LSDS-1619
Version 4.0

Department of the Interior
U.S. Geological Survey

Landsat 8-9
Collection 2 (C2)
Level 2 Science Product (L2SP) Guide

Version 4.0

March 2022

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Collection 2 (C2)
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Executive Summary

This document describes relevant characteristics of the Landsat 8 (L8) and Landsat 9 (L9) Collection 2 (C2) Level 2 Science Products (L2SP) to facilitate their use in the land remote sensing community.

Landsat 8-9 Level 2 Science Products contain:

- Surface Reflectance (SR) derived from Landsat 8-9 Collection 2 Level 1 Operational Land Imager (OLI) data
- Surface Temperature (ST) derived from Landsat 8 Collection 2 Level 1 Thermal Infrared Sensor (TIRS) Band 10 data
- Intermediate bands used in calculation of the ST products
- Quality Assessment (QA) masks indicating the usefulness of the pixel data

Landsat 8-9 SR products are created with the Land Surface Reflectance Code (LaSRC). Landsat 8-9 ST products are created with a single channel algorithm jointly created by the Rochester Institute of Technology (RIT) and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL).

A primary characteristic of Collection 2 data is the implementation of the Sentinel 2 Global Reference Image (GRI) into updated Landsat 8 OLI ground control points for improved geometric accuracy. This improves interoperability of the Landsat archive both through time and with other remotely sensed datasets. Additionally, Collection 2 includes updated global digital elevation modeling sources and calibration and validation updates.

Information about Landsat 4-7 Collection 2 Level 2 products can be found in the Landsat 4-7 Collection 2 Level 2 Science Product Guide.

Document History

Document Number	Document Version	Publication Date	Change Number
LSDS-1619	Version 1.0	May 2020	CR 15400
LSDS-1619	Version 2.0	September 2020	CR 20016
LSDS-1619	Version 3.0	September 2021	CR 20746
LSDS-1619	Version 4.0	March 2022	CR 20976

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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 datasets. To alleviate this burden on the user, the USGS has initiated an effort to produce a collection of Landsat Level 2 Science Products (L2SP) to support land surface change studies.

Landsat Collection 2 (C2) marks the second major reprocessing effort on the Landsat archive by the USGS that results in several data product improvements that harness recent advancements in data processing, algorithm development, and data access and distribution capabilities.

1.1.1 Surface Reflectance

Landsat 8-9 Surface Reflectance (SR) Science Products are generated from Land Surface Reflectance Code (LaSRC) version 1.5.0 (derived from NASA LaSRC version 3.5.5). The original LaSRC algorithm was developed by Dr. Eric Vermote, National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and was modified by the USGS Earth Resources Observation and Science (EROS) Center. LaSRC generates Top of Atmosphere (TOA) Reflectance and TOA Brightness Temperature (BT) using the calibration parameters from the metadata. Atmospheric correction routines are then applied to Landsat 8-9 TOA Reflectance data, using auxiliary input data such as water vapor, ozone, and Aerosol Optical Thickness (AOT) retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS), and digital elevation derived from Earth Topography Five Minute Grid (ETOPO5) to generate Surface Reflectance. The result is delivered as the Landsat Surface Reflectance data product.

Specific details about the SR algorithm can be found in Section 4.7 of the Landsat 8-9 Calibration and Validation (Cal/Val) Algorithm Description Document (ADD).

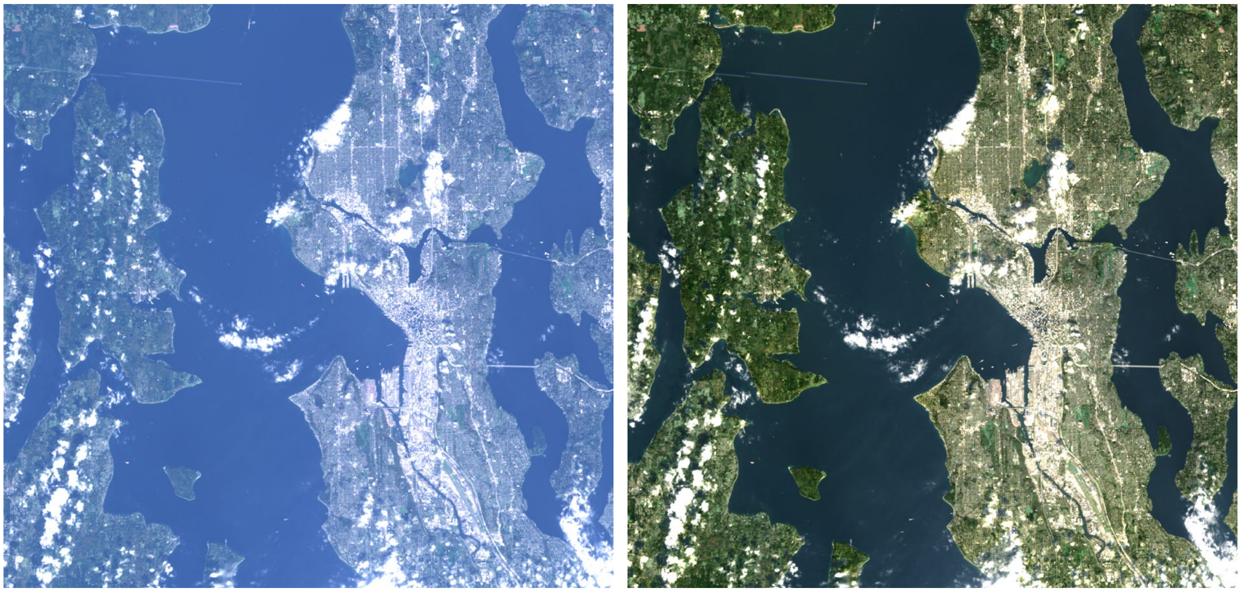

Figure 1-1. Example of LaSRC Atmospheric Correction: Landsat 8 Top of Atmosphere Reflectance RGB (4,3,2) composite (left) and the corresponding Landsat 8 Surface Reflectance product (right)

Figure 1-1 shows a comparison of a Landsat 8 TOA Reflectance composite (Bands 4,3,2), and a Surface Reflectance composite image of Seattle, WA, using data acquired by Landsat 8 (Path 47 Row 27) on October 14, 2013. Both images are linearly scaled from ρ=0.0 to 0.15.

