ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

L1 Processing and Products
Science Team Meeting
21MAR2019

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L1 Overview

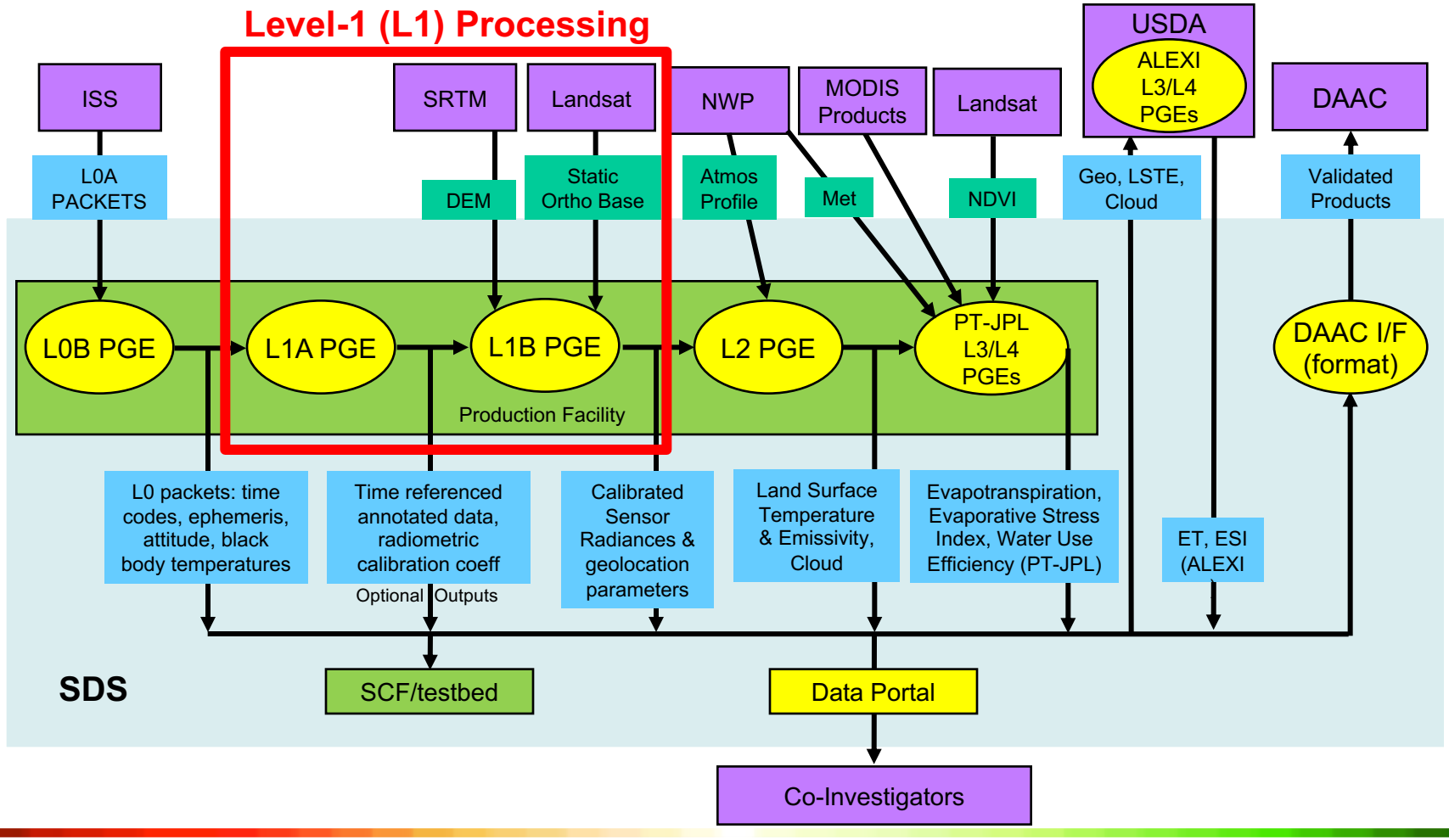
Level-1 Introduction

- 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

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

SDS Processing Flow

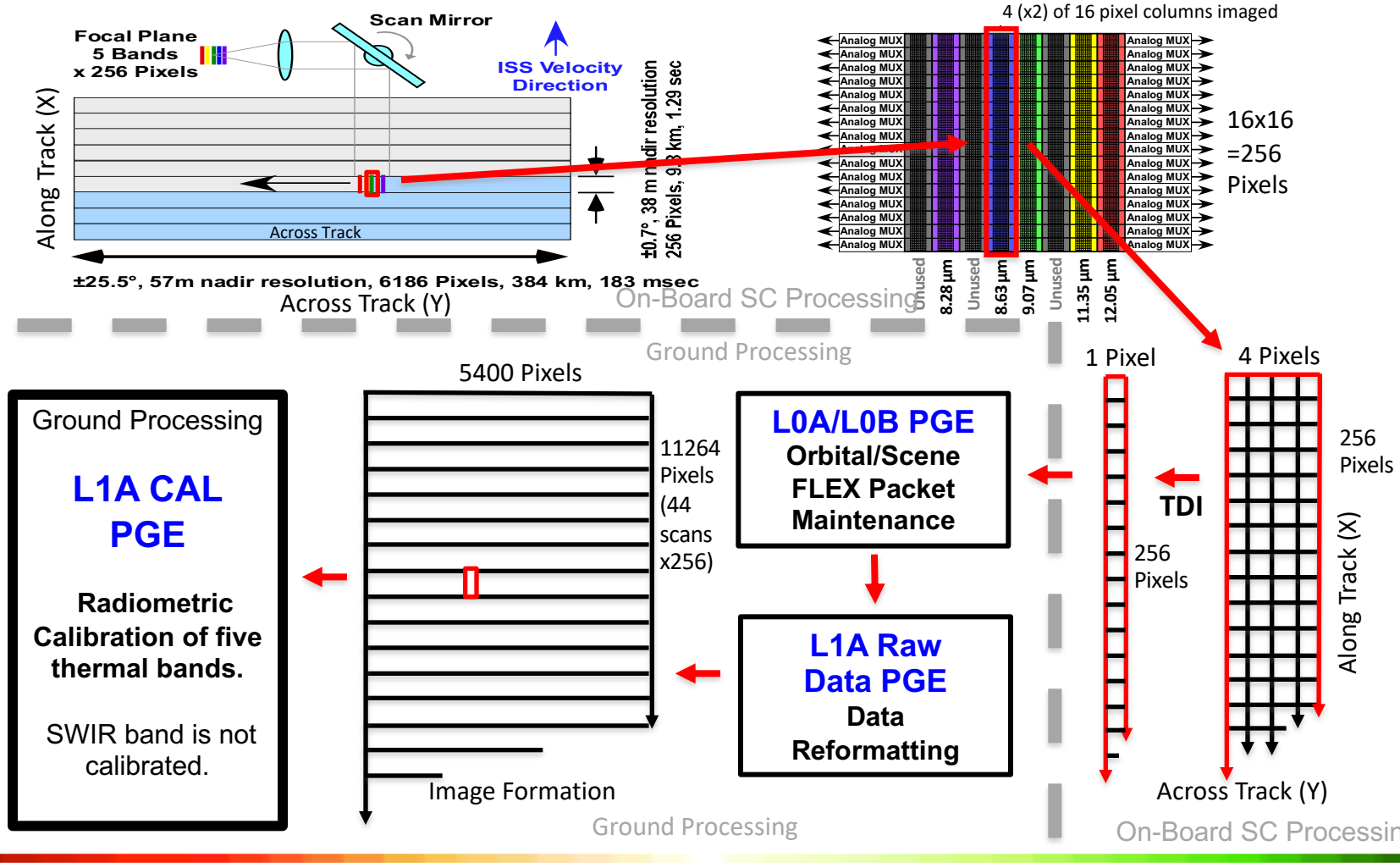


Level-1 Description Overview

- L1 Processing consists of four PGEs (Product Generation Executives)
  - L1A
    - Raw Data Processing (Chu)
      - Reformat Incoming ISS data packets, metadata, and ancillary data
        - Formulate Focal Plane (FPA) Earth images by spectral band DNs
        - Formulate on-board FPA Blackbody Calibration image DNs
    - Radiometric Calibration (Logan and Johnson)
      - 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 and Radiance Delivery (Smyth)
      - Merge Focal Plane overlap and average pixels (lines) to improve signal.
      - Fill Missing Data (Nguyen and Hulley)
    - Geolocation (Smyth)
      - Geolocation Matching (using Landsat orthobase) to correct for Positional Errors
      - Geolocated L1B Products

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.

- Accuracy is expected to be ~1.0 Kelvin. The Science Team can also choose between two Planck algorithms and linearly fine tune each TIR band radiance.

- TOA Radiance and Temperature images can be generated for Validation and Verification purposes as necessary.

