ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

L1 Processing and Products

Science Team Meeting
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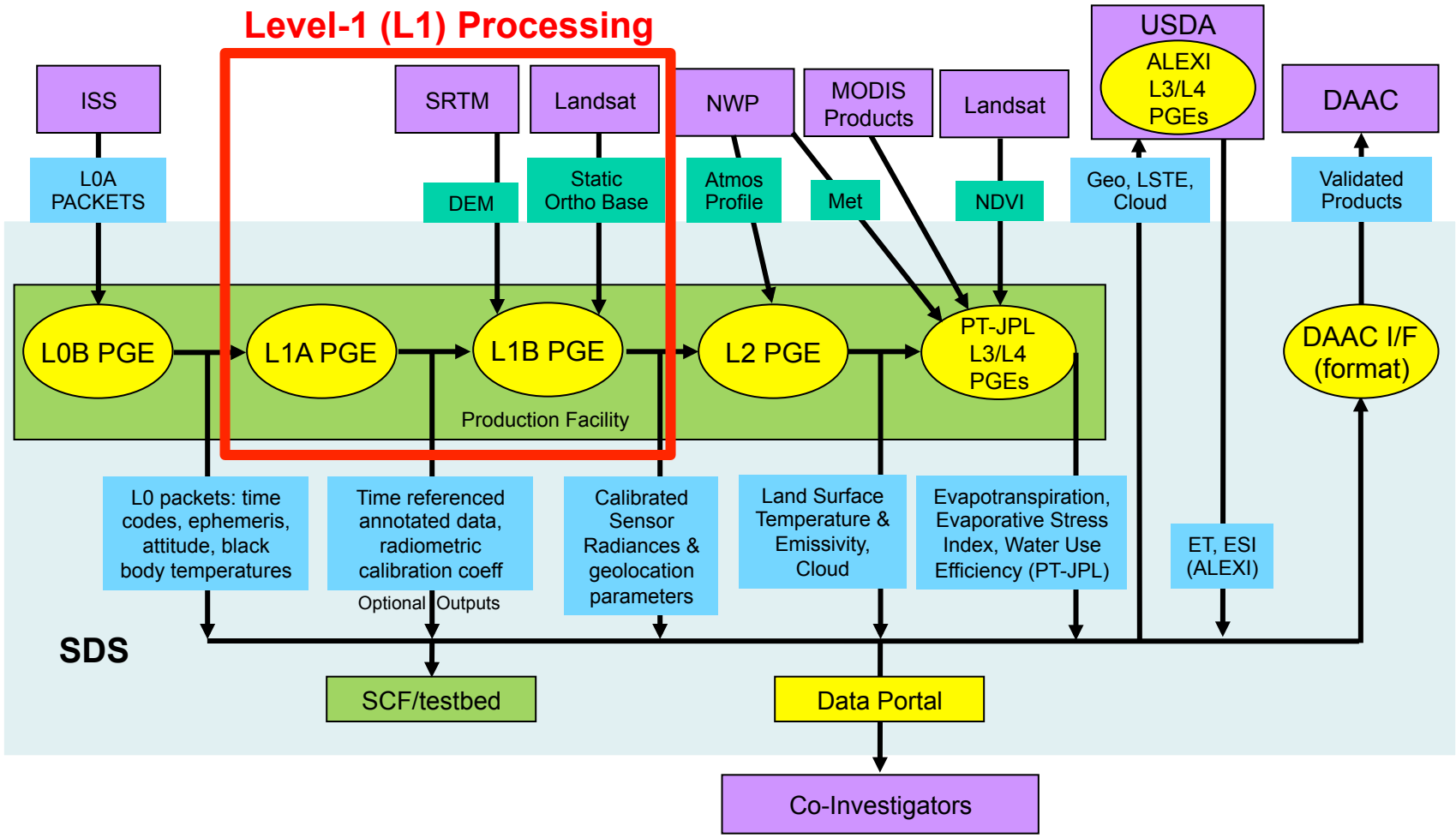
Level-1 Introduction

- 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

Science Data Products	
L0	Raw data
L1	Radiometrically corrected Radiances
L2	Surface Temperature and Emissivity
L3	Evapotranspiration
L4	Water Use Efficiency, Evaporative Stress Index

