L1 Overview

Level-1 Introduction

- Level-1 (L1) is part of the Science Data System (SDS), where the SDS:
  - Creates L0, L1, L2, L3, and L4 products, and
  - Delivers products to the Land Process DAAC (Sioux Falls, SD)
- Level-1 Inputs include:
  - L0 Data
    - Raw Image Data Packets
    - Ground Imagery and BlackBody packets
  - Spacecraft Orbital Metadata
  - Ancillary Data
    - Landsat Ortho-Rectified Image Base (geolocation)
    - Digital Terrain Models (pass-through)
      - Elevation
      - Land/Water Mask
- Level-1 Outputs include:
  - Calibrated Radiance images with
  - Geolocation (position) and
  - Associated metadata
L1 Overview

L1 in the SDS Processing Flow

Level-1 (L1) Processing

- L0B PGE
- L1A PGE
- L1B PGE
- L2 PGE
- PT-JPL L3/L4 PGEs

SDS

- ISS
- L0A PACKETS
- SRTM
- Landsat
- DEM
- Static Ortho Base
- NWP
- MODIS Products
- Landsat
- Atmos Profile
- Met
- NDVI
- Geo, LSTE, Cloud
- Validated Products

DAAC

- USDA ALEXI L3/L4 PGEs
- DAAC I/F (format)

Production Facility

- L0 packets: time codes, ephemeris, attitude, black body temperatures
- Time referenced annotated data, radiometric calibration coeff
- Optional Outputs
- Calibrated Sensor Radiances & geolocation parameters
- Land Surface Temperature & Emissivity, Cloud
- Evapotranspiration, Evaporative Stress Index, Water Use Efficiency (PT-JPL)
- ET, ESI (ALEXI)

SCF/testbed

Data Portal

Co-Investigators
Level-1 Description Overview

- L1 Processing consists of two PGEs (Product Generation Executives)
  - L1A
    - Raw Data Processing
      - Reformat Incoming ISS data packets, metadata, and ancillary data
        - Formulate Focal Plane (FPA) Earth images by spectral band
        - Formulate on-board FPA Blackbody Calibration images and files
    - Radiometric Calibration
      - Convert Image Pixel DNs to Radiance Coefficients
        - FPA Blackbody temperatures are converted to radiances using the Planck function.
        - FPA DNs are converted to radiance values using a two-point affine transformation. Conversions are stored as coefficients.
  - L1B
    - Resampling
      - Merge Focal Plane overlap and average pixels (lines) to improve signal.
    - Geolocation
      - Initial Map Projection from ISS Ephemeris and Pointing data
      - Geolocation Matching (using Landsat orthobase) to correct for Positional Errors
L0 Inputs to L1A Raw Data PGE

L0 to L1 Travel Path of the ECOSTRESS Pixel

Ground Processing

L1A Raw Data PGE

Data Reformatting:
Six Image Bands
Hot & Cold BlackBody Images
and Metadata

Along Track (X)

Across Track (Y)

Focal Plane 5 Bands x 256 Pixels
Scan Mirror
ISS Velocity Direction

40.7° ± 25.5°, 57m nadir resolution, 6186 Pixels, 384 km, 183 msec

Along Track (X)

Across Track (Y)

On-Board SC Processing

Ground Processing

5400 Pixels

1 Pixel

4 Pixels

4 (x2) of 16 pixel columns imaged

16x16 Pixels = 256

256 Pixels

256 Pixels

11264 Pixels (44 scans x256)

L1 Input

TDI

Across Track (Y)

Along Track (X)
L1A Radiometric Calibration Steps*

- **Purpose:** Convert Image TIR DNs to Radiance
  - **Procedure for each image:**
    - Read temperatures from Sensor’s Cold (~295K) and Hot (~325K) Blackbodies.
    - Create synthetic FPA temperature images of Cold and Hot Blackbodies and convert them to Radiance (Watt/m²/sr/um) using the center wavelength of each TIR band and the Planck function.
    - Collect push-whisk FPA Digital Number (DN) scans of the Cold and Hot Blackbodies And Ground for all wavelengths.
    - Using the FPA Radiance values and corresponding FPA DNs, use a two-point affine transformation (creating gain/offset coefficients) to convert each Ground pixel’s DN to Radiance.

