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LANDSAT 8
SURFACE REFLECTANCE CODE (LASRC)
PRODUCT GUIDE

Version 2.0

May 2019

USGS
science for a changing world

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PRODUCT GUIDE

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Executive Summary

This document describes relevant characteristics of the Landsat 8 Surface Reflectance (SR), Top of Atmosphere (TOA) Reflectance, and TOA Brightness Temperature (BT) products to facilitate their use in the land remote sensing community.

SR and TOA Reflectance are derived from Landsat 8 Operational Land Imager (OLI); TOA BT is derived from Landsat 8 OLI and Thermal Infrared Sensor (TIRS) data using the Landsat 8 Surface Reflectance Code (LaSRC).

Information about Surface Reflectance processing of Landsat 4-5, and Landsat 7 data can be found in the Landsat 4-7 Ecosystem Disturbance Adaptive Processing System (LEDAPS) Product Guide.

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

Document History

Document Number	Document Version	Publication Date	Change Number
LSDS-1368	Version 1.0	December 2018	CR 14577
LSDS-1368	Version 2.0	May 2019	CR 14853

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Section 1 Introduction

1.1 Background

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

Landsat 8 SR data products are generated from specialized software called Landsat 8 Surface Reflectance Code (LaSRC). The original Landsat 8 Surface Reflectance Code (LaSRC) algorithm was developed by Dr. Eric Vermote, National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), and was modified by staff at 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 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 GTOPO5 to generate Surface Reflectance. The result is delivered as the Landsat Surface Reflectance data product.

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

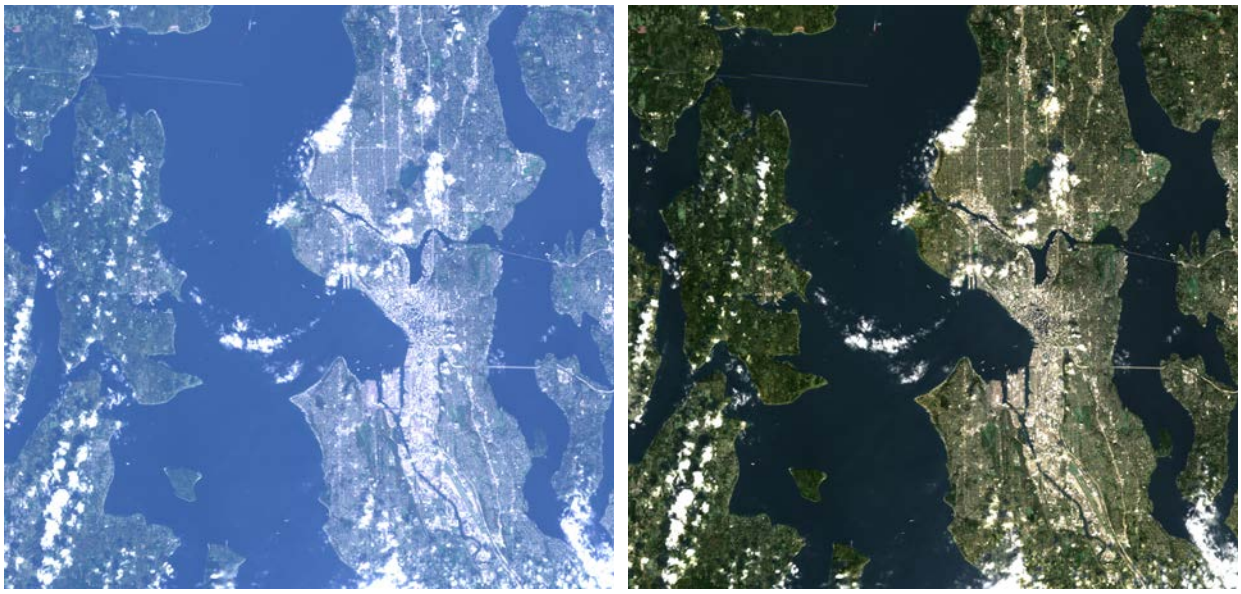

Figure 1-1. Example of LaSRC Atmospheric Correction: Left, Top of Atmosphere Reflectance Image; Right, Surface Reflectance Image

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

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

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

1.2 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 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 auxiliary data
- Section 8 provides document citation information
- Section 9 provides document acknowledgements
- Section 10 provides User Services contact information
- Appendix A provides glossary terms and definitions
- Appendix A provides a list of metadata fields
- Appendix C provides a list of acronyms
- Appendix A provides the document change history
- The References section contains a list of reference documents

Section 2 Known Issues

The missing Climate Modeling Grid (CMG) aerosol values can cause a “blockiness” artifact in the 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_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.

