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Landsat 4-9 Collection 2 Level-3 Provisional Actual Evapotranspiration Product Guide

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Landsat 4-9 Collection 2 Level-3 Provisional Actual Evapotranspiration Product Guide

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Executive Summary

This product guide describes the characteristics of the Landsat 4-9 Collection 2 Level-3 (L3) Provisional Actual Evapotranspiration (ETa) science product to facilitate its use in various water management, agricultural, and research applications using remote sensing data.

ETa is the quantity of water that is removed from a surface due to the processes of evaporation and transpiration. The Landsat 4-9 Collection 2 Provisional Actual Evapotranspiration science product is generated by solving the surface energy balance equation for the latent heat flux using a robust model and can be fundamental in the understanding of the spatiotemporal dynamics of water use over land surfaces.

This document is under Landsat Satellites Data System (LSDS) Configuration Control Board (CCB) control. Please submit changes to this document, as well as supportive material justifying the proposed changes, via Change Request (CR) to the Configuration Management Tool.

Document History

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Section 1 Introduction

1.1 Background

Landsat satellite data have been produced, archived, and distributed by the U.S. Geological Survey (USGS) since 1972. Users rely upon these data for conducting historical studies of land surface change and monitoring the Earth's surface but have shouldered the burden of post-production processing to create application-ready datasets. To alleviate this burden, 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 (BA), Fractional Snow Covered Area (fSCA), and Evapotranspiration (ET), as well as aquatic variables such as Dynamic Surface Water Extent (DSWE) and Aquatic Reflectance (AR) that are suitable for monitoring, assessing, and predicting the Earth surface change over time.

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.

This product guide describes the characteristics of the Landsat 4-9 Collection 2 Level-3 (L3) Provisional Actual Evapotranspiration (ETa) science product. The ETa is derived from the Landsat C2 Level-2 (L2) ST science product. The C2 L2 ST is input to a surface energy balance model with external auxiliary data to retrieve the daily total of ETa. The surface energy balance model used in this ETa calculation is directly derived from the Operational Simplified Surface Energy Balance (SSEBop) model (Senay et al., 2013; Senay, 2018). The SSEBop setup is based on the Simplified Surface Energy Balance (SSEB) approach (Senay et al., 2007, 2011) with a unique parameterization for operational applications. It combines ET fractions generated from Landsat C2 L2 ST with reference ET using a thermal index approach based on the principle of satellite psychrometry (Senay, 2018). The unique feature of the SSEBop parameterization is that it uses pre-defined, seasonally dynamic, boundary conditions that are specific to each pixel for the "hot/dry" and "cold/wet" reference points. The original formulation of SSEB is based on the hot and cold pixel principles of SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2007) models. For more information about the SSEBop algorithm, please see Senay (2018) in the References section and the LSDS-2150 Landsat 4-9 Collection 2 Level-3 Provisional Actual Evapotranspiration Algorithm Description Document (ADD).

The Landsat C2 Surface Temperature Level-2 science product (L2SP) and auxiliary data are required for successful processing of the C2 ETa. The ETa auxiliary data include the temperature difference between hot/dry and cold/wet limits (dT), maximum daily air temperature (Ta), and alfalfa-reference ET (ETr) data. The dT dataset is determined using net radiation inputs under gray-sky conditions and is derived from the ERA-5 satellite imagery (Kagone and Senay 2022). The maximum daily air temperature is a 1981-2010 climatological normal of Daymet Version 4 over North America and

1981-2010 climatological normal from the CHELSA Version 2 dataset for all other areas outside of North America (Karger et al., 2021; Thornton et al., 2020). The ETr data (Schauer et al., 2022) is a fusion of several remote sensing products: 1981-2010 climatological normal ETr from Gridmet over the continental United States and Merra Fine Resolution ETr for all areas outside of the continental United States that has been scaled and corrected via terrestrial ecoregions from OneEarth and scaled Worldclim Version 3 ET_0 (Abatzoglou 2013; Dinerstein et al., 2017; Hobbins et al., 2022; Zomer et al., 2022). The auxiliary data for ETa calculation are pre-processed, so it is not a dominating factor in the ETa latency. The latency of the C2 ETa science product for the new Landsat acquisitions is dependent on the availability of C2 L2 ST science product (between 4-11 days for Landsat 8 and approximately 3 days for Landsat 9).

