	NA	NA	0.0100

7.3.3 TOA Reflectance Special Notes

Metadata are 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.

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 LaSRC, ancillary data are assimilated from satellite observations from the MODIS instruments aboard the Terra and Aqua satellites. 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-A**.

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 http://landsat.usgs.gov/CDR_LSR.php.

Table 8-A Ancillary Data for LaSRC

AOT Aerosol Optical Thickness, MODIS Moderate Resolution Imaging Spectroradiometer, MOD MODIS Terra, MYD Modis Aqua

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	MOD/MYD09 CMG	ftp://ladssci.nascom.nasa.gov	v006	Terra & Aqua	0.05° x 0.05°	5/4/2002	Present	N/A	N/A	N/A	2/19/2016 - 2/27/2016; 8/11/2016 - 8/13/2016	N/A
Air Temperature	MOD/MYD09 CMA											
Water Vapor	MOD/MYD09 CMA											
AOT (550 nm)	MOD/MYD09 CMA											

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 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.

Vermote, E., Justice, C., Claverie, M., & Franch, B. (2016). Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product. Remote Sensing of Environment. http://dx.doi.org/10.1016/j.rse.2016.04.008.

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 10 Acknowledgments

The original Landsat 8 Surface Reflectance algorithm was developed by Dr. Eric Vermote, NASA Goddard Space Flight Center (GSFC).

The original CFmask software, Fmask, was developed 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
https://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

Campbell, J. W., and 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.

Vermote, E., Justice, C., Claverie, M., & Franch, B. (2016). Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product. Remote Sensing of Environment. http://dx.doi.org/10.1016/j.rse.2016.04.008.

Zhu, Z., and Woodcock, C. E. (2012). Object-based cloud and cloud shadow detection in Landsat imagery, *Remote Sensing of Environment* 118:83-94. http://dx.doi.org/10.1016/j.rse.2011.10.028.

Zhu, Z., Wang, S., and Woodcock, C. E. (2015). Improvement and expansion of the Fmask algorithm: cloud, cloud shadow, and snow detection for Landsats 4–7, 8, and Sentinel 2 images. *Remote Sensing of Environment* 159:269-277. http://dx.doi.org/10.1016/j.rse.2014.12.014.

Appendix A Default File Characteristics

Table 0-A Pre-Collection Default File Characteristics

Description	Example File Size (bytes)	Example File Name
Source Bands (11)	126,491,737	LC80430312013179LGN00_B*.tif
Source Band QA	126,491,737	LC80430312013179LGN00_QA.tif
Source Metadata	7,791	LC80430312013179LGN00_MTL.txt
TOA Reflectance Bands (8)	126,491,785	LC80430312013179LGN00_toa_band*.tif
TOA Brightness Temperature Bands (2)	126,491,785	LC80430312013179LGN00_toa_band*.tif
Surface Reflectance Bands (7)	126,491,751	LC80430312013179LGN00_sr_band*.tif
Surface Reflectance Cloud QA Band (1)	63,278,592	LC80430312013179LGN00_sr_cloud.tif
Surface Reflectance Interpolation Flag QA Band (1)	63,278,592	LC80430312013179LGN00_sr_ipflag.tif
CFmask Band	63,278,592	LC80430312013179LGN00_cfmask.tif
CFmask Cloud Confidence Band	63,278,592	LC80430312013179LGN00_cfmask_conf.tif
Metadata	23,532	LC80430312013179LGN00.xml

Table 0-B Collection 1 Default File Characteristics

Description	Example File Size (bytes)	Example File Name
Source Bands (11)	126,491,737	LC08_L1TP_043031_20130628_20170101_01_T1_B*.tif
Source Band QA	126,491,737	LC08_L1TP_043031_20130628_20170101_01_T1_BQA.tif
Source Metadata	7,791	LC08_L1TP_043031_20130628_20170101_01_T1_MTL.txt
TOA Reflectance Bands (8)	126,491,785	LC08_L1TP_043031_20130628_20170101_01_T1_toa_band*.tif
TOA Brightness Temperature Bands (2)	126,491,785	LC08_L1TP_043031_20130628_20170101_01_T1_toa_band*.tif
Surface Reflectance Bands (7)	126,491,751	LC08_L1TP_043031_20130628_20170101_01_T1_sr_band*.tif

Surface Reflectance Aerosol QA Band (1)	63,278,592	LC08_L1TP_043031_20130628_20170101_01_T1_sr_aerosol_qa.tif
Level-2 Pixel QA (1)	63,278,592	LC08_L1TP_043031_20130628_20170101_01_T1_pixel_qa.tif
Metadata	23,532	LC08_L1TP_043031_20130628_20170101_01_T1.xml

Appendix B Metadata Field

Pre-Collection:

Example of global XML metadata:

```
<global_metadata>
      <data_provider>USGS/EROS</data_provider>
      <satellite>LANDSAT_8</satellite>
      <instrument>OLI_TIRS</instrument>
      <acquisition_date>2013-06-28</acquisition_date>
      <scene_center_time>18:40:39.8204854Z</scene_center_time>
      <level1_production_date>2014-11-13T15:01:34Z</level1_production_date>
      <solar_angles zenith="24.733788" azimuth="131.660614" units="degrees"/>
      <wrs system="2" path="43" row="31"/>
      <lpgs_metadata_file>LC80430312013179LGN00_MTL.txt</lpgs_metadata_file>
      <corner location="UL" latitude="42.801350" longitude="-120.700400"/>
      <corner location="LR" latitude="40.691440" longitude="-117.783500"/>
      <bounding_coordinates>
         <west>-120.700594</west>
         <east>-117.783319</east>
         <north>42.858456</north>
         <south>40.638480</south>
      </bounding_coordinates>
      <projection_information projection="UTM" datum="WGS84" units="meters">
         <corner_point location="UL" x="197400.000000" y="4745400.000000"/>
         <corner_point location="LR" x="433800.000000" y="4504800.000000"/>
         <grid_origin>CENTER</grid_origin>
         <utm_proj_params>
            <zone_code>11</zone_code>
         </utm_proj_params>
      </projection_information>
      <orientation_angle>0.000000</orientation_angle>
   </global_metadata>
```

Example of per-band XML metadata:

```
<band product="sr_refl" name="sr_band1" category="image" data_type="INT16" nlines="8021"
nsamps="7881" fill_value="-9999" scale_factor="0.000100">
         <short_name>LC8SR</short_name>
         <long_name>band 1 surface reflectance</long_name>
         <file_name>LC80430312013179LGN00_sr_band1.tif</file_name>
         <pixel_size x="30" y="30" units="meters"/>
         <data_units>reflectance</data_units>
         <valid_range min="-2000" max="16000"/>
         <app_version>l8_surface_reflectance_0.1.0</app_version>
         <production_date>2014-11-13T15:42:29Z</production_date>
      </band>
```

Collection 1:

Example of global XML metadata:

```
<global_metadata>
```

```
    <data_provider>USGS/EROS</data_provider>
    <satellite>LANDSAT_8</satellite>
    <instrument>OLI_TIRS</instrument>
    <acquisition_date>2013-06-28</acquisition_date>
    <scene_center_time>18:40:39.8204854Z</scene_center_time>
    <level1_production_date>2017-01-01T15:01:34Z</level1_production_date>
    <solar_angles zenith="24.733788" azimuth="131.660614" units="degrees"/>
    <wrs system="2" path="43" row="31"/>
    <lpgs_metadata_file> LC08_L1TP_043031_20130628_20170101_01_T1_MTL.txt</lpgs_metadata_file>
    <corner location="UL" latitude="42.801350" longitude="-120.700400"/>
    <corner location="LR" latitude="40.691440" longitude="-117.783500"/>
    <bounding_coordinates>
      <west>-120.700594</west>
      <east>-117.783319</east>
      <north>42.858456</north>
      <south>40.638480</south>
    </bounding_coordinates>
    <projection_information projection="UTM" datum="WGS84" units="meters">
      <corner_point location="UL" x="197400.000000" y="4745400.000000"/>
      <corner_point location="LR" x="433800.000000" y="4504800.000000"/>
      <grid_origin>CENTER</grid_origin>
      <utm_proj_params>
        <zone_code>11</zone_code>
      </utm_proj_params>
    </projection_information>
    <orientation_angle>0.000000</orientation_angle>
  </global_metadata>
```

Example of per-band XML metadata:

```
<band product="sr_refl" name="sr_band1" category="image" data_type="INT16" nlines="8021"
nsamps="7881" fill_value="-9999" scale_factor="0.000100">
        <short_name>LC8SR</short_name>
        <long_name>band 1 surface reflectance</long_name>
        <file_name> LC08_L1TP_043031_20130628_20170101_01_T1_sr_band1.tif</file_name>
        <pixel_size x="30" y="30" units="meters"/>
        <data_units>reflectance</data_units>
        <valid_range min="-2000" max="16000"/>
        <app_version>l8_surface_reflectance_0.1.0</app_version>
        <production_date>2017-02-22T15:42:29Z</production_date>
    </band>
```

Appendix C Acronyms

Acronym	Description
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
CDR	Climate Data Record
CFMask	C version of Function of Mask (USGS EROS)
CMA	Climate Modeling Grid - Aerosols
CMG	Climate Modeling Grid - Ozone
CSV	Comma Separated Values
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
L8SR	Provisional Landsat 8 Surface Reflectance Algorithm (Note: no longer used)
LaSRC	Landsat Surface Reflectance Code
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
MOD	MODIS Terra
MODIS	Moderate Resolution Imaging Spectroradiometer
MSAVI	Modified Soil Adjusted Vegetation Index
MSB	Most Significant Bit
MYD	MODIS Aqua
NA	Not Applicable
NASA	National Aeronautic and Space Administration
NBR	Normalized Burn Ratio
NBR2	Normalized Burn Ratio 2
NC	NetCDF File Format
NCEP	National Centers for Environmental Prediction

NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
PS	Polar Stereographic
QA	Quality Assurance
SAVI	Soil Adjusted Vegetation Index
sceneID	Scene Identifier
SLC	Scan Line Corrector
SR	Surface Reflectance
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
UINT	Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WRS	Worldwide Reference System
xml	Extensible Markup Language