The LaSRC algorithm is distinctly different from the algorithm used to process Landsat 4–5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level 1 (L1) products to Surface Reflectance, known as the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). Details of these differences are described in Table 1-1.

Parameter	LEDAPS	LaSRC
Instruments	Landsat 4-5 TM, Landsat 7 ETM+	Landsat 8-9 OLI/TIRS
(Original) research grant	NASA GSFC, MEaSUREs	NASA GSFC
Principal Investigator	Jeff Masek, NASA	Eric Vermote, NASA
Global coverage	Yes	Yes
TOA Reflectance	Visible (Bands 1–5,7)	Visible (Bands 1–7, 9 OLI)
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	Calculated internally based on elevation
Water vapor	NCEP Grid	MODIS CMG

Parameter	LEDAPS	LaSRC
Air temperature	NCEP Grid	not used
DEM	ETOPO5 (CMGDEM)	ETOPO5 (CMGDEM)
Ozone	OMI/TOMS	MODIS CMG Coarse resolution ozone
AOT	Correlation between chlorophyll absorption and bound water absorption of scene	Internal Algorithm
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	CFMask (v3.3.1)	CFMask (v3.3.1)
Data format	UINT16	UINT16
Fill values	0	0
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 = Land 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 (LEDAPS) and Landsat 8-9 (LaSRC) Surface Reflectance Algorithms

1.1.2 Surface Temperature

The Landsat 8-9 Surface Temperature (ST) product is generated from the single channel algorithm version 1.3.0 (derived from June 2017 version of RIT ST code). The Landsat 8-9 Collection 2 ST is derived from the Collection 2 Level 1 Thermal Infrared Sensor (TIRS) band 10 using Top of Atmosphere (TOA) Reflectance, TOA Brightness Temperature (BT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Dataset (GED) data, ASTER Normalized Difference Vegetation Index (NDVI) data, and atmospheric profiles of geopotential height, specific humidity, and air temperature extracted from reanalysis data.

Specific details about the ST algorithm can be found in Section 4.7 of the Landsat 8-9 Calibration and Validation (Cal/Val) Algorithm Description Document (ADD).

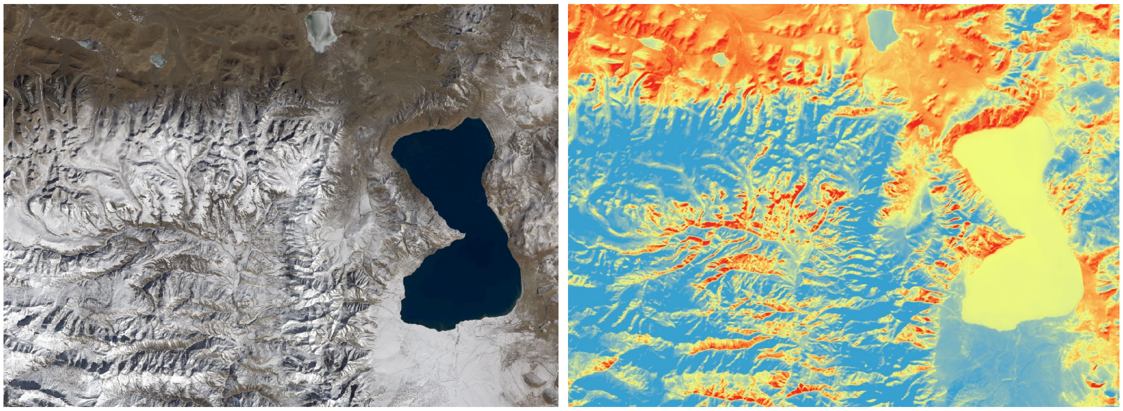

Figure 1-2. Example of Landsat 9 Surface Reflectance RGB composite (Bands 4,3,2) (left) and the corresponding color-enhanced Surface Temperature (right)

Figure 1-2 shows a comparison of a Landsat 9 Surface Reflectance composite (Bands 4,3,2), and color-enhanced Surface Temperature for an area in Nepal, using data acquired by Landsat 9 (Path 141 Row 40) on January 19, 2022. Blue areas in the Surface Temperature product indicate cooler temperatures; red areas indicate warmer temperatures.

1.2 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 describes known issues
- Section 3 provides an explanation of caveats and constraints
- Section 4 provides details on product access
- Section 5 provides details on product packaging
- Section 6 provides an explanation of product characteristics
- Section 7 provides information on auxiliary data used in creation of the product
- Section 8 provides document citation information
- Section 9 provides document acknowledgments
- Section 10 provides User Services contact information
- Appendix A provides a table of default file characteristics
- 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 Known Issues

2.1 Surface Reflectance

The missing Climate Modeling Grid (CMG) aerosol values can cause a “blockiness” artifact in the Landsat 8-9 Surface Reflectance data products. To prevent this, LaSRC interpolates missing aerosol grid values to fit continuously within the Landsat grid cells. While making the resulting data product appear consistent, interpolated values are not direct measurements. Therefore, a Quality Assessment (QA) band (SR_QA_AEROSOL) is provided with the Surface Reflectance data product that shows whether the aerosol was a valid retrieval, or it was interpolated from the surrounding grid points.

