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

Level 1 Product User Guide

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Contents

1 Introduction 6
1.1 File formats for L1B products 6
1.2 L1B Products 7
1.3 Product Availability 7
2 Description of instrument 8
3 Radiance 9
3.1 Description of file format 9
3.1.1 Data fields 9
3.1.2 Metadata 10
3.2 Overlap in radiance image 12
3.3 Special data value and data quality indicators. 13
3.3.1 Band to band, pixel not seen 14
3.3.2 Missing scan data 14
3.4 Description of flipping data 15
3.5 Radiometric Accuracy 16
3.6 SWIR Data 16
4 Geolocation 16
4.1 Description of file format 16
4.2 Geolocation accuracy 17
5 Map Product 18
5.1 Description of file format 18
5.2 Description of rotated map 20
6 References 21

1 Introduction

This is the user guide for the ECOSTRESS Level-1 Radiance, Geolocation, and Map products. The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) mission consists of a thermal infrared (TIR) multispectral scanner with five spectral bands operating between 8 and 12.5 µm. The TIR data is acquired at a spatial resolution of approximately 35m x 70m with a swath width of approximately 400 km. The Level-1B Radiance product resamples the 5 TIR bands so they are spatially co-registered, and averages in the line direction to produce roughly 70m x 70m pixels. The Level-1B Geolocation product corrects the ISS reported ephemeris and attitude data by image matching with a global ortho-base (based on Landsat data), and then using this improved navigation information to assign latitude and longitude values to each of the Level-1 Radiance pixels. When image matching is successful, the data is geolocated to better than 50-meter accuracy. In addition, related information about solar and view geometry, surface height, and fraction of pixel on land vs. water are generated.

Both the Level-1B Radiance and Level-1B Geolocation products are swath products, with latitude/longitude geo-tagging. The Level-1B Map product does a second resampling step to produce map registered data in a standard latitude/longitude grid. The latitude/longitude grid is rotated to approximately the orbit path.

The algorithms and data content of the Level-1B 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. Overviews of the file formats are provided first followed by descriptions of the algorithm and product contents including all metadata.

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. Work was done to implement a direct streaming option, which bypasses the need for mass storage units. The streaming acquisition mode changes 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 resumed 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 Level-1B Product Generation Executive (PGE) code are 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 formats for L1B products

The ECOSTRESS L1B 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 data fields with metadata describing information about the data. More detailed information on HDF5 data types may be found in the L1 Product Specification Document (PSD) available at https://ecostress.jpl.nasa.gov/products.

The L1B data product files contain one set of metadata describing information relevant to production, archiving, user services, input products, geolocation and analysis of data. This metadata listed in Table 3.1.2 are not described further in this user guide.

1.2 L1B Products

The L1B radiance and geolocation 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 the center pixel is approximately 70m × 70m with 5632 pixels along track and 5400 pixels per line for each scene. The pixel size varies, with a resolution of about 90m x 90m at the edge of the swath.

The L1B Map product is produced as a map registered product. It is in a rotated geographic projection. The spatial resolution of each pixel is set to 70m x 70m.

Table 1.2.1 shows a summary of the L1B product characteristics.

Table 1.2.1: Summary of the ECOSTRESS L1B products

Earth Science Data Type (ESDT)	**Product Level**	**Data Dimension**	**Spatial Resolution**	**Temporal Resolution**	**Map Projection**
ECOSTRESS_L1B_RAD	L1	5632 lines by 5400 pixels per line	70 m (center)	Swath	None (lat,lon tagged)
ECOSTRESS_L1B_GEO	L1	5632 lines by 5400 pixels per line	70 m (center)	Swath	None (lat,lon tagged)
ECOSTRESS_L1B_MAP_RAD	L1	Varies	70 m (all pixels)	Swath	Rotated geographic

1.3 Product Availability

The ECOSTRESS L1B products will be made available at the NASA Land Processes Distributed Active Archive Center (LPDAAC) and through NASA Earthdata (https://earthdata.nasa.gov).