L1 Overview

L1 in the SDS Processing Flow

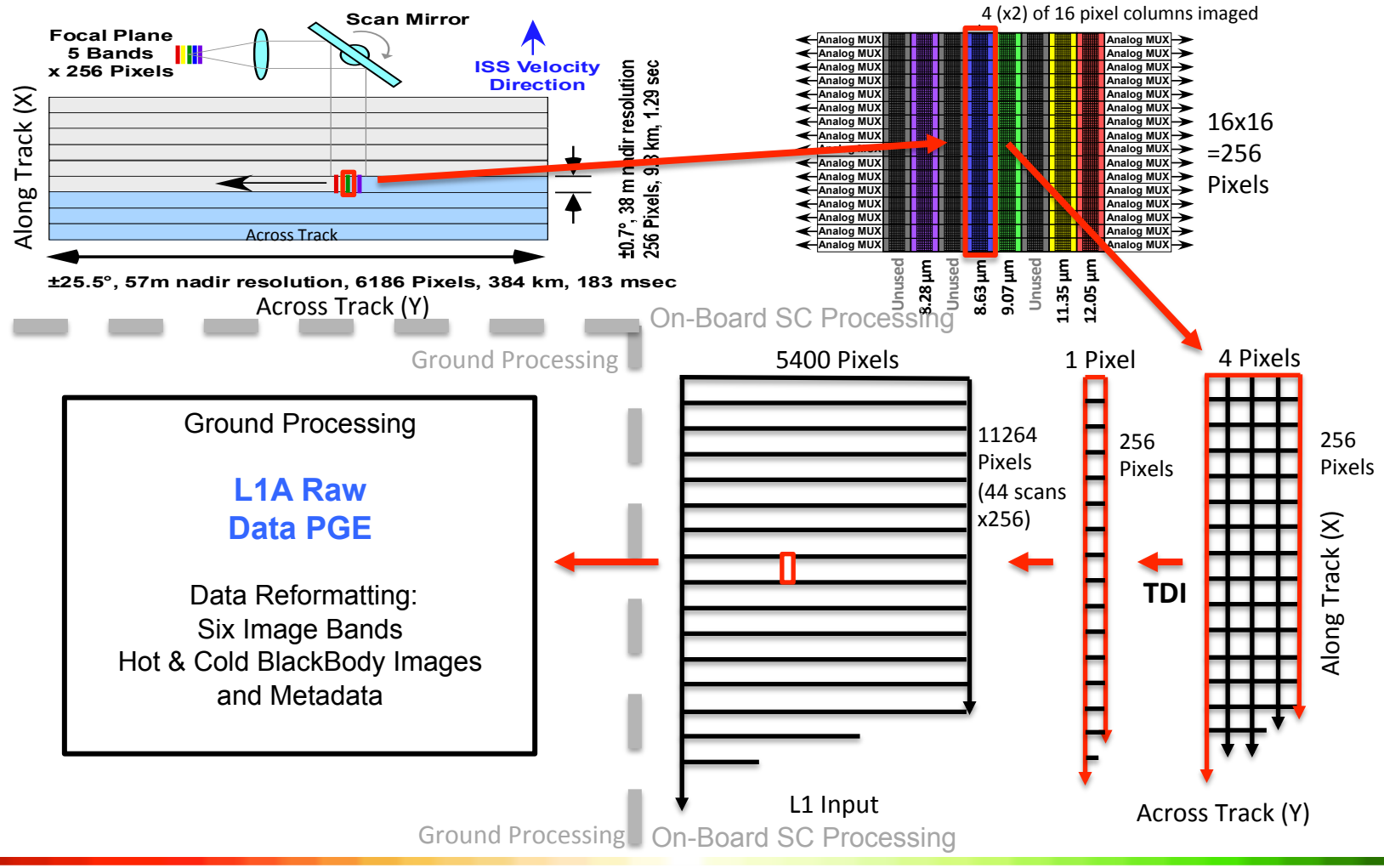


Level-1 Description Overview

- 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



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.

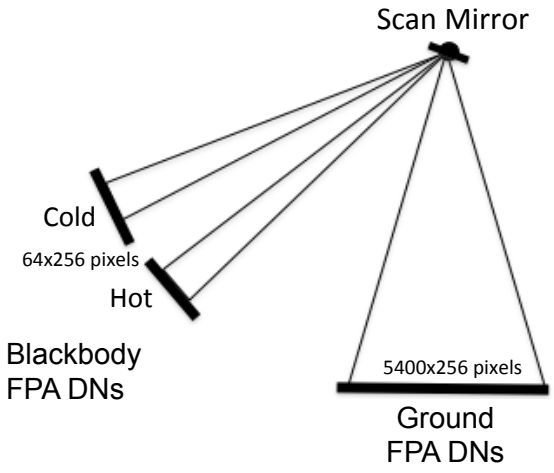
- SWIR band is *not* radiometrically calibrated, but has Dark Current subtracted. Flat-Field artifact correction is TBD.

*Documented in: "Level-1 Focal Plane Array and Radiometric Calibration Algorithm Theoretical Basis Document (ATBD)," JPL D-94803.

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

$$R_\lambda = a + bD_\lambda$$

$$a = \frac{R_h D_c - R_c D_h}{D_c - D_h} \qquad b = \frac{R_c - R_h}{D_c - D_h}$$

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)*

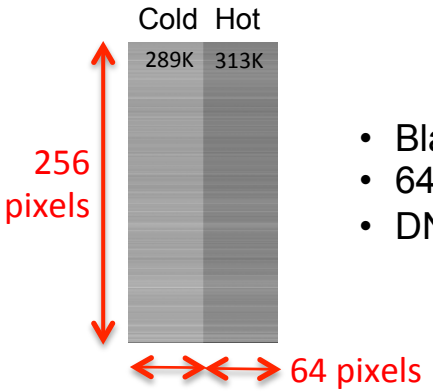
D_c = *Digital Number (DN) from the Cold Blackbody Calibration File (Section 3.3.3)*

D_h = *Digital Number (DN) from the Hot Blackbody Calibration File (Section 3.3.3)*

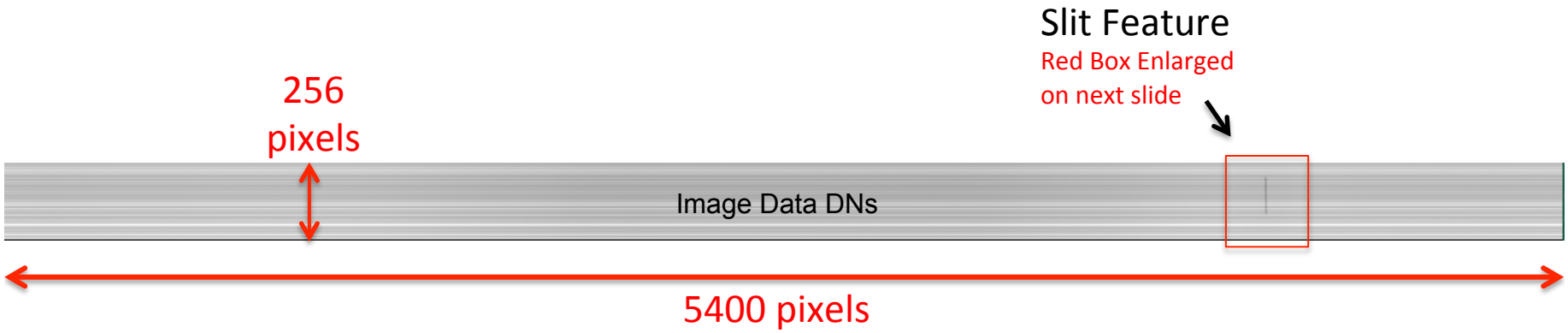
Referenced Sections are in: "Level-1 Focal Plane Array and Radiometric Calibration Algorithm Theoretical Basis Document (ATBD)," JPL D-94803.