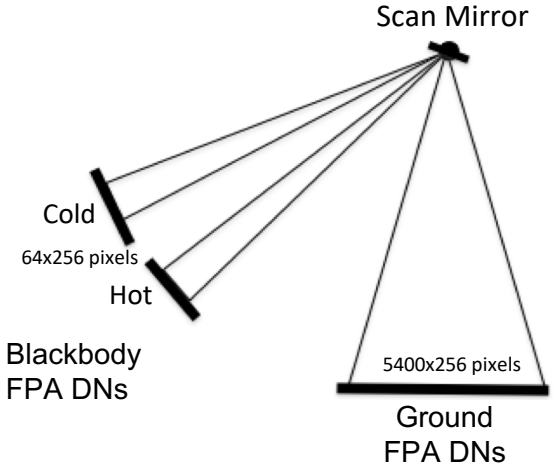
- SWIR band is not radiometrically calibrated. It was intended for Geolocation "matching," but provided unsuitable. It maybe provided as a non-science "visual" product.

*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)*

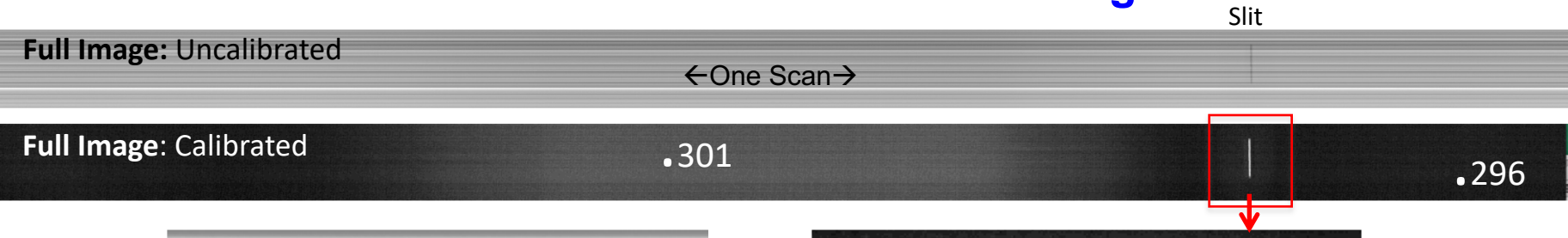
D_c = *Digital Number (DN) from the Cold Blackbody Calibration File (Section 3.3.3)*

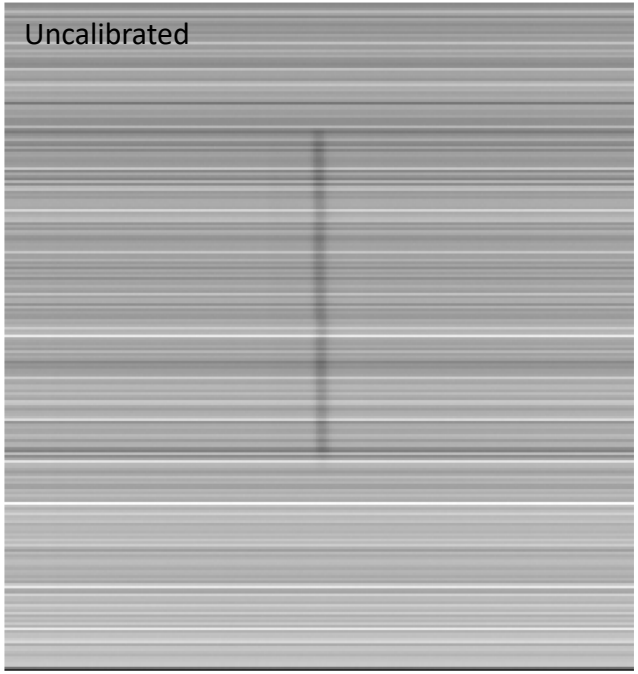
D_h = *Digital Number (DN) from the Hot Blackbody Calibration File (Section 3.3.3)*