LaSRC uses an internal algorithm to identify water pixels. Some low-radiance speckling may appear over water in some Surface Reflectance bands. Shown in Figure 2-1, the speckling exists over water in Band 7 (shortwave infrared 2). The images were created using Landsat 8 data (Path 13, Row 10) acquired on March 30, 2013.

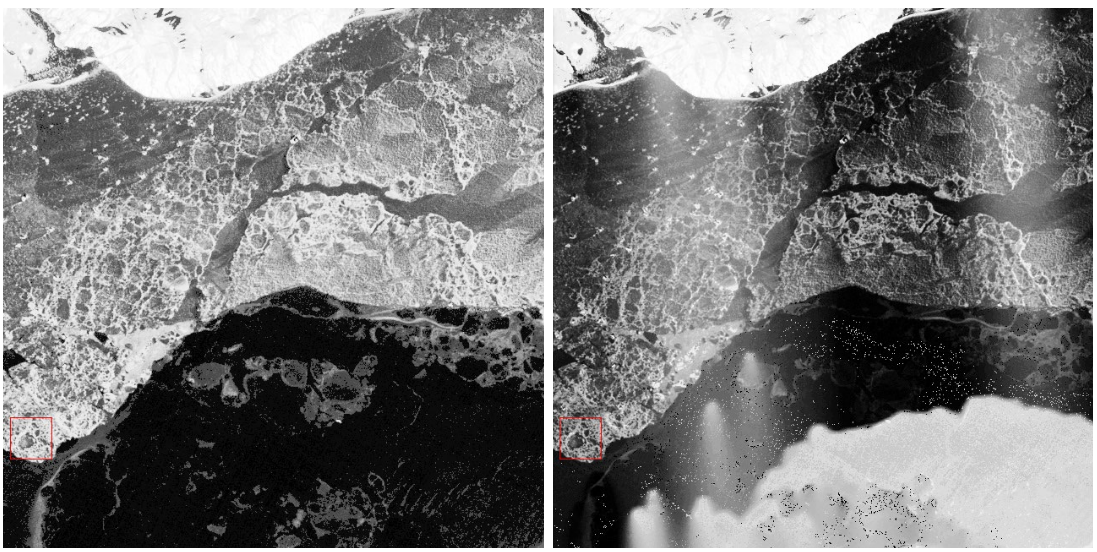

Figure 2-1. Landsat 8 Top of Atmosphere (TOA) Reflectance for the SWIR-2 band (left) and an example of the speckle observed in the corresponding Surface Reflectance product (right)

For a full list of known issues in Collection 2 Level 2 science products, please visit https://www.usgs.gov/landsat-missions/landsat-collection-2-known-issues.

Section 3 Caveats and Constraints

3.1 Surface Reflectance

1. Landsat 8-9 Collection 2 Surface Reflectance (SR) products are generated only from scenes that have been processed to Tier 1 (T1) or Tier 2 (T2); Real-Time (RT) data cannot be used to create SR products. When acquired, scenes are processed and placed into the RT Tier. Landsat 9 data are processed to T1 or T2 upon downlink, usually within 4-6 hours of data acquisition. For Landsat 8, however, follow-on processing to apply refined Thermal Infrared Sensor (TIRS) instrument line of sight model parameters takes place 14 to 16 days later, and the scenes are then placed into T1 or T2. The SR processing is done within 24 hours of availability of T1/T2 and necessary auxiliary data. **In summary, Landsat 8 Collection 2 SR data become available 15 to 17 days after data acquisition.** Visit the [Landsat Collection 2 Generation Timeline] for a visual look at this timeframe.
2. The following date range applies to the availability of Landsat archive for Surface Reflectance processing, with the exceptions noted in #3 below:
   - Landsat 8 OLI/TIRS: March 18, 2013 to present
   - Landsat 9 OLI/TIRS: October 31, 2021 to present
3. Landsat 8-9 data cannot be processed to Surface Reflectance between specific dates. More information pertaining to the auxiliary data characteristics and availability is shown in Section 7. The most up-to-date information regarding data gaps is in the “Caveats and Constraints” section of https://www.usgs.gov/core-science-systems/nli/landsat/landsat-collection-2-surface-reflectance.
4. Landsat 8-9 OLI Band 8 (panchromatic band) is not processed to Top of Atmosphere or Surface Reflectance.
5. 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.
6. For reasons mentioned in #5 above, the Surface Reflectance data processed over high latitudes (> 65º) have larger uncertainty and should be analyzed carefully.

7. Corrections from Landsat 8-9 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.
8. Users are cautioned against using pixels flagged as high aerosol content. See Section 6.1.3 for details.
9. Aerosol retrieval is attempted over all pixels, although a separate routine is used for pixels flagged by LaSRC as water. These conditions are detailed in the Aerosol QA band (Section 6.1.3).
10. There are additional adverse conditions that can affect the efficacy of Landsat 8-9 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

3.2 Surface Temperature

1. For the reasons mentioned in Section 3.1, Landsat 8 Collection 2 ST products become available 15 to 17 days after data acquisition.
2. Landsat 8-9 TIRS-only data (LT08/LT09) cannot be processed to TOA Brightness Temperature or Surface Temperature.
3. The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Dataset (ASTER GED) by Land Processes Distributed Active Archive Center (LP DAAC) is used in the ST algorithm for TIRS data. Where ASTER GED data is missing, there will be missing data in the Landsat ST product. Figure 3-1 shows a map of ASTER GED emissivity tiles coverage.

   Note: To investigate the availability of any given pixel, the “ASTER Global Emissivity Dataset 100 meter HDF5 V003” data can be attained from https://www.doi.org/10.5067/Community/ASTER_GED/AG100.003.