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. This resulted in significant blockiness along the coastal areas. Given the change in the new version of LaSRC to use a separate algorithm for pixels identified as water, the coastal water mask has been removed from the processing stream.

However, some low-radiance speckling still appears 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.

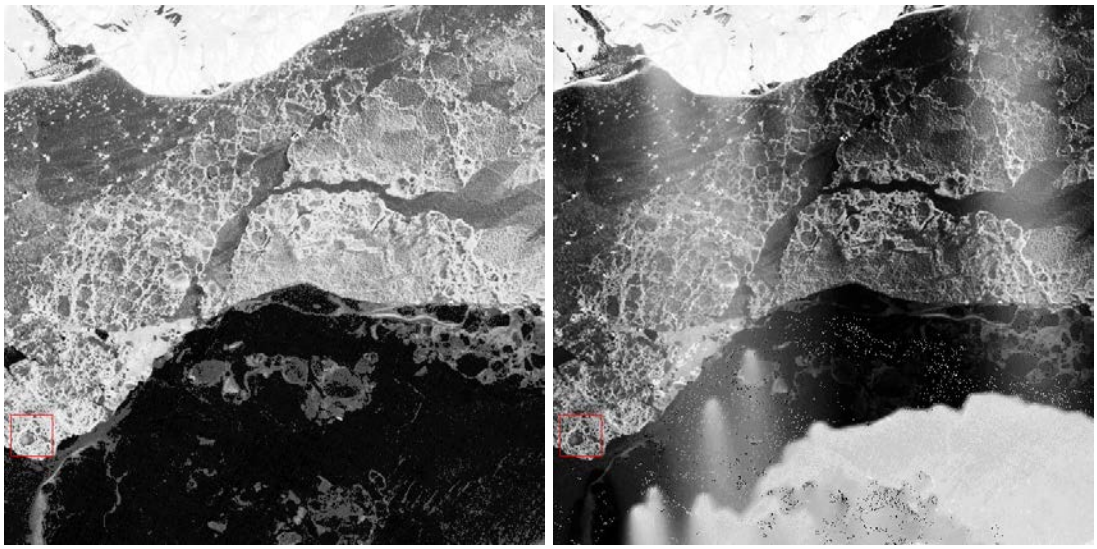

Figure 2-1. Example of speckling in Surface Reflectance bands (right), with Top of Atmosphere (TOA) Reflectance (left) shown for reference.

Section 3 Caveats and Constraints

1. Surface Reflectance can be processed on Landsat scenes within 3-5 days of acquisition.
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. The following date range apply to the availability of Landsat archive for Surface Reflectance processing, with the exceptions noted in #4 below:
    - Landsat 8 OLI/ TIRS: February 2013 to within one week of present
4. Landsat 8 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/land-resources/nli/landsat/landsat-surface-reflectance.
5. 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 6.1.2).
6. Surface Reflectance cannot be run on Landsat 8 Pre-Worldwide Reference System 2 (WRS-2) scenes. More information about Pre-WRS-2 scenes can be found at https://www.usgs.gov/land-resources/nli/landsat/landsat-8.
7. TOA Reflectance data are derived using per-pixel solar illumination angles generated from the angle coefficient file. Previously, the scene center solar illumination angle from the Metadata text file extension (MTL) file was used. This will impact the SR data products, as they are derived from TOA Reflectance.
    - This should ideally improve the accuracy of the TOA Reflectance and subsequent SR corrections.
    - Scene center solar illumination and sensor view angles (i.e., not per-pixel) are still used in the SR processing, as the Lookup Table routines are called on a grid that is spatially coarser than the resolution of the Landsat data, therefore not necessitating per-pixel angle information.
8. Landsat 8 Real-Time (RT) Collection 1 data can be processed to Surface Reflectance once the auxiliary data become available. Note that RT data will not have finalized geometric or radiometric processing, so the follow-on processing to place the data in Tier 1 (T1) or Tier 2 (T2) categories (approx. 14 days after acquisition) will likely be different than the Real Time data. See https://www.usgs.gov/land-resources/nli/landsat/landsat-collection-1 for more information on the differences between RT and T1/T2 data sets.
9. Landsat 8 TIRS-only data (LT08) cannot currently be processed to TOA Brightness Temperature.