Figure 1-1 shows an example of the C2 ETa product for the agricultural fields of Western San Joaquin Valley, using data acquired by Landsat 8 (Path 43 Row 35) on July 15, 2019. The SR natural color composite image (Bands 4,3,2) is shown for reference.

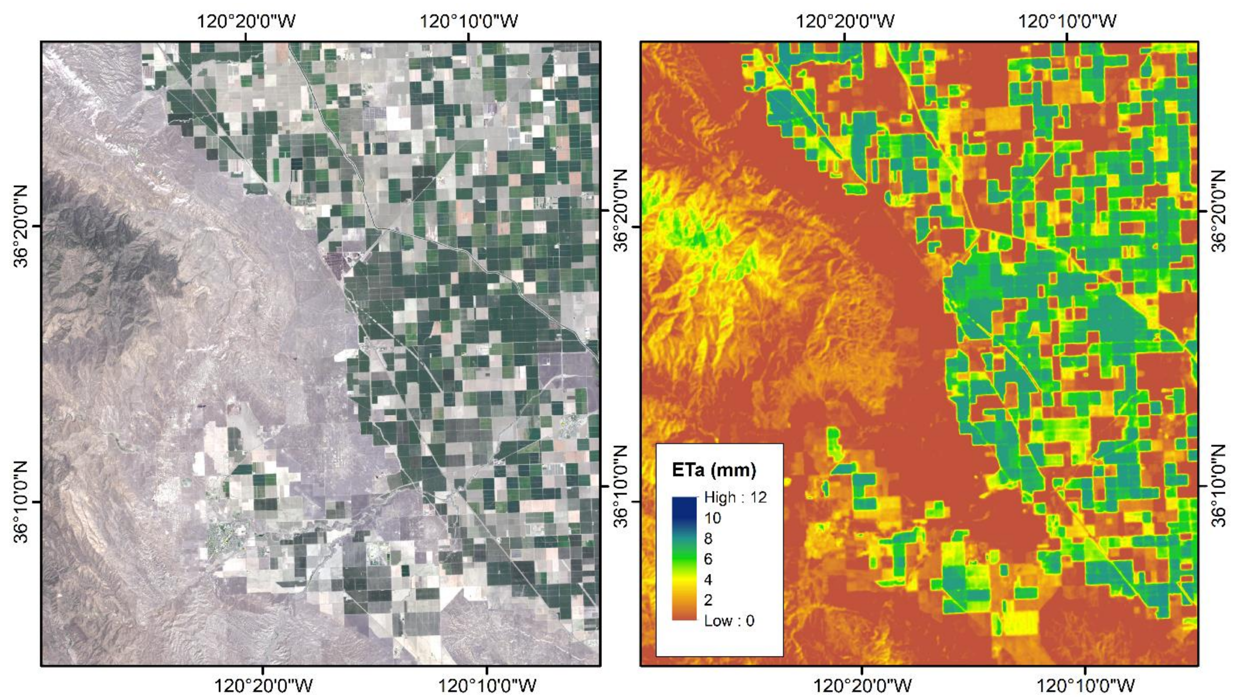

Figure 1-1. Example of Landsat C2 L2 Provisional Actual Evapotranspiration; Left: Natural Color SR Image, Right: Actual Evapotranspiration Image

Unlike Collection 1 ETa, which was limited to Conterminous United States (CONUS), the Collection 2 L3 ETa product is available globally.

