

Department of the Interior  
U.S. Geological Survey

# LANDSAT SURFACE TEMPERATURE (ST) PRODUCT GUIDE

**Version 2.0**

**October 2018**



# LANDSAT SURFACE TEMPERATURE (ST) PRODUCT GUIDE

October 2018

Approved By:

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## Executive Summary

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This document describes the relevant characteristics of the Landsat Level 2 Surface Temperature (ST) Science Product to facilitate its use in the land remote sensing community.

Landsat Level 2 Science Products are derived from U.S. Landsat Analysis Ready Data (ARD). U.S. Landsat ARD consist of the most geometrically accurate Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS) data that are consistently processed to the highest scientific standards and level of processing required for direct use in monitoring and assessing landscape change. Additional information specific to U.S. Landsat ARD product characteristics is located on <https://landsat.usgs.gov/ard>.

## Document History

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# Contents

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<b>Executive Summary</b> .....	<b>iii</b>
<b>Document History</b> .....	<b>iv</b>
<b>Contents</b> .....	<b>v</b>
<b>List of Figures</b> .....	<b>vi</b>
<b>List of Tables</b> .....	<b>vi</b>
<b>Section 1 Introduction</b> .....	<b>1</b>
1.1 Background.....	1
1.2 Purpose and Scope .....	1
1.3 Document Organization .....	2
<b>Section 2 Caveats and Constraints</b> .....	<b>3</b>
<b>Section 3 Product Packaging</b> .....	<b>6</b>
3.1 Package Filename .....	6
3.2 Product Filename.....	6
<b>Section 4 Product Characteristics</b> .....	<b>8</b>
4.1 Available Products .....	8
4.2 Product Specifications .....	9
<b>Section 5 Product Access</b> .....	<b>13</b>
<b>Section 6 Citation Information</b> .....	<b>14</b>
<b>Section 7 Acknowledgements</b> .....	<b>15</b>
<b>Section 8 User Services</b> .....	<b>16</b>
<b>Appendix A Default File Characteristics</b> .....	<b>17</b>
<b>Appendix B Metadata Fields</b> .....	<b>18</b>
<b>Appendix C NARR Grid Spatial Extent</b> .....	<b>22</b>
<b>Appendix D Acronyms</b> .....	<b>23</b>
<b>References</b> .....	<b>25</b>

## List of Figures

---

Figure 1-1. Examples of Landsat Surface Reflectance (left) and Surface Temperature (right) images. ....	1
Figure 2-1. WRS Scene (left) and U.S. Landsat ARD Tiles (right) .....	4
Figure 1-1. Examples of Landsat Surface Reflectance (left) and Surface Temperature (right) images. ....	1
Figure 2-1. WRS Scene (left) and U.S. Landsat ARD Tiles (right) .....	4
Figure D-1. NARR Grid Extent .....	22

## List of Tables

---

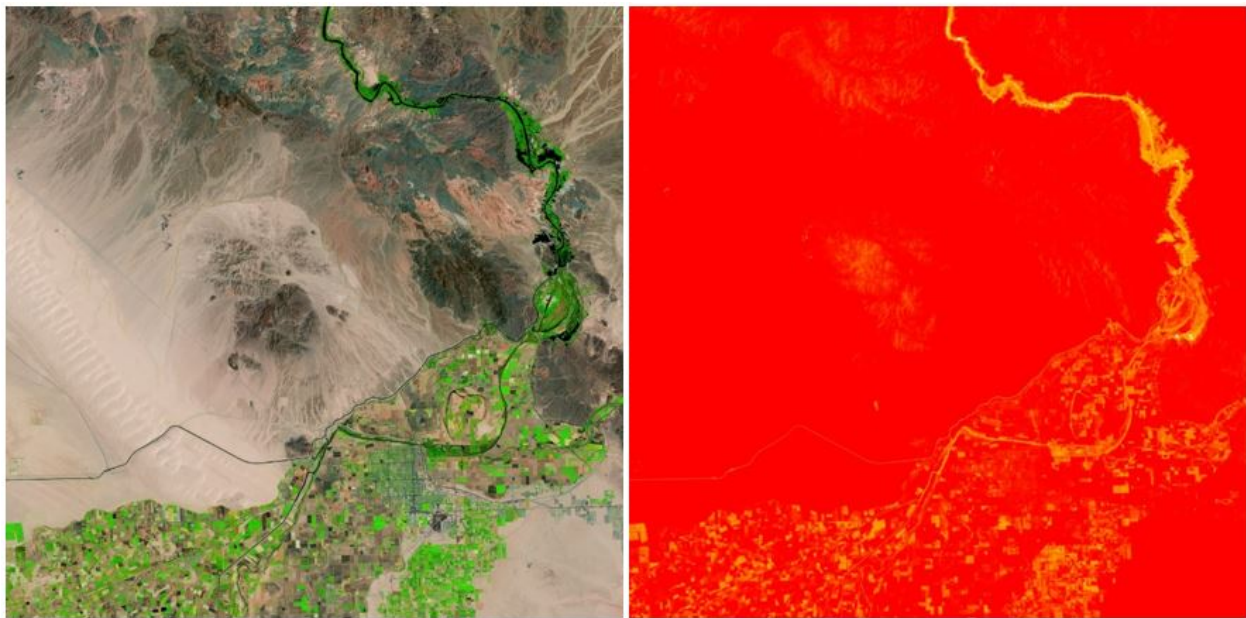
Table 4-1. ST Product Overall Specifications .....	9
Table 4-2. Landsat 4-7 QA Bands Specifications .....	10
Table 4-3. Landsat 8 QA Bands Specifications .....	10
Table 4-4. Landsat 4-7 Pixel QA Bit Index .....	10
Table 4-5. Landsat 4-7 Radiometric Saturation QA Bit Index .....	11
Table 4-6. Landsat 8 Pixel QA Bit Index .....	11
Table 4-7. Landsat 8 Radiometric Saturation QA Bit Index .....	12
Table A-1. Example ST Product Files .....	17

## Section 1 Introduction

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### 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), Surface Temperature (ST), Burned Area, fractional Snow Covered Area (fSCA), and Dynamic Surface Water Extent (DSWE) that are suitable for monitoring, assessing, and predicting land surface change over time.