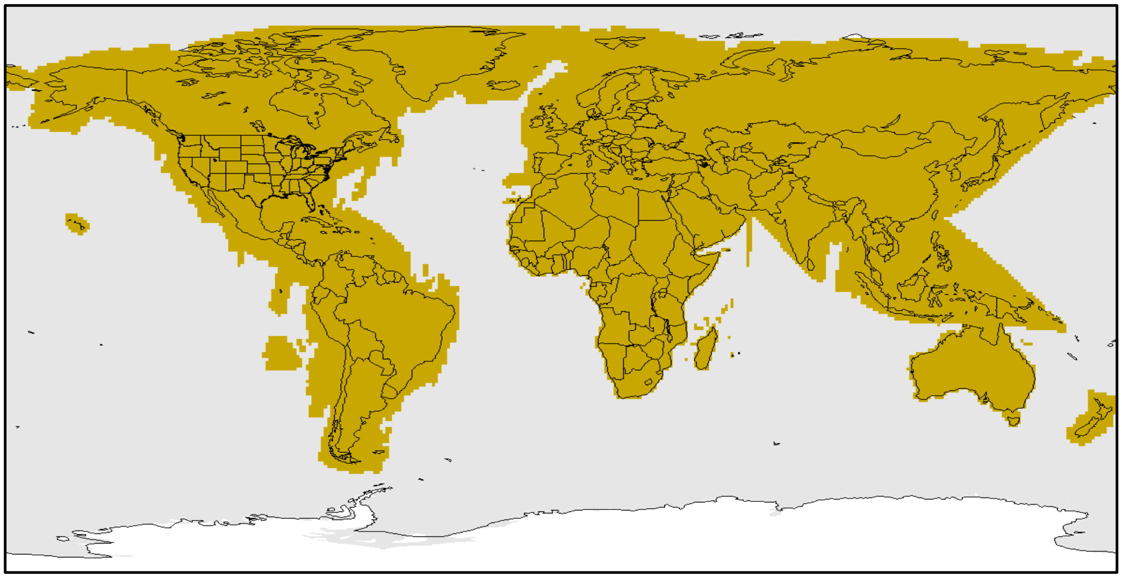

Figure 3-1. Spatial Extent of ASTER GED Emissivity

4. Goddard Earth Observing System, Version 5 (GEOS-5) Forward Processing for Instrument Teams (FP-IT) data are used in the Single Channel algorithm for atmospheric correction of Landsat 8-9 data.
5. Atmospheric auxiliary data used for processing a Level 1 product into the ST are described in the Landsat Atmospheric Auxiliary Data Data Format Control Book (DFCB).
6. Data products must contain both sunlit optical and thermal data (e.g., LC08 products for Landsat 8, LC09 products for Landsat 9) to be successfully processed to Surface Temperature, as Landsat NDVI and Normalized Difference Snow Index (NDSI) are required to temporally adjust the ASTER GED product to the target Landsat scene. Therefore, nighttime acquisitions cannot be processed to Surface Temperature.

A known error exists in the Landsat Surface Temperature retrievals relative to clouds and possibly cloud shadows. The characterization of these issues has been documented by Cook et al., 2014 (see the References section for more details).

Section 4 Product Access

Landsat 8-9 SR and ST products can be downloaded from EarthExplorer (EE). The datasets for each sensor are located under the **Landsat** category, **Landsat Collection 2 Level 2** subcategory: **Landsat 8-9 OLI/TIRS C2 L2**.

After reviewing the search results and selecting a scene, users can download all bands or select and download selected bands.

Direct access to Landsat 8-9 Collection 2 SR and ST is also available via commercial cloud environment. For additional information, please visit Landsat Commercial Cloud Data Access.

Visit the Landsat Data Access webpage for information about downloading Landsat products.

Section 5 Product Packaging

Landsat Collection 2 L2SP can be downloaded as individual bands as Cloud Optimized Georeferenced Tagged Image File Format (GeoTIFF) (COG) files. The filenames are structured as the Level 2 product identifier (ProductID) appended with the suffix "_SR_" followed by a band designation to denote the Surface Reflectance transformation. The Surface Temperature filenames use ProductID appended with the suffix "_ST_" followed by the band designation.

Following are the components of a typical ProductID:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX
(e.g., LC08_L2SP_039037_20150728_20200318_02_T1)

L	Landsat
X	Sensor ("O" = OLI; "T" = TIRS; "C" = OLI/TIRS)
SS	Satellite ("08" = Landsat 8, "09" = Landsat 9)
LLLL	Processing correction level ("L2SP" if SR and ST are generated or "L2SR" if ST could not be generated)
PPP	Path
RRR	Row
YYYY	Year of acquisition
MM	Month of acquisition
DD	Day of acquisition
yyyy	Year of Level 2 processing
mm	Month of Level 2 processing
dd	Day of Level 2 processing
CX	Collection number ("02")
TX	Collection category ("T1" = Tier 1; "T2" = Tier 2)

The suffixes that append the file names are listed in Table 6-1, and typically include a band type (SR, ST, QA), a band name, and a file format extension ('TIF', 'xml', 'txt', 'json').

Section 6 Product Characteristics

6.1 Band Specifications

Collection 2 Landsat 8-9 L2SP are generated at 30-meter spatial resolution on a Universal Transverse Mercator (UTM) or Polar Stereographic (PS) mapping grid. Table 6-1 lists the specifications for Collection 2 L2SP bands. All packages include Extensible Markup Language (XML) and JavaScript Object Notation (JSON)-based metadata.

Collection 2 Landsat 8-9 L2SP are delivered in files named with the ProductID and appended with "_SR_" or "_ST_" followed by the band designation. The default file format is COG. The QA_PIXEL, SR_QA_AEROSOL, and QA_RADSAT bands are delivered as bit-packed layers.