2 Description of instrument

The TIR instrument operates as a push-whisk scanner, collecting 256 pixels in the cross-whisk direction for each spectral channel, which enables a wide swath and high spatial resolution. As the ISS moves forward, the scan mirror sweeps the focal plane ground projection in the cross-track direction. The different spectral bands are swept across a given point on the ground sequentially. A wide continuous swath is produced, with a nominal width of 400 km. In Level-1 Radiance, the 256 pixels in one scan are averaged to 128 pixels, giving a nearly square pixel of approximately 70m x 70m in the center of the image. The scan mirror rotates at a constant angular speed sweeping the focal plane image 53 degrees across nadir. The wide angular range gives a variable pixel size of approximately 70m x 70m in the center of the swath, growing to about 90m x 90m at the edge of the swath.

A conceptual layout for the instrument is shown in Figure 2.1.

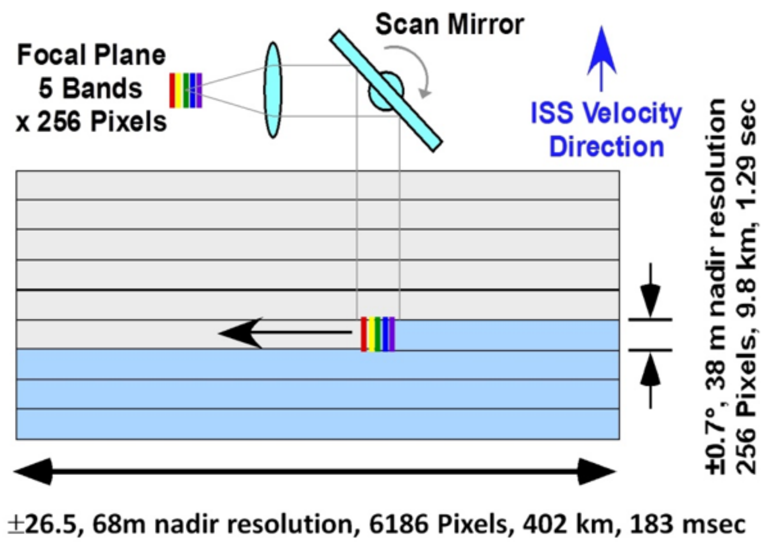

Figure 2.1: ECOSTRESS TIR Scanning Scheme

Figure 2.2 provides a more detailed view of the focal plane array, with the corresponding axis along the scanning and cross-scanning directions.

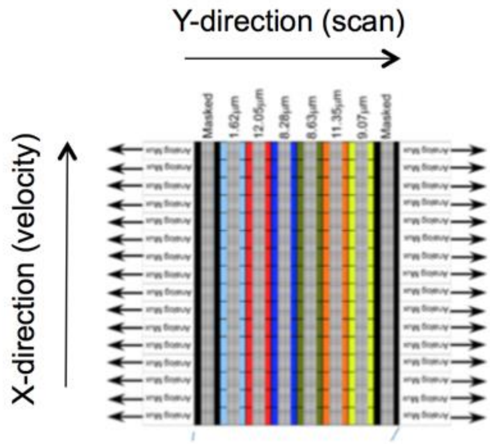

Figure 2.2: Focal plane axis convention. Y is the scanning direction and X the cross-scan (ISS velocity) direction

3 Radiance

The Level-1B radiance product converts the raw DN values acquired by ECOSTRESS into radiance units. In addition, it co-registers the 5 TIR bands.

3.1 Description of file format

3.1.1 Data fields

The ECOSTRESS Level-1 Radiance product has data fields for each of the 5 bands of radiance, associated data quality indicators, and ancillary data.

Table 3.1.1: The fields in the ECOSTRESS L1B Radiance product

Field Name	**Type**	**Units**	**Field Data**
Group	**Radiance**		
radiance_1	Float32	Watt/m2/sr/um	TIR 8.285 microns. For data acquired May 15th 2019 this is fill data only
radiance_2	Float32	Watt/m2/sr/um	TIR 8.785 microns.
radiance_3	Float32	Watt/m2/sr/um	TIR 9.060 microns. . For data acquired May 15th 2019 this is fill data only
radiance_4	Float32	Watt/m2/sr/um	TIR 10.522 microns.
radiance_5	Float32	Watt/m2/sr/um	TIR 12.001 microns
data_quality_1	Int8	None	
data_quality_2	Int8	None	
data_quality_3	Int8	None	

Field Name	**Type**	**Units**	**Field Data**
data_quality_4	Int8	None	
data_quality_5	Int8	None	
Group	**SWIR**		
swir_dn	Int16	DN	Uncalibrated SWIR data with Deprecated Counts Correction. For data acquired after May 15th 2019 this is fill data only
Group	**FPIEencoder**		
EncoderValue	Uint32	None	Mirror encoder value for each focal plane in each scan
Group	**Time**		
line_start_time_j2000	Float64	Second	J2000 time of fir pixel in line

3.1.2 Metadata

Archived with the HDF fields are 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. Descriptions of the metadata are given here to assist the user in understanding them. ECOSTRESS products consist of a set of standard metadata (Table 3.1.2) and product-specific metadata (Table 3.1.3).