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

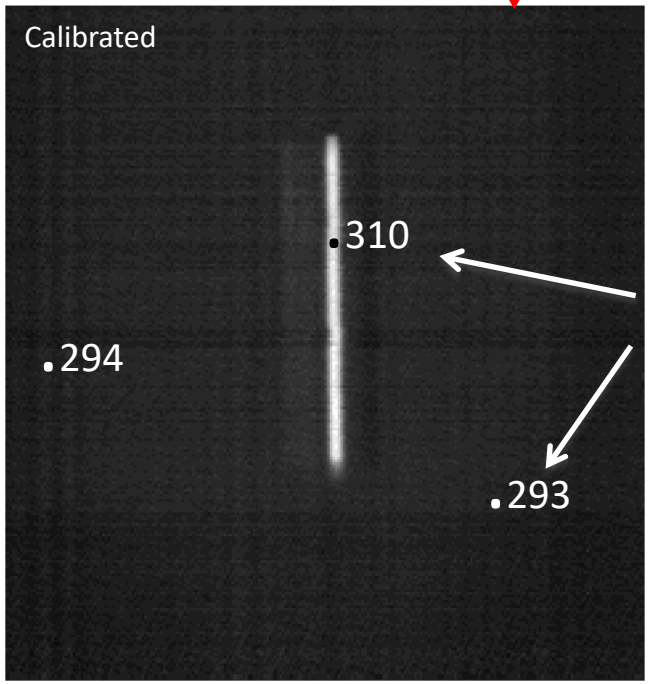
FPA Test Data from 20170404

2-Point Radiometric Calibration Test using TIR 12um





Raw Image



Calibrated Kelvin Temperature Values at Location

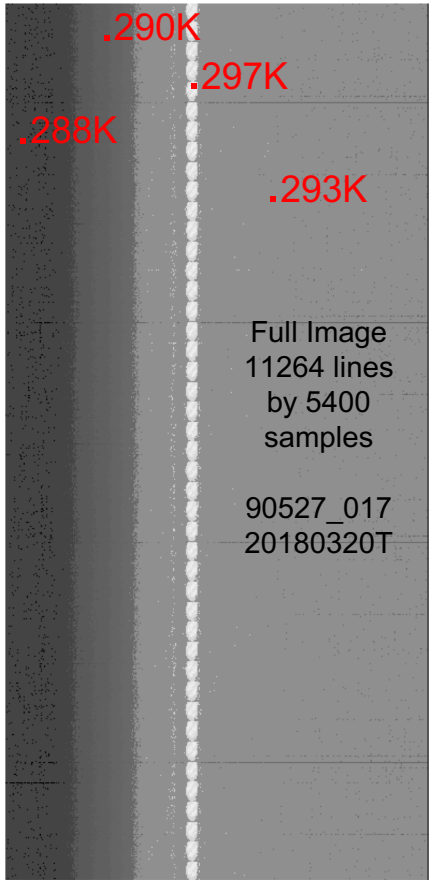
2pt Calibration Temperatures (K)

Mean = 294.88 Deg Kelvin (22C; 71F)

