JPL D-103137

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) Mission

Level 2 Product User Guide

Version 2
18 June, 2019

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This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Note:
The users' guide is designed to be a living document that describes the ECOSTRESS Land Surface Temperature and Emissivity (LST&E) product. The document describes the current state of the art, and is revised as progress is made in the development and assessment of the LST product. The primary purpose of the document is to present an overview of the ECOSTRESS L2 data product to the potential user. For more detailed information on the physical basis and algorithm details please see the Algorithm Theoretical Basis Document (ATBD).

Change History Log

Revision	Effective Date	Prepared by	Description of Changes
Draft	6/4/2018	Glynn Hulley	User Guide first draft based on MxD21/VNP21 products
Version 1	10/23/2018	Glynn Hulley	Remove bit 4 from cloud mask product (table 7). Other small edits and clarifications in document.
Version 2	06/18/2019	Glynn Hulley	Updates to account for MSU failure anomaly.

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1 Introduction

This is the user guide for the ECOSTRESS Level-2 Land Surface Temperature and Emissivity (LST&E) products.. The L2 product uses a physics-based algorithm to dynamically retrieve both the LST&E simultaneously for the five ECOSTRESS thermal infrared bands at a spatial resolution of ~70×70 m. The algorithm is based on the ASTER Temperature Emissivity Separation (TES) algorithm, which uses full radiative transfer simulations for the atmospheric correction, and an emissivity model based on the variability in the surface radiance data to dynamically retrieve both LST and spectral emissivity. The TES algorithm is combined with an improved Water Vapor Scaling (WVS) atmospheric correction scheme to stabilize the retrieval and improve accuracy in hot and humid conditions. Simulations and validation results available in the ATBD have shown consistent accuracies at the 1 K level over all land surface types including vegetation, water, and deserts.

The ECOSTRESS L2 product will include a swath product in standard geographic (lat, lon tagged) format. The algorithms and data content of the LST&E and cloud products are briefly described in this guide, with the purpose of providing a user with sufficient information about the content and structure of the data files to enable the user to access and use the data, in addition to understanding the uncertainties involved with the product and how to interpret the cloud mask information. Overviews of the file formats and provided first followed by descriptions of the algorithm and product contents including all metadata. Publications and documents related to the ECOSTRESS LST&E and cloud products are listed in the final section.

On September 29th 2018, ECOSTRESS experienced an anomaly with its primary mass storage unit (MSU). ECOSTRESS has a primary and secondary MSU (A and B). On December 5th, the instrument was switched to the secondary MSU and operations resumed with initial acquisitions over Australia and wider coverage resumed on January 9th 2019. The initial anomaly was attributed to exposure to high radiation regions, primarily over the Southern Atlantic Anomaly, and the acquisition strategy was revised to exclude these regions from future acquisitions. On March 14th 2019, the secondary MSU experienced an anomaly, and acquisitions are temporarily on hold. Work is underway to implement a direct streaming option, which will bypass the need for mass storage units. The streaming acquisition mode will change the format of the data being collected. Specifically, the new collection mode will eliminate the 1.6 μm (SWIR), 8.2 μm (TIR), and 9.0 μm (TIR) bands. To simplify product formats, the L1 and L2 products will continue to contain the datasets for these bands, but the datasets will contain fill values. This will be seen in products generated after May 15th 2019, when the instrument resumes operations. These changes are described in the detailed product specifications.

A description of the major components of the ECOSTRESS algorithm implemented in version 1 of the LST&E Product Generation Executive (PGE) code are shown in Table 1 and described in depth in the ATBD available at https://ecostress.jpl.nasa.gov/products. The primary purpose of this document is to supply a user with sufficient information about the content and structure of the data files so that the users will be able to access and use the data with confidence.