- Ground Radiance and Temperature images can be generated for Validation and Verification purposes as necessary (optional parameter).

- Accuracy is expected to be *better* than the 1.0 Kelvin requirement.

- SWIR band is *not* radiometrically calibrated, but has Dark Current subtracted. Flat-Field artifact correction is TBD.

L1A Radiometric Two-Point Calibration

**Approach**
- Read BB Temperatures.
- Create synthetic FPA 256x1 Blackbody Temperature Images.
- Convert FPA BB Images to Radiances using Planck Function.
- Collect FPA Blackbody and Ground DNs.
- Apply 2pt Algorithm

**Two-Point Calibration Formula**

\[ R_\lambda = a + bD_\lambda \]

\[ a = \frac{R_h D_c - R_c D_h}{D_c - D_h} \]
\[ b = \frac{R_c - R_h}{D_c - D_h} \]

Where:

- \( R \) = Calculated Radiance of an input Digital Number (DN)
- \( a \) = Offset Term
- \( b \) = Gain Term
- \( D \) = Input Earth Digital Number (DN)

- \( R_c \) = Radiance of the Cold Blackbody (Section 3.3.2)
- \( R_h \) = Radiance of the Hot Blackbody (Section 3.3.2)
- \( D_c \) = Digital Number (DN) from the Cold Blackbody Calibration File (Section 3.3.3)
- \( D_h \) = Digital Number (DN) from the Hot Blackbody Calibration File (Section 3.3.3)

Referenced Sections are in: “Level-1 Focal Plane Array and Radiometric Calibration Algorithm Theoretical Basis Document (ATBD),” JPL D-94803.
FPA Test Data from 20170404

9um Wavelength Data

- Blackbody DNs
- 64x256 pixels are averaged to 1x256
- DNs are Contrast Inverted
FPA Test Data from 20170404

12um 2-Point Radiometric Calibration

<table>
<thead>
<tr>
<th>Full Image: Uncalibrated</th>
<th>Slit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Full Image: Calibrated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>.301</td>
<td>.296</td>
</tr>
</tbody>
</table>

Raw Image

Uncalibrated

Calibrated

Calibrated Kelvin Temperature Values at Location

Mean = 294.88 Deg Kelvin (22C; 71F)
STD = 2.14
FPA Test Data from 20170404

Bands 1-5 Slit Feature
2pt Radiometric Calibration to Temperature (Kelvin)

- 2pt Radiometric Calibration in Degrees Kelvin
  
<table>
<thead>
<tr>
<th>Band</th>
<th>Mean</th>
<th>STD</th>
</tr>
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<tbody>
<tr>
<td>Band 1</td>
<td>294.9</td>
<td>2.14</td>
</tr>
<tr>
<td>Band 2</td>
<td>295.0</td>
<td>2.15</td>
</tr>
<tr>
<td>Band 3</td>
<td>295.0</td>
<td>2.17</td>
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<tr>
<td>Band 4</td>
<td>295.0</td>
<td>2.20</td>
</tr>
<tr>
<td>Band 5</td>
<td>294.8</td>
<td>2.03</td>
</tr>
</tbody>
</table>
FPA Test Data from 20170404

SWIR with Dark Current Subtraction

16 line Striping

Mean = 3DN
STD = 4.42
L1B Resampling PGE

Processing

1) Merge FPA Overlap
2) Average FPA 2-to-1 to improve signal
3) Composite multiple FPAs into one image

Output
5400 Pixels

Along Track (X)
5632 Pixels

L1B Resampled Product (Six Bands)

• L1B Corrections Include:
  • FPA Overlap
  • Resampling
  • Optical Distortion Removal
L1B Geolocation PGE