Table 3.1.2: 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	
CampaignShortName	String	variable	Primary
CollectionLabel	String	variable	
DataFormatType	String	variable	NCSAHDF5
DayNightFlag	String	variable	
EastBoundingCoordinate	LongFloat	8	
HDFVersionId	String	variable	1.8.16
ImageLines	Int32	4	5632

Name	Type	Size	Example
ImageLineSpacing	Float32	4	68.754
ImagePixels	Int32	4	5400
ImagePixelSpacing	Float32	4	65.536
InputPointer	String	variable	InstrumentShortName String variable ECOSTRESS
InstrumentShortName	String	variable	ECOSTRESS
LocalGranuleID	String	variable	
LongName	String	variable	ECOSTRESS
NorthBoundingCoordinate	LongFloat	8	
PGEName	String	variable	L1B_RAD_PGE
PGEVersion	String	variable	6.00
PlatformLongName	String	variable	ISS
PlatformShortName	String	variable	ISS
PlatformType	String	variable	Spacecraft
ProcessingLevelDescription	String	variable	Level 1B Radiance Parameters
ProcessingLevelID	String	variable	1
ProducerAgency	String	variable	JPL
ProducerInstitution	String	variable	Caltech
ProductionDateTime	String	variable	
ProductionLocation	String	variable	
RangeBeginningDate	String	variable	
RangeBeginningTime	String	variable	
RangeEndingDate	String	variable	
RangeEndingTime	String	variable	
RegionID	String	variable	
SISName	String	variable	
SISVersion	String	variable	
SceneID	String	variable	
ShortName	String	variable	L1B_RAD
SouthBoundingCoordinate	LongFloat	8	

Name	Type	Size	Example
StartOrbitNumber	String	variable	
StopOrbitNumber	String	variable	
WestBoundingCoordinate	LongFloat	8	

Table 3.1.3: Product specific metadata for the ECOSTRESS L1B_RAD product

Name	Type	Size	Example
Group	**L1RadMetadata**		
BandSpecification	Float32	µm	Wavelengths available in the L1 product for bands 1-6: 1.6, 8.2, 8.7,9.0, 10.5, 12.0; 0=fill data
QAPercentMissingData	Float32	Percentage	Percentage of data missing from L0B
RadScanLineOrder	String	Variable	One of “Reverse line order” or “Line order”. Indicates if we have reversed the order line order for each scan to produce image with separate scans aligned.

3.2 Overlap in radiance image

By the design of the ECOSTRESS instrument, there is an overlap in between each ECOSTRESS scan and the next. This results in a clear line artifact in the radiance image, and a repeat of data (see 3.2.1).

Note that this overlap is fully accounted for in the Level-1B Geolocation product where the geo-tagging will correctly give pixels in adjacent scans the same ground location.

If you desire to work with data that does not have this type of overlap, the Level-1B Map product averages the overlap data to produce data without overlap.

