LSDS-1618
Version 3.0

Department of the Interior
U.S. Geological Survey

Landsat 4-7
Collection 2 (C2)
Level 2 Science Product (L2SP) Guide

Version 3.0

October 2020

science for a changing world

Landsat 4-7
Collection 2 (C2)
Level 2 Science Product (L2SP) Guide

October 2020

Document Owner:

KRISTI SAYLER Digitally signed by KRISTI SAYLER
Date: 2020.10.27 15:18:39 -05'00'

Kristi Sayler	Date
LSRD Project Manager	
U.S. Geological Survey	

Approved By:

KAREN ZANTER Digitally signed by KAREN ZANTER
Date: 2020.11.02 11:04:21 -06'00'

Karen Zanter	Date
LSDS CCB Chair	
U.S. Geological Survey	

EROS
Sioux Falls, South Dakota

Executive Summary

This document describes relevant characteristics of the Landsat 4-5 and Landsat 7 Collection 2 (C2) Level 2 Science Products (L2SP) to facilitate their use in the land remote sensing community.

Landsat 4-7 L2SP contain:

- Surface Reflectance (SR) derived from Landsat 4-7 Collection 2 Level 1 data
- Surface Temperature (ST) derived from Landsat 4-7 Collection 2 Level 1 data
- Intermediate bands used in calculation of the ST products
- Quality Assessment (QA) masks indicating the usefulness of the pixel data

All SR products are created with the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) code. All ST products are created with a single channel algorithm jointly developed by the Rochester Institute of Technology (RIT) and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL).

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.

Information about Landsat 8 Collection 2 Level 2 products can be found in the Landsat 8 Collection 2 Level 2 Science Product Guide.

Document History

Document Number	Document Version	Publication Date	Change Number
LSDS-1618	Version 1.0	May 2020	CR 15394
LSDS-1618	Version 2.0	September 2020	CR 20017
LSDS-1618	Version 3.0	October 2020	CR 20179

Contents

List of Figures

List of Tables

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, and in compliance with guidelines established through the Global Climate Observing System, 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 4-7 Surface Reflectance (SR) Science Products are generated from specialized software called Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). LEDAPS was originally developed through a National Aeronautics and Space Administration (NASA) Making Earth System Data Records for Use in Research Environments (MEaSUREs) grant by NASA Goddard Space Flight Center (GSFC) and the University of Maryland (Masek et al., 2006). LEDAPS applies atmospheric correction routines to Landsat 4-5 Thematic Mapper (TM) or Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level 1 (L1) data, similar to routines derived from Moderate Resolution Imaging Spectroradiometer (MODIS). LEDAPS generates Top of Atmosphere (TOA) Reflectance and TOA Brightness Temperature (BT) using the calibration parameters from the metadata. Auxiliary data such as water vapor, ozone, geopotential height, Aerosol Optical Thickness (AOT), and digital elevation are then input with Landsat TOA Reflectance and TOA BT to Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer model to generate Surface Reflectance. The result is delivered as the Landsat Surface Reflectance data product.

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

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

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

Parameter	LEDAPS	LaSRC
Instruments	Landsat 4-5 TM, Landsat 7 ETM+	Landsat 8 OLI/TIRS, Landsat 9 OLI2/TIRS2 (Available 2021)
(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
Air temperature	NCEP Grid	not used
DEM	GTOPO5	GTOPO5
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

Parameter	LEDAPS	LaSRC
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 and Landsat 8 Surface Reflectance Algorithms

1.1.2 Surface Temperature

Landsat 4-7 Surface Temperature (ST) products are generated from the Landsat Collection 2 Level 1 thermal infrared bands using Top of Atmosphere (TOA) Reflectance, TOA Brightness Temperature (BT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Database (GED) data, ASTER Normalized Difference Vegetation Index (NDVI) data, and atmospheric profiles of geopotential height, specific humidity, and air temperature extracted from reanalysis data.

For Landsat 7 products, the Band 6 TOA BT product is generated from ETM+ Band 6 High gain (6H) and Band 6 Low gain (6L) merged together. The merged Band 6 is comprised of pixels that are not saturated in Band 6H. When Band 6H pixels are saturated with a brightness temperature outside of the 6H dynamic range (from 240K to 322K), they will be filled with pixels from the 6L band even if those pixels are saturated.

1.2 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 provides an explanation of caveats and constraints
- Section 3 provides details on product access
- Section 4 provides details on product packaging
- Section 5 provides an explanation of product characteristics
- Section 6 provides details on detecting product uncertainty
- Section 7 provides auxiliary data
- Section 8 provides document citation information
- Section 9 provides document acknowledgements
- Section 10 provides User Services contact information
- Appendix A provides a list 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 Caveats and Constraints

2.1 Surface Reflectance

1. Landsat 4-7 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. Follow-on processing to apply refined bumper mode parameters takes place 24-26 days later, and the scenes are then placed into T1 or T2. SR processing then is done within 24 hours. **In summary, Landsat 4-7 Collection 2 SR data become available 25 to 27 days after data acquisition.** Visit the Landsat Collection 2 Generation Timeline for a visual look at this timeframe.
2. The following date ranges apply to the availability of the Landsat archive for Surface Reflectance processing, with the exceptions noted in #3 below:
    - Landsat 4 TM: July 1982 to December 1993
    - Landsat 5 TM: March 1984 to May 2012
    - Landsat 7 ETM+: April 1999 to present
3. Landsat 4-5 TM data cannot be processed to Surface Reflectance between specific dates because some auxiliary data required for Surface Reflectance processing are missing. See Section 7 for more information. The most up-to-date information regarding data gaps is in the “Caveats and Constraints” section of https://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance.
4. TOA Reflectance data are derived using per-pixel solar illumination angles generated from the angle coefficient file. Previously, the scene center solar illumination angle from the Level 1 Metadata (MTL) file was used. This will impact the SR data products, as they are derived from TOA Reflectance.
    - This should ideally improve the accuracy of the TOA Reflectance and subsequent SR corrections.
    - Scene center solar illumination and sensor view angles (i.e., not per-pixel) are still used in the SR processing, as the Look-up Table (LUT) routines are called on a grid that is spatially coarser than the resolution of the Landsat data, therefore not necessitating per-pixel angle information.
5. Landsat 7 ETM+ inputs are not gap-filled in Surface Reflectance production, and gapped areas are not processed for Surface Reflectance. See https://www.usgs.gov/land-resources/nli/landsat/landsat-7 for information on Landsat 7 Scan Line Corrector (SLC)-off data products.
6. 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.

7. For reasons mentioned above, the data acquired over high latitudes (> 65º) will not be processed to Surface Reflectance.
8. There are additional adverse conditions that can affect the efficacy of Landsat SR retrievals, such as:
    - Hyper-arid or snow-covered regions
    - Low sun angle conditions
    - Coastal regions where land area is small relative to adjacent water
    - Areas with extensive cloud contamination
9. Refer to the Quality Assessment (QA) bands for pixel-level condition and validity flags. For cloud masking, users are advised to use the cloud bits populated in the Level 1 QA Band.
10. The cloud and cloud shadow indicators in the Surface Reflectance data product are known to report erroneous conditions in areas where temperature differentials are either too large or too small. For example, a warm cloud over extremely cold ground may not calculate enough difference in temperature to identify the cloud. Conversely, residual ice surrounded by unusually warm ground can potentially be identified as cloud.
11. Landsat 7 Band 8 (panchromatic band) is not processed to Top of Atmosphere or Surface Reflectance.

2.2 Surface Temperature

1. For the reasons mentioned in Section 2.1, Landsat 4-7 Collection 2 Surface Temperature (ST) products become available 25 to 27 days after data acquisition.
2. 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 TM and ETM+ data. Where ASTER GED data is missing, there will be missing data in the Landsat ST product. Figure 2-1 shows a map of ASTER GED emissivity coverage.