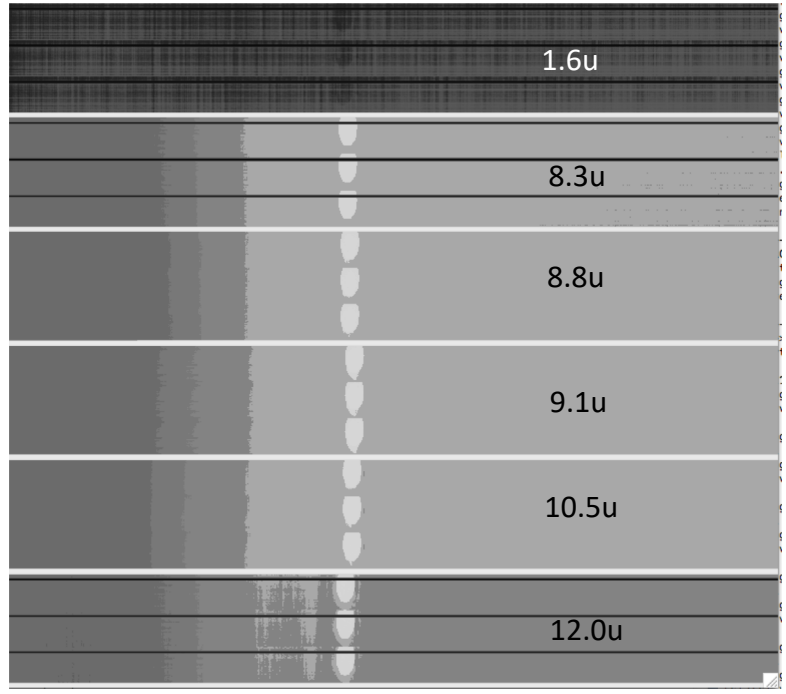
STD= 2.14

FPA Test Data from 20180320

Example L1A_CAL Quicklook Images From TVAC



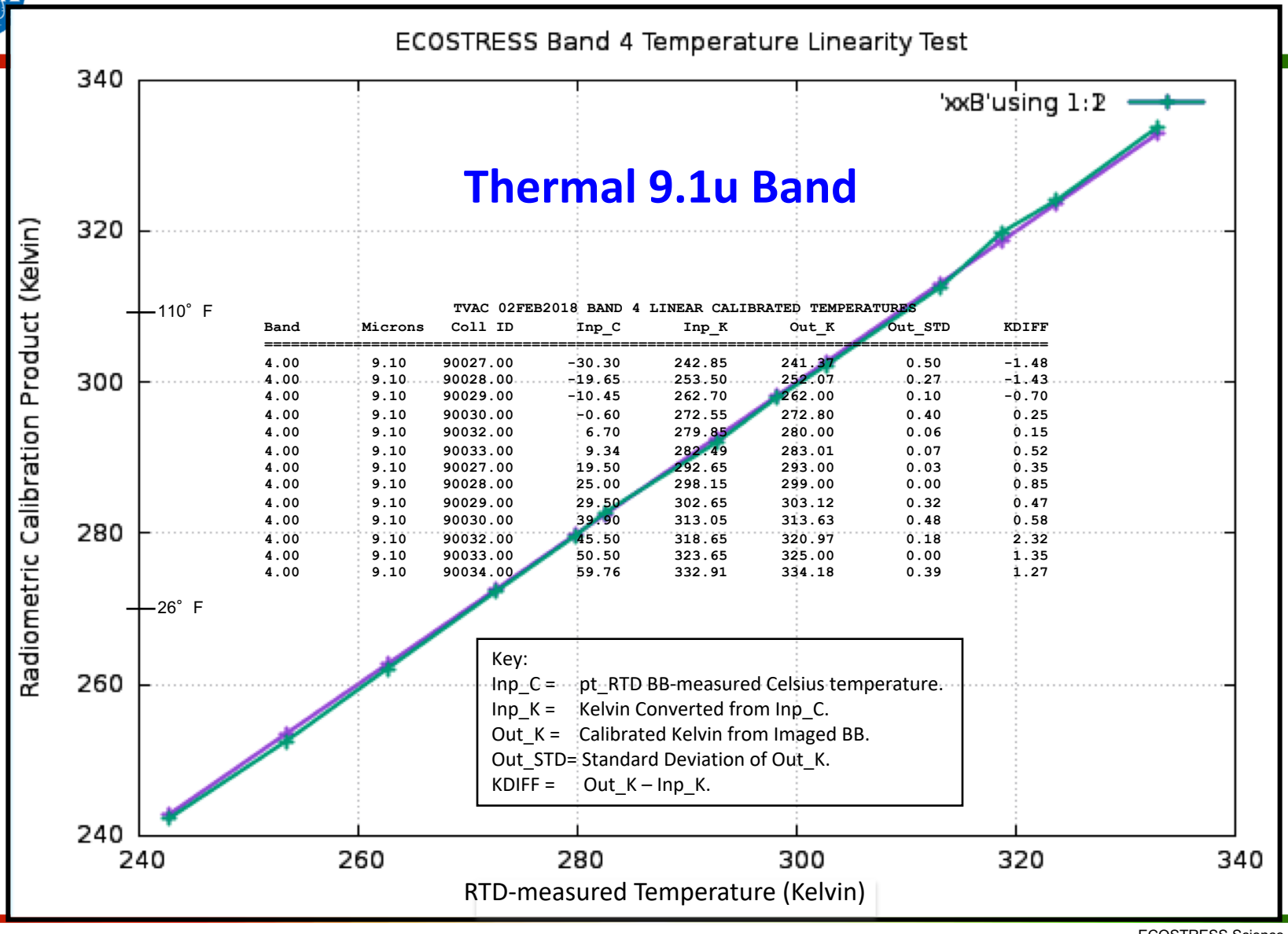
8.7um Full Image
Temperatures K



Top 3 Scans of All Six Bands
Composite Quicklook Temperatures Image

Sets of 16 Dropped Lines occur in SWIR, 8.3u & 12.0u bands. They repeat very 240 lines (15 sets) after an initial offset of 32 lines (2 sets).

FPA Linear Test Data from 20180202



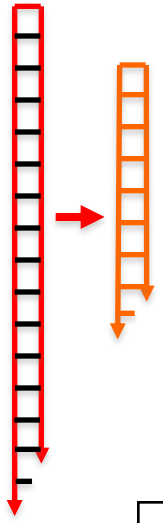
TVAC 02FEB2018 BAND 4 LINEAR CALIBRATED TEMPERATURES

Band	Microns	Coll ID	Inp_C	Inp_K	Out_K	Out_STD	KDIFF
4.00	9.10	90027.00	-30.30	242.85	241.37	0.50	-1.48
4.00	9.10	90028.00	-19.65	253.50	252.07	0.27	-1.43
4.00	9.10	90029.00	-10.45	262.70	262.00	0.10	-0.70
4.00	9.10	90030.00	-0.60	272.55	272.80	0.40	0.25
4.00	9.10	90032.00	6.70	279.85	280.00	0.06	0.15
4.00	9.10	90033.00	9.34	282.49	283.01	0.07	0.52
4.00	9.10	90027.00	19.50	292.65	293.00	0.03	0.35
4.00	9.10	90028.00	25.00	298.15	299.00	0.00	0.85
4.00	9.10	90029.00	29.50	302.65	303.12	0.32	0.47
4.00	9.10	90030.00	39.90	313.05	313.63	0.48	0.58
4.00	9.10	90032.00	45.50	318.65	320.97	0.18	2.32
4.00	9.10	90033.00	50.50	323.65	325.00	0.00	1.35
4.00	9.10	90034.00	59.76	332.91	334.18	0.39	1.27