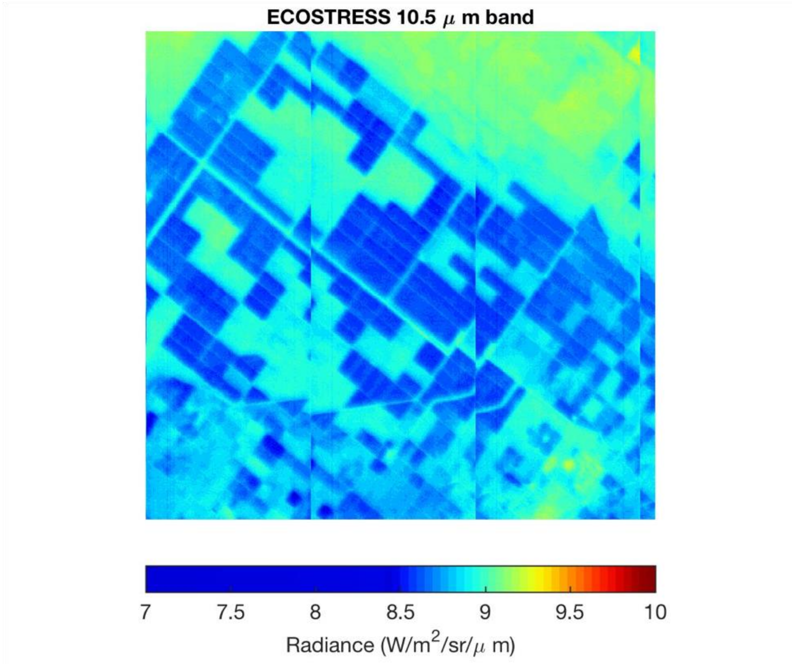

Figure 3.2.1: Illustration of ECOSTRESS Overlap between scans.

3.3 Special data value and data quality indicators.

The radiance data has special fill values of certain conditions, and the data_quality has corresponding values. The special fill values are shown in 3.3.1 and the data_quality values in 3.3.2. The conditions indicated are described in the next two sections.

Table 3.3.1: Special Radiance Data Values

Data Condition	**Value**
Pixel not seen	-9997.0
Missing data due to striping (not filled in)	-9998.0
Missing/bad data	-9999.0

Table 3.3.2: Data Quality Values

Data Quality/Condition	**Value**
Good	0
Missing stripe data, filled in	1
Missing stripe data, not filled in	2
Missing/bad data	3
Not seen	4

3.3.1 Band to band, pixel not seen

By the design of the ECOSTRESS instruments, bands don't see a particular cross scan pixel at the same time. When we co-register bands to the reference band, there are differences in the ground footprint and we miss pixels at the edges of the scanner for some bands (see Figure 3.3.1.1). For pixels that have this property, we use a special fill value in the radiance data fields, a "Pixel is not seen" value of -9997.0, and a corresponding data_quality value of 4.

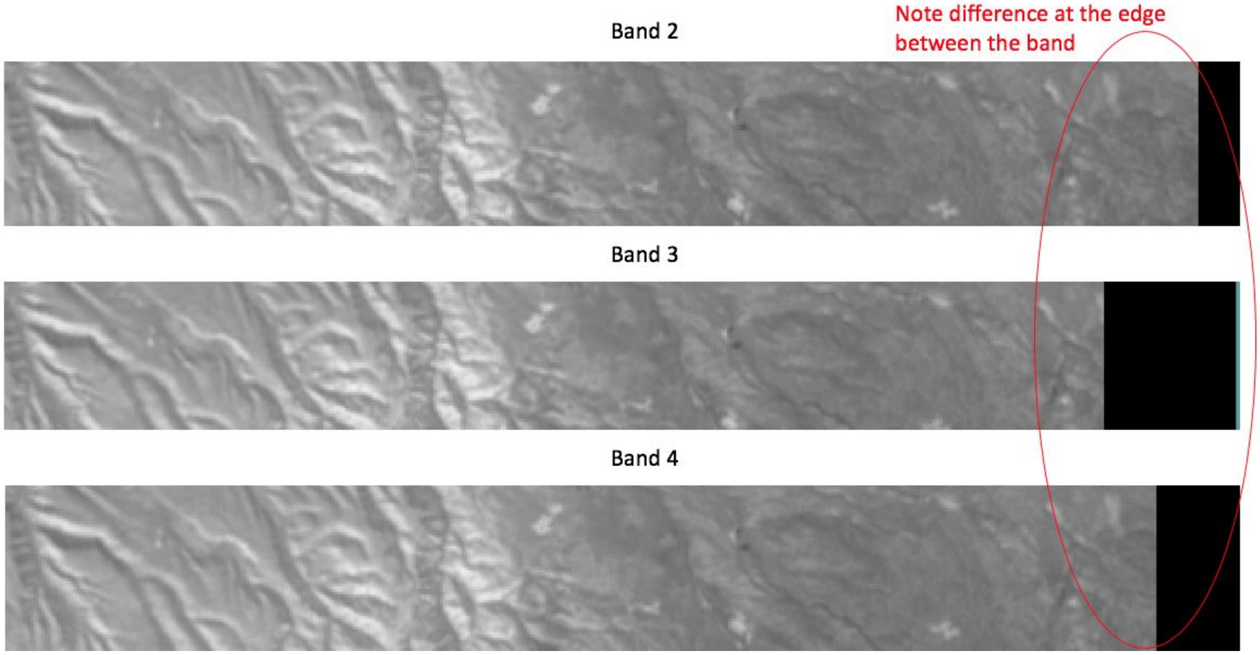

Figure 3.3.1.1: Example of "Pixel not seen"