FPA Test Data from 20170404

9um Wavelength Data

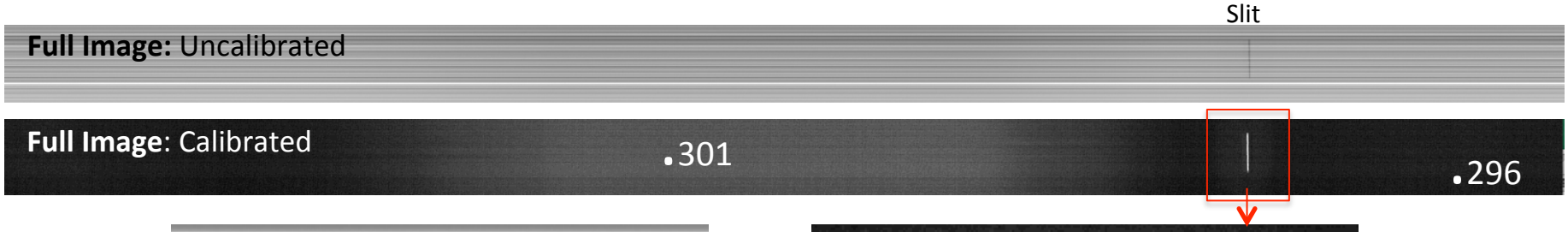


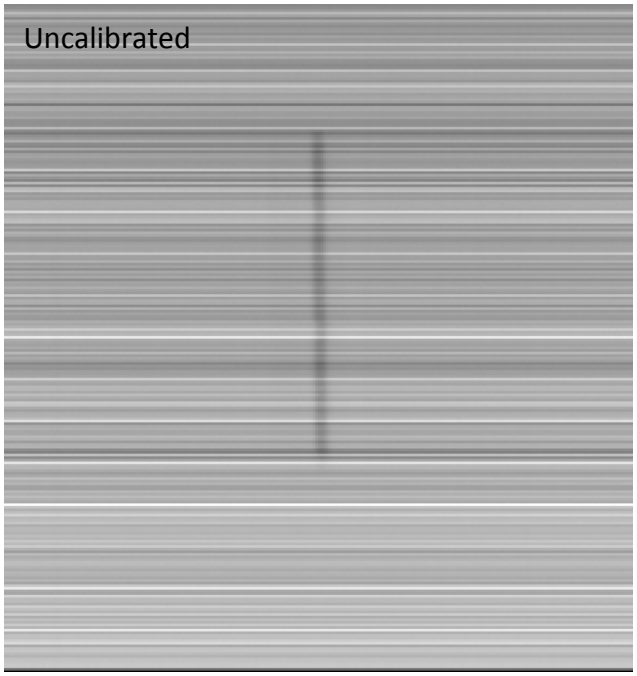
- Blackbody DNs
- 64x256 pixels are averaged to 1x256
- DNs are Contrast Inverted