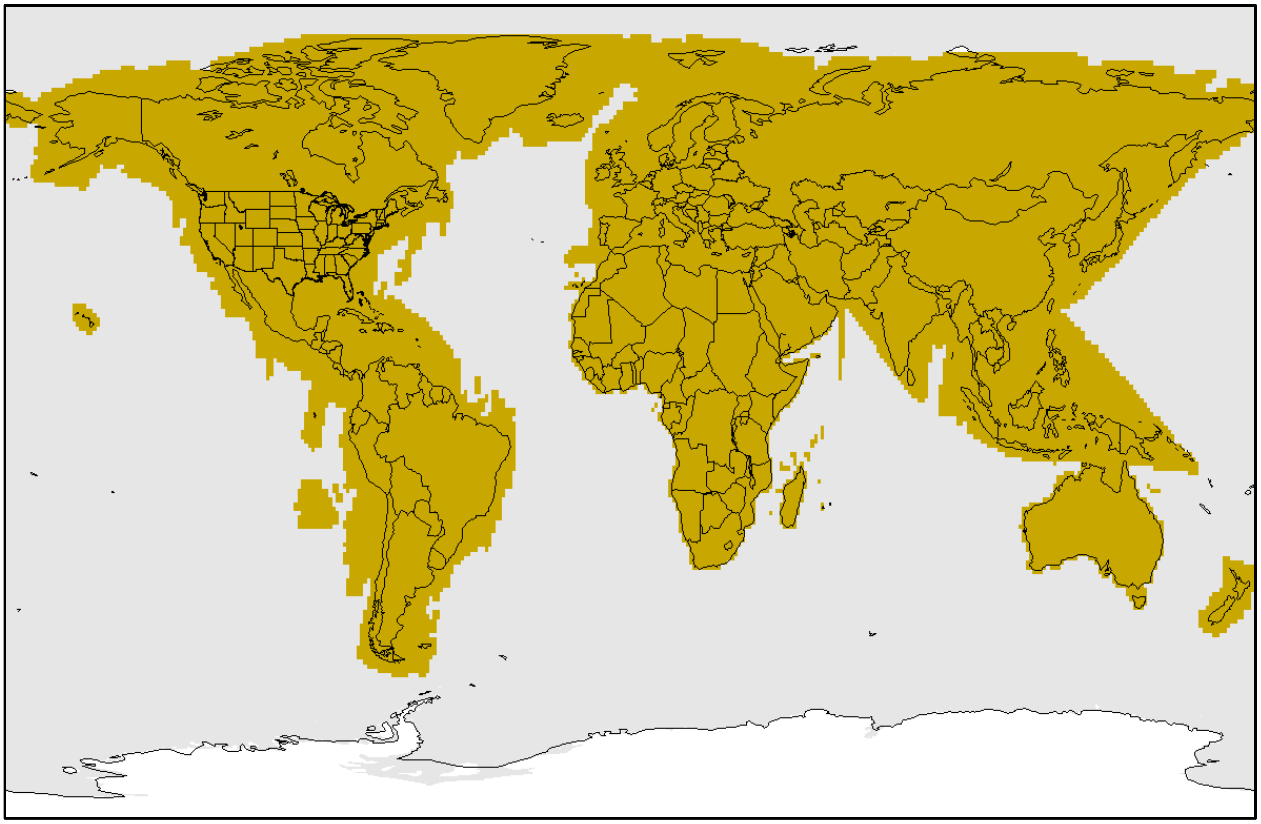

Figure 2-1. ASTER GED Emissivity Coverage

3. 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. If GEOS data are unavailable (for acquisitions before Jan. 1, 2000), then NASA's Modern-Era Retrospective analysis for Research and Application (MERRA-2) reanalysis data are used in its place.
4. 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).
5. Data products must contain both sunlit optical and thermal data 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.
6. 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 3 Product Access

Landsat 4-7 Collection 2 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 4-5 TM C2 L2** and **Landsat 7 ETM+ C2 L2**.

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

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

Section 4 Product Packaging

Landsat Collection 2 L2SP can be downloaded as individual bands as Cloud Optimized Georeferenced Tagged Image File Format (GeoTIFF) (COG) files. The Surface Reflectance 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., LE07_L2SP_039037_20080728_20200319_02_T1_SR_B1)

L	Landsat
X	Sensor ("E" = ETM+; "T" = TM)
SS	Satellite ("07" = Landsat 7; "05" = Landsat 5; "04" = Landsat 4)
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 ("RT" = Real Time; "T1" = Tier 1; "T2" = Tier 2)

Section 5 Product Characteristics

5.1 Band Specifications

Landsat 4-7 Collection 2 L2SP are generated at 30-meter spatial resolution on a Universal Transverse Mercator (UTM) or Polar Stereographic (PS) mapping grid. Table 5-1 lists the specifications for Collection 2 L2SP bands. All packages include metadata provided in Object Description Language (ODL) metadata (MTL), Extensible Markup Language (XML)-based metadata.

Collection 2 Landsat 4-7 L2SP are delivered in files named with the original ProductID and appended with "_SR_" or "_ST_" followed by a band designation. The default file format is GeoTIFF. The QA_PIXEL, QA_RADSAT, and SR_CLOUD_QA 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 ST band converted to thermal surface radiance. The ST_URAD and ST_DRAD bands respectively contain the upwelling and downwelling 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 CDIST band contains the distance of the pixel from the nearest cloud labeled in the QA_PIXEL band, in Kilometers.

Landsat 4-7 Collection 2 L2SP have two separate QA bands for cloud and land cover classification. The SR_CLOUD_QA band is created during LEDAPS processing; its bit assignments are described in Table 5-2 and in greater detail in Table 5-3 and Table 5-4. The QA_PIXEL band is created by the CFMask algorithm; its bit assignments are described in Table 5-5 and Table 5-6. 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.

Band Designation	File Format	Band Name	Data Type	Units	Data Range	Valid Range	Fill Value	Multiplicative Scale Factor	Additive Scale Factor
ProductID_SR_B1	TIF	Band 1 SR	UINT16	Reflectance	1 - 65455	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B2	TIF	Band 2 SR	UINT16	Reflectance	1 - 65455	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B3	TIF	Band 3 SR	UINT16	Reflectance	1 - 65455	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B4	TIF	Band 4 SR	UINT16	Reflectance	1 - 65455	7273 - 43636	0	0.0000275	-0.2
ProductID_SR_B5	TIF	Band 5 SR	UINT16	Reflectance	1 - 65455	7273 - 43636	0	0.0000275	-0.2
ProductID_ST_B6	TIF	Band 6 ST	UINT16	Kelvin	1 - 65535	1 - 65535	0	0.00341802	149
ProductID _SR_ATMOS_OPACITY	TIF	Atmospheric Opacity	INT16	Unitless	0 - 32767	0 - 10000	-9999	0.001	NA
ProductID_QA_PIXEL	TIF	Level 2 Pixel Quality Band	UINT16	Bit Index	1 - 65535	5440 – 16382	1	NA	NA
ProductID_QA_RADSAT	TIF	Radiometric Saturation QA	UINT16	Bit Index	0 - 32768	0 - 3829	NA	NA	NA
ProductID_SR_CLOUD_QA	TIF	Surface Reflectance Cloud QA	UINT8	Bit Index	0 - 255	1 - 56	0	NA	NA
ProductID_ST_QA	TIF	Surface Temperature Uncertainty	INT16	Kelvin	0 - 32767	0 - 32767	-9999	0.01	NA
ProductID_ST_TRAD	TIF	Thermal Band in Radiance	UINT16	W/(m^2 sr μm)/DN	0 - 22000	0 – 22000	-9999	0.001	NA
ProductID_ST_URAD	TIF	Upwelled Radiance	UINT16	W/(m^2 sr μm)/DN	0 - 28000	0 – 28000	-9999	0.001	NA
ProductID_ST_DRAD	TIF	Downwelled Radiance	UINT16	W/(m^2 sr μm)/DN	0 - 28000	0 - 28000	-9999	0.001	NA
ProductID_ST_ATRAN	TIF	Atmospheric Transmittance	UINT16	Unitless	0 - 10000	0 - 10000	-9999	0.0001	NA
ProductID_ST_EMIS	TIF	Emissivity estimated from ASTER GED	UINT16	Unitless	0 - 10000	0 - 10000	-9999	0.0001	NA
ProductID_ST_EMSD	TIF	Emissivity standard deviation	UINT16	Unitless	0 - 65535	0 – 10000	-9999	0.0001	NA
ProductID_ST_CDIST	TIF	Pixel distance to cloud	UINT16	Kilometers	0 - 24000	0 – 24000	-9999	0.01	NA
ProductID_MTL	txt and xml	Level 1 Metadata file	NA	NA	NA	NA	NA	NA	NA

Table 5-1. Collection 2 (C2) Level 2 Science Product (L2SP) Band Specifications

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

Table 5-2. Landsat 4-7 Cloud Quality Assessment (SR_CLOUD_QA) Bit Index

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

Table 5-3. Landsat 4-7 Cloud Quality Assessment (SR_CLOUD_QA) Values

Pixel Value	DDV	Cloud	Cloud shadow	Adjacent to cloud	Snow	Water	Pixel Description
0	No	No	No	No	No	No	Fill
1	Yes	No	No	No	No	No	DDV
2	No	Yes	No	No	No	No	Cloud
4	No	No	Yes	No	No	No	Cloud shadow
8	No	No	No	Yes	No	No	Adjacent to cloud
9	Yes	No	No	Yes	No	No	DDV, adjacent to cloud
12	No	No	Yes	Yes	No	No	Adjacent to cloud, cloud shadow
16	No	No	No	No	Yes	No	Snow
20	No	No	Yes	No	Yes	No	Cloud shadow, snow
24	No	No	No	Yes	Yes	No	Adjacent to cloud, snow
32	No	No	No	No	No	Yes	Water
34	No	Yes	No	No	No	Yes	Cloud, water
36	No	No	Yes	No	No	Yes	Cloud shadow, water
40	No	No	No	Yes	No	Yes	Adjacent to cloud, water
48	No	No	No	No	Yes	Yes	Snow, water
52	No	No	Yes	No	Yes	Yes	Cloud shadow, snow, water
56	No	No	No	Yes	Yes	Yes	Adjacent to cloud, snow, water

Table 5-4. Landsat 4-7 Cloud Quality Assessment (SR_CLOUD_QA) Value Interpretations

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	Unused	Unused
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	Unused	Unused

Table 5-5. Landsat 4-7 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	N/A	No	No	No	No	No	None	None	None	None	Fill
5440	No	No	N/A	No	No	No	Yes	No	Low	Low	Low	None	Clear with lows set
5442	No	Yes	N/A	No	No	No	Yes	No	Low	Low	Low	None	Dilated cloud over land
5504	No	No	N/A	No	No	No	No	Yes	Low	Low	Low	None	Water with lows set
5506	No	Yes	N/A	No	No	No	No	Yes	Low	Low	Low	None	Dilated cloud over water
5696	No	No	N/A	No	No	No	Yes	No	Mid	Low	Low	None	Mid conf cloud
5760	No	No	N/A	No	No	No	No	Yes	Mid	Low	Low	None	Mid conf cloud over water
5896	No	No	N/A	Yes	No	No	No	No	High	Low	Low	None	High conf Cloud
7440	No	No	N/A	No	Yes	No	No	No	Low	High	Low	None	High conf cloud shadow
7568	No	No	N/A	No	Yes	No	No	Yes	Low	High	Low	None	Water with cloud shadow
7696	No	No	N/A	No	Yes	No	No	No	Mid	High	Low	None	Mid conf cloud with shadow
7824	No	No	N/A	No	Yes	No	No	Yes	Mid	High	Low	None	Mid conf cloud with shadow over water
7960	No	No	N/A	Yes	Yes	No	No	No	High	High	Low	None	High conf cloud with shadow
8088	No	No	N/A	Yes	Yes	No	No	Yes	High	High	Low	None	High conf cloud with shadow over water
13664	No	No	N/A	No	No	Yes	Yes	No	Low	Low	High	None	High conf snow/ice

Table 5-6. Landsat 4-7 Pixel Quality Assessment (QA_PIXEL) Value Interpretations*

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

5.1.1 Radiometric Saturation Band

The Radiometric Saturation Quality (QA_RADSAT) band is a bit-packed representation of which sensor bands were saturated during data capture, yielding unusable data. Table 5-7 displays the interpretation of possible pixel values expected in the QA_RADSAT band after its bits are unpacked. For example, a pixel value of 8 indicates that Band 3 is saturated. Table 5-7 describes the bit assignments for the QA_RADSAT band.