3.3.2 Missing scan data

During testing, an instrument artifact was encountered in ECOSTRESS bands 1 and 5. Both of these bands had 16 out of the 256 pixels that do not return any signal, resulting in a black "stripe" in the ECOSTRESS image.

The Level-1B radiance processing fills this data in using a machine learning algorithm. The algorithm is applied in the neighbourhood of the missing scan data to train on the full 5 bands of good data and then used to predict the data missing in band 1 and band 5 due to the "striping" based on bands 2 through 4. For data acquired after May 15th 2019 the algorithm is modified to train on the 3 non-fill bands, and used to predict the data missing in band 5 only (band 1 contains only fill data).

When the process is successful, a radiance value is placed in the radiance image. To indicate that this value was filled in rather than a true measurement, the data_quality pixel value is set to the "Missing stripe data, filled in" value of 1. For instances where a pixel is not successfully filled in (e.g., band 2 through 4 is missing data), the radiance value is set to the value -9998.0 and the data_quality is set to the value "Missing stripe data, not filled in" value of 2.

A full report on the techniques and uncertainty analysis involved with the missing scan filling is available upon request from the science team. For example, total estimated errors in the retrieved L2 surface temperature and emissivity are elevated over the filled stripes due to the uncertainty involved with the interpolation techniques used.

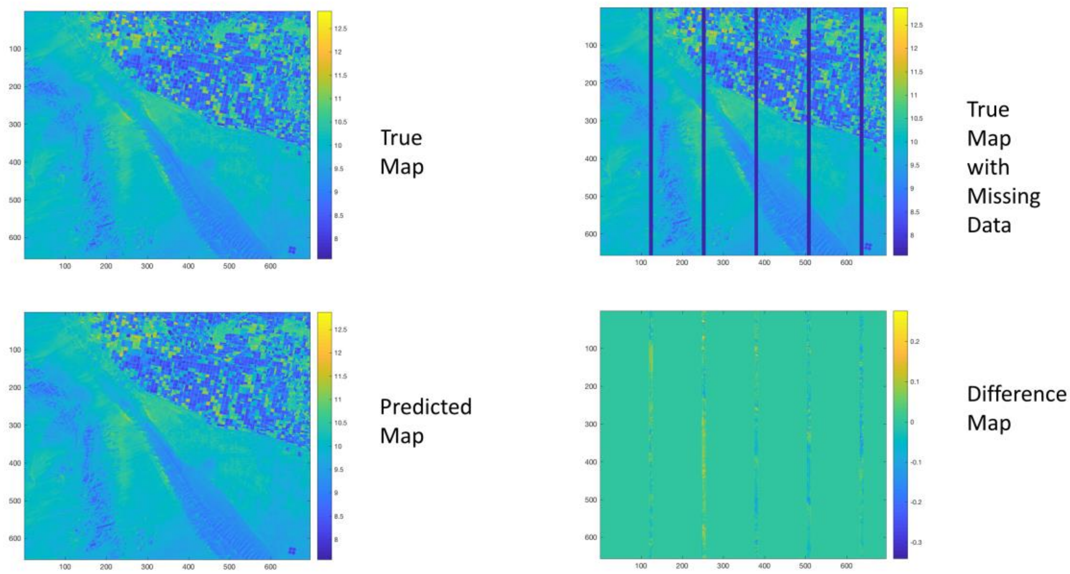

Figure 3.3.2.1: Example of missing scan data with correction using simulated ASTER data over the Imperial Valley in Southern California

3.4 Description of flipping data

The ECOSTRESS instrument is oriented with the ISS so that in the nominal ISS orientation the readout of 256 cross-whisk pixels goes in the negative velocity direction. This means the raw data (L1A-Pixel data) will look "upside down" when visualized. This is fully accounted for in the instrument model, but results in data that is harder to visualize. To improve the visualization of the data, in L1B-Radiance processing we flip the presentation of the data (see Figure 3.4.1). The larger index cross-whisk pixel is presented first in each scan.