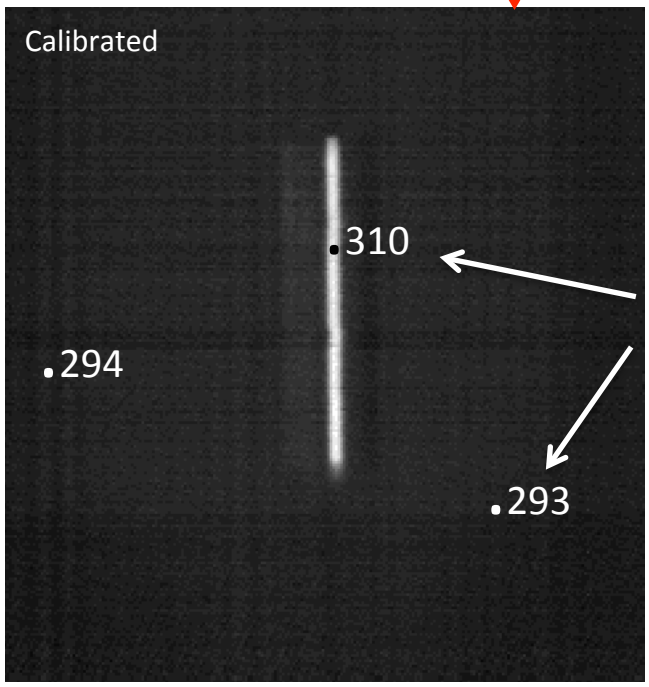
FPA Test Data from 20170404

12um 2-Point Radiometric Calibration





Raw Image



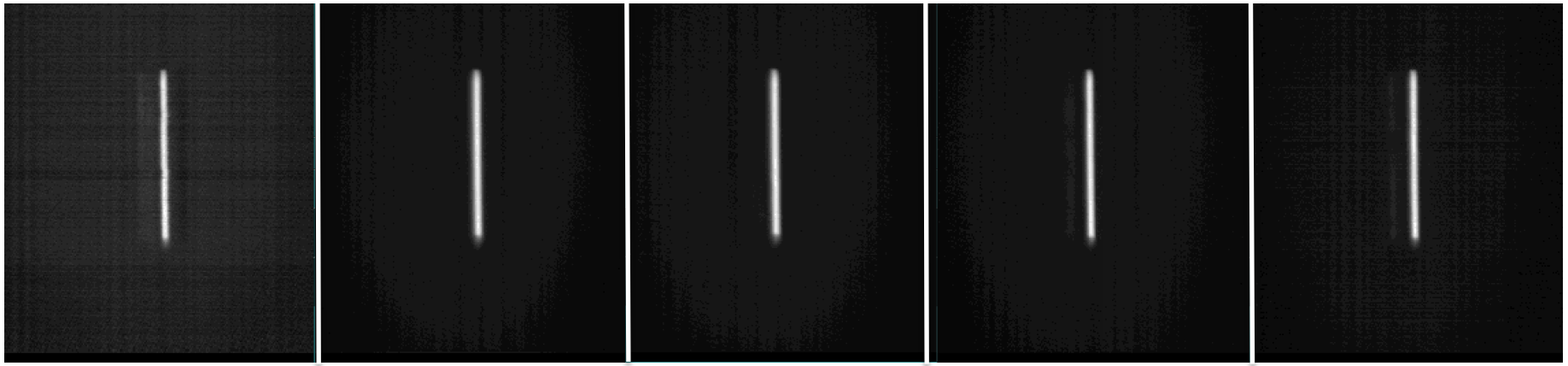
2pt Calibration Temperatures (K)

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)



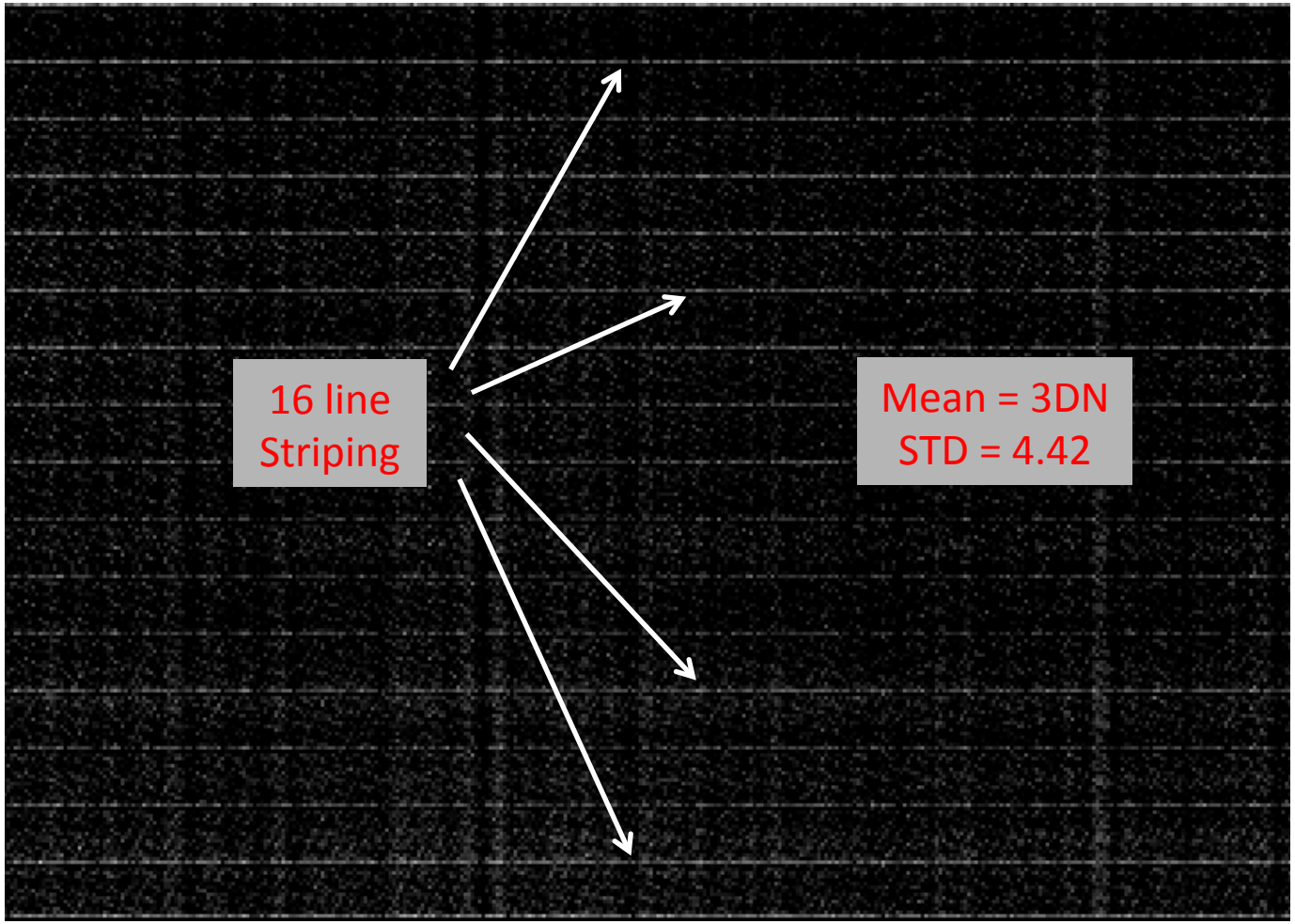
Band1 (12.1um) Band2 (10.56um) Band3 (9.2um) Band4 (8.8um) Band5 8.3um)