L1B Geolocation*

- Purpose: Calculate the Latitude and Longitude of each image pixel.
  - Corrections for Small Errors (less than 2 pixels):
    - Focal Plane Scan-Line Offsets.
    - Extrapolate Ephemeris and Pointing information from the ISS to the ECOSTRESS camera on the JEM module.
    - ISS altitude, pitch, yaw, and roll.
    - Orbital position uncertainties and camera jitter.
  - Corrections for Large Errors (2.5km to 7.5km):
    - Attitude drift can be large as position must be extrapolated from the ISS (No Star Tracker).
    - Attitude correction is performed by co-registration/matching an ECOSTRESS image with a similar wavelength ortho-rectified Landsat mosaic.
    - Testbed results suggest ECOSTRESS images with positional offset errors up to 12.5km can be geolocated to about 0.1pixel RMS.
- Geolocation accuracy is expected to be better than the 50m positional requirement.
- Latitude and Longitude coordinates are extracted and supplied for each input 75.30x68.51m Ecostress pixel.

*Documented in: "Level-1B Resampling and Geolocation Algorithm Theoretical Basis Document (ATBD)," JPL D-94641
L1B Geolocation Testbed

Position Correction
ECOSTRESS SWIR Band Registered to Landsat SWIR Ortho-Base

Incoming 1.6u SWIR Band (Simulated from ASTER Band4) With initial (weak) Geolocation is Registered to Landsat 7 Global Ortho-Base Band5 (SWIR) Band Co-Registration provides precise Geolocation
ECOSTRESS Band 1 (1.6u) Simulation Derived from ASTER Band 4 (1.60-1.70u)

- Matched with Landsat7 Band 5 (1.55-1.75u) at 75x68m/pxl
- Registration Parameters:
  - 24x24 FFT Grid
  - 256 pixel size FFT
  - Magnification 4->2

**STATISTICAL SUMMARY**

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEAN</th>
<th>STD DEV</th>
<th>MIN</th>
<th>MAX</th>
</tr>
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<tbody>
<tr>
<td>PXL_RMS</td>
<td>0.0861</td>
<td>0.0202</td>
<td>0.0497</td>
<td>0.1256</td>
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<tr>
<td>LINE_ERR</td>
<td>0.0179</td>
<td>0.0481</td>
<td>-0.0606</td>
<td>0.0901</td>
</tr>
<tr>
<td>SAMP_ERR</td>
<td>0.0038</td>
<td>0.0503</td>
<td>-0.0767</td>
<td>0.0725</td>
</tr>
</tbody>
</table>

**SWIR 1.6u Co-Registration Test Results (0-12.5km Offset)**

ECOSTRESS/Landsat SWIR Registration

0.0861 Mean Pixel Error RMS

0-12.5km of Image Offset Error

Pixel Error RMS vs Positional Offset Error in Kilometers

x:B' using 1:2
L1 Process Summary & Products

L1A Output Product
- L1A_CAL
  - L1B_RAD
    - L1B_GEODATA
    - L1B_ATT
    - L1B_RAD
- L1A_PIX
  - L1B_RAD
    - L1B_GEODATA
    - L1B_ATT
- L1A_RAW_ATT
  - L1A_RAW_PIX
  - L1A_RAW_ATT

L1B Output Products
- L1A_ENG
  - L1A_RAW_PIX
  - L1A_RAW_ATT
- L1A_CAL
  - L1A_RAD
    - L1A_GEODATA
    - L1A_ATT
- L1A_RAW_PIX
  - L1A_RAW_ATT

PGEs
- L1A Products
- L1B Products
- Intermediate data
- Other data
# L1 Products