1.1 File format for L2 products

The ECOSTRESS LST&E and cloud products are distributed in HDF5 format and can be read in by HDF5 software. Information on Hierarchical Data Format 5 (HDF5) may be found at

https://www.hdfgroup.org/HDF5/. The HDF format was developed by NCSA, and has been widely used in the scientific domain. HDF5 can store two primary types of objects: datasets and groups. A dataset is essentially a multidimensional array of data elements, and a group is a structure for organizing objects in an HDF5 file. HDF5 was designed to address some of the limitations of the HDF4. Using these two basic objects, one can create and store almost any kind of scientific data structure, such as images, arrays of vectors, and structured and unstructured grids. They can be mixed and matched in HDF5 files according to user needs. HDF5 does not limit the size of files or the size or number of objects in a file. The scientific data results are delivered as SDSs with local attributes including summary statistics and other information about the data. More detailed information on HDF5 data types may be found in the L2 Product Specification Document (PSD) available at https://ecostress.jpl.nasa.gov/products.

The ECOSTRESS LST&E and cloud data product files contain one set of Attributes (metadata) describing information relevant to production, archiving, user services, input products, geolocation and analysis of data, as well as provenance and Digital Object Identifier (DOI) of the product attached to the root group (the file). The attributes listed in Table 4 are not described further in this user guide.

1.2 LST&E and Cloud Product

The ECOSTRESS LST&E and cloud data products are produced in swath format, i.e. each pixel is lat/lon tagged. The image scene (swath) consists of 44 scans of the instrument mirror, with each scan taking approximately 1.181 seconds, and each image scene taking approximately 52 seconds. Each image scene starts at the beginning of the first target area encountered during each orbit. Each orbit is defined as the equatorial crossing of an ascending International Space Station (ISS) orbit. The spatial resolution of each pixel is 70×70 m with 5632 pixels along track and 5400 pixels per line for each scene. Table 1 shows a summary of the L2 product characteristics.

Other data product levels briefly described: Level 1B (L1B) is a swath (scene) of measured radiance data geolocated to latitude and longitude centers of 70m resolution pixels. A level 2 (L2) product is a geophysical product retrieved from the L1B data that remains in latitude and longitude orientation; it has not been temporally or spatially manipulated. The level 3 and 4 (L3, L4) ECOSTRESS products consist of a higher level geophysical variables output from models (evapotranspiration, evaporative stress index, water use efficiency) derived from the L2 and other ancillary data, and are output in the same latitude/longitude swath orientation.

Table 1: Summary of the ECOSTRESS LST&E and cloud products.

Earth Science Data Type (ESDT)	**Product Level**	**Data Dimension**	**Spatial Resolution**	**Temporal Resolution**	**Map Projection**
ECOSTRESS_L2_LSTE ECOSTRESS_L2_CLOUD	L2	5632 lines by 5400 pixels per line	70 m	Swath	None, (lat, lon tagged)

1.3 Product Availability

The ECOSTRESS L2 product will be made available at the NASA Land Processes Distribution Active Archive Center (LPDAAC)(https://lpdaac.usgs.gov/dataset_discovery/ECOSTRESS), accessed via the Earthdata search engine (https://search.earthdata.nasa.gov/), or in the Data Pool.

2 ECOSTRESS_L2_LSTE Product

2.1 Algorithm Description

For a full detailed description of each module within the L2 PGE please see the ATBD at https://ecostress.jpl.nasa.gov/products. The algorithm uses a physical-based Temperature and Emissivity Separation (TES) algorithm to retrieve the Land Surface Temperature and Emissivity (LST&E) products (Gillespie et al. 1998; Hulley and Hook 2011). The atmospheric correction of the ECOSTRESS thermal infrared (TIR) bands 1-5 are performed using the RTTOV radiative transfer model (Matricardi 2008; Saunders et al. 1999) with input atmospheric profiles from the GEOS5 reanalysis product produced by the NASA Global Modeling and Assimilation Office (GMAO) (Rienecker et al. 2011). The GEOS5 data are provided on a ~1/3 degree longitude, 1/4 degree latitude spatial grid every 3 hours, with data provided in near real-time via ftp.