The primary raster bands in Actual Evapotranspiration science product are the ET fraction (ETf) and the actual ET (ETa) bands. The ETa product also includes a Quality Assessment (QA) band that provide per-pixel quantitative information about uncertainty of calculated ETa. The L2 pixel Quality Assessment (QA_PIXEL) and metadata are also delivered within the product file package. Section 3 details the specifications of the product.

1.2 Purpose and Scope

The primary purpose of this document is to provide a detailed description of the Landsat 4-9 C2 ETa science product, its characteristics, product packaging, and download accessibility.

The scope of this document is the C2 ETa science product generated by the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA).

1.3 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 provides information about product packaging
- Section 3 provides product characteristics
- Section 4 provides information about product access
- Section 5 provides citation information
- Section 6 provides acknowledgment
- Section 7 provides the contact information of the user services
- Appendix A provides default file characteristics
- Appendix B provides sample metadata fields
- Appendix C contains a list of acronyms
- The References section contains a list of reference documents

Section 2 Product Packaging

2.1 Package Filename

The Landsat 4-9 C2 ETa science product is supplied in a compressed gzip file (.tar.gz). The package filename is structured similarly to the Landsat products delivered through ESPA. The following is an example of a typical ETa product package filename.

LXSSPPPRRRYYYYMMDDCCTX-SCyyyymmddhhmmss.tar.gz
(e.g., LC08001089201905060 2T1-SC20220719150513.tar.gz)

L Landsat
X Sensor (“C” = OLI/TIRS, “E” = ETM+, “T” = TM)
SS Satellite (“09” = Landsat 9, “08” = Landsat 8, “07” = Landsat 7, “05” = Landsat 5, “04” = Landsat 4)
PPP Path
RRR Row
YYYY Year of acquisition
MM Acquisition month
DD Acquisition day
CC Landsat Collection number (“02” for Collection 2)
TX Tier (“01” for Tier 1; “02” for Tier 2)
SC Science dataset
yyyy Year of ESPA processing
mm Month of ESPA processing
dd Day of ESPA processing
hh Hour of ESPA processing
ss Seconds of ESPA processing

Additional information about product packaging of the science products processed in ESPA is provided in the ESPA On-Demand Interface User Guide.

2.2 Product Filename

Unzipping the Landsat C2 ETa gzip package produces a tarball (.tar), which will “untar” into four individual raster files and supporting metadata files in Extensible Markup Language (XML) (.xml) and text (.txt) format. The four raster files include actual ET (ETA), ET fraction (ETF), ET Uncertainty (ETUN), and the L2 Pixel QA (QA_PIXEL) band.

The filenames are based on the Landsat C2 L2 Product Identifier (ProductID). Section 3 describes the product in further detail. The following is an example of an ETa product filename:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CX_TX_prod.ext

(e.g., LC08_L2SP_029029_20130712_20200912_02_T1_ETA.TIF)

L Landsat
X Sensor ("C" = OLI/TIRS, "E" = ETM+, "T" = TM)
SS Satellite ("09" = Landsat 9, "08" = Landsat 8, "07" = Landsat 7, "05" = Landsat 5, "04" = Landsat 4)
LLLL Processing correction level ("L2SP" = Level-2 SR and ST are generated)
PPP Path
RRR Row
YYYY Year of acquisition
MM Month of acquisition
DD Day of acquisition
yyyy Year of Level-1 processing
mm Month of Level-1 processing
dd Day of Level-1 processing
CX Collection number ("02" for Collection 2)
TX Collection category ("T1" = Tier 1; "T2" = Tier 2)
prod Product ("ETA" = actual ET, "ETF" = ET fraction, and "ETUN" = ET Uncertainty)
ext File format extension, such as "TIF", "tif", "img", "hdr", "hdf", "nc", "xml", or "txt"