**Figure 1-1. Examples of Landsat Surface Reflectance (left) and Surface Temperature (right) images.**

In Figure 1-1, the images were derived from Landsat 7 Analysis Ready Data (ARD) Tile H005V013 of the Conterminous U.S. (CONUS), August 16, 2000.

### 1.2 Purpose and Scope

This guide describes the Landsat Level 2 ST Science Product. ST products are generated from the [U.S. Landsat Analysis Ready Data \(ARD\)](#) Top of Atmosphere (TOA) reflectance, Top of Atmosphere Brightness Temperature (TOA BT) bands, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Database (GED) data, and ASTER Normalized Difference Vegetation Index (NDVI) data. U.S. Landsat ARD consist of Landsat 4-5 Thematic Mapper (TM), Landsat 7

Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Thermal Infrared Sensor (TIRS) data.

Landsat ST packages contain nine acquisition-based raster products that represent the temperature of the Earth's land surface, as well as three Quality Assessment (QA) bands. Intermediate bands used to produce the ST product are also provided. Section 4 details the ST product specifications.

The methodologies used in this algorithm are derived directly from work performed by Hulley, Hughes, and Hook (2012), Cook (2014), Cook et al. (2014), and Cook and Schott (2014). Please see the References section for more information.

### **1.3 Document Organization**

This document contains the following sections:

- Section 1 provides an introduction.
- Section 2 provides caveats and constraints for the ST product.
- Section 3 provides information about ST product packaging.
- Section 4 provides a description of ST product characteristics.
- Section 5 provides information about accessing the ST product.
- Section 6 provides ST product citation information.
- Section 7 provides acknowledgements for this product guide.
- Section 8 provides USGS user services.
- Appendix A provides the default file characteristics for the ST product.
- Appendix B provides metadata fields for the ST product.
- Appendix C provides a diagram of the North American Regional Reanalysis (NARR) grid spatial extent.
- Appendix D provides a list of acronyms.
- The References section contains a list of reference documents.

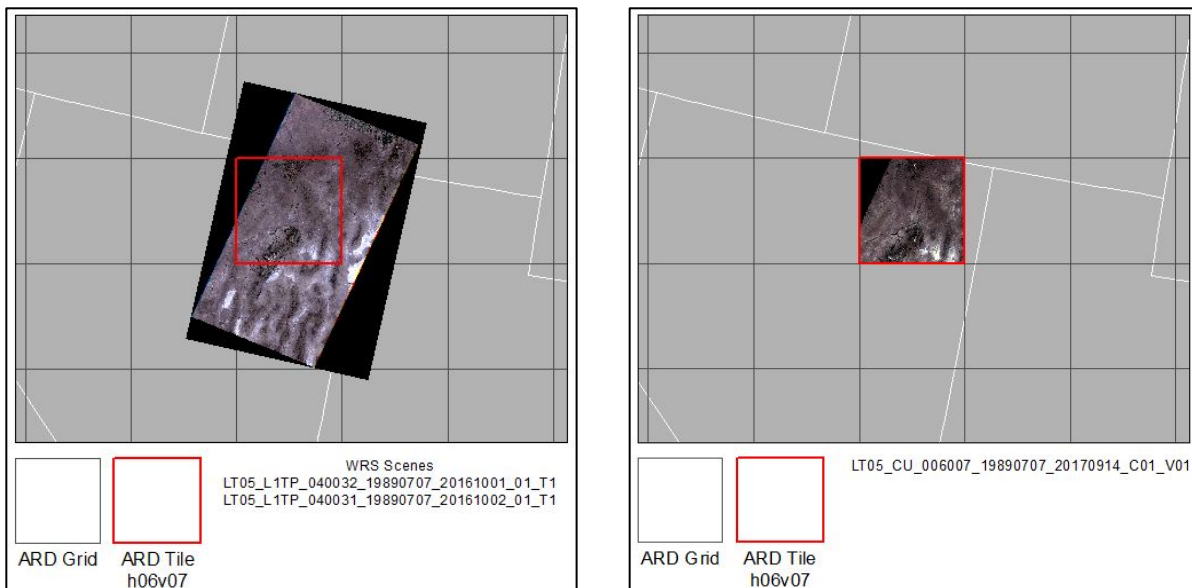


## **Section 2 Caveats and Constraints**

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1. The ST product will occasionally include missing data, particularly over both inland and coastal waters, due to missing data in the ASTER GED. Any missing data are assigned as “NoData” in the ST data product.
2. The ST product is geographically limited within the boundary of the North American Regional Reanalysis (NARR) grid, which is the climate data set used in the atmospheric correction algorithm. The ground area imaged must fall completely within this grid extent for the data product to be successfully processed.