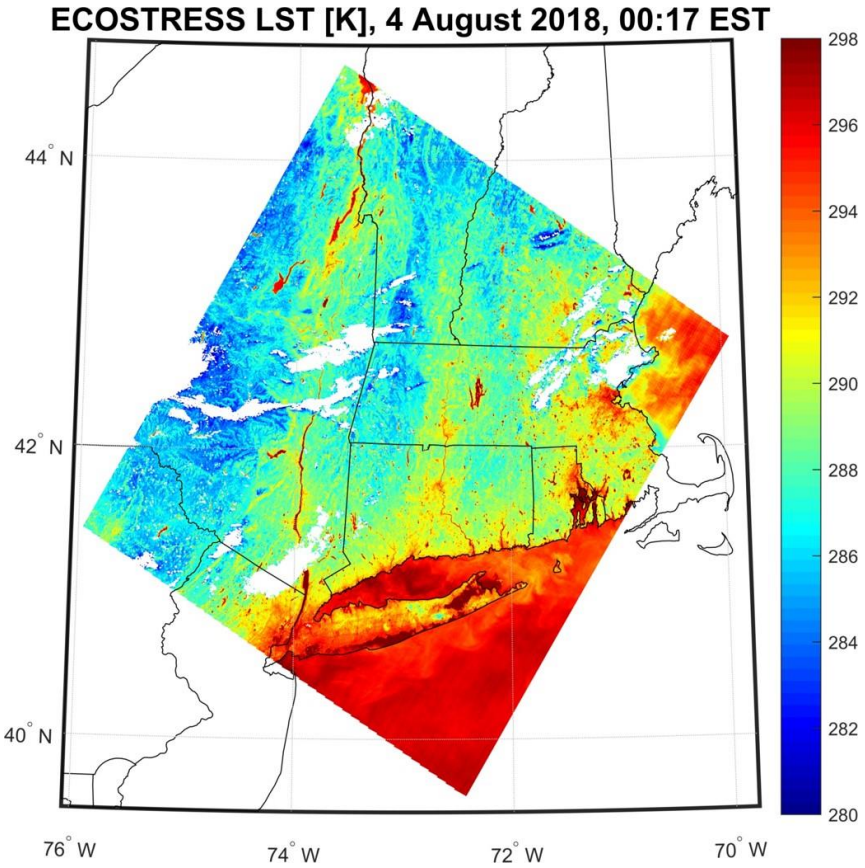

Figure 1. ECOSTRESS L2 Land Surface Temperature (LST) scene on 4 August 2018. Cloudy pixels have been masked using the L2 cloud mask product and appear as white space within the scene.

A Water Vapor Scaling (WVS) model is further employed to improve the atmospheric correction accuracy under conditions of heavy water vapor loadings on a pixel-by-pixel basis (Malakar and Hulley 2016; Tonooka 2005). The ECOSTRESS LST&E product will be produced for all acquired ECOSTRESS scenes and for every pixel of data regardless of cloud. The L2 product also includes a full set of error estimates for both the LST and all five emissivity bands generated from an uncertainty model (Hulley et al. 2012). Figure 2 shows a schematic detailing the flow of the ECOSTRESS PGE within the JPL Science Data System (SDS) including the primary input datasets, and subprocesses.

Due to the MSU failure anomalies, L2 products generated after May 15th 2019 will use a 3-band version of the TES algorithm with bands 2, 4 and 5. This will result in emissivity only being produced in those bands and the remaining bands will have fill values. The dropped bands will have no effect on the cloud mask algorithm that only uses bands 4 and 5. The retrieved LST with a 3-band approach will also result in degraded accuracy when compared to the 5-band approach. Simulations show that total RMS errors will increase from approximately 1 K to near 1.5 K. More details on these changes and uncertainty estimates are available by the science team.

Data inputs to the ECOSTRESS L2 algorithm are listed in Table 2. An additional L2 cloud mask will be provided and details of this product are shown in Table 3. Note that the L2 algorithm will run on all pixels regardless of cloud, primarily due to the limitations of having only thermal bands available for the cloud mask detection algorithm. The result is that for certain difficult case scenarios (e.g. low warm clouds at night, cold clouds over cold surfaces such as ice/snow), the cloud mask could potentially overestimate/underestimate the clouds present in a scene. For cases such as this the user would need to further explore the outputs from different cloud tests from the cloud mask 8-bit product detailed in section 3, and/or adapt and modify the cloud mask thresholds for their particular use case. In addition, longwave retrieved emissivity bands (e.g. 4 and 5) are usually good indicators of cloud contamination. e.g. band 4 emissivity values less than 0.9 should be regarded as suspect and possibly cloud contaminated in the presence of nearby cloud.