Bit	Flag Description		Value
	Landsat 4-5	Landsat 7	
0	Band 1 Data Saturation	Band 1 Data Saturation	0 no saturation 1 saturated data
1	Band 2 Data Saturation	Band 2 Data Saturation	0 no saturation 1 saturated data
2	Band 3 Data Saturation	Band 3 Data Saturation	0 no saturation 1 saturated data
3	Band 4 Data Saturation	Band 4 Data Saturation	0 no saturation 1 saturated data
4	Band 5 Data Saturation	Band 5 Data Saturation	0 no saturation 1 saturated data
5	Band 6 Data Saturation	Band 6L Data Saturation	0 no saturation 1 saturated data
6	Band 7 Data Saturation	Band 7 Data Saturation	0 no saturation 1 saturated data
7	Unused	Unused	0 not checked
8	Unused	Band 6H Data Saturation	0 no saturation 1 saturated data
9	Dropped Pixel	Dropped Pixel	0 Pixel present 1 detector doesn't have a value – no data
10	Unused	Unused	0
11	Unused	Unused	0
12	Unused	Unused	0
13	Unused	Unused	0
14	Unused	Unused	0
15	Unused	Unused	0

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

5.1.2 Atmospheric Opacity Band

The SR_ATMOS_OPACITY band is a general interpretation of atmospheric opacity generated by LEDAPS and based on the radiance viewed over Dark Dense Vegetation (DDV) within the scene. A general interpretation of atmospheric opacity is that values less than 0.1 are clear, 0.1-0.3 are average, and values greater than 0.3 indicate haze or other cloud situations. SR values from pixels with high atmospheric opacity will be less reliable, especially under high solar zenith angle conditions. The SR_ATMOS_OPACITY band is provided for advanced users and for product quality assessment and has not been validated. Most users are advised to instead use the QA_PIXEL band information for cloud discrimination.

5.1.3 L2SP Metadata

Each Surface Reflectance file is accompanied by an XML-based metadata file. Examples of the metadata included in the XML are listed in Appendix A.

5.1.4 L2SP Special Notes

Metadata is included to help define the orientation of Polar Stereographic scenes acquired in ascending orbit over Antarctica. Whether on a descending or ascending orbit path, the first pixels acquired in a Landsat scene comprise the upper portion of an image. As Landsat crosses the southern polar region, it views the southern latitudes first and progresses north. This places pixels in southern latitudes in the upper part of the image so that it appears to the user that south is 'up' and north is 'down.' The <corner> field in the metadata xml clarifies the upper left and lower right corners of the scene.

5.2 Cloud and Cloud Shadow Specifications

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

The information with the QA_PIXEL band is likely to present more accurate results than the QA bands provided by the LEDAPS processing (SR_CLOUD_QA). The algorithm underlying the QA_PIXEL band is CFMask, which 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 Earth Resources Observation and Science (EROS) Center, where it is implemented as the C version of Fmask (CFMask).

5.2.1 Cloud Algorithm Known Issues

1. The cloud indicators in the LEDAPS and CFMask algorithms are known to report erroneous cloud conditions when temperature differentials are either too large or too small. For example, a warm cloud over extremely cold ground may not calculate enough difference in temperature to identify the cloud. Conversely, residual ice surrounded by unusually warm ground can potentially be identified as cloud.
2. Cloud algorithms 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 all cloud algorithms.

Section 6 Initial Characterization of Product Uncertainty

Several studies have been performed in regard to uncertainty of surface reflectance retrievals performed by the LEDAPS algorithm. Uncertainty is generally established through comparison of validated and reliable datasets that are independent of Landsat TM and ETM+ data. Maiersperger et al. (2013) compared LEDAPS' Aerosol Optical Thickness (AOT) estimates with AERONET AOT, field spectrometer data, and the MODIS Surface Reflectance product over the conterminous United States. Claverie et al. (2015) used a similar methodology but added Bidirectional Reflectance Distribution Function (BRDF)-corrected MODIS Terra/Aqua data, Landsat 5 TM and Landsat 7 ETM+ data corrected with AERONET AOT (Ju et al., 2012), and LEDAPS-corrected Landsat 5 TM data to expand the spatial coverage to the entire world.

Claverie et al. (2015) performed their comparisons with the AERONET-derived reflectance, LEDAPS-derived reflectance, and MODIS reflectance using the metrics of Accuracy, Precision, and Uncertainty (APU). APU was originally implemented by Vermote and Kotchenova (2008), where:

A = accuracy, as the mean bias of the satellite retrievals, versus the truth data
P = precision, as the standard deviation of the satellite retrievals from the truth data and from the mean bias
U = uncertainty, as the squared sum of the mean bias and standard deviation

For the resulting APU metrics, Claverie et al. (2015) established specification thresholds, or S, for the LEDAPS-AERONET comparisons and the LEDAPS-MODIS comparisons. The specifications are defined as:

$$S_{LEDAPSxAERONET} = 0.05\rho + 0.005$$
$$S_{MODISxLEDAPS} = 0.071\rho + 0.0071$$

where ρ is the reflectance. The LEDAPS-AERONET specification (~5% error threshold) is identical to that of the MODIS APU specification. The specifications for the LEDAPS-MODIS comparison (~7.1% error threshold) are defined differently to account for the BRDF and spectral corrections applied to the MODIS surface reflectance.

The overall results showed that most LEDAPS retrievals fell within the defined specification, with the highest error being in the blue band. There is not a significant difference in performance between Landsat 5 TM and Landsat 7 ETM+. Compared with MODIS surface reflectance, Landsat 7 ETM+ had better performance over Landsat 5 TM due to ETM+ and MODIS having similar sun-view geometry characteristics. There was no significant inter-annual variation between Landsat sensors. Geographic uncertainty is greatest in high latitude areas and over tropical evergreen forests.

Section 7 Auxiliary Data

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

NOTE: LEDAPS does not use auxiliary data for aerosols, but instead uses the Dark Dense Vegetation (DDV) method using Landsat's multispectral information. Please see *Masek et al., 2006* (see References) for more information pertaining to DDV's use and relative performance in LEDAPS.

7.1 Surface Reflectance Auxiliary Data

7.1.1 CMGDEM

The Climate Modeling Grid Digital Elevation Model (CMGDEM) is a file of global elevations used for surface reflectance calculations on data from Landsat 4-8 sensors. This file is static and is not updated.

7.1.2 NCEP/NCAR Reanalysis 1

The National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) Reanalysis 1 products are annual Network Common Data Form (netCDF) files, provided by the National Oceanic and Atmospheric Association (NOAA), which contain daily values for surface pressure, precipitable water, and air temperature. NCEP data are used in LEDAPS for Landsat 4-7 data. The NCEP products are repackaged into daily Hierarchical Data Format (HDF) files that contain Scientific Datasets (SDS) for surface pressure, precipitable water, and air temperature, stored as floating-point values.

7.1.3 TOMS

Ozone data products are available for the Total Ozone Mapping Spectrometer (TOMS) instruments and for the Ozone Monitoring Instrument (OMI), and are used in LEDAPS for Landsat 4-7 data. Different sources are used for different date ranges:

- **Nimbus7 TOMS**: October 24, 1978 to May 6, 1993
- **Meteor3 TOMS**: August 22, 1991 to Nov 24, 1994
- **Earth Probe TOMS**: July 6, 1996 to Dec 14, 2005
- **Aura OMI**: July 15, 2004 to present

The ozone products are repackaged into daily HDF files that contain ozone data stored as 16-bit integers.

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, 90-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 4-8 data.

7.2.2 GOES-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 4-7 data starting in Jan 1, 2000, 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.

7.2.3 MERRA-2 Data

Modern Era Retrospective analysis for Research and Applications Version 2 (MERRA-2) is a NASA atmospheric reanalysis that provides atmospheric and land cover data beginning in 1980. MERRA-2 is the first long-term global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other geophysical processes in the climate system.

Section 8 Citation Information

There are no restrictions on the use of these Landsat Science Products. It is not a requirement of data use, but the following citation may be used in publication or presentation materials to acknowledge the USGS as a data source, and to credit the original research.

Landsat Science Products courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center.

Masek, J.G., Vermote, E.F., Saleous N.E., Wolfe, R., Hall, F.G., Huemmrich, K.F., Gao, F., Kutler, J., and Lim, T-K. (2006). A Landsat surface reflectance dataset for North America, 1990–2000. IEEE Geoscience and Remote Sensing Letters 3(1):68-72. http://dx.doi.org/10.1109/LGRS.2005.857030.

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

Section 9 Acknowledgments

The original LEDAPS software was developed by Eric Vermote, Nazmi Saleous, Jonathan Kutler, and Robert Wolfe with support from the NASA Terrestrial Ecology program (Principal Investigator: Jeff Masek). Subsequent versions were adapted by Dr. Feng Gao (GSFC/ERT Corp.) with support from the NASA Advancing Collaborative Connections for Earth System Science (ACCESS) and the USGS Landsat Programs.

The original 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

NOTE: A Landsat 7 ETM+ product ID is used only as an example. Landsat 4 and 5 TM files have similar characteristics.