The ST intermediate bands are delivered with the ST product. These layer bands are used in the creation of the ST band. The ST_TRAD band contains the Level 1 thermal band converted to thermal surface radiance. The ST_URAD and ST_DRAD bands respectively contain the upwelled and downwelled thermal radiance. The ST_ATRAN band contains the atmospheric transmittance. The ST_EMIS band and ST_EMSD band contain the calculated surface emissivity and its expected standard deviation.

The ST_QA band contains the uncertainty of the ST band, in Kelvin. The ST_CDIST band contains the distance of the pixel from the nearest cloud labeled in the QA_PIXEL band, in kilometers.

Band Designation	Band Name	Data Type	Units	Data Range	Valid Range	Fill Value	Multiplicative Scale Factor	Additive Offset
ProductID_SR_B1	Band 1 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B2	Band 2 SR	UINT16	Reflectance	1 - 65535	7273 – 43636	0	0.0000275	-0.2
ProductID_SR_B3	Band 3 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B4	Band 4 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B5	Band 5 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B6	Band 6 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B7	Band 7 SR	UINT16	Reflectance	1 - 65535	7273 - 43636	0	0.0000275	-0.2
ProductID_ST_B10	Band 10 ST	UINT16	Kelvin	1 - 65535	293 - 61440	0	0.00341802	149
ProductID_QA_PIXEL	Level 2 Pixel Quality Band	UINT16	Bit Index	1 - 65535	21824 – 65534	1	NA	NA
ProductID_SR_QA_AEROSOL	Aerosol QA	UINT8	Bit Index	0 - 255	1 - 255	1	NA	NA
ProductID_QA_RADSAT	Radiometric Saturation QA	UINT16	Bit Index	0 - 65535	0 - 3829	NA	NA	NA
ProductID_ST_QA	Surface Temperature Uncertainty	INT16	Kelvin	0 - 32767	0 - 32767	-9999	0.01	NA
ProductID_ST_TRAD	Thermal Radiance	INT16	W/(m^2.sr.μm)/ DN	0 - 22000	0 – 22000	-9999	0.001	NA
ProductID_ST_URAD	Upwelled Radiance	INT16	W/(m^2.sr.μm)/ DN	0 - 28000	0 – 28000	-9999	0.001	NA
ProductID_ST_DRAD	Downwelled Radiance	INT16	W/(m^2.sr.μm)/ DN	0 - 28000	0 - 28000	-9999	0.001	NA
ProductID_ST_ATRAN	Atmospheric Transmittance	INT16	Unitless	0 - 10000	0 - 10000	-9999	0.0001	NA
ProductID_ST_EMIS	Emissivity estimated from ASTER GED	INT16	Unitless	0 - 10000	0 - 10000	-9999	0.0001	NA
ProductID_ST_EMSD	Emissivity standard deviation	INT16	Unitless	0 - 32767	0 – 10000	-9999	0.0001	NA
ProductID_ST_CDIST	Pixel distance to cloud	INT16	Kilometers	0 - 24000	0 – 24000	-9999	0.01	NA
ProductID_MTL	Level 2 Metadata file	NA	NA	NA	NA	NA	NA	NA

Table 6-1. Collection 2 (C2) Landsat 8-9 Level 2 Science Products (L2SP) Band Specifications

6.1.1 Cloud and Cloud Shadow Specifications

The Level 2 Pixel Quality Assessment band (QA_PIXEL) includes the information from the Level 1 Quality Assessment (QA_PIXEL) band which is carried through unchanged into Level 2 product package. The Cloud Confidence, Cloud Shadow, and Snow/Ice flags derived from the CFMask algorithm version 3.3.1. In order to support higher level science data products, water values are re-calculated, and high-confidence cloud pixels are dilated, making QA_PIXEL comparable to the legacy CFMask bands. Cloud Shadow, Snow/Ice, and Cirrus Confidence flags in bits 10-15 each have a reserved value for future improvements. They match the respective flags in bits 2, 4, and 5 and may be used interchangeably. Specific details about Landsat Collection 2 Cloud Cover Assessment (CCA) algorithm can be found in Section 4.4.18 of the LSDS-1747 Landsat 8-9 OLI/TIRS Calibration / Validation Algorithm Description Document.

Table 6-2 describes the bit assignments for the QA_PIXEL band. Most common QA_PIXEL bit values are given in Table 6-3.

Bit	Flag Description	Values
0	Fill	0 for image data 1 for fill data
1	Dilated Cloud	0 for cloud is not dilated or no cloud 1 for cloud dilation
2	Cirrus	0 for Cirrus Confidence: no confidence level set or Low Confidence 1 for high confidence cirrus
3	Cloud	0 for cloud confidence is not high 1 for high confidence cloud
4	Cloud Shadow	0 for Cloud Shadow Confidence is not high 1 for high confidence cloud shadow
5	Snow	0 for Snow/Ice Confidence is not high 1 for high confidence snow cover
6	Clear	0 if Cloud or Dilated Cloud bits are set 1 if Cloud and Dilated Cloud bits are not set
7	Water	0 for land or cloud 1 for water
8-9	Cloud Confidence	00 for no confidence level set 01 Low confidence 10 Medium confidence 11 High confidence
10-11	Cloud Shadow Confidence	00 for no confidence level set 01 Low confidence 10 Reserved 11 High confidence
12-13	Snow/Ice Confidence	00 for no confidence level set 01 Low confidence 10 Reserved 11 High confidence
14-15	Cirrus Confidence	00 for no confidence level set 01 Low confidence 10 Reserved 11 High confidence