The ASTER GED v3 emissivity product (Hulley et al. 2015) is used to assign the correct emissivity-dependent coefficients in the WVS model on a scene-by-scene basis. Details of this procedure are available in the ECOSTRESS ATBD.

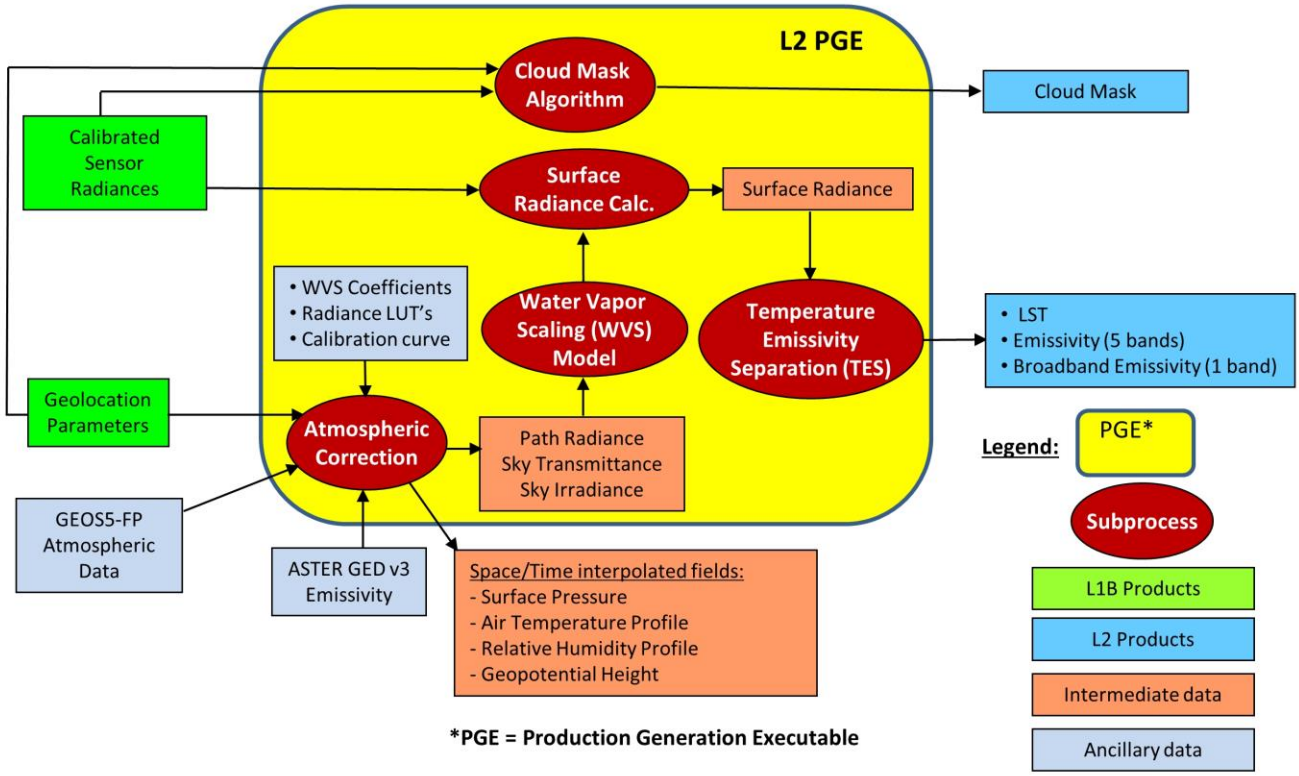

Figure 2. Schematic detailing the flow of the ECOSTRESS LST PGE within the JPL Science Data System.

Table 2: ECOSTRESS input products and ancillary data required to produce the L2 LST&E product.