L1B Resampling

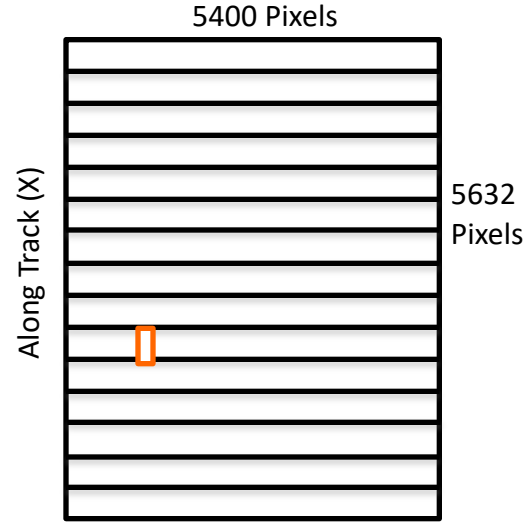
Processing

1) Average FPA 2-to-1 to improve signal



2) Composite multiple FPAs into one image
3) Fill Dropped Lines

Output



L1B Resampled Product (Six Bands)

- L1B Corrections Include:
  - FPA Overlap
  - Resampling
  - Optical Distortion Removal
  - Data Fill for Dropped Lines using Machine Learning

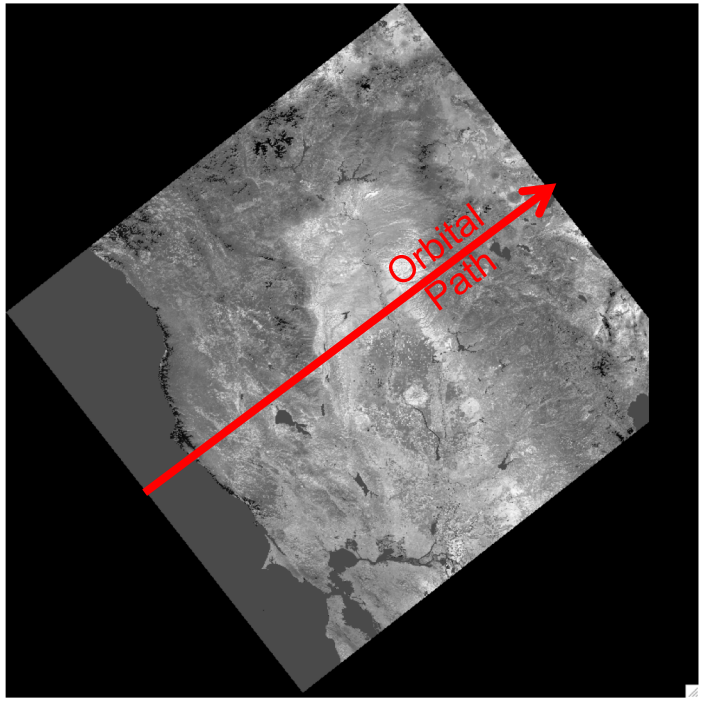
L1B Geolocation*

- Purpose: Calculate the Latitude and Longitude of each image pixel.
  - Corrections for Small Errors (less than 2 pixels):
    - Focal Plane Scan-Line Offsets.
    - 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 (position must be extrapolated from the ISS. No Star Tracker).
      - Attitude correction is performed by co-registration/matching an ECOSTRESS TIR image with a similar ortho-rectified Landsat wavelength.
      - 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 meet the 50m positional requirement.
- Latitude and Longitude coordinates are extracted and supplied for each input 75x68m ECOSTRESS pixel. Note that pixel size will vary with ISS Altitude.