Section 3 Product Characteristics

Landsat C2 Provisional Actual Evapotranspiration products are generated at the 30-meter spatial resolution for Landsat 4-5 TM, Landsat 7 ETM+, and Landsat 8-9 OLI/TIRS. The thermal bands from these three sensors have different spatial resolutions (120-meter in Landsat 4-5 TM, 60-meter in Landsat 7 ETM+, and 100-meter in Landsat 8-9 TIRS) though the Level-1 pixels are resampled to 30-meter resolution to match multispectral reflective bands. The default projection system for Landsat science products is Universal Transverse Mercator (UTM), but other projection systems such as Albers Equal Area (AEA), Geographic, and Polar Stereographic (PS) are available through the ESPA on-demand interface. The default file format is Cloud Optimized GeoTIFF (COG; *.TIF), but options for delivery in Georeferenced Tagged Image File Format (GeoTIFF; *.tif), Hierarchical Data Format – Earth Observing System – 2 (HDF-EOS2; *.hdf), Network Common Data Form (NetCDF; *.nc), or Exelis Visual Information Solutions (ENVI) binary (*.img) are available. More information on Landsat output formats supported by ESPA is available in the ESPA On-Demand Interface User Guide.

3.1 Available Products

The files included in Landsat C2 ETa product are listed below:

1. Actual Evapotranspiration (ETA) – Provides a per-pixel estimate of daily water transfer from the Earth's surface to the atmosphere in units of water depth (mm).

2. ET fraction (ETF) – Represents unitless fraction of reference alfalfa potential ET (ETr), nominally varying between 0 and 1 (in SSEBop model the maximum ET fraction is 1.0). This could be used in combination with user provided reference ET (ETr) to create a more accurate ETa which takes into account local weather conditions.

3. ET Uncertainty (ETUN) – Provides ET product uncertainty in units of water depth (mm) using ETr auxiliary data.

4. Pixel Quality Assessment (QA_PIXEL) – The bit combinations that define certain quality conditions. Additional information about the Collection 2 Pixel QA band are provided in the Landsat 4-7 Collection 2 Level-2 Science Product Guide and Landsat 8-9 Collection 2 Level-2 Science Product Guide.

5. Metadata – Includes Actual Evapotranspiration information in XML format (Product_ID.xml) and Level-1 metadata both in .txt and XML format.

3.2 Product Specifications

Table 3-1 lists the specifications for each band included in the Actual Evapotranspiration product.

Description	Band Name	Valid Range	Scale Factor	Unit	Fill Value	Data Type
Actual ET (ETa)	ProductID_ETA	0 - 20000	0.001	mm	-9999	INT16
ET Fraction (ETf)	ProductID_ETF	0 - 10000	0.0001	Unitless	-9999	INT16
ET Uncertainty (ETUN)	ProductID_ETUN	0 - 15000	0.001	mm	-9999	INT16
Level-2 Pixel QA	ProductID_QA_PIXEL	0 - 65535	NA	Bit Index	1 (bit 0)	UINT16
Level-3 XML Metadata file	ProductID.xml	N/A	N/A	N/A	N/A	N/A
Level-1 MTL Metadata files	.txt and .xml	N/A	N/A	N/A	N/A	N/A

Table 3-1. Landsat C2 Provisional Actual Evapotranspiration Product Specifications

3.2.1 Metadata

Each Landsat Provisional Actual Evapotranspiration product will be accompanied by an XML-based metadata file. The metadata fields included in the XML are listed in Appendix B.

3.3 Caveats and Constraints

1. The current Landsat 4-9 C2 Actual Evapotranspiration science product is considered provisional. The ET algorithm outputs that are generated using C2 ST have not been completely validated. In preliminary validations, the daily and monthly Landsat ETa compared reasonably well with the in-situ data obtained from Eddy-Covariance Flux Towers from the Ameriflux network (Senay et al., 2017; Senay et al., 2019). For additional information about the preliminary validation details, see the References section.

2. Both reflective and thermal Landsat bands are required for the successful processing of the ETa science product. Therefore OLI-only or TIRS-only Landsat 8 or 9 scenes cannot be processed to ETa.