Ancillary Data Set	**Long Name**	**Data Used**
ECOSTRESS_L1B	ECOSTRESS Level-1B calibrated and geolocated radiances	Radiance_1…5
ECOSTRESS_L1B_GEO	Geolocation	Land/ocean mask Elevation Sensor and solar zenith angles Latitude, Longitude
ASTER GEDv3	ASTER Global Emissivity Dataset v3	Emis 10..14 NDVI
GEOS5-FP	Atmospheric reanalysis data from the Global Modeling and Assimilation Office (GMAO)	Pressure and geopotential height Temperature Specific Humidity Surface Pressure

2.2 Scientific Data Sets (SDS)

The ECOSTRESS Level-2 LST&E product contains 15 scientific data sets (SDSs): LST, LST_err, QC, Emis1, Emis2, Emis3, Emis4, Emis5, Emis1_err, Emis2_err, Emis3_err, Emis4_err, Emis5_err, EmisWB, and PWV. All SDS data are output at native ECOSTRESS 70m resolution pixels. The *_Err SDSs are calculated using a LST&E uncertainty simulator and includes the maximum total uncertainty for a specific pixel based on view angle, total water vapor, and land cover type (Hulley et al. 2012b). Furthermore, a spatially and temporally interpolated Precipitable Water Vapor (PWV) estimate from GEOS5 data is included in the SDS as an indicator for the amount of water vapor present in the atmosphere, the primary driving factor for atmospheric correction uncertainty in retrieving LST&E. Details of each SDS including fill and scale factors are shown in Table 3.

Table 3. The Scientific Data Sets (SDS) in the ECOSTRESS L2 product.

SDS	Long Name	Data type	Units	Valid Range	Fill Value	Scale Factor	Offset
Group	**SDS (5632 lines, 5400 pixels)**						
LST	Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC	Quality control for LST and emissivity	uint16	n/a	0-65535	0	n/a	n/a
Emis1	Band 1 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis2	Band 2 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis3	Band 3 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis4	Band 4 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis5	Band 5 emissivity	uint8	n/a	1-255	0	0.002	0.49
LST_Err	Land Surface Temperature error	uint8	K	1-255	0	0.04	0.0
Emis1_Err	Band 1 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis2_Err	Band 2 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis3_Err	Band 3 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis4_Err	Band 4 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis5_Err	Band 5 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
EmisWB	Wideband emissivity	uint8	n/a	1-255	0	0.002	0.49

PWV	Precipitable Water Vapor	uint16	cm	0-65535	0	0.001	0.0

2.3 Attributes

Archived with the SDS are attributes (metadata) describing characteristics of the data. Contents of these attributes were determined and written during generation of the product at JPL by the Process Control System (PCS) and are used in archiving and populating the database at the LPDAAC to support user services. They are stored as very long character strings in parameter value language (PVL) format. Descriptions of the attributes are given here to assist the user in understanding them. ECOSTRESS products consist of a set of standard metadata (Table 4) and product-specific metadata (Table 5). The product specific metadata in Table 5 give details on percent cloud cover, cloud temperatures, percent good quality data, and average LST and emissivity values for the entire scene.

Table 4. Standard product metadata included in all ECOSTRESS products.

Name	Type	Size	Example
Group	**StandardMetadata**		
AncillaryInputPointer	String	variable	Group name of ancillary file list
AutomaticQualityFlag	String	variable	PASS/FAIL (of product data)
BuildId	String	variable	
CollectionLabel	String	variable	
DataFormatType	String	variable	NCSAHDF5
DayNightFlag	String	variable	
EastBoundingCoordinate	LongFloat	8	
HDFVersionId	String	variable	1.8.16
ImageLines	Int32	4	5632
ImageLineSpacing	Float32	4	68.754
ImagePixels	Int32	4	5400
ImagePixelSpacing	Float32	4	65.536
InputPointer	String	variable	
InstrumentShortName	String	variable	ECOSTRESS
LocalGranuleID	String	variable	
LongName	String	variable	ECOSTRESS
NorthBoundingCoordinate	LongFloat	8	
PGEName	String	variable	L2_LSTE (L2_CLOUD)
PGEVersion	String	variable	
PlatformLongName	String	variable	ISS
PlatformShortName	String	variable	ISS
PlatformType	String	variable	Spacecraft