Description	Example File Size (Kbytes)	Example File Name
Surface Reflectance Bands (6)	56,000	LE07_L2SP_042027_20050927_20190828_02_T1_SR_B*.TIF
Surface Temperature Band	65,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_B6_VCID_1.TIF
Level 2 Pixel QA	2,000	LE07_L2SP_042027_20050927_20190828_02_T1_QA_PIXEL.TIF
Surface Reflectance Atmospheric Opacity Band	8,000	LE07_L2SP_042027_20050927_20190828_02_T1_SR_ATMOS_OPACITY.TIF
Surface Reflectance Cloud Quality Assessment Band	6,000	LE07_L2SP_042027_20050927_20190828_02_T1_SR_CLOUD_QA.TIF
Radiometric Saturation Band	512	LE07_L2SP_042027_20050927_20190828_02_T1_QA_RADSAT.TIF
Surface Temperature Atmospheric Transmittance Band	40,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_ATRAN.TIF
Pixel Distance to Cloud Band	22,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_CDIST.TIF
Thermal Downwelled Radiance Band	42,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_DRAD.TIF
Emissivity Band	40,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_EMIS.TIF
Emissivity Band Standard Deviation	27,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_EMSD.TIF
Surface Temperature Uncertainty Band	29,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_QA.TIF
Thermal Radiance Band	31,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_TRAD.TIF
Thermal Upwelled Radiance Band	36,000	LE07_L2SP_042027_20050927_20190828_02_T1_ST_URAD.TIF
Source Level 1XML Metadata	16	LE07_L2SP_042027_20050927_20190828_02_T1_MTL.txt
Level 2 Metadata	23	LE07_L2SP_042027_20050927_20190828_02_T1_MTL.xml