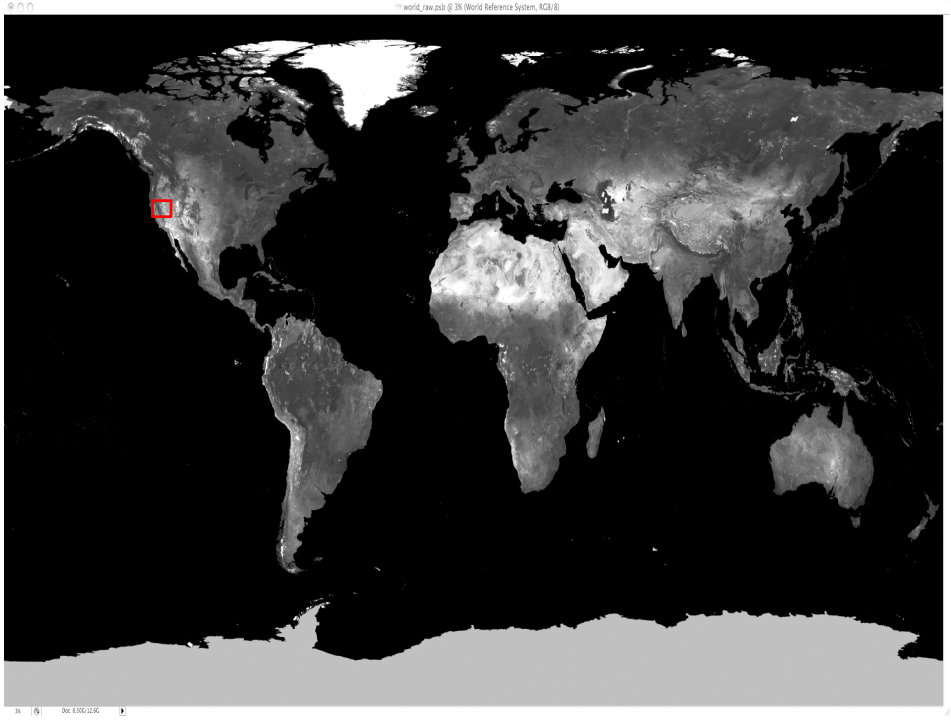
*Documented in: “Level-1B Resampling and Geolocation Algorithm Theoretical Basis Document (ATBD),” JPL D-94641

L1B Geolocation Testbed

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



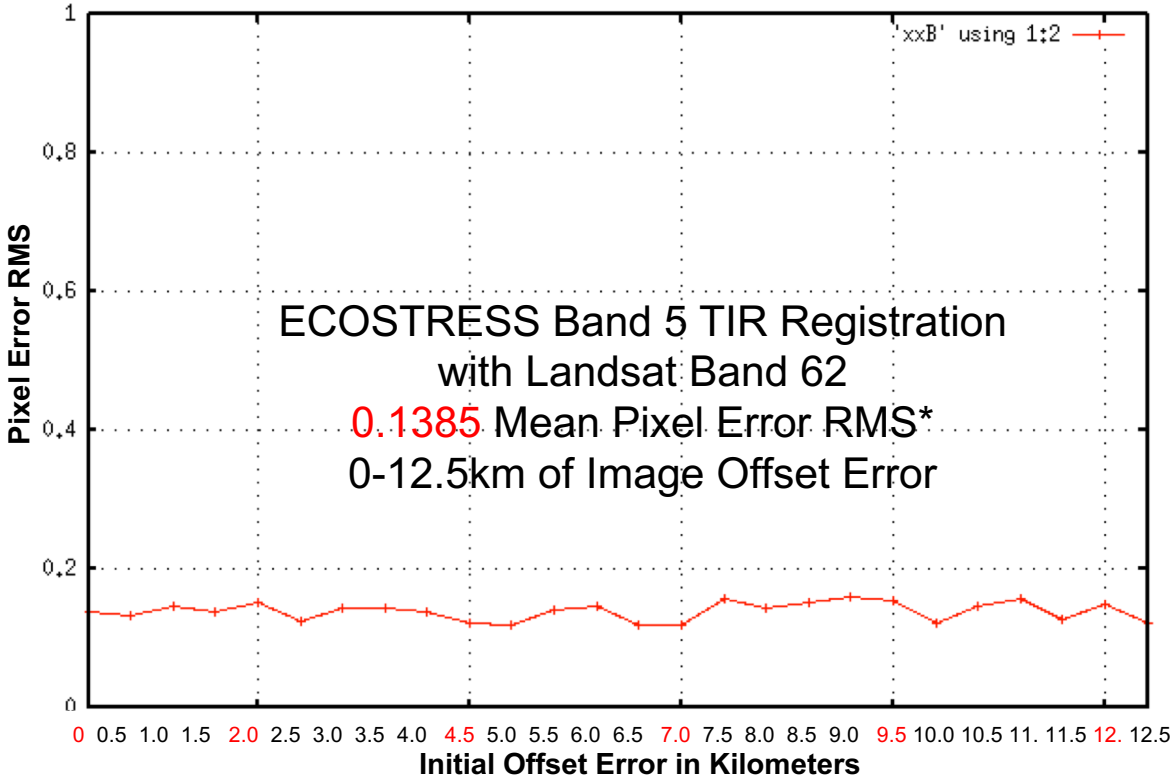
ECOSTRESS TIR Band
Simulated from ASTER Band14 (11u)
With Rotation for Geolocation Matching