- 2pt Radiometric Calibration in Degrees Kelvin

Band	Mean	STD
Band 1:	294.9	2.14
Band 2:	295.0	2.15
Band 3:	295.0	2.17
Band 4:	295.0	2.20
Band 5:	294.8	2.03

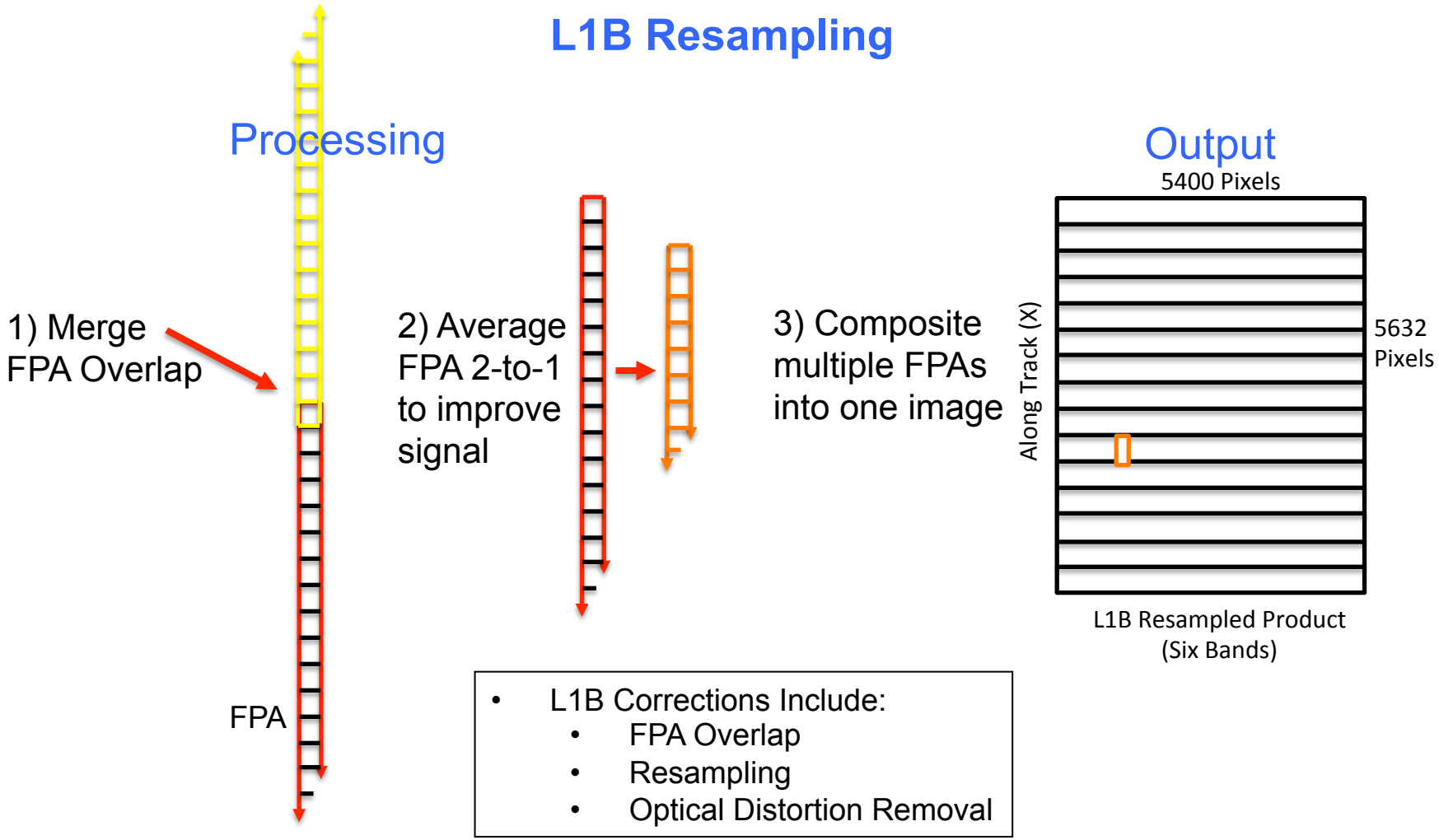
FPA Test Data from 20170404

SWIR with Dark Current Subtraction



L1B Resampling PGE

L1B Resampling



- L1B Corrections Include:
  - FPA Overlap
  - Resampling
  - Optical Distortion Removal