3. The Actual ET product may contain NoData pixels within the valid areas of the Landsat scene. These NoData pixels are usually the cloud, cloud shadow, or pixels with radiometric saturation that are masked. They could also be due to missing ASTER GED auxiliary data required for C2 ST processing. For additional information about gaps in ASTER GED data please see https://www.usgs.gov/landsat-missions/landsat-collection-2-surface-temperature-data-gaps-due-missing-aster-ged.

4. The Landsat Collection 2 Level-2 ST is the primary input to the ETa algorithm. The blockiness artifact and vegetation adjustment anomaly present in Collection 2 ST may also appear in C2 ETa. For further information, please refer to https://www.usgs.gov/landsat-missions/landsat-collection-2-known-issues.

5. It is important to note that there are two major products: ET fraction (ETf) and actual ET (ETa). The ETa is based on the product of ETf and a climatology (long term normal) reference ET (ETr). Because the ETr is a climatology and does not capture the day-to-day weather variability, comparison against flux tower data may produce relatively larger deviations on a given day, but this effect would be minimized when the ETa data are aggregated to larger time scales such as monthly. Users are encouraged to use the provided ETf with the best available ETr for the corresponding day for evaluating the performance of the model against daily flux towers or other independent datasets. However, the ETa data are expected to capture the spatial variability adequately.

Section 4 Product Access

Landsat 4-9 C2 Provisional ETa products can be requested through the USGS EROS Science Processing Architecture (ESPA) On-demand Interface (https://espa.cr.usgs.gov/). ESPA offers additional customization services such as reprojection, spatial subsetting, and pixel resizing. More information about ESPA's processing options can be found in the ESPA On-Demand Interface User Guide.

Section 5 Citation Information

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

Landsat Collection 2 Level-3 Provisional Actual Evapotranspiration Science Product courtesy of the U.S. Geological Survey.

Senay, G.B., Parrish, G.E., Schauer, M., Friedrichs, M., Khand, K., Boiko, O., Kagone, S., Dittmeier, R., Arab, S. and Ji, L., (2023). Improving the Operational Simplified Surface Energy Balance Evapotranspiration Model Using the Forcing and Normalizing Operation. Remote Sensing, 15(1), 260. https://doi.org/10.3390/rs15010260

Senay, G.B. (2018). Satellite Psychrometric Formulation of the Operational Simplified Surface Energy Balance (SSEBop) Model for Quantifying and Mapping Evapotranspiration. Applied Engineering in Agriculture, 34(3),555-566. https://doi.org/10.13031/aea.12614

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 6 Acknowledgment

The Landsat Provisional Actual Evapotranspiration algorithm is based on the SSEBop model developed by Gabriel Senay (USGS EROS).

Section 7 User Services

Landsat Science Products and associated interfaces are supported by User Services staff at the USGS Earth Resources Observation and Science (EROS) Center. Questions or comments regarding Landsat Science Products or interfaces are welcome and can be sent via email or by phone.

USGS EROS User Services
Email: custserv@usgs.gov
Phone: 800-252-4547

USGS Landsat Missions Website (LMWS)
https://www.usgs.gov/landsat-missions

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

A typical Landsat Provisional Actual Evapotranspiration file size and product naming convention are illustrated below.

Description	Example File Size (Kbytes)	Example File Name
Actual Evapotranspiration (ETa)	78,900	LC08_L2SP_029029_20130712_20200912_02_T1_ETA.TIF
Evapotranspiration fraction (ETf)	83,700	LC08_L2SP_029029_20130712_20200912_02_T1_ETF.TIF
Evapotranspiration Uncertainty (ETUN)	31,500	LC08_L2SP_029029_20130712_20200912_02_T1_ETUN.TIF
Level-2 Pixel Quality Assessment (QA)	824	LC08_L2SP_029029_20130712_20200912_02_T1_QA_PIXEL.TIF
Metadata	24	LC08_L2SP_029029_20130712_20200912_02_T1.xml