3. NARR Grid Spatial Extent displays a map of the NARR grid extents.
4. External collaborators are testing the Modern-Era Retrospective Analysis for Research and Applications (MERRA) grid for implementation as a global product, thus allowing ST to be produced globally. More information about this initiative was presented at a Landsat Science Team meeting briefing. For more information, please reference [https://landsat.usgs.gov/sites/default/files/documents/Laraby12\\_2015to\\_science\\_team.pdf](https://landsat.usgs.gov/sites/default/files/documents/Laraby12_2015to_science_team.pdf).
5. Data products must contain both optical and thermal data (e.g., LC08 products for Landsat 8) to be successfully processed to ST, as Landsat NDVI is required to temporally adjust the ASTER GED product to the target Landsat scene. Therefore, night time acquisitions cannot be processed to ST.
6. A known error exists of ST 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).
7. Unlike the standard Landsat Level 1 Worldwide Reference System (WRS) scenes in Universal Transverse Mercator (UTM) projection into which Landsat data have always been processed, U.S. Landsat ARD products are immediately processed to Albers Equal Area Conic (AEA) projection and divided into equal-sized tiles with static extents. Figure 2-1 illustrates how an ARD tile compares to two WRS scenes. Three sets of AEA projection parameters and tile grid extents are used for Landsat ARD on the three distinct regions of the U.S., which consist of the CONUS, Alaska, and Hawaii. ST products are available for all three regions. The [Landsat ARD](#) web page describes the use of AEA and tiling grids in more detail.



**Figure 2-1. WRS Scene (left) and U.S. Landsat ARD Tiles (right)**

NOTE: WRS scenes (left) have always been the standard Landsat product size. U.S. ARD tiles (right) are created from Landsat data in AEA projection, divided into equal-sized areas.

8. U.S. Landsat ARD products are generated from the highest quality data in the [Landsat Level 1 Collection](#). Landsat 4-7 Tier 1 (T1) and Landsat 8 T1 and Tier 2 (T2) scenes are processed to ARD. Newly acquired scenes in the Collection archive are given a Real-Time (RT) designation. These newly acquired data are not processed to ARD until radiometric and geometric parameters are finalized and reprocessed into their appropriate Tier (about 26 days for Landsat 7 and about 16 days for Landsat 8 after acquisition).
9. Landsat 7 ETM+ inputs are not gap-filled in TOA reflectance and TOA BT production; therefore, gapped areas are not processed to TOA Reflectance or TOA BT. See the [Landsat 7](#) web page for information on Landsat 7 Scan Line Corrector-off (SLC-off) data products.
10. The Emissivity Standard Deviation band has known out-of-bound values, which originate from the unphysical retrievals of emissivity >1.0. This typically occurs when there is undetected cloud in the ASTER Temperature Emissivity Separation (TES) algorithm.
11. A known issue exists with ST product generation when there are cloud free acquisitions. If the input Level 2 Pixel Quality Assessment (PIXELQA) band has no pixels flagged as cloud, the Surface Temperature Quality Assessment (STQA) band generation procedure fails, and an ST product is not generated for that cloud free acquisition.
12. It is possible, but infrequent, that the distance to cloud (CDIST) value might exceed the maximum (i.e., 24,000) that is listed in the metadata file and product specifications.
13. It is possible that, over hot spot regions such as volcanoes and fires, the thermal radiance (TRAD) value might exceed the maximum (i.e., 22,000) that is listed in the metadata file and product specifications.

## Section 3 Product Packaging

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This product guide is specific to the Landsat Level 2 ST Science Product. Details of other Landsat Science Products are covered in separate product guides.

### 3.1 Package Filename

All ST products are delivered in tar packages (.tar) specific to individual U.S. Landsat ARD tiles. The package filenames are structured similar to the original ARD tile identifiers (IDs) appended with the ST package name suffix. The following is an example of a typical ST package filename.

**LXSS\_US\_HHHVVV\_YYYYMMDD\_yyyymmdd\_CCC\_VVV\_PACKAGE.tar**  
(e.g., LC08\_CU\_006006\_20160715\_20171205\_C01\_V01\_ST.tar)

L	Landsat
X	Sensor (“C” = OLI/TIRS, “E” = ETM+, “T” = TM)
SS	Satellite (“08” = Landsat 8, “07” = Landsat 7, “05” = Landsat 5, “04” = Landsat 4)
US	Regional grid of the U.S. (“CU” = CONUS, “AK” = Alaska, “HI” = Hawaii)
HHH	Horizontal tile number
VVV	Vertical tile number
YYYY	Acquisition year
MM	Acquisition month
DD	Acquisition day
yyyy	Production year
mm	Production month
dd	Production day
CCC	Level 1 Collection number (“C01”, “C02”, etc.)
VVV	Analysis Ready Data (ARD) Version number (“V01”, “V02”, etc.)
PACKAGE	Data package (“ST” = Surface Temperature package)

### 3.2 Product Filename

The ST .tar packages “untar” (unzip) into 12 individual Georeferenced Tagged Image File Format (GeoTIFF) (.tif) raster files and an Extensible Markup Language (XML) (.xml) metadata file. The 12 raster files include ST, STQA, atmospheric transmittance, emissivity, emissivity standard deviation, upwelled radiance, downwelled radiance, thermal radiance, distance to cloud, pixel QA, radiometric saturation QA, and a lineage QA band. Section 4 describes the products in more detail. The following is an example of an ST product filename:

**LXSS\_US\_HHHVVV\_YYYYMMDD\_yyyymmdd\_CCC\_VVV\_PRODUCT.ext**  
(e.g., LC08\_CU\_006006\_20160715\_20171205\_C01\_V01\_ST.tif)

L	Landsat
X	Sensor (“C” = OLI/TIRS, “E” = ETM+, “T” = TM)
SS	Satellite (“08” = Landsat 8, “07” = Landsat 7, “05” = Landsat 5, “04” = Landsat 4)
US	Regional grid of the U.S. (“CU” = CONUS, “AK” = Alaska, “HI” = Hawaii)
HHH	Horizontal tile number
VVV	Vertical tile number
YYYY	Acquisition year
MM	Acquisition month
DD	Acquisition day
yyyy	Production year
mm	Production month
dd	Production day
CCC	Level-1 Collection number (“C01”, “C02”, etc.)
VVV	Analysis Ready Data (ARD) Version number (“V01”, “V02”, etc.)
PRODUCT	Data product (“ST” = Surface Temperature, “STQA” = Surface Temperature Quality Assessment, “ATRAN” = Atmospheric Transmittance, “EMIS” = Emissivity, “EMSD” = Emissivity Standard Deviation, “URAD” = Upwelled Radiance, “DRAD” = Downwelled Radiance, “TRAD” = Thermal Radiance, “CDIST” = Distance to Cloud, “PIXELQA” = Pixel Quality Assessment, “RADSATQA” = Radiometric Saturation, “LINEAGEQA” = Lineage Index)
ext	File extension (“.tif” = GeoTIFF, “.xml” = Extensible Markup Language)

## Section 4 Product Characteristics

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All ST products are generated from [U.S. Landsat ARD](#) TOA reflectance and TOA BT products. In addition to U.S. Landsat ARD, the ST algorithm uses ASTER GED data as well as ASTER NDVI data as inputs. ST products are processed to 30-meter spatial resolution in AEA projection using the World Geodetic System 1984 (WGS84) datum and gridded to a common tiling scheme. Products are delivered in various formats, including GeoTIFF files for all ST raster products and XML metadata files. Spatial reference information is embedded within the GeoTIFF files. ST products are available for 1982 to the present for CONUS, Alaska, and Hawaii.

### 4.1 Available Products

Available ST products include nine raster layers and an .xml metadata file. The following list provides descriptions of the ST products. 4.2 describes specifications for each output raster layer. ST products include the following:

1. Surface Temperature (ST) – Represents the temperature of the Earth’s surface in Kelvin (K).
2. Surface Temperature Quality Assessment (STQA) – Provides the ST product uncertainty using a combination of uncertainty values and distance to cloud values.
3. Atmospheric Transmittance layer (ATRAN) – Displays the ratio of the transmitted radiation to the total radiation incident upon the medium (atmosphere).
4. Emissivity layer (EMIS) – Displays the ratio of the energy radiated from a material’s surface to that radiated from a blackbody.
5. Emissivity Standard Deviation (EMSD) – The extent of deviation for the emissivity product. This layer is used with CDIST to create the STQA product.
6. Upwelled Radiance layer (URAD) – Displays the amount of electromagnetic radiation reflected upward from the ground’s surface.
7. Downwelled Radiance layer (DRAD) – Displays the thermal energy radiated onto the ground by all objects in a hemisphere surrounding it.
8. Thermal Radiance layer (TRAD) – Displays the values produced when thermal band reflectance is converted to radiance.
9. Distance to Cloud (CDIST) – Represents the distance, in kilometers, that a pixel is from the nearest cloud pixel. This layer is used with EMSD to create the STQA product.

10. Pixel Quality Assessment (PIXELQA) – The bit combinations that define certain quality conditions. Unpacking the bits represented by the pixel values deconstructs them into comprehensible condition descriptions.
11. Radiometric Saturation (RADSATQA) – A bit packed representation of which sensor bands were saturated during data capture, yielding unusable data.
12. Lineage Index (LINEAGEQA) – Indicates which Level 2 scene was the source for each pixel. The lineage index pixel values are used in conjunction with the metadata file to retrieve scene-specific information.
13. Metadata – Includes tile-based and input scene-based information in XML format.

## 4.2 Product Specifications

Table 4-1 describes the overall specifications for the ST products.

Band Name	Description	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
<i>tileID_ST</i>	Surface Temperature	INT16	Kelvin	1500 - 3730	1500 - 3730	-9999	NA	0.1
<i>tileID_STQA</i>	Surface Temperature Quality Band	INT16	Kelvin	0 - 32767	0 - 32767	-9999	NA	0.01
<i>tileID_ATRAN</i>	Atmospheric Transmittance	INT16	Radiance	0 - 10000	0 - 10000	-9999	NA	0.0001
<i>tileID_DRAD</i>	Downwelled Radiance	INT16	Radiance	0 - 28000	0 - 28000	-9999	NA	0.001
<i>tileID_URAD</i>	Upwelled Radiance	INT16	Radiance	0 - 28000	0 - 28000	-9999	NA	0.001
<i>tileID_TRAD</i>	Thermal band converted to radiance	INT16	Radiance	0 - 22000	0 - 22000	-9999	NA	0.001
<i>tileID_EMIS</i>	Landsat Emissivity estimated from ASTER GED data	INT16	Emissivity coefficient	0 - 10000	0 - 10000	-9999	NA	0.0001
<i>tileID_EMSD</i>	Landsat Emissivity Standard Deviation	INT16	Emissivity coefficient	0 - 32767	0 - 10000	-9999	NA	0.0001
<i>tileID_CDIST</i>	Pixel distance to cloud	INT16	Kilometers	0 - 24000	0 - 24000	-9999	NA	0.01

**Table 4-1. ST Product Overall Specifications**

Table 4-2 and Table 4-3 describe the overall specifications of the QA bands of Landsat 4-7 and Landsat 8, respectively.