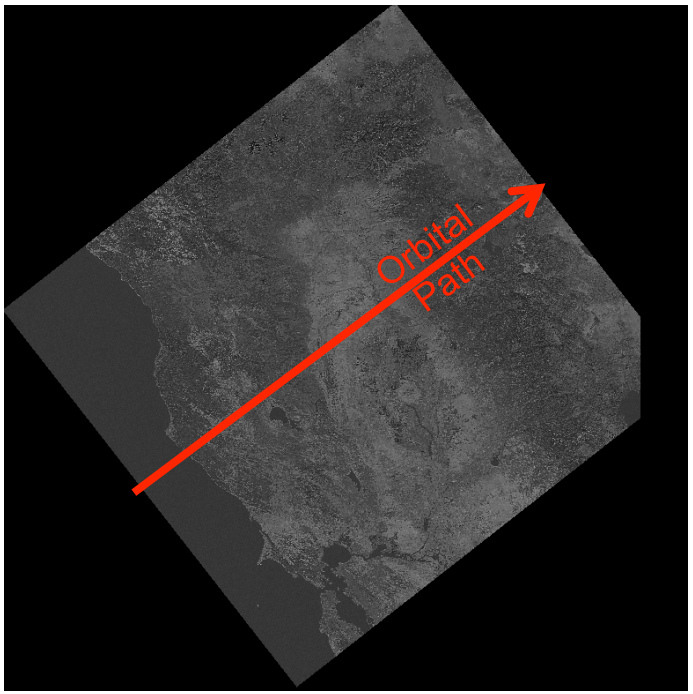
L1B Geolocation*

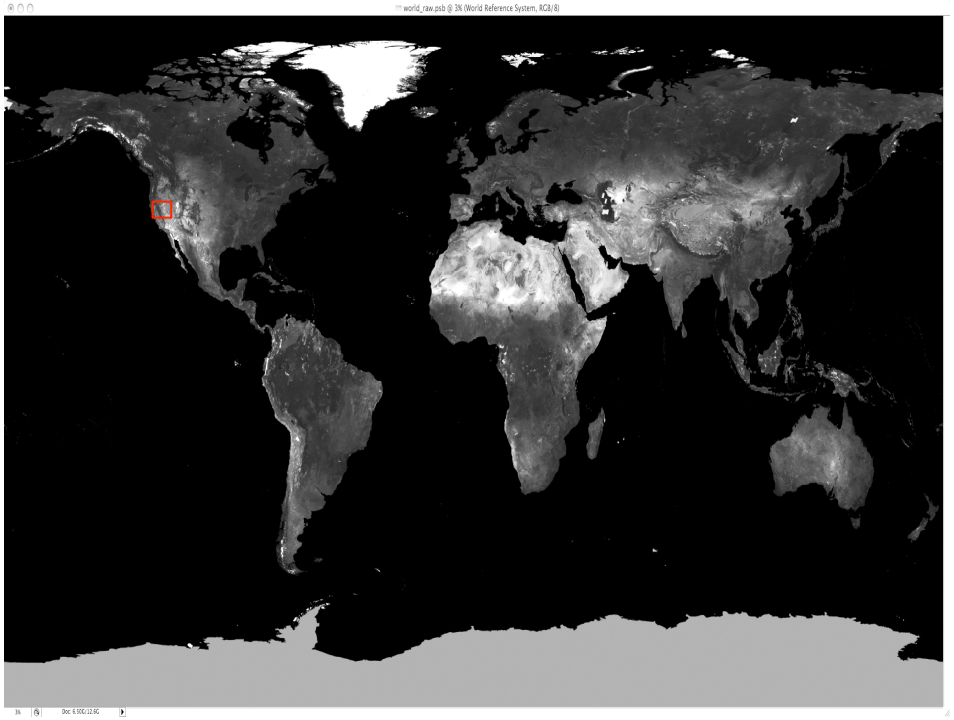
- Purpose: Calculate the Latitude and Longitude of each image pixel.
  - Corrections for Small Errors (less than 2 pixels):
    - Focal Plane Scan-Line Offsets.
    - Extrapolate Ephemeris and Pointing information from the ISS to the ECOSTRESS camera on the JEM module.
    - ISS altitude, pitch, yaw, 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





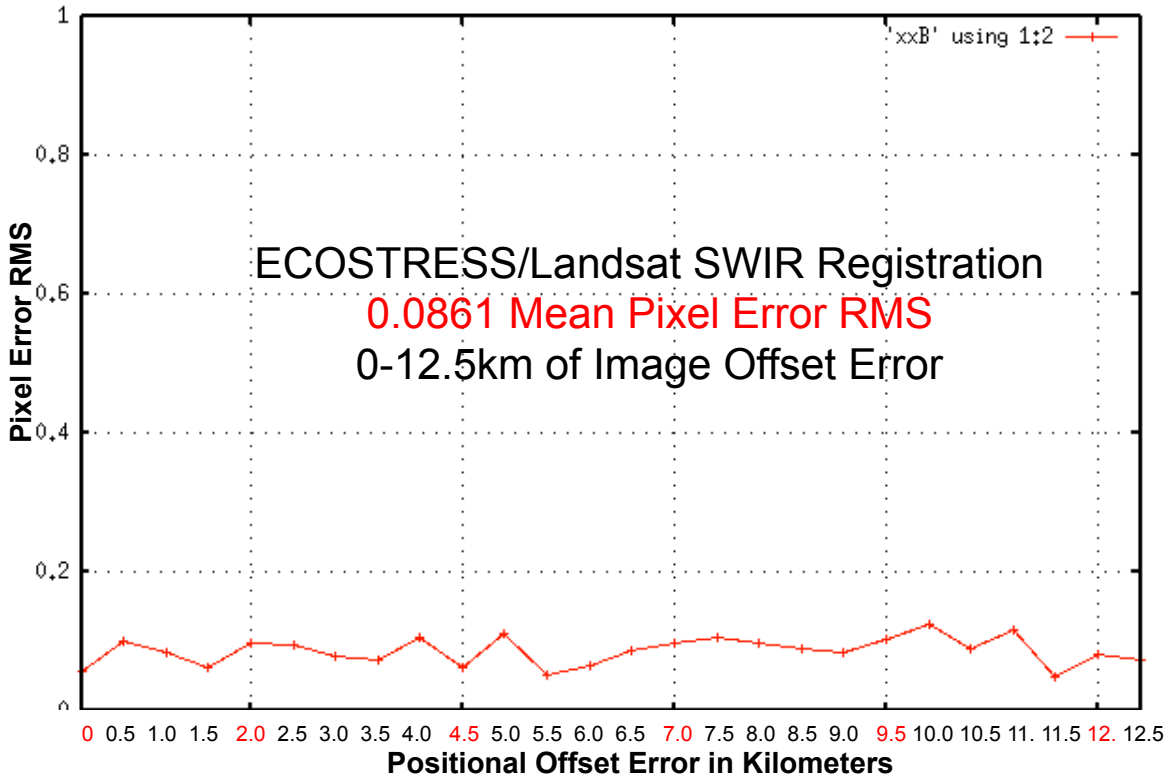
Incoming 1.6u SWIR Band (Simulated from ASTER Band4) With initial (weak) Geolocation

is Registered to

Landsat 7 Global Ortho-Base Band5 (SWIR) Band
Co-Registration provides precise Geolocation