Table A-1. Example Landsat Provisional Actual Evapotranspiration Files

Appendix B Metadata Fields

Example of global XML metadata:

```
<global_metadata>
  <data_provider>USGS/EROS</data_provider>
  <satellite>LANDSAT_8</satellite>
  <instrument>OLI_TIRS</instrument>
  <acquisition_date>2019-07-15</acquisition_date>
  <scene_center_time>18:40:14.5589870Z</scene_center_time>
  <level1_production_date>2020-08-27T18:33:45Z</level1_production_date>
  <solar_angles zenith="24.351212" azimuth="120.647911" units="degrees"/>
  <earth_sun_distance>1.016454</earth_sun_distance>
  <wrs system="2" path="43" row="35"/>
  <product_id>LC08_L2SP_043035_20190715_20200827_02_T1</product_id>

<lpgs_metadata_file>LC08_L2SP_043035_20190715_20200827_02_T1_MTL.txt</lpgs_me
tadata_file>
  <corner location="UL" latitude="37.098660" longitude="-122.222390"/>
  <corner location="LR" latitude="34.966810" longitude="-119.746090"/>
  <bounding_coordinates>
    <west>-122.242852</west>
    <east>-119.658878</east>
    <north>37.098797</north>
    <south>34.966667</south>
  </bounding_coordinates>
  <projection_information projection="UTM" datum="WGS84" units="meters">
    <corner_point location="UL" x="569100.000000" y="4106100.000000"/>
    <corner_point location="LR" x="797100.000000" y="3874200.000000"/>
    <grid_origin>CENTER</grid_origin>
    <utm_proj_params>
      <zone_code>10</zone_code>
    </utm_proj_params>
  </projection_information>
  <orientation_angle>0.000000</orientation_angle>
</global_metadata>
```

Example of Actual Evapotranspiration XML metadata:

```
<band product="evapotranspiration" source="sr_refl" name="ETUN" category="qa"
data_type="INT16" scale_factor="0.001" nlines="7731" nsamps="7601"
fill_value="-9999">
  <short_name>LC08ETUN</short_name>
  <long_name>Evapotranspiration Quantitative Uncertainty QA Band</long_name>
  <file_name>LC08_L2SP_043035_20190715_20200827_02_T1_ETUN.img</file_name>
  <pixel_size x="30" y="30" units="meters"/>
  <resample_method>none</resample_method>
  <data_units>mm</data_units>
  <valid_range min="0.0" max="15000"/>
  <app_version>et_3.0.0 (Collection 2)</app_version>
  <production_date>2022-07-13T17:21:16Z</production_date>
</band>
<band product="evapotranspiration" source="sr_refl" name="ETF"
category="image" data_type="INT16" scale_factor="0.0001" nlines="7731"
nsamps="7601" fill_value="-9999">
```

```
  <short_name>LC08ETF</short_name>
  <long_name>Evapotranspiration fraction</long_name>
  <file_name>LC08_L2SP_043035_20190715_20200827_02_T1_ETF.img</file_name>
  <pixel_size x="30" y="30" units="meters"/>
  <resample_method>none</resample_method>
  <data_units>unitless</data_units>
  <valid_range min="0.0" max="10000.0"/>
  <app_version>et_3.0.0 (Collection 2)</app_version>
  <production_date>2022-07-13T17:22:28Z</production_date>
</band>
<band product="evapotranspiration" source="sr_refl" name="ETA"
category="image" data_type="INT16" scale_factor="0.001" nlines="7731"
nsamps="7601" fill_value="-9999">
  <short_name>LC08ETA</short_name>
  <long_name>Evapotranspiration actual</long_name>
  <file_name>LC08_L2SP_043035_20190715_20200827_02_T1_ETA.img</file_name>
  <pixel_size x="30" y="30" units="meters"/>
  <resample_method>none</resample_method>
  <data_units>mm</data_units>
  <valid_range min="0.0" max="20000.0"/>
  <app_version>et_3.0.0 (Collection 2)</app_version>
  <production_date>2022-07-13T17:22:28Z</production_date>
</band>
```