## L1A_PIX: Calibration Inputs

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Units</th>
<th>Field Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
<td><strong>UncalibratedDN</strong></td>
<td>(Size 11264x5400)</td>
<td>(CW)</td>
</tr>
<tr>
<td>b1_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 1 Raw image Pixel Data (12.09µm)</td>
</tr>
<tr>
<td>b2_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 2 Raw image Pixel Data (10.56µm)</td>
</tr>
<tr>
<td>b3_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 3 Raw image Pixel Data (9.20µm)</td>
</tr>
<tr>
<td>b4_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 4 Raw image Pixel Data (8.80µm)</td>
</tr>
<tr>
<td>b5_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 5 Raw image Pixel Data (8.29µm)</td>
</tr>
<tr>
<td>b6_image</td>
<td>Int16</td>
<td>DN</td>
<td>Band 6 Raw image Pixel Data (1.66um SWIR)</td>
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<tr>
<td><strong>Group</strong></td>
<td><strong>BlackbodyTemp</strong></td>
<td>(Size 11264x1)</td>
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<td>fpa_325</td>
<td>Float32</td>
<td>Kelvin</td>
<td>Calibrated 325 Kelvin Blackbody Focal Plane</td>
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<tr>
<td>fpa_295</td>
<td>Float32</td>
<td>Kelvin</td>
<td>Calibrated 295 Kelvin Blackbody Focal Plane</td>
</tr>
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<td><strong>Group</strong></td>
<td><strong>BlackbodyBandDN</strong></td>
<td>(Size 11264x1)</td>
<td></td>
</tr>
<tr>
<td>b1_325</td>
<td>Float32</td>
<td>DN</td>
<td>B1 Focal Plane Averaged DN for 325k BB</td>
</tr>
<tr>
<td>b1_295</td>
<td>Float32</td>
<td>DN</td>
<td>B1 Focal Plane Averaged DN for 295k BB</td>
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<tr>
<td>b2_325</td>
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<td>DN</td>
<td>B2 Focal Plane Averaged DN for 325k BB</td>
</tr>
<tr>
<td>b2_295</td>
<td>Float32</td>
<td>DN</td>
<td>B2 Focal Plane Averaged DN for 295k BB</td>
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<tr>
<td>b3_325</td>
<td>Float32</td>
<td>DN</td>
<td>B3 Focal Plane Averaged DN for 325k BB</td>
</tr>
<tr>
<td>b3_295</td>
<td>Float32</td>
<td>DN</td>
<td>B3 Focal Plane Averaged DN for 295k BB</td>
</tr>
<tr>
<td>b4_325</td>
<td>Float32</td>
<td>DN</td>
<td>B4 Focal Plane Averaged DN for 325k BB</td>
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<td>DN</td>
<td>B4 Focal Plane Averaged DN for 295k BB</td>
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<tr>
<td>b5_325</td>
<td>Float32</td>
<td>DN</td>
<td>B5 Focal Plane Averaged DN for 325k BB</td>
</tr>
<tr>
<td>b5_295</td>
<td>Float32</td>
<td>DN</td>
<td>B5 Focal Plane Averaged DN for 295k BB</td>
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<td>b6_325</td>
<td>Float32</td>
<td>DN</td>
<td>B6 Focal Plane Averaged DN for 325k BB</td>
</tr>
<tr>
<td>b6_295</td>
<td>Float32</td>
<td>DN</td>
<td>B6 Focal Plane Averaged DN for 295k BB</td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td><strong>Time</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>line_start_time_j2000</td>
<td>Float64</td>
<td>Second</td>
<td>J2000 time of first pixel in line</td>
</tr>
</tbody>
</table>