To accommodate docking, the ISS will sometimes fly with a nearly 180 degrees yaw (i.e., it "flies backwards"). In this configuration, the ECOSTRESS instrument is oriented in the positive velocity direction. The raw data will look "right side up". To improve visualization, the L1B-Radiance processing will not flip the presentation of the data.

The L1B-Radiance processing software detects which configuration in the ISS is flying in, and then “does the right thing” in determining if we present the scan in reverse line order or not.

To indicate what was done with the data, the "L1B_RADMetadata/RadScanLineOrder" field in the L1B_RAD product will be set to one of "Reverse line order" or "Line order".

Note that the L1B_GEO fully accounts for this. Users of the L1B_RAD product generally do not need to do any special handling based on the "L1B_RADMetadata/RadScanLineOrder" value, this is just given for informational purposes. This distinction is only important if there is a need to trace back to the raw L1A-Pixel data.

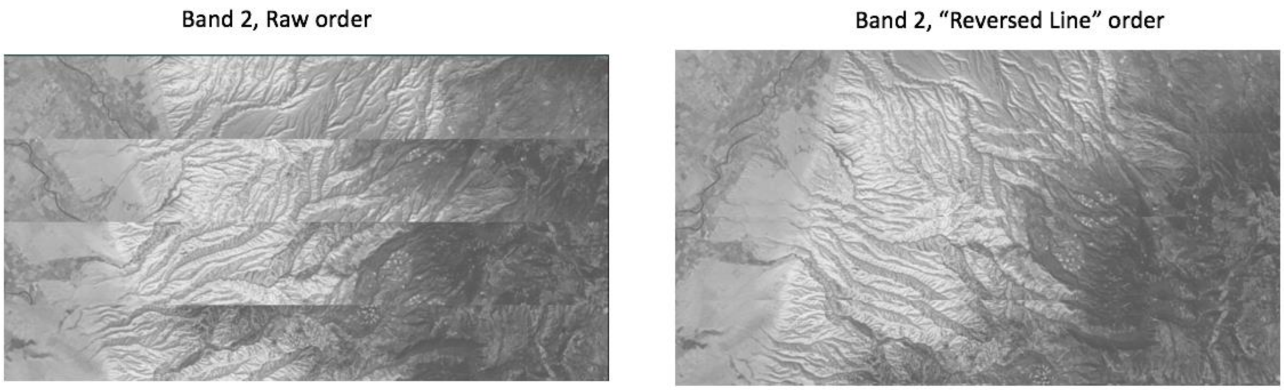

Figure 3.4.1: Raw order vs “Reversed Line” order

3.5 Radiometric Accuracy

ECOSTRESS Level-1 Radiance data shows high correlation with in-situ ground measurements (R2 = 0.99 in all bands). Currently, ECOSTRESS has a cold bias of approximately 0.7K, which will be corrected through calibration in future data releases

3.6 SWIR Data

In addition to the 5 thermal bands, ECOSTRESS has a SWIR (Short Wave Infrared) channel. The SWIR band has the same scan overlap, scan flipping, and stripping features as the thermal bands. The SWIR was intended to support geolocation and cloud detection without radiometric calibration or focal plane artifact correction. During on-orbit testing, the SWIR focal plane was determined to be photon-limited and a histogram equalization algorithm was employed on a concatenated scan-line basis to maximize available signal and provide a “visual” product. SWIR collections prior to May 15, 2019 (and with Build ID 6.0 or greater) may contain ground detail depending upon the amount of incident sunlight. Collections after May 15, 2019 do not include a SWIR channel, although a placeholder file containing fill values will be present.

4 Geolocation

The geolocation product gives geo-tagging to each of the radiance pixels.

The geolocation processing corrects the ISS-reported ephemeris and attitude data by image matching with a global ortho-base (based on Landsat data), and then using this improved navigation information to assign latitude and longitude values to each of the Level-1 Radiance pixels. When image matching is successful, the data is geolocated to better than 50-meter accuracy. In addition, related information about solar and view geometry, surface height, and fraction of pixel on land vs. water is generated.

4.1 Description of file format

The ECOSTRESS Level-1 Geolocation product has latitude, longitude and height of each ECOSTRESS Level-1 Radiance product pixel. In addition, it has view, solar geometry, and land fraction for each pixel. The fields are show in 4.1.1 and the product specific metadata in 4.1.2.