10. 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.
11. For reasons mentioned above, users are cautioned against processing data acquired over high latitudes (> 65º) to Surface Reflectance.
12. Users are cautioned against using pixels flagged as high aerosol content. See Section 6.1.2 for details.
13. There are additional adverse conditions that can affect the efficacy of Landsat 8 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
14. Landsat 8 OLI Band 8 (panchromatic band) is not processed to Top of Atmosphere or Surface Reflectance.

Section 4 Product Access

Processing requests for Landsat 8 Surface Reflectance data products can be submitted through EarthExplorer, under the “Data Sets” tab > “Landsat” > “Landsat Collection 1 Level 2 (On Demand)”, then “Landsat 8 OLI/TIRS C1 Level 2”.

The USGS EROS Center Science Processing Architecture (ESPA) On-demand interface (https://espa.cr.usgs.gov/) offers Landsat 8 Surface Reflectance, in addition to Input Level 1 Products and Metadata, TOA Reflectance, TOA Brightness Temperature, NDVI, NDMI, NBR, NBR2, SAVI, MSAVI, and EVI data products. Services such as reprojection, spatial subsetting, and pixel resizing are also available.

Additional information about ESPA’s spectral indices and service processing options for Landsat 4–8 can be found on the Landsat Surface Reflectance Spectral Indices web page and in the ESPA On-Demand Interface User Guide.

Section 5 Product Packaging

Surface Reflectance products are supplied in a gzip file (.tar.gz). Unzipping this file produces a tarball (.tar), which will “untar” to a Georeferenced Tagged Image File Format (GeoTIFF; .tif) file. The filenames are structured as the Level 1 product identifier (productID) appended with the suffix “_sr_” followed by a band designation to denote the Surface Reflectance transformation.

Following are the components of a typical Collection 1 file:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX_prod_band.ext
(e.g., 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 Level 1 processing
mm	Month of Level 1 processing
dd	Day of Level 1 processing
CX	Collection number (“01”, “02”, etc.)
TX	Collection category (“RT” = Real-Time; “T1” = Tier 1; “T2” = Tier 2)
prod	Product, such as “toa” or “sr”
band	Band, such as “band<1-11>,” “qa,” or spectral index.
ext	File format extension, such as “tif”, “tfw”, “xml”, “hdf”, “hdr”, “nc”, or “img”

Section 6 Product Characteristics

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

6.1 Surface Reflectance Specifications

Landsat 8 Surface Reflectance products are generated at 30-meter spatial resolution on a Universal Transverse Mercator (UTM) or Polar Stereographic (PS) mapping grid. The default file format is GeoTIFF, but options for delivery in Hierarchical Data Format – Earth Observing System – 2 (HDF-EOS-2; .hdf), Network Common Data Form (.NetCDF) or Exelis Visual Information Solutions (ENVI) binary (.img) are available through the ESPA Ordering Interface. More information on output formats currently used for Landsat 4–8 can be found in the ESPA On Demand Interface User Guide.

Landsat 8 Surface Reflectance are delivered in files named with the productID and appended with "_sr_" followed by a band designation. All packages include Extensible Markup Language (xml)-based metadata.

The Surface Reflectance bands are delivered in separate, condition-specific files, with the exception of the Aerosol QA Band, which is delivered in a single bit-packed layer (For more details on Aerosol QA band see Section 6.1.2). Table 6-1 lists the specifications for the bands included in a Surface Reflectance data file. Table 6-2 describes the bit assignments for the pixel_qa band. The pixel_qa bit values are given in Table 6-3, and shown in greater detail in Table 6-4.