Table A-1. Collection 2 Default File Characteristics

Appendix B Metadata Fields

Example of global XML metadata:


```xml
<?xml version="1.0" encoding="UTF-8"?>
<LANDSAT_METADATA_FILE>

  <PRODUCT_CONTENTS>
    <ORIGIN>Image courtesy of the U.S. Geological Survey</ORIGIN>

<DIGITAL_OBJECT_IDENTIFIER>https://doi.org/10.5066/P9C7I13B</DIGITAL_OBJECT_I
DENTIFIER>

<LANDSAT_PRODUCT_ID>LE07_L2SP_042027_20050927_20200409_02_T1</LANDSAT_PRODUCT
_ID>
    <PROCESSING_LEVEL>L2SP</PROCESSING_LEVEL>
    <COLLECTION_NUMBER>02</COLLECTION_NUMBER>
    <COLLECTION_CATEGORY>T1</COLLECTION_CATEGORY>
    <OUTPUT_FORMAT>GEOTIFF</OUTPUT_FORMAT>

<FILE_NAME_BAND_1>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B1.TIF</FILE_NA
ME_BAND_1>

<FILE_NAME_BAND_2>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B2.TIF</FILE_NA
ME_BAND_2>

<FILE_NAME_BAND_3>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B3.TIF</FILE_NA
ME_BAND_3>

<FILE_NAME_BAND_4>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B4.TIF</FILE_NA
ME_BAND_4>

<FILE_NAME_BAND_5>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B5.TIF</FILE_NA
ME_BAND_5>

<FILE_NAME_BAND_ST_B6>LE07_L2SP_042027_20050927_20200409_02_T1_ST_B6.TIF</FIL
E_NAME_BAND_ST_B6>

<FILE_NAME_BAND_7>LE07_L2SP_042027_20050927_20200409_02_T1_SR_B7.TIF</FILE_NA
ME_BAND_7>

<FILE_NAME_THERMAL_RADIANCE>LE07_L2SP_042027_20050927_20200409_02_T1_ST_TRAD.
TIF</FILE_NAME_THERMAL_RADIANCE>

<FILE_NAME_UPWELL_RADIANCE>LE07_L2SP_042027_20050927_20200409_02_T1_ST_URAD.T
IF</FILE_NAME_UPWELL_RADIANCE>

<FILE_NAME_DOWNWELL_RADIANCE>LE07_L2SP_042027_20050927_20200409_02_T1_ST_DRAD
.TIF</FILE_NAME_DOWNWELL_RADIANCE>

<FILE_NAME_ATMOSPHERIC_TRANSMITTANCE>LE07_L2SP_042027_20050927_20200409_02_T1
_ST_ATRAN.TIF</FILE_NAME_ATMOSPHERIC_TRANSMITTANCE>

<FILE_NAME_EMISSIVITY>LE07_L2SP_042027_20050927_20200409_02_T1_ST_EMIS.TIF</F
ILE_NAME_EMISSIVITY>
```

```
<FILE_NAME_EMISSIVITY_STDEV>LE07_L2SP_042027_20050927_20200409_02_T1_ST_EMSD.TIF</FILE_NAME_EMISSIVITY_STDEV>

<FILE_NAME_CLOUD_DISTANCE>LE07_L2SP_042027_20050927_20200409_02_T1_ST_CDIST.TIF</FILE_NAME_CLOUD_DISTANCE>

<FILE_NAME_ATMOSPHERIC_OPACITY>LE07_L2SP_042027_20050927_20200409_02_T1_SR_ATMOS_OPACITY.TIF</FILE_NAME_ATMOSPHERIC_OPACITY>

<FILE_NAME_QUALITY_L2_SURFACE_REFLECTANCE_CLOUD>LE07_L2SP_042027_20050927_20200409_02_T1_SR_CLOUD_QA.TIF</FILE_NAME_QUALITY_L2_SURFACE_REFLECTANCE_CLOUD>

<FILE_NAME_QUALITY_L2_SURFACE_TEMPERATURE>LE07_L2SP_042027_20050927_20200409_02_T1_ST_QA.TIF</FILE_NAME_QUALITY_L2_SURFACE_TEMPERATURE>

<FILE_NAME_QUALITY_L1_PIXEL>LE07_L2SP_042027_20050927_20200409_02_T1_QA_PIXEL.TIF</FILE_NAME_QUALITY_L1_PIXEL>

<FILE_NAME_QUALITY_L1_RADIOMETRIC_SATURATION>LE07_L2SP_042027_20050927_20200409_02_T1_QA_RADSAT.TIF</FILE_NAME_QUALITY_L1_RADIOMETRIC_SATURATION>

<FILE_NAME_ANGLE_COEFFICIENT>LE07_L2SP_042027_20050927_20200409_02_T1_ANG.txt</FILE_NAME_ANGLE_COEFFICIENT>

<FILE_NAME_METADATA_ODL>LE07_L2SP_042027_20050927_20200409_02_T1_MTL.txt</FILE_NAME_METADATA_ODL>

<FILE_NAME_METADATA_XML>LE07_L2SP_042027_20050927_20200409_02_T1_MTL.xml</FILE_NAME_METADATA_XML>
    <DATA_TYPE_BAND_1>UINT16</DATA_TYPE_BAND_1>
    <DATA_TYPE_BAND_2>UINT16</DATA_TYPE_BAND_2>
    <DATA_TYPE_BAND_3>UINT16</DATA_TYPE_BAND_3>
    <DATA_TYPE_BAND_4>UINT16</DATA_TYPE_BAND_4>
    <DATA_TYPE_BAND_5>UINT16</DATA_TYPE_BAND_5>
    <DATA_TYPE_BAND_ST_B6>UINT16</DATA_TYPE_BAND_ST_B6>
    <DATA_TYPE_BAND_7>UINT16</DATA_TYPE_BAND_7>
    <DATA_TYPE_THERMAL_RADIANCE>INT16</DATA_TYPE_THERMAL_RADIANCE>
    <DATA_TYPE_UPWELL_RADIANCE>INT16</DATA_TYPE_UPWELL_RADIANCE>
    <DATA_TYPE_DOWNWELL_RADIANCE>INT16</DATA_TYPE_DOWNWELL_RADIANCE>

<DATA_TYPE_ATMOSPHERIC_TRANSMITTANCE>INT16</DATA_TYPE_ATMOSPHERIC_TRANSMITTANCE>
    <DATA_TYPE_EMISSIVITY>INT16</DATA_TYPE_EMISSIVITY>
    <DATA_TYPE_EMISSIVITY_STDEV>INT16</DATA_TYPE_EMISSIVITY_STDEV>
    <DATA_TYPE_CLOUD_DISTANCE>INT16</DATA_TYPE_CLOUD_DISTANCE>
    <DATA_TYPE_ATMOSPHERIC_OPACITY>INT16</DATA_TYPE_ATMOSPHERIC_OPACITY>

<DATA_TYPE_QUALITY_L2_SURFACE_REFLECTANCE_CLOUD>UINT8</DATA_TYPE_QUALITY_L2_SURFACE_REFLECTANCE_CLOUD>

<DATA_TYPE_QUALITY_L2_SURFACE_TEMPERATURE>INT16</DATA_TYPE_QUALITY_L2_SURFACE_TEMPERATURE>
    <DATA_TYPE_QUALITY_L1_PIXEL>UINT16</DATA_TYPE_QUALITY_L1_PIXEL>
```

```
<DATA_TYPE_QUALITY_L1_RADIOMETRIC_SATURATION>UINT16</DATA_TYPE_QUALITY_L1_RADIOMETRIC_SATURATION>
  </PRODUCT_CONTENTS>

  <IMAGE_ATTRIBUTES>
    <SPACECRAFT_ID>LANDSAT_7</SPACECRAFT_ID>
    <SENSOR_ID>ETM</SENSOR_ID>
    <WRS_TYPE>2</WRS_TYPE>
    <WRS_PATH>042</WRS_PATH>
    <WRS_ROW>027</WRS_ROW>
    <DATE_ACQUIRED>2005-09-27</DATE_ACQUIRED>
    <SCENE_CENTER_TIME>18:20:00.1881414Z</SCENE_CENTER_TIME>
    <STATION_ID>EDC</STATION_ID>
    <CLOUD_COVER>5.00</CLOUD_COVER>
    <CLOUD_COVER_LAND>5.00</CLOUD_COVER_LAND>
    <IMAGE_QUALITY>9</IMAGE_QUALITY>
    <SATURATION_BAND_1>Y</SATURATION_BAND_1>
    <SATURATION_BAND_2>Y</SATURATION_BAND_2>
    <SATURATION_BAND_3>Y</SATURATION_BAND_3>
    <SATURATION_BAND_4>Y</SATURATION_BAND_4>
    <SATURATION_BAND_5>Y</SATURATION_BAND_5>
    <SATURATION_BAND_6_VCID_1>Y</SATURATION_BAND_6_VCID_1>
    <SATURATION_BAND_6_VCID_2>Y</SATURATION_BAND_6_VCID_2>
    <SATURATION_BAND_7>Y</SATURATION_BAND_7>
    <SATURATION_BAND_8>N</SATURATION_BAND_8>
    <SUN_AZIMUTH>156.24786492</SUN_AZIMUTH>
    <SUN_ELEVATION>38.04866994</SUN_ELEVATION>
    <EARTH_SUN_DISTANCE>1.0021400</EARTH_SUN_DISTANCE>
    <SENSOR_MODE>SAM</SENSOR_MODE>
    <SENSOR_MODE_SLC>OFF</SENSOR_MODE_SLC>
    <SENSOR_ANOMALIES>NONE</SENSOR_ANOMALIES>
  </IMAGE_ATTRIBUTES>

  <PROJECTION_ATTRIBUTES>
    <MAP_PROJECTION>UTM</MAP_PROJECTION>
    <DATUM>WGS84</DATUM>
    <ELLIPSOID>WGS84</ELLIPSOID>
    <UTM_ZONE>11</UTM_ZONE>
    <GRID_CELL_SIZE_REFLECTIVE>30.00</GRID_CELL_SIZE_REFLECTIVE>
    <GRID_CELL_SIZE_THERMAL>30.00</GRID_CELL_SIZE_THERMAL>
    <REFLECTIVE_LINES>7291</REFLECTIVE_LINES>
    <REFLECTIVE_SAMPLES>7981</REFLECTIVE_SAMPLES>
    <THERMAL_LINES>7291</THERMAL_LINES>
    <THERMAL_SAMPLES>7981</THERMAL_SAMPLES>
    <ORIENTATION>NORTH_UP</ORIENTATION>
    <CORNER_UL_LAT_PRODUCT>48.44764</CORNER_UL_LAT_PRODUCT>
    <CORNER_UL_LON_PRODUCT>-117.30292</CORNER_UL_LON_PRODUCT>
    <CORNER_UR_LAT_PRODUCT>48.41066</CORNER_UR_LAT_PRODUCT>
    <CORNER_UR_LON_PRODUCT>-114.06748</CORNER_UR_LON_PRODUCT>
    <CORNER_LL_LAT_PRODUCT>46.47980</CORNER_LL_LAT_PRODUCT>
    <CORNER_LL_LON_PRODUCT>-117.29182</CORNER_LL_LON_PRODUCT>
    <CORNER_LR_LAT_PRODUCT>46.44526</CORNER_LR_LAT_PRODUCT>
    <CORNER_LR_LON_PRODUCT>-114.17475</CORNER_LR_LON_PRODUCT>

<CORNER_UL_PROJECTION_X_PRODUCT>477600.000</CORNER_UL_PROJECTION_X_PRODUCT>
```

```xml
<CORNER_UL_PROJECTION_Y_PRODUCT>5366100.000</CORNER_UL_PROJECTION_Y_PRODUCT>
<CORNER_UR_PROJECTION_X_PRODUCT>717000.000</CORNER_UR_PROJECTION_X_PRODUCT>
<CORNER_UR_PROJECTION_Y_PRODUCT>5366100.000</CORNER_UR_PROJECTION_Y_PRODUCT>
<CORNER_LL_PROJECTION_X_PRODUCT>477600.000</CORNER_LL_PROJECTION_X_PRODUCT>
<CORNER_LL_PROJECTION_Y_PRODUCT>5147400.000</CORNER_LL_PROJECTION_Y_PRODUCT>
<CORNER_LR_PROJECTION_X_PRODUCT>717000.000</CORNER_LR_PROJECTION_X_PRODUCT>
<CORNER_LR_PROJECTION_Y_PRODUCT>5147400.000</CORNER_LR_PROJECTION_Y_PRODUCT>
  </PROJECTION_ATTRIBUTES>
  <LEVEL2_PROCESSING_RECORD>
    <ORIGIN>Image courtesy of the U.S. Geological Survey</ORIGIN>
<DIGITAL_OBJECT_IDENTIFIER>https://doi.org/10.5066/P9C7I13B</DIGITAL_OBJECT_IDENTIFIER>
    <REQUEST_ID>0522004096557_00002</REQUEST_ID>
<LANDSAT_PRODUCT_ID>LE07_L2SP_042027_20050927_20200409_02_T1</LANDSAT_PRODUCT_ID>
    <PROCESSING_LEVEL>L2SP</PROCESSING_LEVEL>
    <OUTPUT_FORMAT>GEOTIFF</OUTPUT_FORMAT>
    <DATE_PRODUCT_GENERATED>2020-04-09T17:29:34Z</DATE_PRODUCT_GENERATED>
    <PROCESSING_SOFTWARE_VERSION>LPGS_15.3.0</PROCESSING_SOFTWARE_VERSION>
<ALGORITHM_SOURCE_SURFACE_REFLECTANCE>LEDAPS_3.4.0</ALGORITHM_SOURCE_SURFACE_REFLECTANCE>
    <DATA_SOURCE_OZONE>TOMS</DATA_SOURCE_OZONE>
    <DATA_SOURCE_PRESSURE>NCEP</DATA_SOURCE_PRESSURE>
    <DATA_SOURCE_WATER_VAPOR>NCEP</DATA_SOURCE_WATER_VAPOR>
    <DATA_SOURCE_AIR_TEMPERATURE>NCEP</DATA_SOURCE_AIR_TEMPERATURE>
<ALGORITHM_SOURCE_SURFACE_TEMPERATURE>st_1.3.0</ALGORITHM_SOURCE_SURFACE_TEMPERATURE>
    <DATA_SOURCE_REANALYSIS>GEOS-5 FP-IT</DATA_SOURCE_REANALYSIS>
  </LEVEL2_PROCESSING_RECORD>
  <LEVEL2_SURFACE_REFLECTANCE_PARAMETERS>
    <REFLECTANCE_MAXIMUM_BAND_1>1.602213</REFLECTANCE_MAXIMUM_BAND_1>
    <REFLECTANCE_MINIMUM_BAND_1>-0.199972</REFLECTANCE_MINIMUM_BAND_1>
    <REFLECTANCE_MAXIMUM_BAND_2>1.602213</REFLECTANCE_MAXIMUM_BAND_2>
    <REFLECTANCE_MINIMUM_BAND_2>-0.199972</REFLECTANCE_MINIMUM_BAND_2>
    <REFLECTANCE_MAXIMUM_BAND_3>1.602213</REFLECTANCE_MAXIMUM_BAND_3>
    <REFLECTANCE_MINIMUM_BAND_3>-0.199972</REFLECTANCE_MINIMUM_BAND_3>
    <REFLECTANCE_MAXIMUM_BAND_4>1.602213</REFLECTANCE_MAXIMUM_BAND_4>
    <REFLECTANCE_MINIMUM_BAND_4>-0.199972</REFLECTANCE_MINIMUM_BAND_4>
    <REFLECTANCE_MAXIMUM_BAND_5>1.602213</REFLECTANCE_MAXIMUM_BAND_5>
    <REFLECTANCE_MINIMUM_BAND_5>-0.199972</REFLECTANCE_MINIMUM_BAND_5>
    <REFLECTANCE_MAXIMUM_BAND_7>1.602213</REFLECTANCE_MAXIMUM_BAND_7>
    <REFLECTANCE_MINIMUM_BAND_7>-0.199972</REFLECTANCE_MINIMUM_BAND_7>
    <QUANTIZE_CAL_MAX_BAND_1>65535</QUANTIZE_CAL_MAX_BAND_1>
```

```
    <QUANTIZE_CAL_MIN_BAND_1>1</QUANTIZE_CAL_MIN_BAND_1>
    <QUANTIZE_CAL_MAX_BAND_2>65535</QUANTIZE_CAL_MAX_BAND_2>
    <QUANTIZE_CAL_MIN_BAND_2>1</QUANTIZE_CAL_MIN_BAND_2>
    <QUANTIZE_CAL_MAX_BAND_3>65535</QUANTIZE_CAL_MAX_BAND_3>
    <QUANTIZE_CAL_MIN_BAND_3>1</QUANTIZE_CAL_MIN_BAND_3>
    <QUANTIZE_CAL_MAX_BAND_4>65535</QUANTIZE_CAL_MAX_BAND_4>
    <QUANTIZE_CAL_MIN_BAND_4>1</QUANTIZE_CAL_MIN_BAND_4>
    <QUANTIZE_CAL_MAX_BAND_5>65535</QUANTIZE_CAL_MAX_BAND_5>
    <QUANTIZE_CAL_MIN_BAND_5>1</QUANTIZE_CAL_MIN_BAND_5>
    <QUANTIZE_CAL_MAX_BAND_7>65535</QUANTIZE_CAL_MAX_BAND_7>
    <QUANTIZE_CAL_MIN_BAND_7>1</QUANTIZE_CAL_MIN_BAND_7>
    <REFLECTANCE_MULT_BAND_1>2.75e-05</REFLECTANCE_MULT_BAND_1>
    <REFLECTANCE_MULT_BAND_2>2.75e-05</REFLECTANCE_MULT_BAND_2>
    <REFLECTANCE_MULT_BAND_3>2.75e-05</REFLECTANCE_MULT_BAND_3>
    <REFLECTANCE_MULT_BAND_4>2.75e-05</REFLECTANCE_MULT_BAND_4>
    <REFLECTANCE_MULT_BAND_5>2.75e-05</REFLECTANCE_MULT_BAND_5>
    <REFLECTANCE_MULT_BAND_7>2.75e-05</REFLECTANCE_MULT_BAND_7>
    <REFLECTANCE_ADD_BAND_1>-0.2</REFLECTANCE_ADD_BAND_1>
    <REFLECTANCE_ADD_BAND_2>-0.2</REFLECTANCE_ADD_BAND_2>
    <REFLECTANCE_ADD_BAND_3>-0.2</REFLECTANCE_ADD_BAND_3>
    <REFLECTANCE_ADD_BAND_4>-0.2</REFLECTANCE_ADD_BAND_4>
    <REFLECTANCE_ADD_BAND_5>-0.2</REFLECTANCE_ADD_BAND_5>
    <REFLECTANCE_ADD_BAND_7>-0.2</REFLECTANCE_ADD_BAND_7>
  </LEVEL2_SURFACE_REFLECTANCE_PARAMETERS>

  <LEVEL2_SURFACE_TEMPERATURE_PARAMETERS>

<TEMPERATURE_MAXIMUM_BAND_ST_B6>372.999941</TEMPERATURE_MAXIMUM_BAND_ST_B6>

<TEMPERATURE_MINIMUM_BAND_ST_B6>149.003418</TEMPERATURE_MINIMUM_BAND_ST_B6>
    <QUANTIZE_CAL_MAXIMUM_BAND_ST_B6>65535</QUANTIZE_CAL_MAXIMUM_BAND_ST_B6>
    <QUANTIZE_CAL_MINIMUM_BAND_ST_B6>1</QUANTIZE_CAL_MINIMUM_BAND_ST_B6>
    <TEMPERATURE_MULT_BAND_ST_B6>0.00341802</TEMPERATURE_MULT_BAND_ST_B6>
    <TEMPERATURE_ADD_BAND_ST_B6>149.0</TEMPERATURE_ADD_BAND_ST_B6>
  </LEVEL2_SURFACE_TEMPERATURE_PARAMETERS>
  <LEVEL1_PROCESSING_RECORD>
    <ORIGIN>Image courtesy of the U.S. Geological Survey</ORIGIN>

<DIGITAL_OBJECT_IDENTIFIER>https://doi.org/10.5066/P9TU80IG</DIGITAL_OBJECT_I
DENTIFIER>
    <REQUEST_ID>0522004096557_00002</REQUEST_ID>
    <LANDSAT_SCENE_ID>LE70420272005270EDC00</LANDSAT_SCENE_ID>

<LANDSAT_PRODUCT_ID>LE07_L1TP_042027_20050927_20200409_02_T1</LANDSAT_PRODUCT
_ID>
    <PROCESSING_LEVEL>L1TP</PROCESSING_LEVEL>
    <COLLECTION_CATEGORY>T1</COLLECTION_CATEGORY>
    <OUTPUT_FORMAT>GEOTIFF</OUTPUT_FORMAT>
    <DATE_PRODUCT_GENERATED>2020-04-09T17:20:44Z</DATE_PRODUCT_GENERATED>
    <PROCESSING_SOFTWARE_VERSION>LPGS_15.3.0</PROCESSING_SOFTWARE_VERSION>

<FILE_NAME_BAND_1>LE07_L1TP_042027_20050927_20200409_02_T1_B1.TIF</FILE_NAME_
BAND_1>

<FILE_NAME_BAND_2>LE07_L1TP_042027_20050927_20200409_02_T1_B2.TIF</FILE_NAME_
BAND_2>
```