Band Name	Description	Data Type	Units	Range	Valid Range	Fill Value
<i>tileID_PIXELQA</i>	Pixel Quality Assessment	UINT16	Bit Index	1 – 65535	1 – 255	1 (bit 0)
<i>tileID_RADSATQA</i>	Radiometric Saturation QA	UINT8	Bit Index	0 – 255	0 – 255	1 (bit 0)
<i>tileID_LINEAGEQA</i>	Lineage QA	UINT8	NA	0 – 255	0 – 3	0

**Table 4-2. Landsat 4-7 QA Bands Specifications**

Band Name	Description	Data Type	Units	Range	Valid Range	Fill Value
<i>tileID_PIXELQA</i>	Pixel Quality Assessment	UINT16	Bit Index	1 – 65535	1 – 2047	1 (bit 0)
<i>tileID_RADSATQA</i>	Radiometric Saturation QA	UINT16	Bit Index	0 – 65535	0 – 3839	1 (bit 0)
<i>tileID_LINEAGEQA</i>	Lineage QA	UINT8	NA	0 – 255	0 – 3	0

**Table 4-3. Landsat 8 QA Bands Specifications**

Table 4-4 through Table 4-7 display the interpretation of possible pixel values expected in PIXELQA and RADSATQA bands. More information about the Landsat ARD QA bands can be found at the U.S. Landsat ARD [Data Format Control Book \(DFCB\)](#).

Bit	Value	Cumulative Sum	Interpretation
<b>Bits are numbered from right to left (bit 0 = LSB, bit 15 = MSB)</b>			
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	Unused
9	512	1023	Unused
10	1024	2047	Unused
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65535	Unused

\*LSB=least significant bit, MSB=most significant bit

**Table 4-4. Landsat 4-7 Pixel QA Bit Index**



Bit	Value	Cumulative Sum	Description
<b>Bits are numbered from right to left (bit 0 = LSB, bit 7 = MSB)</b>			
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)

\*LSB=least significant bit, MSB=most significant bit

**Table 4-5. Landsat 4-7 Radiometric Saturation QA Bit Index**

Bit	Value	Cumulative Sum	Interpretation
<b>Bits are numbered from right to left (bit 0 = LSB, bit 15 = MSB)</b>			
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
7	128	255	10 = Medium 11 = High
8	256	511	Cirrus Confidence 00 = Not set 01 = Low from OLI Band 9 reflectance
9	512	1023	10 = Medium from OLI Band 9 reflectance 11 = High from OLI Band 9 reflectance
10	1024	2047	Terrain Occlusion
11	2048	4095	Unused
12	4096	8191	Unused
13	8192	16383	Unused
14	16384	32767	Unused
15	32786	65535	Unused

\*LSB = least significant bit, MSB = most significant bit, OLI = operational land imager

**Table 4-6. Landsat 8 Pixel QA Bit Index**

Bit	Value	Cumulative Sum	Description
<b>Bits are numbered from right to left (bit 0 = LSB, bit 7 = MSB)</b>			
0	1	1	Data Fill Flag (0 valid data, 1 invalid data)
1	2	3	Band 1 Data Saturation Flag (0 valid data, 1 saturated data)
2	4	7	Band 2 Data Saturation Flag (0 valid data, 1 saturated data)
3	8	15	Band 3 Data Saturation Flag (0 valid data, 1 saturated data)
4	16	31	Band 4 Data Saturation Flag (0 valid data, 1 saturated data)
5	32	63	Band 5 Data Saturation Flag (0 valid data, 1 saturated data)
6	64	127	Band 6 Data Saturation Flag (0 valid data, 1 saturated data)
7	128	255	Band 7 Data Saturation Flag (0 valid data, 1 saturated data)
8	N/A	N/A	Not used
9	512	1023	Band 9 Data Saturation Flag (0 valid data, 1 saturated data)
10	1024	2047	Band 10 Data Saturation Flag (0 valid data, 1 saturated data)
11	2048	4095	Band 11 Data Saturation Flag (0 valid data, 1 saturated data)

*\*LSB=least significant bit, MSB=most significant bit*

**Table 4-7. Landsat 8 Radiometric Saturation QA Bit Index**

## Section 5 Product Access

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Landsat Level 2 ST Science Products are accessible through [EarthExplorer](#).

## Section 6 Citation Information

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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 Level 2 Surface Temperature (ST) Science Products courtesy of the U.S. Geological Survey.*

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

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

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 contact information provided in Section 7.

## **Section 7 Acknowledgements**

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The original Landsat Level 2 ST Science Product algorithm was developed at the Rochester Institute of Technology (RIT). ASTER GED product and temporal adjustment used in the ST algorithm was developed at the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL).

## Section 8 User Services

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Landsat Science Products and associated interfaces are supported by USGS User Services staff at the USGS Earth Resources Observation and Science (EROS) Center. Questions or comments regarding Landsat Science Products or interfaces are welcome through the Landsat “Contact Us” online correspondence form. E-mail can also be sent to the USGS User Services address with the same indication of topic.