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
ProductID_sr_band1	Band 1	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band2	Band 2	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band3	Band 3	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band4	Band 4	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band5	Band 5	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band6	Band 6	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_sr_band7	Band 7	INT16	Reflectance	-2000 – 16000	0 - 10000	-9999	20000	0.0001
ProductID_pixel_qa	Level 2 Pixel Quality Band	UINT16	Bit Index	0-32768	0-32768	1 (bit 0)	NA	NA
ProductID_sr_aerosol	Aerosol QA	UINT8	Bit Index	0 - 255	0 - 255	NA	NA	NA
ProductID_radsat_qa	Radiometric Saturation QA	UINT16	Bit Index	0-32768	0-3839	1 (bit 0)	NA	NA
ProductID_MTL.txt	Level 1 Metadata file	NA	NA	NA	NA	NA	NA	NA

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
ProductID_ANG.txt	Level 1 Angle Coefficient file	NA	NA	NA	NA	NA	NA	NA
INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, QA = quality assessment, CFMask = C version of Function of Mask, NA = not applicable								

Table 6-1. Surface Reflectance Specifications

Bit	Bit Value	Cumulative Sum	Attribute
0	1	1	Fill
1	2	3	Clear
2	4	7	Water
3	8	15	Cloud Shadow
4	16	31	Snow
5	32	63	Cloud
6	64	127	Cloud Confidence 00 = None 01 = Low 10 = Medium 11 = High
7	128	255	
8	256	511	Cirrus Confidence 00 = Not set 01 = low from OLI band 9 reflectance 10 = medium from OLI band 9 reflectance (Not used) 11 = high from OLI band 9 reflectance
9	512	1023	
10	1024	2047	Terrain Occlusion
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32768	65535	Unused

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

Attribute	Pixel Value
Fill	1
Clear	322, 386, 834, 898, 1346
Water	324, 388, 836, 900, 1348
Cloud shadow	328, 392, 840, 904, 1350
Snow/ice	336, 368, 400, 432, 848, 880, 912, 944, 1352
Cloud	352, 368, 416, 432, 480, 864, 880, 928, 944, 992
Low confidence cloud	322, 324, 328, 336, 352, 368, 834, 836, 840, 848, 864, 880
Medium confidence cloud	386, 388, 392, 400, 416, 432, 898, 900, 904, 928, 944
High confidence cloud	480, 992
Low confidence cirrus	322, 324, 328, 336, 352, 368, 386, 388, 392, 400, 416, 432, 480
High confidence cirrus	834, 836, 840, 848, 864, 880, 898, 900, 904, 912, 928, 944, 992
Terrain occlusion	1346, 1348, 1350, 1352

Table 6-3. Landsat 8 Pixel Quality Assessment (pixel_qa) Values

Pixel Value	Fill	Clear	Water	Cloud Shadow	Snow	Cloud	Cloud Confidence	Cirrus Confidence	Terrain Occlusion	Pixel Description
1	Yes	No	No	No	No	No	None	None	No	Fill value
322	No	Yes	No	No	No	No	Low	Low	No	Clear terrain, low-confidence cloud, low-confidence cirrus
324	No	No	Yes	No	No	No	Low	Low	No	Water, low-confidence cloud, low-confidence cirrus
328	No	No	No	Yes	No	No	Low	Low	No	Cloud shadow, low-confidence cloud, low-confidence cirrus
336	No	No	No	No	Yes	No	Low	Low	No	Snow/ice, low-confidence cloud, low-confidence cirrus
352	No	No	No	No	No	Yes	Low	Low	No	Cloud, low-confidence cloud, low-confidence cirrus
368	No	No	No	No	Yes	Yes	Low	Low	No	Snow/ice, cloud, low-confidence cloud, low confidence cirrus
386	No	Yes	No	No	No	No	Medium	Low	No	Clear terrain, medium-confidence cloud, low-confidence cirrus
388	No	No	Yes	No	No	No	Medium	Low	No	Water, medium-confidence cloud, low-confidence cirrus
392	No	No	No	Yes	No	No	Medium	Low	No	Cloud shadow, medium-confidence cloud, low-confidence cirrus

Pixel Value	Fill	Clear	Water	Cloud Shadow	Snow	Cloud	Cloud Confidence	Cirrus Confidence	Terrain Occlusion	Pixel Description
400	No	No	No	No	Yes	No	Medium	Low	No	Snow/ice, medium-confidence cloud, low-confidence cirrus
416	No	No	No	No	No	Yes	Medium	Low	No	Cloud, medium-confidence cloud, low-confidence cirrus
432	No	No	No	No	Yes	Yes	Medium	Low	No	Snow/ice, cloud, medium-confidence cloud, low-confidence cirrus
480	No	No	No	No	No	Yes	High	Low	No	Cloud, high-confidence cloud, low-confidence cirrus
834	No	Yes	No	No	No	No	Low	High	No	Clear terrain, low-confidence cloud, high-confidence cirrus
836	No	No	Yes	No	No	No	Low	High	No	Water, low-confidence cloud, high-confidence cirrus
840	No	No	No	Yes	No	No	Low	High	No	Cloud shadow, low-confidence cloud, high-confidence cirrus
848	No	No	No	No	Yes	No	Low	High	No	Snow/ice, low-confidence cloud, high-confidence cirrus
864	No	No	No	No	No	Yes	Low	High	No	Cloud, low-confidence cloud, high-confidence cirrus
880	No	No	No	No	Yes	Yes	Low	High	No	Cloud, snow/ice, low conf. cloud, high conf. cirrus