ProcessingLevelID	String	variable	1
ProcessingLevelDescription	String	variable	Level 2 Land Surface Temperatures and Emissivity (Level 2 Cloud mask)
ProducerAgency	String	variable	JPL
ProducerInstitution	String	variable	Caltech
ProductionDateTime	String	variable	
ProductionLocation	String	variable	
CampaignShortName	String	variable	Primary
RangeBeginningDate	String	variable	
RangeBeginningTime	String	variable	
RangeEndingDate	String	variable	
RangeEndingTime	String	variable	
SceneID	String	variable	
ShortName	String	variable	L2_LSTE (L2_CLOUD)
SISName	String	variable	
SISVersion	String	variable	
SouthBoundingCoordinate	LongFloat	8	
StartOrbitNumber	String	variable	
StopOrbitNumber	String	variable	
WestBoundingCoordinate	LongFloat	8	

Table 5.Product specific metadata for the ECOSTRESS L2 product.

Name	**Type**	**Size**	**Example**
Group	**L2 LSTE Metadata**		
QAPercentCloudCover	Int	4	80
CloudMeanTemperature	LongFloat	8	231
CloudMaxTemperature	LongFloat	8	275
CloudMinTemperature	LongFloat	8	221
CloudSDevTemperature	LongFloat	8	0.45
QAFractionGoodQuality	Int	4	0.7
LSTGoodAvg	LongFloat	8	285.4
Emis1GoodAvg	LongFloat	8	0.95
Emis2GoodAvg	LongFloat	8	0.95
Emis3GoodAvg	LongFloat	8	0.95
Emis4GoodAvg	LongFloat	8	0.95
Emis5GoodAvg	LongFloat	8	0.95
AncillaryGEOS5	Str	255	GEOS.fp.asm.inst3_3d_asm_Np.20140702_0000.V01
BandSpecification	Float32	µm	Wavelengths used in the L2 retrieval for bands 1-6: 1.6, 8.2, 8.7,9.0, 10.5, 12.0; 0=fill data

2.4 Quality Assurance (QA)

Indicators of quality are described exclusively in the quality control (QC) SDS generated during production. In addition to data quality, the QC SDS provides information on algorithm metrics for each pixel (e.g. convergence statistics). The QC SDS unsigned 16-bit data are stored as bit flags in the SDS. This QC information can be extracted by reading the bits in the 16-bit unsigned integer. The purpose of the QC SDS is to give the user information on algorithm results for each pixel that can be viewed in a spatial context. The QC information tells if algorithm results were nominal, abnormal, or if other defined conditions were encountered for a pixel. The QC information should be used to help determine the usefulness of the LST and Emissivity data for a users' needs. The bit flags in the QC SDS are listed in Table 6 and consist of flags related to data quality, cloud, TES algorithm diagnostics, and error estimates.

A value for bits 1&0 = 00 in the QC bit flags indicates best quality, cloud-free data and generally no further analysis of the QC bits is necessary. However, given the limitation of having thermal-only bands in the cloud mask algorithm, on some occasions false positive cloud may be detected, and for that reason the L2 retrieval runs on all pixels regardless of cloud, and the user may then further inspect the cloud bit mask to tailor the results to his/her needs, or to even produce their own cloud mask.

Users may also include data of 'nominal quality' (bits 1&0 = 01) in their analysis, however, caution should be taken since either one of the following algorithmic conditions are met, and more detailed analysis of other QC bits is recommended:

1. The retrieved emissivity in both longwave bands 4 (10.6 micron) and 5 (12 micron) is < 0.95 indicating possible cloud contamination.
2. The pixel falls on a missing scan line in bands 1 and 5, in which the radiance was filled using a spatial neural net technique (see Appendix A for more details). The user should check error estimates for this pixel to see if they fall within tolerable bounds.
3. The pixel had transmissivity less than 0.4 indicating either possible cloud contamination or high humidity, which would result in higher uncertainty in the TES retrieval. The user is encourage to check error estimates before using this pixel for science analysis.