### **USGS User Services**

605-594-6151

1-800-252-4547

[custserv@usgs.gov](mailto:custserv@usgs.gov)

User support is available Monday through Friday from 8:00 a.m. – 4:00 p.m. Central Time. Inquiries received outside of these hours are addressed during the next business day.

## Appendix A Default File Characteristics

*ST – Surface Temperature, STQA – Surface Temperature Quality Assessment, CDIST – Distance to Cloud, EMIS – Emissivity, EMSD – Emissivity Standard Deviation, ATRAN – Atmospheric Transmittance, DRAD – Downwelled Radiance, TRAD – Thermal Radiance, URAD – Upwelled Radiance, PIXELQA – Pixel Quality Assessment, RADSATQA – Radiometric Saturation, LINEAGEQA – Lineage Index, TIF - Tagged Image File Format, XML - Extensible Markup Language*

Description	Example File Size (Kbytes)	Example File Name
Surface temperature	9,310	LT04_CU_024014_19930716_20180509_C01_V01_ST.tif
Surface temperature quality assessment	8,272	LT04_CU_024014_19930716_20180509_C01_V01_STQA.tif
Distance to cloud	2,637	LT04_CU_024014_19930716_20180509_C01_V01_CDIST.tif
Emissivity	15,872	LT04_CU_024014_19930716_20180509_C01_V01_EMIS.tif
Emissivity Standard Deviation	4,824	LT04_CU_024014_19930716_20180509_C01_V01 EMSD.tif
Atmospheric transmittance	1,590	LT04_CU_024014_19930716_20180509_C01_V01_ATRAN.tif
Downwelled radiance	1,549	LT04_CU_024014_19930716_20180509_C01_V01_DRAD.tif
Thermal radiance	5,457	LT04_CU_024014_19930716_20180509_C01_V01_TRAD.tif
Upwelled radiance	1,467	LT04_CU_024014_19930716_20180509_C01_V01_URAD.tif
Pixel Quality Assessment	847	LT04_CU_024014_19930716_20180509_C01_V01_PIXELQA.tif
Radiometric Saturation QA	321	LT04_CU_024014_19930716_20180509_C01_V01_RADSATQA.tif
Lineage QA	91	LT04_CU_024014_19930716_20180509_C01_V01_LINEAGEQA.tif
Metadata	80	LT04_CU_024014_19930716_20180509_C01_V01.xml

**Table A-1. Example ST Product Files**

## Appendix B Metadata Fields

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### Example of ST tile global metadata:

```
<global_metadata>
  <data_provider>USGS/EROS</data_provider>
  <satellite>LANDSAT_4</satellite>
  <instrument>TM</instrument>
  <level1_collection>01</level1_collection>
  <ard_version>01</ard_version>
  <region>CU</region>
  <acquisition_date>1993-07-16</acquisition_date>
  <product_id>LT04_CU_024014_19930716_20180509_C01_V01</product_id>
  <production_date>2018-05-09T23:46:52Z</production_date>
  <bounding_coordinates>
    <west>-84.9598732072</west>
    <east>-83.1618657863</east>
    <north>33.4508300435</north>
    <south>31.9483312747</south>
  </bounding_coordinates>
  <projection_information datum="WGS84" projection="AEA" units="meters">
    <corner_point location="UL" x="1034415.000000" y="1214805.000000"/>
    <corner_point location="LR" x="1184415.000000" y="1064805.000000"/>
    <grid_origin>UL</grid_origin>
    <albers_proj_params>
      <standard_parallel1>29.500000</standard_parallel1>
      <standard_parallel2>45.500000</standard_parallel2>
      <central_meridian>-96.000000</central_meridian>
      <origin_latitude>23.000000</origin_latitude>
      <>false_easting>0.000000</false_easting>
      <>false_northing>0.000000</false_northing>
    </albers_proj_params>
  </projection_information>
  <orientation_angle>0.000000</orientation_angle>
  <tile_grid h="024" v="014"/>
  <scene_count>2</scene_count>
  <cloud_cover>8.4825</cloud_cover>
  <cloud_shadow>4.3212</cloud_shadow>
  <snow_ice>0.0000</snow_ice>
  <fill>33.2799</fill>
</global_metadata>
```

### Example of ST tile band metadata:

```
<band category="image" data_type="INT16" fill_value="-9999" name="EMIS" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.000100" source="toa_refl">
  <short_name>LT04EMIS</short_name>
  <long_name>Landsat emissivity estimated from ASTER GED data</long_name>
  <file_name>EMIS</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>Emissivity Coefficient</data_units>
  <valid_range max="10000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
```



```

    <production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="EMSD" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.000100" source="toa_refl">
  <short_name>LT04EMIS_STDEV</short_name>
  <long_name>Landsat emissivity standard deviation estimated from ASTER GED data</long_name>
  <file_name>EMSD</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>Emissivity Coefficient</data_units>
  <valid_range max="10000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
</production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="TRAD" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.001000" source="level1">
  <short_name>LT04ST_THERMAL_RADIANCE</short_name>
  <long_name>thermal band converted to radiance</long_name>
  <file_name>TRAD</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>radiance (W m(-2) sr(-1) mu(-1))</data_units>
  <valid_range max="22000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
</production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="ATLAN" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.000100" source="level1">
  <short_name>LT04ST_ATMOSPHERIC_TRANSMITTANCE</short_name>
  <long_name>atmospheric transmittance</long_name>
  <file_name>ATLAN</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>radiance (W m(-2) sr(-1) mu(-1))</data_units>
  <valid_range max="10000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
</production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="URAD" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.001000" source="level1">
  <short_name>LT04ST_UPWELLED_RADIANCE</short_name>
  <long_name>upwelled radiance</long_name>
  <file_name>URAD</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>radiance (W m(-2) sr(-1) mu(-1))</data_units>
  <valid_range max="28000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
</production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="DRAD" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.001000" source="level1">
  <short_name>LT04ST_DOWNWELLED_RADIANCE</short_name>
  <long_name>downwelled radiance</long_name>
  <file_name>DRAD</file_name>
  <pixel_size units="meters" x="30" y="30"/>