Pixel Value	Fill	Clear	Water	Cloud Shadow	Snow	Cloud	Cloud Confidence	Cirrus Confidence	Terrain Occlusion	Pixel Description
898	No	Yes	No	No	No	No	Medium	High	No	Clear terrain, medium-confidence cloud, high-confidence cirrus
900	No	No	Yes	No	No	No	Medium	High	No	Water, medium-confidence cloud, high-confidence cirrus
904	No	No	No	Yes	No	No	Medium	High	No	Cloud shadow, medium-confidence cloud, high-confidence cirrus
912	No	No	No	No	Yes	No	Medium	High	No	Snow/ice, medium-confidence cloud, high-confidence cirrus
928	No	No	No	No	No	Yes	Medium	High	No	Cloud, medium-confidence cloud, high-confidence cirrus
944	No	No	No	No	Yes	Yes	Medium	High	No	Cloud, snow/ice, medium conf. cloud, high conf. cirrus
992	No	No	No	No	No	Yes	High	High	No	Cloud, high-confidence cloud, high-confidence cirrus
1346	No	Yes	No	No	No	No	Low	Low	Yes	Clear terrain, terrain occluded
1348	No	No	Yes	No	No	No	Low	Low	Yes	Water, terrain occluded
1350	No	Yes	Yes	No	No	No	Low	Low	Yes	Clear, water, terrain occluded
1352	No	No	No	Yes	No	No	Low	Low	Yes	Cloud shadow, terrain occluded

Table 6-4. Landsat 8 Pixel Quality Assessment (pixel_qa) Value Interpretations

6.1.1 Radiometric Saturation Band

The Radiometric Saturation Quality Assessment (radsat_qa) band is a bit packed representation of which sensor bands were saturated during data capture, yielding unusable data. Table 6-5 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 impervious surfaces in the optical bands, or volcanoes and wild land fires 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 will not occur with the TIRS thermal bands. The L8 radsat_qa band will flag only the saturation cases. Table 6-5 describes the bit assignments for the radsat_qa band.

Bit	Bit Value	Cumulative Sum	Description
Bits are numbered from right to left (bit 1 = LSB, bit 11 = 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	NA	NA	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)
LSB = Least Significant Bit, MSB = Most Significant Bit			

Table 6-5. Landsat 8 Radiometric Saturation Quality Assessment (radsat_qa) Bit Index

6.1.2 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 (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 6-6). The sr_aerosol bit values are given in Table 6-7, and shown in greater detail in Table 6-8.

Bit	Bit Value	Cumulative Sum	Attribute
0	1	1	Fill
1	2	3	Valid Aerosol Retrieval (center pixel of 3x3 pixel window)
2	4	7	Water Pixel (or water pixel was used in the fill-the-window interpolation)
3	8	15	Cloud or Cirrus
4	16	31	Cloud Shadow

Bit	Bit Value	Cumulative Sum	Attribute
5	32	63	Non-center window pixel for which aerosol was interpolated from surrounding 3x3 window center pixels
6	64	127	Aerosol Level 00 = Climatology 01 = Low 10 = Medium 11 = High
7	128	255	

Table 6-6. Landsat 8 Internal Surface Reflectance Aerosol Quality Assessment (sr_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
Cloud or Cirrus	8, 72, 136, 200
Cloud Shadow	16, 80, 144, 208
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, 72, 80, 96, 100
Medium-level aerosol	130, 132, 136, 144, 160, 164
High-level aerosol	194, 196, 200, 208, 224, 228