**HDF5 Format**
L1 Products

**L1B_RAD: Calibrated Output Radiance Images**

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Units</th>
<th>Field Data</th>
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<tbody>
<tr>
<td>Group</td>
<td>Radiance</td>
<td>(Size 5632x5400)</td>
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</tr>
<tr>
<td>radiance_1</td>
<td>Float32</td>
<td>Watt/m2/sr/um</td>
<td>75.30x68.51m pixel size</td>
</tr>
<tr>
<td>radiance_2</td>
<td>Float32</td>
<td>Watt/m2/sr/um</td>
<td>75.30x68.51m pixel size</td>
</tr>
<tr>
<td>radiance_3</td>
<td>Float32</td>
<td>Watt/m2/sr/um</td>
<td>75.30x68.51m pixel size</td>
</tr>
<tr>
<td>radiance_4</td>
<td>Float32</td>
<td>Watt/m2/sr/um</td>
<td>75.30x68.51m pixel size</td>
</tr>
<tr>
<td>radiance_5</td>
<td>Float32</td>
<td>Watt/m2/sr/um</td>
<td>75.30x68.51m pixel size</td>
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<tr>
<td>Group</td>
<td>SWIR</td>
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</tr>
<tr>
<td>swir_dn</td>
<td>Int16</td>
<td>DN</td>
<td>Uncalibrated SWIR data with Dark Current subtracted</td>
</tr>
<tr>
<td>Group</td>
<td>Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>line_start_time_j2000</td>
<td>Float64</td>
<td>Second</td>
<td>J2000 time of first pixel in line</td>
</tr>
</tbody>
</table>

**HDF5 Format**
## L1 Products

### L1B_GEO: Output Geolocation Metadata
*(Provided for Each Pixel)*

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Units</th>
<th>Field Data</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
<td><strong>Geolocation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>height (elevation)</td>
<td>Float32</td>
<td>Meter</td>
<td></td>
</tr>
<tr>
<td>land_fraction</td>
<td>Float32</td>
<td>Percentage</td>
<td>Percentage of pixel that is land, from 0 - 100</td>
</tr>
<tr>
<td>latitude</td>
<td>Float64</td>
<td>Degrees</td>
<td></td>
</tr>
<tr>
<td>line_start_time_j2000</td>
<td>Float64</td>
<td>Second</td>
<td>J2000 time of first pixel in line</td>
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<td>longitude</td>
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<tr>
<td>solar_azimuth</td>
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<td></td>
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<td>solar_zenith</td>
<td>Float32</td>
<td>Degrees</td>
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<td>view_azimuth</td>
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<td>Degrees</td>
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<td>view_zenith</td>
<td>Float32</td>
<td>Degrees</td>
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</table>

### HDF5 Format

* Radiance products are in Swath image alignment
### L1B_ATT: Corrected Spacecraft Ephemeris and Attitude

*(Orbital Data at One Second Intervals)*

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Units</th>
<th>Field Data</th>
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<tbody>
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<td>Float64</td>
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<td>Seconds from J2000 epoch</td>
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<tr>
<td>eci_position</td>
<td>Float64</td>
<td>Meters</td>
<td>Position in ECI coordinate</td>
</tr>
<tr>
<td>eci_velocity</td>
<td>Float64</td>
<td>m/s</td>
<td>Velocity in ECI coordinates</td>
</tr>
<tr>
<td>Group Attitude</td>
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<td>quaternion</td>
<td>Float64</td>
<td>None</td>
<td>Attitude quaternion</td>
</tr>
</tbody>
</table>

**HDF5 Format**
• AFIDS FFT Approach
  • Uses a grid of 2-D Fast Fourier Transforms (FFTs*) to produce tie points between images.
  • The FFT’s Size initially starts out big (to cover large geographic areas) in order to catch the offset between two images, then reduces in size as the ability to predict the next tie point location improves.
  • A list of tie point matches with correlation and offset values is produced and processed to remove outliers.
  • The remaining best correlation points are used to create a polynominial fit between the two images and generate an ultra fine resolution correction grid.
  • A triangular interpolation between points in the correction grid is used to war/register the two images together.

A grid of FFT tiepoints is used to match two images. FFT size starts large then decreases as matching becomes reliable. Tie point matching location order is randomly controlled by a “seed” value. A subset of tiepoints are selected based on correlation score and offsets. Outliers are discarded. The maximum number of FFTs is 4096. A polynomial fit is applied to the tiepoints to create an Ultra Fine grid of registration correction points. Fit options include Quad, Cubic, Linear, Keystone, and Thiessen. A triangular interpolation is performed between points in the correction grid to produced the final registered image.