Table 6-2. Landsat 8-9 Pixel Quality Assessment (QA_PIXEL) Bit Index

Pixel Value	Fill	Dilated Cloud	Cirrus	Cloud	Cloud Shadow	Snow	Clear	Water	Cloud Conf.	Cloud Shadow Conf.	Snow/ Ice Conf.	Cirrus Conf.	Pixel Description
1	Yes	No	No	No	No	No	No	No	None	None	None	None	Fill
21824	No	No	No	No	No	No	Yes	No	Low	Low	Low	Low	Clear with lows set
21826	No	Yes	No	No	No	No	Yes	No	Low	Low	Low	Low	Dilated cloud over land
21888	No	No	No	No	No	No	No	Yes	Low	Low	Low	Low	Water with lows set
21890	No	Yes	No	No	No	No	No	Yes	Low	Low	Low	Low	Dilated cloud over water
22080	No	No	No	No	No	No	Yes	No	Mid	Low	Low	Low	Mid conf cloud
22144	No	No	No	No	No	No	No	Yes	Mid	Low	Low	Low	Mid conf cloud over water
22280	No	No	No	Yes	No	No	No	No	High	Low	Low	Low	High conf Cloud
23888	No	No	No	No	Yes	No	Yes	No	Low	High	Low	Low	High conf cloud shadow
23952	No	No	No	No	Yes	No	No	Yes	Low	High	Low	Low	Water with cloud shadow
24088	No	No	No	Yes	Yes	No	No	No	Mid	High	Low	Low	Mid conf cloud with shadow
24216	No	No	No	Yes	Yes	No	No	Yes	Mid	High	Low	Low	Mid conf cloud with shadow over water
24344	No	No	No	Yes	Yes	No	No	No	High	High	Low	Low	High conf cloud with shadow
24472	No	No	No	Yes	Yes	No	No	Yes	High	High	Low	Low	High conf cloud with shadow over water
30048	No	No	No	No	No	Yes	Yes	No	Low	Low	High	Low	High conf snow/ice
54596	No	No	Yes	No	No	No	Yes	No	Low	Low	Low	High	High conf Cirrus
54852	No	No	Yes	No	No	No	Yes	No	Mid	Low	Low	High	Cirrus, mid cloud
55052	No	No	Yes	Yes	No	No	No	No	High	Low	Low	High	Cirrus, high cloud
56856	No	No	No	Yes	Yes	No	No	No	Mid	High	Low	High	Cirrus, mid conf cloud, shadow
56984	No	No	No	Yes	Yes	No	No	Yes	Mid	High	Low	High	Cirrus, mid conf cloud, shadow, over water
57240	No	No	No	Yes	Yes	No	No	Yes	High	High	Low	High	Cirrus, high conf cloud, shadow

Table 6-3. Landsat 8-9 Pixel Quality Assessment (QA_PIXEL) Value Interpretations

The algorithm underlying the QA_PIXEL band, 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 (CFMask). The Collection 2 QA_PIXEL is generated from CFMask version 3.3.1 (derived from Fmask version 3.3).

6.1.1.1 CFMask Algorithm Known Issues

1. The cloud indicators in the CFMask algorithm 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.

6.1.2 Radiometric Saturation Band

The Radiometric Saturation Quality Assessment (QA_RADSAT) band is a bit-packed representation of which sensor bands were saturated during data capture, yielding unusable data. Table 6-4 displays the interpretation of possible pixel values expected in the QA_RADSAT band after its bits are unpacked. For example, a pixel value of 512 indicates that OLI Band 9 is saturated.

Saturation in Landsat 8-9 is not common. When saturation does occur, it happens over reflective surfaces in the optical bands, or volcanoes and wildfires in the Shortwave Infrared (SWIR) and thermal bands. Saturation can be found in two forms: one, saturated pixels can show as the maximum unsigned 16-bit value of 65535; or two, 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 only occurs with OLI and will not occur with the TIRS thermal bands. The L8-L9 QA_RADSAT band will flag only the saturation cases. Table 6-4 describes the bit assignments for the QA_RADSAT band.

Bit	Flag Description	Values
0	Band 1 Data Saturation	0 no saturation 1 saturated data
1	Band 2 Data Saturation	0 no saturation 1 saturated data
2	Band 3 Data Saturation	0 no saturation 1 saturated data
3	Band 4 Data Saturation	0 no saturation 1 saturated data
4	Band 5 Data Saturation	0 no saturation 1 saturated data
5	Band 6 Data Saturation	0 no saturation 1 saturated data
6	Band 7 Data Saturation	0 no saturation 1 saturated data
7	Unused	0 not checked
8	Band 9 Data Saturation	0 no saturation 1 saturated data
9	Unused	0
10	Unused	0
11	Terrain occlusion	0 no terrain occlusion 1 terrain occlusion
12	Unused	0
13	Unused	0
14	Unused	0
15	Unused	0

Table 6-4. Landsat 8-9 Radiometric Saturation Quality Assessment (QA_RADSAT) Bit Index

6.1.3 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 Assessment (QA_SR_AEROSOL) band is delivered with the Surface Reflectance product to provide low-level detail about the factors that may have influenced the final product result (as shown in Table 6-5). Example QA_SR_AEROSOL bit values are given in Table 6-6, and shown in greater detail in Table 6-7.