Table 6-7. Landsat 8 sr_aerosol Values

Pixel Value	Fill	Aerosol Retrieval – Valid (center of 3x3 window)	Water	Cloud/ Cirrus	Cloud Shadow	Aerosol Retrieval – Interpolated (non-center of 3x3 window)	Aerosol	Pixel Description
1	Yes	No	No	No	No	No	NA	Fill
2	No	Yes	No	No	No	No	Climatology	Valid aerosol retrieval
4	No	No	Yes	No	No	No	Climatology	Water
8	No	No	No	Yes	No	No	Climatology	Cloud/cirrus
16	No	No	No	No	Yes	No	Climatology	Cloud shadow
32	No	No	No	No	No	Yes	Climatology	Aerosol interpolated
66	No	Yes	No	No	No	No	Low	Valid aerosol ret., low aerosol
68	No	No	Yes	No	No	No	Low	Water, low aerosol
72	No	No	No	Yes	No	No	Low	Cloud/cirrus, low aerosol
80	No	No	No	No	Yes	No	Low	Cloud shadow, low aerosol
96	No	No	No	No	No	Yes	Low	Aerosol interpolated, low aerosol
100	No	No	Yes	No	No	Yes	Low	Water pixel used in

Pixel Value	Fill	Aerosol Retrieval – Valid (center of 3x3 window)	Water	Cloud/ Cirrus	Cloud Shadow	Aerosol Retrieval – Interpolated (non-center of 3x3 window)	Aerosol	Pixel Description
								interpolation, aerosol interpolated, low aerosol
130	No	Yes	No	No	No	No	Medium	Valid aerosol retrieval, medium aerosol
132	No	No	Yes	No	No	No	Medium	Water, medium aerosol
136	No	No	No	Yes	No	No	Medium	Cloud/cirrus, medium aerosol
144	No	No	No	No	Yes	No	Medium	Cloud shadow, medium aerosol
160	No	No	No	No	No	Yes	Medium	Aerosol interpolated, medium aerosol
164	No	No	Yes	No	No	Yes	Medium	Water pixel used in interpolation, aerosol interpolated, medium aerosol
194	No	Yes	No	No	No	No	High	Valid aerosol retrieval, high aerosol
196	No	No	Yes	No	No	No	High	Water, high aerosol
200	No	No	No	Yes	No	No	High	Cloud/cirrus, high aerosol
208	No	No	No	No	Yes	No	High	Cloud shadow, high aerosol
224	No	No	No	No	No	Yes	High	Aerosol interpolated, high aerosol
228	No	No	Yes	No	No	Yes	High	Water pixel used in interpolation, aerosol interpolated, high aerosol

Table 6-8. Landsat 8 sr_aerosol Value Interpretations

6.1.3 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 A.

6.1.4 Angle Coefficient Files

Each Landsat 8 Surface Reflectance product contains an angle coefficient file ("_ANG.txt"). This file consists of angle coefficients that can be used as input into a set of tools to generate per-pixel solar and sensor azimuth and zenith angle values. For

more details on Angle Coefficient Files see https://www.usgs.gov/land-resources/nli/landsat/solar-illumination-and-sensor-viewing-angle-coefficient-files.

6.1.5 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.

6.2 Cloud and Cloud Shadow Specifications

The Level 2 Pixel Quality Assessment band (pixel_qa; Table 6-2) is populated using information from the Level 1 Quality Assessment band, specifically Cloud Confidence, Cloud Shadow, and Snow/Ice flags derived from the CFMask algorithm. In order to support science data products using Level 2 as input, water values are re-calculated, and high-confidence cloud pixels are dilated, making pixel_qa comparable to the legacy CFMask bands.

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

6.2.1 CFMask Algorithm Known Issues

1. The cloud indicators in the 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.

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

6.3.1 TOA Reflectance - Bands 1–7, 9 Specifications

Calibration coefficients are applied to Landsat Digital Numbers (DN) to derive the TOA Reflectance component, using per-pixel solar angles derived from band 4 (closest to center of focal plane.) 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. Note: TOA Reflectance is not processed for thermal Bands 10 and 11 but can be ordered separately as TOA Brightness Temperature (see Section 6.3.2).