L1B Geolocation Testbed

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



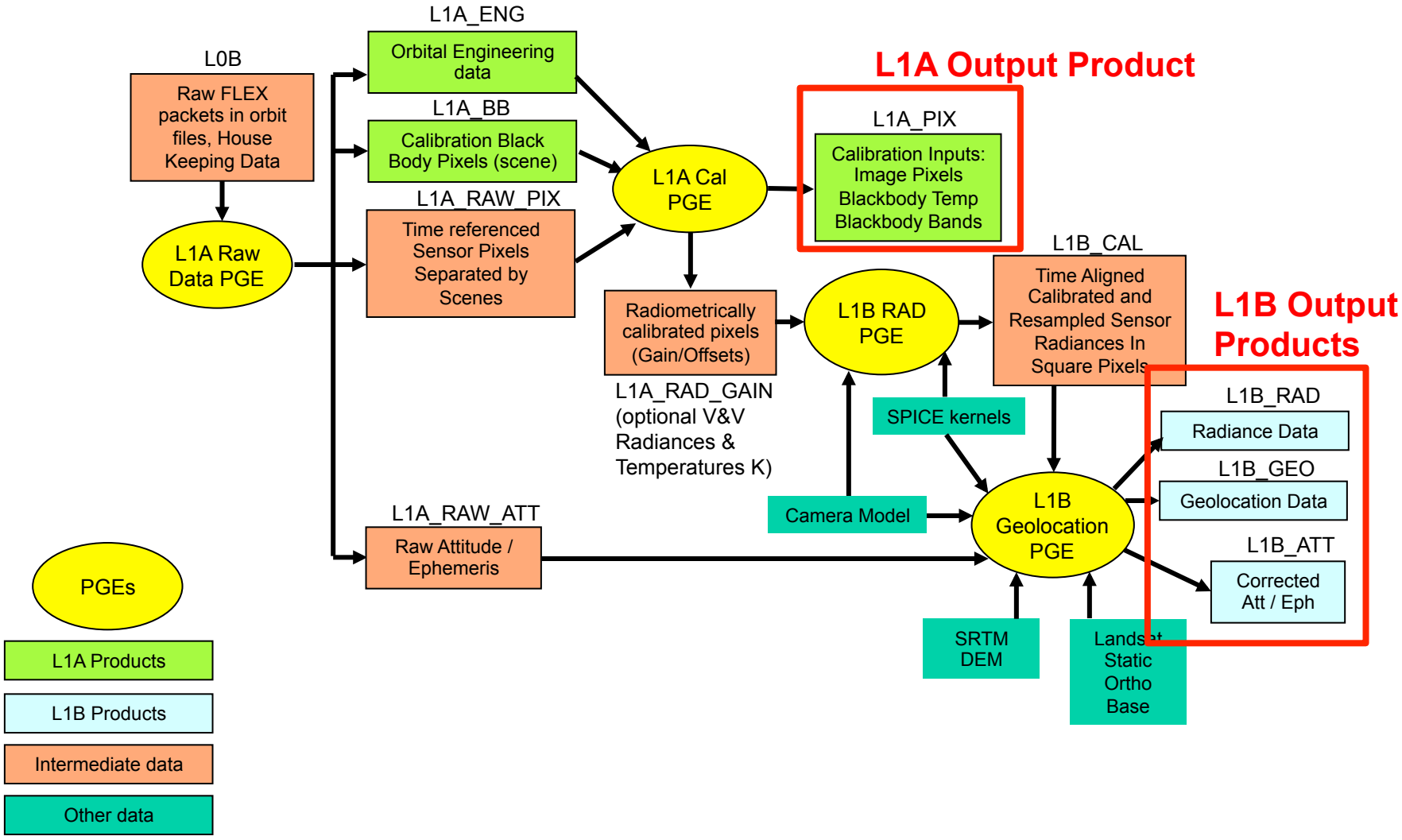
- ECOSTRESS Band 1 (1.6u) Simulation Derived from ASTER Band 4 (1.60-1.70u)
- Matched with Landsat7 Band 5 (1.55-1.75u) at 75x68m/pxl
- Registration Parameters:
  - 24x24 FFT Grid
  - 256 pixel size FFT
  - Magnification 4->2

STATISTICAL SUMMARY

NUMBER OF CASES: 26

NAME	MEAN	STD DEV	MIN	MAX
PXL_RMS	0.0861	0.0202	0.0497	0.1256
LINE_ERR	0.0179	0.0481	-0.0606	0.0901
SAMP_ERR	0.0038	0.0503	-0.0767	0.0725