A value for bits 1&0 = 01 indicates cloud was detected, while a value for bits 1&0=11 indicates that the pixel was not produced due to poorly calibrated or missing radiance data, or the TES algorithm failed to converge (rare).

Table 6. Bit flags defined in the QC SDS in the MxD21_L2 product. (Note: Bit 0 is the least significant bit).

Bits	Long Name	Description
1&0	Mandatory QA flags	00 = Pixel produced, best quality 01 = Pixel produced, nominal quality. Either one or more of the following conditions are met:

		1. Emissivity in both bands 4 and 5 < 0.95, i.e. possible cloud contamination 2. Low transmissivity due to high water vapor loading (<0.4), check PWV values and error estimates 3. Pixel falls on missing scan line in bands 1&5, and filled using spatial neural net. Check error estimates. Recommend more detailed analysis of other QC information 10 = Pixel produced, but cloud detected 11 = Pixel not produced due to missing/bad data, or TES divergence, user should check data quality flag bits.
3 & 2	Data quality flag	00 = Good quality L1B data 01 = Missing stripe pixel in bands 1 and 5 10 = not set 11 = Missing/bad L1B data
5 & 4	Cloud/Ocean Flag	Not set. Please check ECOSTRESS GEO and CLOUD products for this information.
7 & 6	Iterations	00 = Slow convergence 01 = Nominal 10 = Nominal 11 = Fast
9 & 8	Atmospheric Opacity	00 = >=3 (Warm, humid air; or cold land) 01 = 0.2 - 0.3 (Nominal value) 10 = 0.1 - 0.2 (Nominal value) 11 = <0.1 (Dry, or high altitude pixel)
11 & 10	MMD	00 = > 0.15 (Most silicate rocks) 01 = 0.1 - 0.15 (Rocks, sand, some soils) 10 = 0.03 - 0.1 (Mostly soils, mixed pixel) 11 = <0.03 (Vegetation, snow, water, ice)
13 & 12	Emissivity accuracy	00 = >0.02 (Poor performance)

	(Average of all bands)	01 = 0.015 - 0.02 (Marginal performance) 10 = 0.01 - 0.015 (Good performance) 11 = <0.01 (Excellent performance)
15 & 14	LST accuracy	00 = >2 K (Poor performance) 01 = 1.5 - 2 K (Marginal performance) 10 = 1 - 1.5 K (Good performance) 11 = <1 K (Excellent performance)

3 ECOSTRESS_L2_Cloud Product

The ECOSTRESS Level-2 Cloud product is output in a separate file to the LST&E product and consists of an 8-bit flag of cloud mask and cloud tests shown in Table 7. The ECOSTRESS cloud mask is derived from the 5 calibrated thermal bands only as the SWIR band 6 used for geolocation is uncalibrated and not suitable for cloud masking. Full details of the thermal tests and thresholds employed are available in the Cloud mask ATBD at https://ecostress.jpl.nasa.gov/products/

3.1 Algorithm Description and Bit Mask Interpretation

The ECOSTRESS cloud mask algorithm (ECOCLOUD) uses the five calibrated ECOSTRESS thermal bands in a multispectral cloud-conservative thresholding approach. The primary purpose of the uncalibrated VSWIR band 6 is for geolocation purposes and is not suitable for inclusion in the automonous cloud detection algorithm since thresholds set would need to change from scene to scene. However users could still use the VSWIR data to employ their own custom cloud masks for their particular scene or use case.

ECOCLOUD will use all available thermal tests currently used by the MODIS and VIIRS cloud mask algorithms. These include a threshold based on 11 micron brightness temperature, and a thermal difference test based on differences between the 10.6 and 12 micron bands. All these tests and thresholds used are detailed in the ATBD and we refer the users there for further details. Table 7 shows the data fields included in the 8 bit mask.

Users can interpret the bit fields in a number of different ways depending on their specific use case. For example:

1. Read the first bit to determine if cloud mask was calculated or not. The cloud mask will not be calculated for pixels with bad or missing radiance data.
2. Read the second bit to determine if cloud was detected or not in either of tests 1-2 (1 = cloud, 0 = clear)
3. If upon further analysis it appears that there are false positive detections, the user may tailor the final cloud mask as needed based on the outcome of cloud tests in bits 1-3.