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

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

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
toa_band1	Band 1 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band2	Band 2 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band3	Band 3 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band4	Band 4 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band5	Band 5 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band6	Band 6 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band7	Band 7 Reflectance	INT16	Reflectance	-2000 – 16000	0 – 10000	-9999	20000	0.0001
toa_band9	Band 9 Reflectance	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
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	-18000 - 18000	-32768	NA	0.0100
solar_zenith_band4	Solar Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	0 – 9000	-32768	NA	0.0100

sensor_zenith_band4	Sensor Azimuth Angles Band 4	INT16	Degrees	-32768 - 32767	0 - 9000	-32768	NA	0.0100
sensor_azimuth_band4	Sensor Zenith Angles Band 4	INT16	Degrees	-32768 - 32767	-18000 - 18000	-32768	NA	0.0100
INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, TOA = top of atmosphere, QA = quality assessment, NA = not applicable								

Table 6-9. Top of Atmosphere Reflectance – Bands 1-7, 9 Specifications

6.3.2 TOA Brightness Temperature - Bands 10–11 Specifications

Bands 10–11 TOA Brightness Temperature is derived from TOA radiance and two thermal constants, as described on https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product. A QA band is also provided with this output product. The associated header and metadata files present the same kind of information as described for Surface Reflectance, but they are specific to TOA Brightness Temperature processing. Specifications for TOA Brightness Temperature bands are similar to those for Surface Reflectance, but with a higher minimum value. Table 6-10 lists the data type, units, value range, fill value, saturation value, and scale factor for the TOA Brightness Temperature product bands.

Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
bt_band10	Band 10 TOA Brightness Temperature	INT16	Brightness Temperature (Kelvin)	-100 - 16000	0-10000	-9999	20000	0.1
bt_band11	Band 11 TOA 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
INT16 = 16-bit signed integer, UINT8 = 8-bit unsigned integer, TOA = top of atmosphere, QA = quality assessment, NA = not applicable								

Table 6-10. Top of Atmosphere Brightness Temperature – Bands 10–11 Specifications

6.3.3 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 7 Auxiliary Data

The atmosphere between the satellite and the Earth's surface is composed of different gases that potentially absorb and/or scatter both incoming and reflected sunlight. These gases are primarily aerosols, water vapor and ozone, all of which are partially modulated by the local air temperature. The Landsat instruments do not contain on-board sensors to measure these conditions, so this information is obtained through other observations, known as auxiliary data. For 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, which have their own unique properties, as described in Table 7-1.

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

Data	Product	Source	Version	Instrument	Grid Resolution	Date Begin	Date End	Backup	Backup Begin	Backup End	Missing Range(s)	Additional Missing Data & Date(s)
Ozone	MOD/ MYD09 CMG	https://ladsweb.modaps.eosdis.nasa.gov	v006	Terra & Aqua	0.05° x 0.05°	5/4/2002	Present	NA	NA	NA	2/19/2016 – 2/27/2016;	NA
Air Temperature	MOD/ MYD09 CMA											
Water Vapor	MOD/ MYD09 CMA											
AOT (550 nm)	MOD/ MYD09 CMA											

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

Table 7-1. Auxiliary Data for LaSRC

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 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 9 Acknowledgments

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

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
Source Level 1 Bands (11)	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_b*.tif
Source Level 1 Panchromatic Band	492,688	LC08_L1TP_043031_20130628_20170309_01_T1_b8.tif
Source Level 1 Metadata	9	LC08_L1TP_043031_20130628_20170309_01_T1_MTL.txt
Level 1 QA Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_bqa.tif
Angle Band Coefficients	115	LC08_L1TP_043031_20130628_20170309_01_T1_ANG.txt
TOA Reflectance Bands (8)	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_toa_band*.tif
TOA Brightness Temperature Bands (2)	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_bt_band*.tif
Surface Reflectance Bands (7)	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_sr_band*.tif
Surface Reflectance Aerosol QA Band	61,642	LC08_L1TP_043031_20130628_20170309_01_T1_sr_aerosol.tif
Level 2 Pixel QA	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_pixel_qa.tif
Radiometric Saturation QA Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_radsat_qa.tif
Sensor Azimuth Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_sensor_azimuth_band4.tif
Sensor Zenith Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_sensor_zenith_band4.tif
Solar Azimuth Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_solar_azimuth_band4.tif
Solar Zenith Band	123,220	LC08_L1TP_043031_20130628_20170309_01_T1_solar_zenith_band4.tif
Level 2 Metadata	31	LC08_L1TP_043031_20130628_201703091_01_T1.xml