```

```

<resample_method>none</resample_method>
<data_units>radiance (W m^(-2) sr^(-1) mu^(-1))</data_units>
<valid_range max="28000.000000" min="0.000000"/>
<app_version>st_1.1.1</app_version>
<production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band add_offset="0.000000" category="image" data_type="INT16" fill_value="-9999" name="ST"
nlines="5000" nsamps="5000" product="st" scale_factor="0.100000" source="toa_refl">
  <short_name>LT04ST</short_name>
  <long_name>Surface Temperature</long_name>
  <file_name>ST</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>temperature (kelvin)</data_units>
  <valid_range max="3730.000000" min="1500.000000"/>
  <app_version>st_1.1.1</app_version>
  <production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="image" data_type="INT16" fill_value="-9999" name="CDIST" nlines="5000"
nsamps="5000" product="st_intermediate" scale_factor="0.010000" source="toa_refl">
  <short_name>LT04ST_CLOUD_DIST</short_name>
  <long_name>Surface temperature distance to cloud band</long_name>
  <file_name>CDIST</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>distance (km)</data_units>
  <valid_range max="24000.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
  <production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="qa" data_type="INT16" fill_value="-9999" name="STQA" nlines="5000" nsamps="5000"
product="st_qa" scale_factor="0.010000" source="toa_refl">
  <short_name>LT04STQA</short_name>
  <long_name>Surface temperature quality band</long_name>
  <file_name>STQA</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>temperature (kelvin)</data_units>
  <valid_range max="32767.000000" min="0.000000"/>
  <app_version>st_1.1.1</app_version>
  <production_date>2018-05-09T23:46:52Z</production_date>
</band>

```

#### Example of QA bands metadata:

```

<band category="metadata" data_type="UINT8" fill_value="0" name="LINEAGEQA" nlines="5000"
nsamps="5000" product="scene_index" source="level2">
  <short_name>TILEIDX</short_name>
  <long_name>index</long_name>
  <file_name>LT04_CU_024014_19930716_20180509_C01_V01_LINEAGEQA.tif</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>index</data_units>
  <valid_range max="255.000000" min="0.000000"/>