<FILE_NAME_BAND_3>**LE07_L1TP_042027_20050927_20200409_02_T1_B3.TIF**</FILE_NAME_BAND_3>

<FILE_NAME_BAND_4>**LE07_L1TP_042027_20050927_20200409_02_T1_B4.TIF**</FILE_NAME_BAND_4>

<FILE_NAME_BAND_5>**LE07_L1TP_042027_20050927_20200409_02_T1_B5.TIF**</FILE_NAME_BAND_5>

<FILE_NAME_BAND_6_VCID_1>**LE07_L1TP_042027_20050927_20200409_02_T1_B6_VCID_1.TIF**</FILE_NAME_BAND_6_VCID_1>

<FILE_NAME_BAND_6_VCID_2>**LE07_L1TP_042027_20050927_20200409_02_T1_B6_VCID_2.TIF**</FILE_NAME_BAND_6_VCID_2>

<FILE_NAME_BAND_7>**LE07_L1TP_042027_20050927_20200409_02_T1_B7.TIF**</FILE_NAME_BAND_7>

<FILE_NAME_BAND_8>**LE07_L1TP_042027_20050927_20200409_02_T1_B8.TIF**</FILE_NAME_BAND_8>

<FILE_NAME_QUALITY_L1_PIXEL>**LE07_L1TP_042027_20050927_20200409_02_T1_QA_PIXEL.TIF**</FILE_NAME_QUALITY_L1_PIXEL>

<FILE_NAME_QUALITY_L1_RADIOMETRIC_SATURATION>**LE07_L1TP_042027_20050927_20200409_02_T1_QA_RADSAT.TIF**</FILE_NAME_QUALITY_L1_RADIOMETRIC_SATURATION>

<FILE_NAME_GROUND_CONTROL_POINT>**LE07_L1TP_042027_20050927_20200409_02_T1_GCP.txt**</FILE_NAME_GROUND_CONTROL_POINT>

<FILE_NAME_ANGLE_COEFFICIENT>**LE07_L1TP_042027_20050927_20200409_02_T1_ANG.txt**</FILE_NAME_ANGLE_COEFFICIENT>

<FILE_NAME_ANGLE_SENSOR_AZIMUTH_BAND_4>**LE07_L1TP_042027_20050927_20200409_02_T1_VAA.TIF**</FILE_NAME_ANGLE_SENSOR_AZIMUTH_BAND_4>

<FILE_NAME_ANGLE_SENSOR_ZENITH_BAND_4>**LE07_L1TP_042027_20050927_20200409_02_T1_VZA.TIF**</FILE_NAME_ANGLE_SENSOR_ZENITH_BAND_4>

<FILE_NAME_ANGLE_SOLAR_AZIMUTH_BAND_4>**LE07_L1TP_042027_20050927_20200409_02_T1_SAA.TIF**</FILE_NAME_ANGLE_SOLAR_AZIMUTH_BAND_4>

<FILE_NAME_ANGLE_SOLAR_ZENITH_BAND_4>**LE07_L1TP_042027_20050927_20200409_02_T1_SZA.TIF**</FILE_NAME_ANGLE_SOLAR_ZENITH_BAND_4>