Bit	Flag Description	Values
0	Fill	0 Pixel is not fill 1 Pixel is fill
1	Valid aerosol retrieval	0 Pixel retrieval is not valid 1 Pixel retrieval is valid
2	Water	0 Pixel is not water 1 Pixel is water
3	Unused	0
4	Unused	0
5	Interpolated Aerosol	0 Pixel is not aerosol interpolated 1 Pixel is aerosol interpolated
6 7	Aerosol Level	00 Climatology 01 Low 10 Medium 11 High
0 is Least Significant Bit, 7 is Most Significant Bit		

Table 6-5. Landsat 8-9 Internal Surface Reflectance Aerosol Quality Assessment (SR_QA_AEROSOL) Bit Index

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

Attribute	Pixel Value
Fill	1
Valid Aerosol Retrieval (center pixel of 3x3 window)	2, 66, 130, 194
Water Pixel (or water pixel was used in the fill-the-window interpolation)	4, 68, 100, 132, 164, 196, 228
Non-center window pixel for which aerosol was interpolated from surrounding 3x3 center pixels	32, 96, 100, 160, 164, 224, 228
Low-level aerosol	66, 68, 96, 100
Medium-level aerosol	130, 132, 160, 164
High-level aerosol	192, 194, 196, 224, 228

Table 6-6. Landsat 8-9 SR_QA_AEROSOL Values

Pixel Value	Fill	Aerosol Retrieval – Valid (center of 3x3 window)	Water	Aerosol Retrieval – Interpolated (non-center of 3x3 window)	Aerosol	Pixel Description
1	Yes	No	No	No	NA	Fill
2	No	Yes	No	No	Climatology	Valid aerosol retrieval
4	No	No	Yes	No	Climatology	Water
32	No	No	No	Yes	Climatology	Aerosol interpolated
66	No	Yes	No	No	Low	Valid aerosol ret., low aerosol
68	No	No	Yes	No	Low	Water, low aerosol
96	No	No	No	Yes	Low	Aerosol interpolated, low aerosol
100	No	No	Yes	Yes	Low	Water pixel used in interpolation,

Pixel Value	Fill	Aerosol Retrieval – Valid (center of 3x3 window)	Water	Aerosol Retrieval – Interpolated (non-center of 3x3 window)	Aerosol	Pixel Description
						aerosol interpolated, low aerosol
130	No	Yes	No	No	Medium	Valid aerosol retrieval, medium aerosol
132	No	No	Yes	No	Medium	Water, medium aerosol
160	No	No	No	Yes	Medium	Aerosol interpolated, medium aerosol
164	No	No	Yes	Yes	Medium	Water pixel used in interpolation, aerosol interpolated, medium aerosol
192	No	No	No	No	High	High aerosol
194	No	Yes	No	No	High	Valid aerosol retrieval, high aerosol
196	No	No	Yes	No	High	Water, high aerosol
224	No	No	No	Yes	High	Aerosol interpolated, high aerosol
228	No	No	Yes	Yes	High	Water pixel used in interpolation, aerosol interpolated, high aerosol

Table 6-7. Landsat 8-9 SR_QA_AEROSOL Value Interpretations

6.1.4 Level 2 Metadata

Each Landsat 8-9 Level 2 Science Product package contains an XML-based (_MTL.xml), a JSON-based (_MTL.json), and a text-based (_MTL.txt) metadata file. The metadata parameters included in the xml are listed in Appendix A.

6.1.5 Level 2 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 7 Auxiliary Data

7.1 Surface Reflectance 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 LaSRC, auxiliary 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 auxiliary data within the ground area imaged and time of the Landsat image acquisition. This information is derived from multiple data sources.

7.1.1 Landsat 8 Ratio Map

This file of band ratio averages is used by the LaSRC algorithm for aerosol retrieval calculation in Landsat 8-9 Surface Reflectance processing. This file is static and not updated. It is available at:
https://landsat.usgs.gov/sites/default/files/documents/ratiomapndwiexp.hdf

7.1.2 ETOPO5

The Earth Topography Five Minute Grid (ETOPO5) (CMGDEM) is a gridded global elevation data model derived from several sources at a resolution of 5 minutes and is used in surface reflectance algorithms for Landsat 4-9 data. It is stored in Hierarchical Data Format Version 4 (HDF4) format. This file is static and is not updated.

7.1.3 LDCMLUT

The Landsat Data Continuity Mission Look Up Tables (LDCMLUT) are four files used by the LaSRC algorithm in Landsat 8 Surface Reflectance processing.

- ANGLE_NEW.hdf - scattering, view, and sun angles
- RES_LUT_V3.0-URBANCLEAN-V2.0.hdf - intrinsic reflectance information
- AERO_LUT_V3.0-URBANCLEAN-V2.0.ASCII - spherical albedo information
- TRANS_LUT_V3.0-URBANCLEAN-V2.0.ASCII - transmission information

7.1.4 MODIS Fused Data

Water vapor and ozone data are extracted from two MODIS Climate Modeling Grids for use in the (SR) algorithm for Landsat 8-9 data:

- MODIS Aerosol Optical Thickness Daily Climate Modeling Grid (MOD09CMA and MYD09CMA): Global products generated daily. Pixels with cloud cover or high solar zenith angles are excluded. These products are in geographic projection with a 0.05 degree spatial resolution. Water vapor data are extracted from these products.

- MODIS SR Daily Climate Modeling Grid (MOD09CMG and MYD09CMG): Global products generated daily. Pixels with cloud cover, high solar zenith angle, and high blue reflectance are excluded. These products are in geographic projection with a 0.05 degree spatial resolution. Ozone data is extracted from these products.

The data are combined to create a single daily Hierarchical Data Format (HDF) file that contains only water vapor and ozone values. MODIS Terra data are used, if available for both water vapor and ozone data. When Terra data are not available, MODIS Aqua data are used to fill in missing values (if available). If Terra data and Aqua data are both unavailable, fill values are generated by interpolation.

7.2 Surface Temperature Auxiliary Data

7.2.1 ASTER Emissivity Data

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an instrument on the Terra satellite. ASTER Global Emissivity Dataset (GED) is a global, 100-meter spatial resolution emissivity map of the Earth's non-frozen land surfaces at different wavelengths in the thermal infrared spectrum. ASTER GED emissivity and emissivity standard deviations for Bands 13, 14, and Normalized Difference Vegetation Index (NDVI) are used in the surface temperature algorithm for Landsat 4-9 data.