4. If upon further analysis it appears that there are pixels with undetected cloud, then the user may employ their own tests using either modified thresholds, or tests not included in the cloud mask. For this purpose a land/water mask is included in bit 4 since thresholds may differ depending on if the pixel is over a cooler or warmer surface. Refer to ATBD for more details.

3.2 Scientific Data Sets (SDS)

Table 7. The SDSs in the ECOSTRESS L2 Cloud product.

Bit Field	Long Name	Result
0	Cloud Mask Flag	0 = not determined 1 = determined
1	Final cloud plus region-growing (including region-growing by 5 pixels, and morphological filling in 'holes' between clouds)	0 = no 1 = yes
2	Final cloud (either of bits 3 or 4 set)	0 = no 1 = yes
3	Band 4 brightness threshold test	0 = no 1 = yes
4	Band 4-5 thermal difference test	0 = no 1 = yes
5	land/water mask	0 = land 1 = water

3.3 Attributes

Table 8. The metadata definition in the ECOSTRESS L2 Cloud product.

Name	Type	Size	Example
Group	**L2 CLOUD Metadata**		
QAPercentCloudCover	Int	4	80
CloudMeanTemperature	LongFloat	8	231
CloudMaxTemperature	LongFloat	8	275
CloudMinTemperature	LongFloat	8	221
CloudSDevTemperature	LongFloat	8	0.45

4 References

Gillespie, A., Rokugawa, S., Matsunaga, T., Cothern, J.S., Hook, S., & Kahle, A.B. (1998). A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images. *Ieee Transactions on Geoscience and Remote Sensing, 36*, 1113-1126

Hulley, G.C., & Hook, S.J. (2011). Generating Consistent Land Surface Temperature and Emissivity Products Between ASTER and MODIS Data for Earth Science Research. *Ieee Transactions on Geoscience and Remote Sensing, 49*, 1304-1315

Hulley, G.C., Hook, S.J., Abbott, E., Malakar, N., Islam, T., & Abrams, M. (2015). The ASTER Global Emissivity Dataset (ASTER GED): Mapping Earth's emissivity at 100 meter spatial scale. *Geophysical Research Letters, 42*, 7966-7976

Hulley, G.C., Hughes, C.G., & Hook, S.J. (2012). Quantifying uncertainties in land surface temperature and emissivity retrievals from ASTER and MODIS thermal infrared data. *Journal of Geophysical Research-Atmospheres, 117*

Malakar, N., & Hulley, G.C. (2016). A water vapor scaling model for improved land surface temperature and emissivity separation of MODIS thermal infrared data. *Remote Sensing of Environment, 182*, 252-264

Matricardi, M. (2008). The generation of RTTOV regression coefficients for IASI and AIRS using a new profile training set and a new line-by-line database. In: ECMWF Research Dept. Tech. Memo.

Rienecker, M.M., Suarez, M.J., Gelaro, R., Todling, R., Bacmeister, J., Liu, E., Bosilovich, M.G., Schubert, S.D., Takacs, L., Kim, G.K., Bloom, S., Chen, J.Y., Collins, D., Conaty, A., Da Silva, A., Gu, W., Joiner, J., Koster, R.D., Lucchesi, R., Molod, A., Owens, T., Pawson, S., Pegion, P., Redder, C.R., Reichle, R., Robertson, F.R., Ruddick, A.G., Sienkiewicz, M., & Woollen, J. (2011). MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. *Journal of Climate, 24*, 3624-3648

Saunders, R., Matricardi, M., & Brunel, P. (1999). An improved fast radiative transfer model for assimilation of satellite radiance observations. *Quarterly Journal of the Royal Meteorological Society, 125*, 1407-1425

Tonooka, H. (2005). Accurate atmospheric correction of ASTER thermal infrared imagery using the WVS method. *Ieee Transactions on Geoscience and Remote Sensing, 43*, 2778-2792