<FILE_NAME_METADATA_ODL>**LE07_L1TP_042027_20050927_20200409_02_T1_MTL.txt**</FILE_NAME_METADATA_ODL>

<FILE_NAME_METADATA_XML>**LE07_L1TP_042027_20050927_20200409_02_T1_MTL.xml**</FILE_NAME_METADATA_XML>
<FILE_NAME_CPF>**LE07CPF_20050701_20050930_02.01**</FILE_NAME_CPF>
<DATA_SOURCE_ELEVATION>**GLS2000**</DATA_SOURCE_ELEVATION>
<GROUND_CONTROL_POINTS_VERSION>**5**</GROUND_CONTROL_POINTS_VERSION>
<GROUND_CONTROL_POINTS_MODEL>**1061**</GROUND_CONTROL_POINTS_MODEL>
<GEOMETRIC_RMSE_MODEL>**4.406**</GEOMETRIC_RMSE_MODEL>

```
    <GEOMETRIC_RMSE_MODEL_Y>3.378</GEOMETRIC_RMSE_MODEL_Y>
    <GEOMETRIC_RMSE_MODEL_X>2.829</GEOMETRIC_RMSE_MODEL_X>
    <EPHEMERIS_TYPE>DEFINITIVE</EPHEMERIS_TYPE>
  </LEVEL1_PROCESSING_RECORD>

  <LEVEL1_MIN_MAX_RADIANCE>
    <RADIANCE_MAXIMUM_BAND_1>191.600</RADIANCE_MAXIMUM_BAND_1>
    <RADIANCE_MINIMUM_BAND_1>-6.200</RADIANCE_MINIMUM_BAND_1>
    <RADIANCE_MAXIMUM_BAND_2>196.500</RADIANCE_MAXIMUM_BAND_2>
    <RADIANCE_MINIMUM_BAND_2>-6.400</RADIANCE_MINIMUM_BAND_2>
    <RADIANCE_MAXIMUM_BAND_3>152.900</RADIANCE_MAXIMUM_BAND_3>
    <RADIANCE_MINIMUM_BAND_3>-5.000</RADIANCE_MINIMUM_BAND_3>
    <RADIANCE_MAXIMUM_BAND_4>241.100</RADIANCE_MAXIMUM_BAND_4>
    <RADIANCE_MINIMUM_BAND_4>-5.100</RADIANCE_MINIMUM_BAND_4>
    <RADIANCE_MAXIMUM_BAND_5>31.060</RADIANCE_MAXIMUM_BAND_5>
    <RADIANCE_MINIMUM_BAND_5>-1.000</RADIANCE_MINIMUM_BAND_5>
    <RADIANCE_MAXIMUM_BAND_6_VCID_1>17.040</RADIANCE_MAXIMUM_BAND_6_VCID_1>
    <RADIANCE_MINIMUM_BAND_6_VCID_1>0.000</RADIANCE_MINIMUM_BAND_6_VCID_1>
    <RADIANCE_MAXIMUM_BAND_6_VCID_2>12.650</RADIANCE_MAXIMUM_BAND_6_VCID_2>
    <RADIANCE_MINIMUM_BAND_6_VCID_2>3.200</RADIANCE_MINIMUM_BAND_6_VCID_2>
    <RADIANCE_MAXIMUM_BAND_7>10.800</RADIANCE_MAXIMUM_BAND_7>
    <RADIANCE_MINIMUM_BAND_7>-0.350</RADIANCE_MINIMUM_BAND_7>
    <RADIANCE_MAXIMUM_BAND_8>243.100</RADIANCE_MAXIMUM_BAND_8>
    <RADIANCE_MINIMUM_BAND_8>-4.700</RADIANCE_MINIMUM_BAND_8>
  </LEVEL1_MIN_MAX_RADIANCE>

  <LEVEL1_MIN_MAX_REFLECTANCE>
    <REFLECTANCE_MAXIMUM_BAND_1>0.296910</REFLECTANCE_MAXIMUM_BAND_1>
    <REFLECTANCE_MINIMUM_BAND_1>-0.009608</REFLECTANCE_MINIMUM_BAND_1>
    <REFLECTANCE_MAXIMUM_BAND_2>0.334034</REFLECTANCE_MAXIMUM_BAND_2>
    <REFLECTANCE_MINIMUM_BAND_2>-0.010879</REFLECTANCE_MINIMUM_BAND_2>
    <REFLECTANCE_MAXIMUM_BAND_3>0.316333</REFLECTANCE_MAXIMUM_BAND_3>
    <REFLECTANCE_MINIMUM_BAND_3>-0.010344</REFLECTANCE_MINIMUM_BAND_3>
    <REFLECTANCE_MAXIMUM_BAND_4>0.710255</REFLECTANCE_MAXIMUM_BAND_4>
    <REFLECTANCE_MINIMUM_BAND_4>-0.015024</REFLECTANCE_MINIMUM_BAND_4>
    <REFLECTANCE_MAXIMUM_BAND_5>0.442220</REFLECTANCE_MAXIMUM_BAND_5>
    <REFLECTANCE_MINIMUM_BAND_5>-0.014238</REFLECTANCE_MINIMUM_BAND_5>
    <REFLECTANCE_MAXIMUM_BAND_7>0.418812</REFLECTANCE_MAXIMUM_BAND_7>
    <REFLECTANCE_MINIMUM_BAND_7>-0.013573</REFLECTANCE_MINIMUM_BAND_7>
    <REFLECTANCE_MAXIMUM_BAND_8>0.581496</REFLECTANCE_MAXIMUM_BAND_8>
    <REFLECTANCE_MINIMUM_BAND_8>-0.011242</REFLECTANCE_MINIMUM_BAND_8>
  </LEVEL1_MIN_MAX_REFLECTANCE>

  <LEVEL1_MIN_MAX_PIXEL_VALUE>
    <QUANTIZE_CAL_MAX_BAND_1>255</QUANTIZE_CAL_MAX_BAND_1>
    <QUANTIZE_CAL_MIN_BAND_1>1</QUANTIZE_CAL_MIN_BAND_1>
    <QUANTIZE_CAL_MAX_BAND_2>255</QUANTIZE_CAL_MAX_BAND_2>
    <QUANTIZE_CAL_MIN_BAND_2>1</QUANTIZE_CAL_MIN_BAND_2>
    <QUANTIZE_CAL_MAX_BAND_3>255</QUANTIZE_CAL_MAX_BAND_3>
    <QUANTIZE_CAL_MIN_BAND_3>1</QUANTIZE_CAL_MIN_BAND_3>
    <QUANTIZE_CAL_MAX_BAND_4>255</QUANTIZE_CAL_MAX_BAND_4>
    <QUANTIZE_CAL_MIN_BAND_4>1</QUANTIZE_CAL_MIN_BAND_4>
    <QUANTIZE_CAL_MAX_BAND_5>255</QUANTIZE_CAL_MAX_BAND_5>
    <QUANTIZE_CAL_MIN_BAND_5>1</QUANTIZE_CAL_MIN_BAND_5>
    <QUANTIZE_CAL_MAX_BAND_6_VCID_1>255</QUANTIZE_CAL_MAX_BAND_6_VCID_1>
    <QUANTIZE_CAL_MIN_BAND_6_VCID_1>1</QUANTIZE_CAL_MIN_BAND_6_VCID_1>
```

```
    <QUANTIZE_CAL_MAX_BAND_6_VCID_2>255</QUANTIZE_CAL_MAX_BAND_6_VCID_2>
    <QUANTIZE_CAL_MIN_BAND_6_VCID_2>1</QUANTIZE_CAL_MIN_BAND_6_VCID_2>
    <QUANTIZE_CAL_MAX_BAND_7>255</QUANTIZE_CAL_MAX_BAND_7>
    <QUANTIZE_CAL_MIN_BAND_7>1</QUANTIZE_CAL_MIN_BAND_7>
    <QUANTIZE_CAL_MAX_BAND_8>255</QUANTIZE_CAL_MAX_BAND_8>
    <QUANTIZE_CAL_MIN_BAND_8>1</QUANTIZE_CAL_MIN_BAND_8>
  </LEVEL1_MIN_MAX_PIXEL_VALUE>

  <LEVEL1_RADIOMETRIC_RESCALING>
    <RADIANCE_MULT_BAND_1>7.7874E-01</RADIANCE_MULT_BAND_1>
    <RADIANCE_MULT_BAND_2>7.9882E-01</RADIANCE_MULT_BAND_2>
    <RADIANCE_MULT_BAND_3>6.2165E-01</RADIANCE_MULT_BAND_3>
    <RADIANCE_MULT_BAND_4>9.6929E-01</RADIANCE_MULT_BAND_4>
    <RADIANCE_MULT_BAND_5>1.2622E-01</RADIANCE_MULT_BAND_5>
    <RADIANCE_MULT_BAND_6_VCID_1>6.7087E-02</RADIANCE_MULT_BAND_6_VCID_1>
    <RADIANCE_MULT_BAND_6_VCID_2>3.7205E-02</RADIANCE_MULT_BAND_6_VCID_2>
    <RADIANCE_MULT_BAND_7>4.3898E-02</RADIANCE_MULT_BAND_7>
    <RADIANCE_MULT_BAND_8>9.7559E-01</RADIANCE_MULT_BAND_8>
    <RADIANCE_ADD_BAND_1>-6.97874</RADIANCE_ADD_BAND_1>
    <RADIANCE_ADD_BAND_2>-7.19882</RADIANCE_ADD_BAND_2>
    <RADIANCE_ADD_BAND_3>-5.62165</RADIANCE_ADD_BAND_3>
    <RADIANCE_ADD_BAND_4>-6.06929</RADIANCE_ADD_BAND_4>
    <RADIANCE_ADD_BAND_5>-1.12622</RADIANCE_ADD_BAND_5>
    <RADIANCE_ADD_BAND_6_VCID_1>-0.06709</RADIANCE_ADD_BAND_6_VCID_1>
    <RADIANCE_ADD_BAND_6_VCID_2>3.16280</RADIANCE_ADD_BAND_6_VCID_2>
    <RADIANCE_ADD_BAND_7>-0.39390</RADIANCE_ADD_BAND_7>
    <RADIANCE_ADD_BAND_8>-5.67559</RADIANCE_ADD_BAND_8>
    <REFLECTANCE_MULT_BAND_1>1.2068E-03</REFLECTANCE_MULT_BAND_1>
    <REFLECTANCE_MULT_BAND_2>1.3579E-03</REFLECTANCE_MULT_BAND_2>
    <REFLECTANCE_MULT_BAND_3>1.2861E-03</REFLECTANCE_MULT_BAND_3>
    <REFLECTANCE_MULT_BAND_4>2.8554E-03</REFLECTANCE_MULT_BAND_4>
    <REFLECTANCE_MULT_BAND_5>1.7971E-03</REFLECTANCE_MULT_BAND_5>
    <REFLECTANCE_MULT_BAND_7>1.7023E-03</REFLECTANCE_MULT_BAND_7>
    <REFLECTANCE_MULT_BAND_8>2.3336E-03</REFLECTANCE_MULT_BAND_8>
    <REFLECTANCE_ADD_BAND_1>-0.010814</REFLECTANCE_ADD_BAND_1>
    <REFLECTANCE_ADD_BAND_2>-0.012237</REFLECTANCE_ADD_BAND_2>
    <REFLECTANCE_ADD_BAND_3>-0.011631</REFLECTANCE_ADD_BAND_3>
    <REFLECTANCE_ADD_BAND_4>-0.017879</REFLECTANCE_ADD_BAND_4>
    <REFLECTANCE_ADD_BAND_5>-0.016035</REFLECTANCE_ADD_BAND_5>
    <REFLECTANCE_ADD_BAND_7>-0.015275</REFLECTANCE_ADD_BAND_7>
    <REFLECTANCE_ADD_BAND_8>-0.013576</REFLECTANCE_ADD_BAND_8>
  </LEVEL1_RADIOMETRIC_RESCALING>

  <LEVEL1_THERMAL_CONSTANTS>
    <K1_CONSTANT_BAND_6_VCID_1>666.09</K1_CONSTANT_BAND_6_VCID_1>
    <K2_CONSTANT_BAND_6_VCID_1>1282.71</K2_CONSTANT_BAND_6_VCID_1>
    <K1_CONSTANT_BAND_6_VCID_2>666.09</K1_CONSTANT_BAND_6_VCID_2>
    <K2_CONSTANT_BAND_6_VCID_2>1282.71</K2_CONSTANT_BAND_6_VCID_2>
  </LEVEL1_THERMAL_CONSTANTS>

  <LEVEL1_PROJECTION_PARAMETERS>
    <MAP_PROJECTION>UTM</MAP_PROJECTION>
    <DATUM>WGS84</DATUM>
    <ELLIPSOID>WGS84</ELLIPSOID>
    <UTM_ZONE>11</UTM_ZONE>
    <GRID_CELL_SIZE_PANCHROMATIC>15.00</GRID_CELL_SIZE_PANCHROMATIC>
```

```
    <GRID_CELL_SIZE_REFLECTIVE>30.00</GRID_CELL_SIZE_REFLECTIVE>
    <GRID_CELL_SIZE_THERMAL>30.00</GRID_CELL_SIZE_THERMAL>
    <ORIENTATION>NORTH_UP</ORIENTATION>
    <RESAMPLING_OPTION>CUBIC_CONVOLUTION</RESAMPLING_OPTION>
    <SCAN_GAP_INTERPOLATION>2.0</SCAN_GAP_INTERPOLATION>
  </LEVEL1_PROJECTION_PARAMETERS>

  <PRODUCT_PARAMETERS>
    <CORRECTION_GAIN_BAND_1>CPF</CORRECTION_GAIN_BAND_1>
    <CORRECTION_GAIN_BAND_2>CPF</CORRECTION_GAIN_BAND_2>
    <CORRECTION_GAIN_BAND_3>CPF</CORRECTION_GAIN_BAND_3>
    <CORRECTION_GAIN_BAND_4>CPF</CORRECTION_GAIN_BAND_4>
    <CORRECTION_GAIN_BAND_5>CPF</CORRECTION_GAIN_BAND_5>
    <CORRECTION_GAIN_BAND_6_VCID_1>CPF</CORRECTION_GAIN_BAND_6_VCID_1>
    <CORRECTION_GAIN_BAND_6_VCID_2>CPF</CORRECTION_GAIN_BAND_6_VCID_2>
    <CORRECTION_GAIN_BAND_7>CPF</CORRECTION_GAIN_BAND_7>
    <CORRECTION_GAIN_BAND_8>CPF</CORRECTION_GAIN_BAND_8>
    <CORRECTION_BIAS_BAND_1>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_1>
    <CORRECTION_BIAS_BAND_2>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_2>
    <CORRECTION_BIAS_BAND_3>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_3>
    <CORRECTION_BIAS_BAND_4>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_4>
    <CORRECTION_BIAS_BAND_5>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_5>

<CORRECTION_BIAS_BAND_6_VCID_1>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_6_V
CID_1>

<CORRECTION_BIAS_BAND_6_VCID_2>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_6_V
CID_2>
    <CORRECTION_BIAS_BAND_7>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_7>
    <CORRECTION_BIAS_BAND_8>INTERNAL_CALIBRATION</CORRECTION_BIAS_BAND_8>
    <GAIN_BAND_1>H</GAIN_BAND_1>
    <GAIN_BAND_2>H</GAIN_BAND_2>
    <GAIN_BAND_3>H</GAIN_BAND_3>
    <GAIN_BAND_4>L</GAIN_BAND_4>
    <GAIN_BAND_5>H</GAIN_BAND_5>
    <GAIN_BAND_6_VCID_1>L</GAIN_BAND_6_VCID_1>
    <GAIN_BAND_6_VCID_2>H</GAIN_BAND_6_VCID_2>
    <GAIN_BAND_7>H</GAIN_BAND_7>
    <GAIN_BAND_8>L</GAIN_BAND_8>
    <GAIN_CHANGE_BAND_1>HH</GAIN_CHANGE_BAND_1>
    <GAIN_CHANGE_BAND_2>HH</GAIN_CHANGE_BAND_2>
    <GAIN_CHANGE_BAND_3>HH</GAIN_CHANGE_BAND_3>
    <GAIN_CHANGE_BAND_4>LL</GAIN_CHANGE_BAND_4>
    <GAIN_CHANGE_BAND_5>HH</GAIN_CHANGE_BAND_5>
    <GAIN_CHANGE_BAND_6_VCID_1>LL</GAIN_CHANGE_BAND_6_VCID_1>
    <GAIN_CHANGE_BAND_6_VCID_2>HH</GAIN_CHANGE_BAND_6_VCID_2>
    <GAIN_CHANGE_BAND_7>HH</GAIN_CHANGE_BAND_7>
    <GAIN_CHANGE_BAND_8>LL</GAIN_CHANGE_BAND_8>
    <GAIN_CHANGE_SCAN_BAND_1>0</GAIN_CHANGE_SCAN_BAND_1>
    <GAIN_CHANGE_SCAN_BAND_2>0</GAIN_CHANGE_SCAN_BAND_2>
    <GAIN_CHANGE_SCAN_BAND_3>0</GAIN_CHANGE_SCAN_BAND_3>
    <GAIN_CHANGE_SCAN_BAND_4>0</GAIN_CHANGE_SCAN_BAND_4>
    <GAIN_CHANGE_SCAN_BAND_5>0</GAIN_CHANGE_SCAN_BAND_5>
    <GAIN_CHANGE_SCAN_BAND_6_VCID_1>0</GAIN_CHANGE_SCAN_BAND_6_VCID_1>
    <GAIN_CHANGE_SCAN_BAND_6_VCID_2>0</GAIN_CHANGE_SCAN_BAND_6_VCID_2>
    <GAIN_CHANGE_SCAN_BAND_7>0</GAIN_CHANGE_SCAN_BAND_7>
```

```
    <GAIN_CHANGE_SCAN_BAND_8>0</GAIN_CHANGE_SCAN_BAND_8>
  </PRODUCT_PARAMETERS>
</LANDSAT_METADATA_FILE>
```