```

```

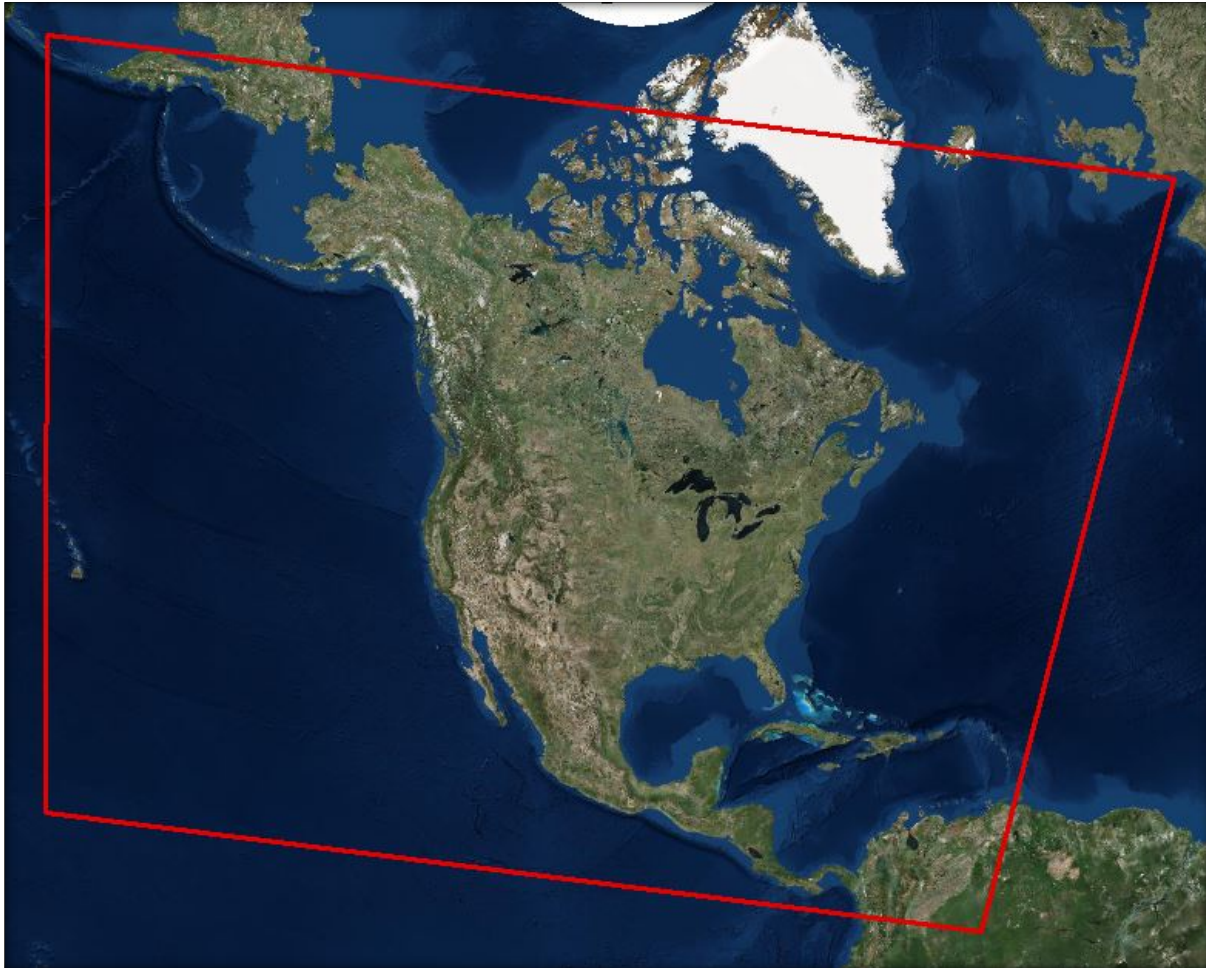
    <production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="qa" data_type="UINT16" fill_value="1" name="PIXELQA" nlines="5000"
nsamps="5000" product="level2_qa" source="level1">
  <short_name>LT04PQA</short_name>
  <long_name>level-2 pixel quality band</long_name>
  <file_name>PIXELQA</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>quality/feature classification</data_units>
  <bitmap_description>
    <bit num="0">fill</bit>
    <bit num="1">clear</bit>
    <bit num="2">water</bit>
    <bit num="3">cloud shadow</bit>
    <bit num="4">snow</bit>
    <bit num="5">cloud</bit>
    <bit num="6">cloud confidence</bit>
    <bit num="7">cloud confidence</bit>
    <bit num="8">unused</bit>
    <bit num="9">unused</bit>
    <bit num="10">unused</bit>
    <bit num="11">unused</bit>
    <bit num="12">unused</bit>
    <bit num="13">unused</bit>
    <bit num="14">unused</bit>
    <bit num="15">unused</bit>
  </bitmap_description>
  <app_version>generate_pixel_qa_1.6.0</app_version>
  <production_date>2018-05-09T23:46:52Z</production_date>
</band>
<band category="qa" data_type="UINT8" fill_value="1" name="RADSATQA" nlines="5000"
nsamps="5000" product="toa_refl" source="level1">
  <short_name>LT04RADSAT</short_name>
  <long_name>saturation mask</long_name>
  <file_name>RADSATQA</file_name>
  <pixel_size units="meters" x="30" y="30"/>
  <resample_method>none</resample_method>
  <data_units>bitmap</data_units>
  <valid_range max="255.000000" min="0.000000"/>
  <bitmap_description>
    <bit num="0">Data Fill Flag (0 = valid data, 1 = invalid data)</bit>
    <bit num="1">Band 1 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="2">Band 2 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="3">Band 3 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="4">Band 4 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="5">Band 5 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="6">Band 6 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
    <bit num="7">Band 7 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit>
  </bitmap_description>
  <app_version>LEDAPS_3.2.1</app_version>
  <production_date>2018-05-09T23:46:52Z</production_date>
</band>

```

## Appendix C NARR Grid Spatial Extent

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The ST algorithm requires input data from the NARR to perform corrections. The NARR grid covers all CONUS, Alaska, and Hawaii, which allows ST to be produced for all three regions.



*Figure C-1. NARR Grid Extent*

## Appendix D Acronyms

.tar	Tape Archive – file extension
.tif	Georeferenced Tagged Image File Format (GeoTIFF) – file extension
.xml	Extensible Markup Language (XML) – file extension
AEA	Albers Equal Area
ARD	Analysis Ready Data
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATRAN	Atmospheric Transmittance Layer
CDIST	Distance to Cloud
CONUS	Conterminous United States
DRAD	Downwelled Radiance Layer
DFCB	Data Format Control Book
DSWE	Dynamic Surface Water Extent
EMIS	Emissivity Layer
EMSD	Emissivity Standard Deviation
EROS	Earth Resources Observation and Science
ETM+	Enhanced Thematic Mapper Plus
fSCA	fractional Snow Covered Area
GED	Global Emissivity Database
GeoTIFF	Geographic Tagged Image File Format
ID	Identifier
INT	Signed Integer
JPL	Jet Propulsion Laboratory
K	Kelvin
LINEAGEQA	Lineage Index
LSB	Least Significant Bit
LST	Land Surface Temperature
M	Meter
MERRA	Modern-Era Retrospective Analysis for Research and Applications
MSB	Most Significant Bit
NA	Not Applicable
NARR	North American Regional Reanalysis
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
PIXELQA	Level 2 Pixel Quality Assessment Band
QA	Quality Assessment
RADSATQA	Level 2 Pixel Radiometric Saturation Band
RIT	Rochester Institute of Technology
RT	Real-Time
SLC	Scan Line Corrector
SR	Surface Reflectance

STT	Surface Temperature
STQA	Surface Temperature Quality Assessment
T1	Tier 1
T2	Tier 2
TES	Temperature Emissivity Separation
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
TOA BT	Top of Atmosphere Brightness Temperature
TRAD	Thermal Radiance
UINT	Unsigned Integer
URAD	Upwelled Radiance Layer
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
WRS	Worldwide Reference System
XML	Extensible Markup Language

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