L1 Process Summary & Products



L1 Products

L1A_PIX: Calibration Inputs

Field Name	Type	Units	Field Data
Group	**UncalibratedDN**	(Size 11264x5400)	(CW)
b1_image	Int16	DN	Band 1 Raw image Pixel Data (12.09um)
b2_image	Int16	DN	Band 2 Raw image Pixel Data (10.56um)
b3_image	Int16	DN	Band 3 Raw image Pixel Data (9.20um)
b4_image	Int16	DN	Band 4 Raw image Pixel Data (8.80um)
b5_image	Int16	DN	Band 5 Raw image Pixel Data (8.29um)
b6_image	Int16	DN	Band 6 Raw image Pixel Data (1.66um SWIR)
Group	**BlackbodyTemp**	(Size 11264x1)	
fpa_325	Float32	Kelvin	Calibrated 325 Kelvin Blackbody Focal Plane
fpa_295	Float32	Kelvin	Calibrated 295 Kelvin Blackbody Focal Plane
Group	**BlackbodyBandDN**	(Size 11264x1)	
b1_325	Float32	DN	B1 Focal Plane Averaged DN for 325k BB
b1_295	Float32	DN	B1 Focal Plane Averaged DN for 295k BB
b2_325	Float32	DN	B2 Focal Plane Averaged DN for 325k BB
b2_295	Float32	DN	B2 Focal Plane Averaged DN for 295k BB
b3_325	Float32	DN	B3 Focal Plane Averaged DN for 325k BB
b3_295	Float32	DN	B3 Focal Plane Averaged DN for 295k BB
b4_325	Float32	DN	B4 Focal Plane Averaged DN for 325k BB
b4_295	Float32	DN	B4 Focal Plane Averaged DN for 295k BB
b5_325	Float32	DN	B5 Focal Plane Averaged DN for 325k BB
b5_295	Float32	DN	B5 Focal Plane Averaged DN for 295k BB
b6_325	Float32	DN	B6 Focal Plane Averaged DN for 325k BB
b6_295	Float32	DN	B6 Focal Plane Averaged DN for 295k BB
Group	**Time**		
line_start_time_j2000	Float64	Second	J2000 time of first pixel in line

HDF5 Format

L1B_RAD: Calibrated Output Radiance Images

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

HDF5
Format

L1B_GEO: Output Geolocation Metadata

(Provided for Each Pixel*)

Field Name	Type	Units	Field Data
Group	**Geolocation**		
height (elevation)	Float32	Meter	
land_fraction	Float32	Percentage	Percentage of pixel that is land, from 0 - 100
latitude	Float64	Degrees	
line_start_time_j2000	Float64	Second	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	

HDF5
Format

* Radiance products are in Swath image alignment

L1B_ATT: Corrected Spacecraft Ephemeris and Attitude

(Orbital Data at One Second Intervals)

Field Name	Type	Units	Field Data
Group	**Ephemeris**		
time_j2000	Float64	Seconds	Seconds from J2000 epoch
eci_position	Float64	Meters	Position in ECI coordinate
eci_velocity	Float64	m/s	Velocity in ECI coordinates
Group	**Attitude**		
time_j2000	Float64	Seconds	Seconds from J2000 epoch
quaternion	Float64	None	Attitude quaternion

HDF5
Format

Backup

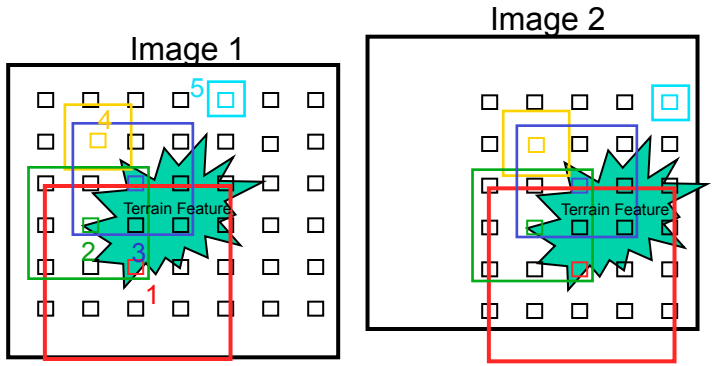
AFIDS FFT Image Registration Process

FFT Co-Registration Approach

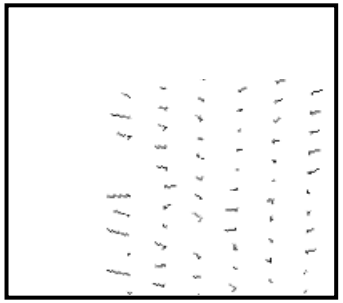
- AFIDS FFT Approach
  - Uses a grid of 2-D Fast Fourier Transforms (FFTs*) to produce tie points between images.
  - The FFT's Size initially starts out big (to cover large geographic areas) in order to catch the offset between two images, then reduces in size as the ability to predict the next tie 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 polynominal 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.

*C.D. Kuglin and D.C. Hines, "The Phase Correlation Image Alignment Method," Proc. Int. Conference on Cybernetics & Society, pp. 163-165., 1975.

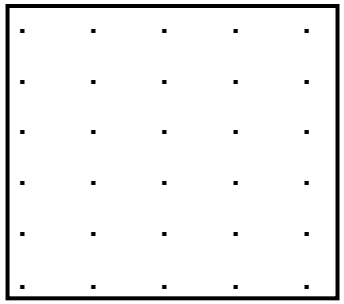
AFIDS FFT Tiepoint Interpolation Approach



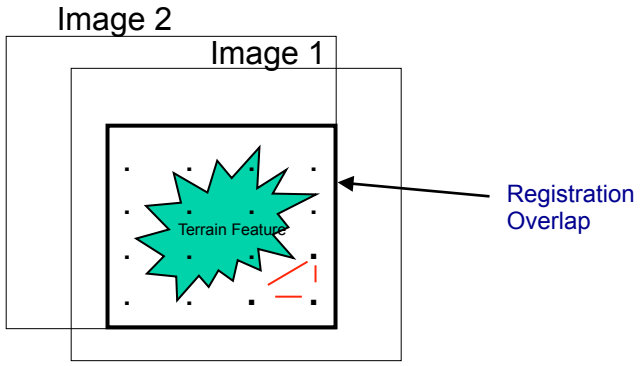
A grid of FFT tiepoints is used to match two images. FFT size starts large then decreases as matching becomes reliable. Tie point matching location order is randomly controlled by a "seed" value.



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.