Table A-1. Collection 1 Default File Characteristics

Appendix B Metadata Field

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

6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ANG	Angle band coefficients file extension
AOT	Aerosol Optical Thickness
BA	Burned Area
BT	Brightness Temperature
CFMask	C version of Function of Mask (USGS EROS)
CMA	Climate Modeling Grid - Aerosols
CMG	Climate Modeling Grid
DDV	Dark Dense Vegetation
DEM	Digital Elevation Model
DN	Digital Number
DSWE	Dynamic Surface Water Extent
ENVI	Exelis Visual Information Solutions
EROS	Earth Resources Observation and Science
ESPA	EROS Science Processing Architecture
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
Fmask	Function of Mask (Boston University)
fSCA	Fractional Snow Covered Area
GSFC	Goddard Space Flight Center
HDF-EOS2	Hierarchical Data Format – Earth Observing System (version 2)
HDR	Header
INT	Integer
INT16	16-bit signed integer
L1GS	Level 1 Geometric Systemic
L1GT	Level 1 Systemic Terrain
L1TP	Level 1 Terrain Precision
LaSRC	Landsat 8 Surface Reflectance Code
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LPGS	Landsat Product Generation System
LSB	Least Significant Bit
m	meter
MATLAB	Matrix Laboratory
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
MTL	Metadata text file extension
MYD	MODIS Aqua

NA	Not Applicable
NASA	National Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NBR2	Normalized Burn Ratio 2
NetCDF	Network Common Data Form
NCEP	National Centers for Environmental Prediction
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
pixel_qa	Pixel Quality Assessment
PS	Polar Stereographic
QA	Quality Assessment
radsat_qa	Radiometric Saturation Quality Assessment
RT	Real-Time
SAVI	Soil Adjusted Vegetation Index
SR	Surface Reflectance
ST	Provisional 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

Appendix D Document Change 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”.

Document Version	Publication Date	Change Description
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” 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.
Version 3.6	03/31/2017	Removal of “Provisional” status for all C1 datasets. Updated angle band zenith valid range to 0-9000; angle band azimuth valid range -18000 – 18000; all angle band nodata to -32768. Removed ‘L8SR’ from Appendix (name no longer used.) Added speckling noise caveat.
Version 3.7	04/06/2017	Removal of Pre-Collection Landsat information.
Version 3.8	05/09/2017	Updated pixel_qa description, added “terrain occlusion” bit, added detailed tables with pixel_qa values. Fixed typo – “sr_aerosol” was listed incorrected as “sr_aerosol_qa”. Added CFMask bands’ discontinuation date (02 June 2017).
Version 3.9	06/02/2017	Added interpretation tables for sr_aerosol band. Changed table and figure designation from number-letter (e.g., 8-A) to number-number (e.g., 8-1). Updated radsat_qa description. Updated TOA Reflectance description, stating TOA is created using per-pixel angles from band 4 (formerly scene center angle.) Updated table names.
Version 4.0	06/07/2017	Corrected typographical errors.
Version 4.1	10/05/2017	Aerosol retrieval is now performed for a 3x3 pixel window versus each pixel. Clouds, water, and cloud shadows are assigned the median aerosol value for clear land pixels. Updated sr_aerosol table with new bit descriptions. Pixels in the pixel_qa band which are high confidence cirrus or terrain occluded no longer unset the clear bit. Given that these pixels are now clear, they

Document Version	Publication Date	Change Description
		could be flagged as water or snow. Updated pixel_qa table. Replaced the terms high level and higher level products with science data products.
Version 4.2	12/04/2017	Added “top of atmosphere” before “brightness temperature” to clarify that BT products are not atmospherically corrected.
Version 4.3	03/30/2018	Correct Product Characteristics table 7.1; remove Solar/Sensor Azimuth/Zenith band information; Add info/reference to L-1 ANG.txt and MTL.txt files that are delivered with SR product.
Version 1.0 LSDS-1368	10/22/2018	Updated Table 1-1 to clarify LEDAPS and LaSRC differences; Updated example Surface Reflectance image; Corrected texts that implied thermal bands were used in LaSRC Surface Reflectance and TOA Reflectance calculation; Corrected the pixel-qa value interpretations in Table 7-4; Corrected the minimum TOA Reflectance in Table 7-9; Removed the incorrect missing dates in Table 8-1.
Version 2.0 LSDS-1368	05/02/2019	Updated Landsat website URL references; Removed the Product Options section since it was mostly about ESPA interface; Corrected the source of DEM.

References

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, 185, 46-56. http://dx.doi.org/10.1016/j.rse.2016.04.008.

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