Table 4.1.1: The fields in the ECOSTRESS L1B Geolocation product

Field Name	**Type**	**Units**	**Field Data**
Group	**Geolocation**		
height	Float32	Meter	
land_fraction	Float32	Percentage	Percentage of pixel that is land
latitude	Float64	Degrees	
line_start_time_j2000	Float64	Degrees	J2000 time of first pixel in line
longitude	Float64	Degrees	
solar_azimuth	Float32	Degrees	
solar_zenith	Float32	Degrees	
view_azimuth	Float32	Degrees	
view_zenith	Float32	Degrees	

Table 4.1.2: Product specific metadata for the ECOSTRESS L1B_GEO product

Name	**Type**	**Size**	**Example**
Group	**L1GEOMetadata**		
AverageSolarZenith	Float64	Degrees	Average solar zenith angle for scene
OrbitCorrectionPerformed	String	None	One of "True or "False"
OverallLandFraction	Float64	Percentage	Overall land fraction for scene

4.2 Geolocation accuracy

The Level 1 processing is sometimes not able to perform image matching with our global ortho-base. When this occurs, we still produce a Level-1B Geolocation product, and subsequent L2 processing. However, the expected geolocation error is significantly larger.

Note that we look at all the scenes for an orbit. If we successfully match any of the scenes, the correction from that scene is applied to all the scenes in the orbit. This works because although the ISS attitude knowledge error can be large, it is slowly varying.

When we successfully match a scene in an orbit, the geolocation accuracy is better than 50 meters. However, we do encounter orbits where no scenes are successfully match. This might occur because scenes are over water, or the scenes are cloudy, or we just have scenes without a lot of features to match. In these cases, the geolocation error is significantly larger. As described in the ATBD, the worst-case geolocation error for uncorrected data is 7 km. Typically we see smaller errors of the 2-4 km range.

We indicate if we have corrected the geolocation error with the metadata field "L1GEOMetadata/OrbitCorrectionPerformed". If this field is "True" the data was corrected, and geolocation accuracy should be better than 50 meters. If this is "False", then the data was processed without correcting the geolocation and we have up to 7 km geolocation error.

Users of the data should determine if they can tolerate larger geolocation errors. If not, then data with the "L1GEOMetadata/OrbitCorrectionPerformed" set to "False" should not be used.

5 Map Product

The map product combines the Radiance and Geolocation products. It supplies map registered radiance data. It accounts for the overlap and variable pixel size in the radiance product, producing a fixed size output pixel.

Note that the data has been resampled, so users interested in working with data closest to that acquired by the instrument may want to work with the swath products. But for users interested in a simpler-to-use product, the map product is appropriate.

To minimize distortion introduced by the resampling, and to reduce the file size, a rotated geographic projection is used. The center line of the map projection is nominally aligned with the center line of the swath (see Figure 5.1).