Appendix C Acronyms

6H	Band 6 High
6L	Band 6 Low
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
ACCESS	Advancing Collaborative Connections for Earth System Science
ANG	Angle Coefficients File
AOT	Aerosol Optical Thickness
APU	Accuracy, Precision, and Uncertainty
ASTER GED	Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Database
BRDF	Bidirectional Reflectance Distribution Function
BT	Brightness Temperature
C1	Landsat Collection 1
C2	Landsat Collection 2
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
EE	EarthExplorer
EROS	Earth Resources Observation and Science
ESPA	EROS Science Processing Architecture
ETM+	Enhanced Thematic Mapper Plus
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
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
LaSRC	Land Surface Reflectance Code

LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LP DAAC	Land Processes Distributed Active Archive Center
LPGS	Landsat Product Generation System
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
MODIS	Moderate Resolution Imaging Spectroradiometer
MTL	Level 1 Metadata
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
ODL	Object Description Language
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
SDS	Scientific Dataset
SLC	Scan Line Corrector
SR	Surface Reflectance
ST	Provisional Surface Temperature
T1	Tier 1
T2	Tier 2
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
UINT	Unsigned Integer
UINT8	8-bit Unsigned Integer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WRS-2	Worldwide Reference System-2
XML	Extensible Markup Language

References

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

Claverie, M., Vermote, E.F., Franch, B., and Masek, J.G. (2015). Evaluation of the Landsat-5 TM and Landsat-7 ETM+ surface reflectance products. Remote Sensing of Environment 169:390-403. http://dx.doi.org/10.1016/j.rse.2015.08.030.

Dwyer, J.L., Roy, D.P., Sauer, B., Jenkerson, C.B., Zhang, H.K., Lymburner, L. (2018). Analysis Ready Data: Enabling Analysis of the Landsat Archive. Remote Sensing of Environment 10(9):1363. https://www.mdpi.com/2072-4292/10/9/1363.

Jones, J.W., Starbuck, M.J., and Jenkerson, C.B. (2013). Landsat surface reflectance quality Assessment extraction (version 1.7) (No. 11-C7). US Geological Survey. http://pubs.usgs.gov/tm/11/c07/pdf/tm11-c7.pdf.

Ju, J., Roy, D.P., Vermote, E., Masek, J., and Kovalskyy, V. (2012). Continental-scale validation of MODIS-based and LEDAPS Landsat ETM+ atmospheric correction methods. Remote Sensing of Environment 122:175-184. http://dx.doi.org/10.1016/j.rse.2011.12.025.

Maiersperger, T., Scaramuzza, P., Leigh, L., Shrestha, S., Gallo, K., Jenkerson, C., and Dwyer, J. (2013). Characterizing LEDAPS surface reflectance products by comparisons with AERONET, field spectrometer, and MODIS data. Remote Sensing of Environment 136:1-13. http://dx.doi.org/10.1016/j.rse.2013.04.007.

Masek, J.G., Huang, C., Wolfe, R., Cohen, W., Hall, F., Kutler, J., and Nelson, P. (2008). North American forest disturbance mapped from a decadal Landsat record. Remote Sensing of Environment 112:2914-2926. http://dx.doi.org/10.1016/j.rse.2008.02.010.

Masek, J.G., Vermote, E.F., Saleous N.E., Wolfe, R., Hall, F.G., Huemmrich, K.F., Gao, F., Kutler, J., and Lim, T-K. (2006). A Landsat surface reflectance dataset for North America, 1990–2000. IEEE Geoscience and Remote Sensing Letters 3(1):68-72. http://dx.doi.org/10.1109/LGRS.2005.857030.

Schmidt, G.L., Jenkerson, C.B., Masek, J., Vermote, E., and Gao, F. (2013). Landsat ecosystem disturbance adaptive processing system (LEDAPS) algorithm description: U.S. Geological Survey Open-File Report 2013–1057, 17 p.

Vermote, E.F., and Kotchenova, S. (2008). Atmospheric correction for the monitoring of land surfaces. Journal of Geophysical Research: Atmospheres (1984–2012) 113(D23). http://dx.doi.org/10.1029/2007JD009662.

Vermote, E.F., El Saleous, N., Justice, C.O., Kaufman, Y.J., Privette, J.L., Remer, L., Roger, J.C., and Tanre, D. (1997). Atmospheric correction of visible to middle-infrared EOS-MODIS data over land surfaces: Background, operational algorithm, and validation. Journal of Geophysical Research 102:17131-17141.

Vermote, E.F., Tanre, D., Deuze, J.L., Herman, M., and Morcrette, J.J. (1997). Second simulation of the satellite signal in the solar spectrum, 6S: An overview. IEEE Transactions on Geoscience and Remote Sensing 35:675-686. http://dx.doi.org/10.1109/36.581987.

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