Appendix C Acronyms

ADD	Algorithm Description Document
AEA	Albers Equal Area
ASTER GED	Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Dataset
BA	Burned Area
C1	Collection 1
C2	Collection 2
CCB	Configuration Control Board
COG	Cloud Optimized GeoTIFF
CONUS	Conterminous United States
CR	Change Request
DSWE	Dynamic Surface Water Extent
dT	Difference between hot and cold temperatures
ENVI	Exelis Visual Information Solutions
EROS	Earth Resources Observation and Science
ESPA	EROS Science Processing Architecture
ET	Evapotranspiration
ETa	Actual Evapotranspiration
ETf	Evapotranspiration fraction
ETM+	Enhanced Thematic Mapper Plus
ETr	Evapotranspiration Alfalfa-Reference Potential
ETUN	Evapotranspiration Uncertainty
fSCA	Fractional Snow Covered Area
GeoTIFF	Georeferenced Tagged Image File Format
HDF	Hierarchical Data Format
HDF-EOS2	Hierarchical Data Format for Earth Observation Systems (version 2)
L1	Level-1
L1GS	Level-1 Geometric Systematic
L1GT	Level-1 Systematic Terrain (Corrected)
L1TP	Level-1 Terrain Precision (Corrected)
L2	Level-2
L3	Level-3
LaSRC	Land Surface Reflectance Code
LMWS	Landsat Missions Website
LSDS	Land Satellites Data System
METRIC	Satellite-Based Energy Balance for Mapping Evapotranspiration With Internalized Calibration
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
PIXELQA	Pixel Quality Assessment
PS	Polar Stereographic
QA	Quality Assessment
RT	Real Time

SEBAL	Surface Energy Balance Algorithm for Land
SR	Surface Reflectance
SSEB	Simplified Surface Energy Balance
SSEBop	Operational Simplified Surface Energy Balance
ST	Surface Temperature
STQA	Surface Temperature Quality Assessment
T1	Tier 1
T2	Tier 2
Ta	Maximum daily air temperature
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
XML	Extensible Markup Language

References

Please see https://www.usgs.gov/landsat-missions/landsat-acronyms for a list of acronyms.

USGS/EROS. LSDS-1618. Landsat 4-7 Collection 2 (C2) Level-2 Science Product (L2SP) Guide
https://www.usgs.gov/media/files/landsat-4-7-collection-2-level-2-science-product-guide

USGS/EROS. LSDS-1619 Landsat 8-9 Collection 2 (C2) Level-2 Science Product (L2SP) Guide
https://www.usgs.gov/media/files/landsat-8-9-collection-2-level-2-science-product-guide

USGS/EROS. LSDS-2150 Landsat 4-9 Collection 2 Level-3 Provisional Actual Evapotranspiration Algorithm Description Document
https://www.usgs.gov/media/files/landsat-4-9-collection-2-level-3-provisional-actual-evapotranspiration-algorithm

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Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag, 1998. The surface energy balance algorithm for land (SEBAL): Part 1 formulation. Journal of Hydrology 212–213: 198–212.

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N.D., Wikramanayake, E., … & Saleem, M. (2017). An ecoregion-based approach to protecting half the terrestrial realm. BioScience, 67(6), 534-545. https://doi.org/10.1093/biosci/bix014

Hobbins, M., Dewes, C., and Jansma, T., 2022, Global reference evapotranspiration for food-security monitoring: U.S. Geological Survey data release, https://doi.org/10.5066/P9IIQMV1.

Ji, L., Senay, G., Velpuri, N., & Kagone, S. (2019). Evaluating the Temperature Difference Parameter in the SSEBop Model with Satellite-Observed Land Surface Temperature Data. Remote Sensing.

Kagone, S., and Senay, G.B., 2022, Global gray-sky dT: the inverse of the surface psychrometric constant parameter in the SSEBop evapotranspiration model: U.S. Geological Survey data release, https://doi.org/10.5066/P9JBW6R9.

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