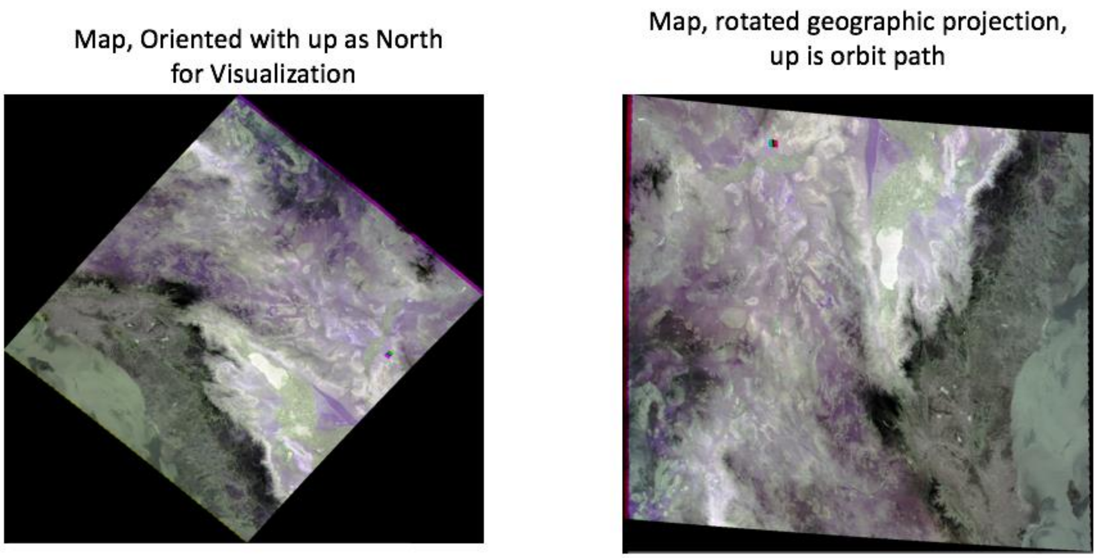

Figure 5.1: Rotated geographic projection

5.1 Description of file format

The ECOSTRESS Level-1 Map product has the fields shown in 5.1.1 and the product specific metadata in 5.1.2.

Table 5.1.1: The fields in the ECOSTRESS L1B MAP product

Field Name	**Type**	**Units**	**Field Data**
Group	**Mapped/MapInformation**		
CoordinateSystem	String	None	Well Known Text (WKT) describing coordinate system
GeoTransform	Float64	None	Affine GeoTransform

Field Name	**Type**	**Units**	**Field Data**
Group	**Mapped**		
data_quality_1	Int8	None	
data_quality_2	Int8	None	
data_quality_3	Int8	None	
data_quality_4	Int8	None	
data_quality_5	Int8	None	
height	Float32	Meter	
land_fraction	Float32	Percentage	Percentage of pixel that is land
latitude	Float64	Degrees	
longitude	Float64	Degrees	
radiance_1	Float32	Watt/m2/sr/um	TIR 8.285 microns. For data acquired May 15th 2019 this is fill data only
radiance_2	Float32	Watt/m2/sr/um	TIR 8.785 microns.
radiance_3	Float32	Watt/m2/sr/um	TIR 9.060 microns. For data acquired May 15th 2019 this is fill data only
radiance_4	Float32	Watt/m2/sr/um	TIR 10.522 microns.
radiance_5	Float32	Watt/m2/sr/um	TIR 12.001 microns.
solar_azimuth	Float32	Degrees	
solar_zenith	Float32	Degrees	
swir_dn	Int16	DN	Uncalibrated SWIR data with Deprecated Counts Correction. For data acquired after May 15th 2019 this is fill data only
view_azimuth	Float32	Degrees	
view_zenith	Float32	Degrees	

Table 5.1.2: Product specific metadata for the ECOSTRESS L1B_MAP_RAD product

Name	**Type**	**Size**	**Example**
Group	**L1GEOMetadata**		
BandSpecification	Float32	µm	Wavelengths available in the L1 product for bands 1-6: 1.6, 8.2, 8.7,9.0, 10.5, 12.0; 0=fill data
OrbitCorrectionPerformed	String	None	One of "True or "False"

Name	Type	Size	Example
QAPercentMissingData	Float32	Percentage	Percentage of data missing from L0B

5.2 Description of rotated map

We specify the Map Information by giving the Coordinate System and an Affine GeoTransform. The Coordinate System is specified as OpenGIS Well Known Text strings(see for example https://en.wikipedia.org/wiki/Well-known_text or http://www.gdal.org/gdal_datamodel.html). This is given in the CoordinateSystem metadata.

We also specify the Affine GeoTransform (as for example in geotiff, see http://geotiff.maptools.org/spec/geotiff2.6.html or GDAL, see http://www.gdal.org/gdal_datamodel.html). This is given in the GeoTransform. We have:

$$\text{longitude} = GT_0 + GT_1 i + GT_2 j$$
$$\text{latitude} = GT_3 + GT_4 i + GT_5 j$$

Where (*i,j*) is the sample, line of the pixel (starting at 0) and longitude and latitude are given in degrees.

Note that in addition, we provide the latitude and longitude fields in the file. This is completely redundant with the map projection information. We supply these fields as a convenience for software that expects this data, but you can directly calculate latitude and longitude from the map information.

6 References

Smyth, Mike & Leprince, Sebastien, *Level-1B Resampling and Geolocation Algorithm Theoretical Basis Document (ATBD)*, JPL D-94641

Chu, Eugene, Logan, Thomas, & Smyth, Mike *Level 1 Product Specification Document*, JPL D-94634

Hulley, Glynn, Upon request, a full report on techniques and uncertainty analysis involved with the missing scan filling (planned paper/report by end of the year).