7.2.2 GEOS-5 FP-IT Data

The Goddard Earth Observing System Model, Version 5, Forward Processing for Instrument Teams (GEOS-5 FP-IT) data is a system of models integrated using the Earth System Modeling Framework that began in 2000. GEOS-5 FP-IT data are used in the surface temperature algorithm for Landsat 8-9 data starting in March 2013, to present. GEOS-5 FP-IT data are updated every three hours and are delivered in 8 files per day. New files that contain the subset of the GEOS-5 FP-IT data are created for Landsat Level 2 surface temperature processing.

Section 8 Citation Information

There are no restrictions on the use of 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 Collection 2 Level 2 Science Products courtesy of the U.S. Geological Survey.

Cook, Monica J., "Atmospheric Compensation for a Landsat Land Surface Temperature Product" (2014). Thesis. Rochester Institute of Technology. Accessed from http://scholarworks.rit.edu/theses/8513.

Cook, M., Schott, J.R., Mandel, J., & Raqueno, N. (2014). Development of an operational calibration methodology for the Landsat thermal data archive and initial testing of the atmospheric compensation component of a Land Surface Temperature (LST) Product from the archive. Remote Sensing, 6(11), 11244-11266. http://dx.doi.org/10.3390/rs61111244.

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, 185, 46-56. 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 9 Acknowledgments

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

The original Landsat Single-Channel Surface Temperature code was developed by Monica Cook at Rochester Institute of Technology.

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/gersl/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

Description	Example File Size (Kbytes)	Example File Name
Surface Reflectance Bands (7)	83,000	LC08_L2SP_140041_20130503_20190828_02_T1_SR_B*.TIF
Surface Temperature Band	83,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_B10.TIF
Level 2 Pixel QA	123,220	LC08_L2SP_140041_20130503_20190828_02_T1_QA_PIXEL.TIF
Surface Reflectance Aerosol QA Band	6,000	LC08_L2SP_140041_20130503_20190828_02_T1_SR_QA_AEROSOL.TIF
Radiometric Saturation QA Band	123,220	LC08_L2SP_140041_20130503_20190828_02_T1_QA_RADSAT.TIF
Surface Temperature Atmospheric Transmittance Band	25,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_ATRAN.TIF
Pixel Distance to Cloud Band	17,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_CDIST.TIF
Thermal Downwelled Radiance Band	29,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_DRAD.TIF
Emissivity Band	33,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_EMIS.TIF
Emissivity Band Standard Deviation	24,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_EMSD.TIF
Surface Temperature Uncertainty Band	29,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_QA.TIF
Thermal Radiance Band	75,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_TRAD.TIF
Thermal Upwelled Radiance Band	24,000	LC08_L2SP_140041_20130503_20190828_02_T1_ST_URAD.TIF
Level 2 Metadata	15	LC08_L2SP_140041_20130503_20190828_02_T1_MTL.txt
Level 2 XML Metadata	23	LC08_L2SP_140041_20130503_20190828_02_T1_MTL.xml

Table A-1. Collection 2 Default File Characteristics

Appendix B Metadata Fields

Example of global XML metadata:


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Appendix C Acronyms

6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ADD	Algorithm Description Document
ANG	Angle Coefficients file extension
AOT	Aerosol Optical Thickness
ASTER GED	Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Dataset
BT	Brightness Temperature
C2	Landsat Collection 2
Cal/Val	Calibration and Validation
CCA	Cloud Cover Assessment
CDIST	Distance to Cloud
CFMask	C version of Function of Mask (USGS EROS)
CMA	Climate Modeling Grid - Aerosol
CMG	Climate Modeling Grid
COG	Cloud Optimized GeoTIFF
DDV	Dark Dense Vegetation
DEM	Digital Elevation Model
DFCB	Data Format Control Book
DN	Digital Number
EE	EarthExplorer
EROS	Earth Resources Observation and Science
ESPA	EROS Science Processing Architecture
ETM+	Enhanced Thematic Mapper Plus
ETOPO5	Earth Topography Five Minute Grid
Fmask	Function of Mask (Boston University)
GEOS-5 FP-IT	Goddard Earth Observing System, Version 5 Forward Processing for Instrument Teams
GeoTIFF	Georeferenced Tagged Image File Format
GRI	Global Reference Image
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
INT	Signed Integer
INT16	16-bit Signed Integer
JPL	Jet Propulsion Laboratory
L1	Level 1
L1GS	Level 1 Systemic
L1GT	Level 1 Systematic Terrain
L1TP	Level 1 Terrain Precision
L2	Level 2
L2SP	Level 2 Science Product
L2SR	Level 2 Science Product, Reflectance only

LaSRC	Land Surface Reflectance Code
LDCM	Landsat Data Continuity Mission
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LP DAAC	Land Processes Distributed Active Archive Center
LSB	Least Significant Bit
LUT	Look-up Table
MATLAB	Matrix Laboratory
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MERRA-2	Modern-Era Retrospective analysis for Research and Application
MOD	MODIS Terra
MODIS	Moderate Resolution Imaging Spectroradiometer
MSB	Most Significant Bit
MTL	Metadata text file extension
MYD	MODIS Aqua
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
PS	Polar Stereographic
QA	Quality Assessment
QA_PIXEL	Pixel Quality Assessment
QA_RADSAT	Radiometric Saturation Quality
RIT	Rochester Institute of Technology
RT	Real-Time
SR	Surface Reflectance
ST	Surface Temperature
SWIR	Shortwave Infrared
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
WRS-2	Worldwide Reference System-2
XML	Extensible Markup Language

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