Landsat 7 Global Ortho-Base
Band6 (TIR) Band (10.4-12.5u)
Co-Registration provides precise Geolocation

L1B Geolocation Testbed

TIR 11u Co-Registration Test Results (0-12.5km Offset)



* About 10m Using Pre-Launch AFIDS beta code

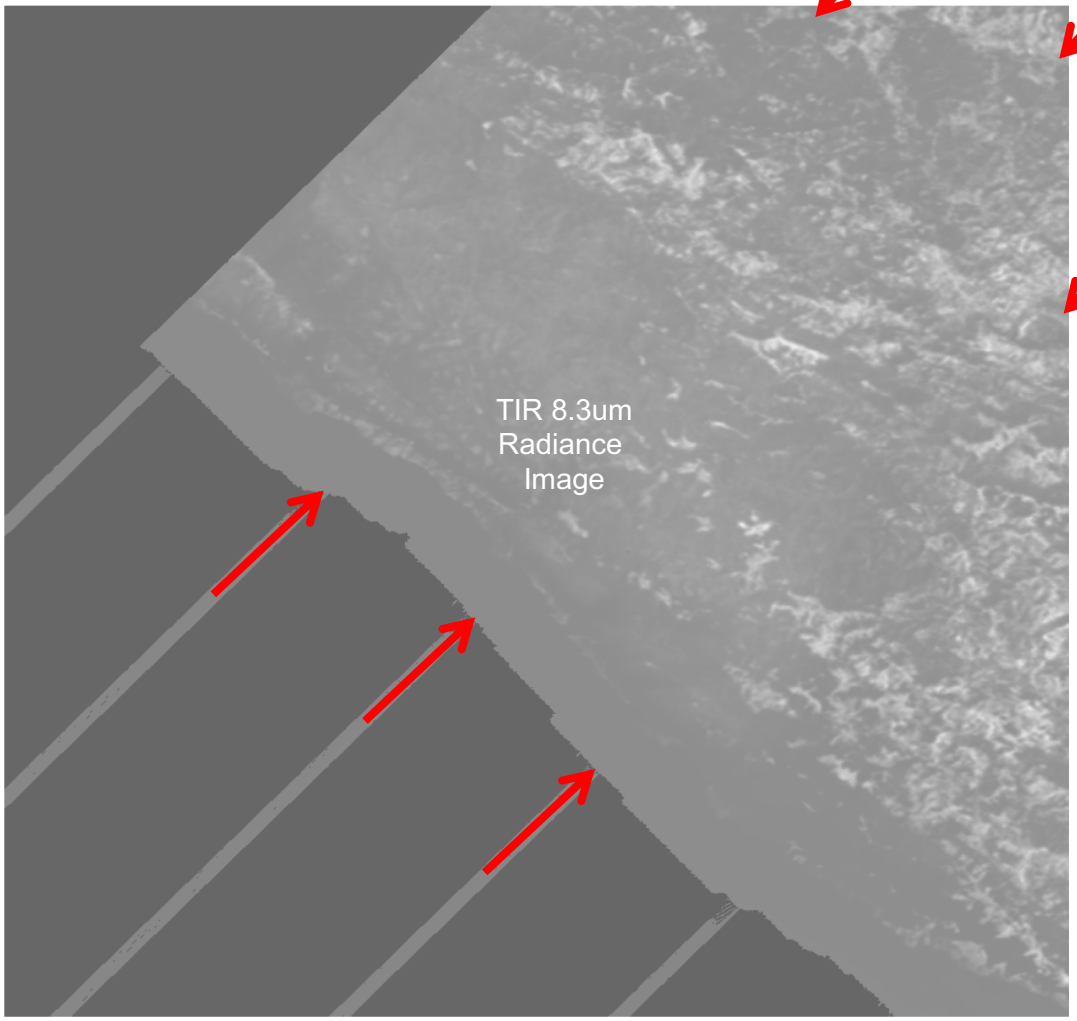
- ECOSTRESS Band 5 (11.33u) Simulation Derived from ASTER Band 14 (10.95-11.65u)
- Matched with Landsat7 Band 62 (10.4-12.5u; High Gain) at 75x68m/pxl
- Registration Parameters:
  - 24x24 FFT Grid
  - 256 pixel size FFT
  - Magnification 4->2

STATISTICAL SUMMARY

NUMBER OF CASES: 26

NAME	MEAN	STD DEV	MIN	MAX
PXL_RMS	0.1385	0.0133	0.1183	0.1600
LINE_ERR	0.0128	0.0302	-0.0478	0.0659
SAMP_ERR	0.0176	0.0350	-0.0575	0.0694

L1B Radiance PGE



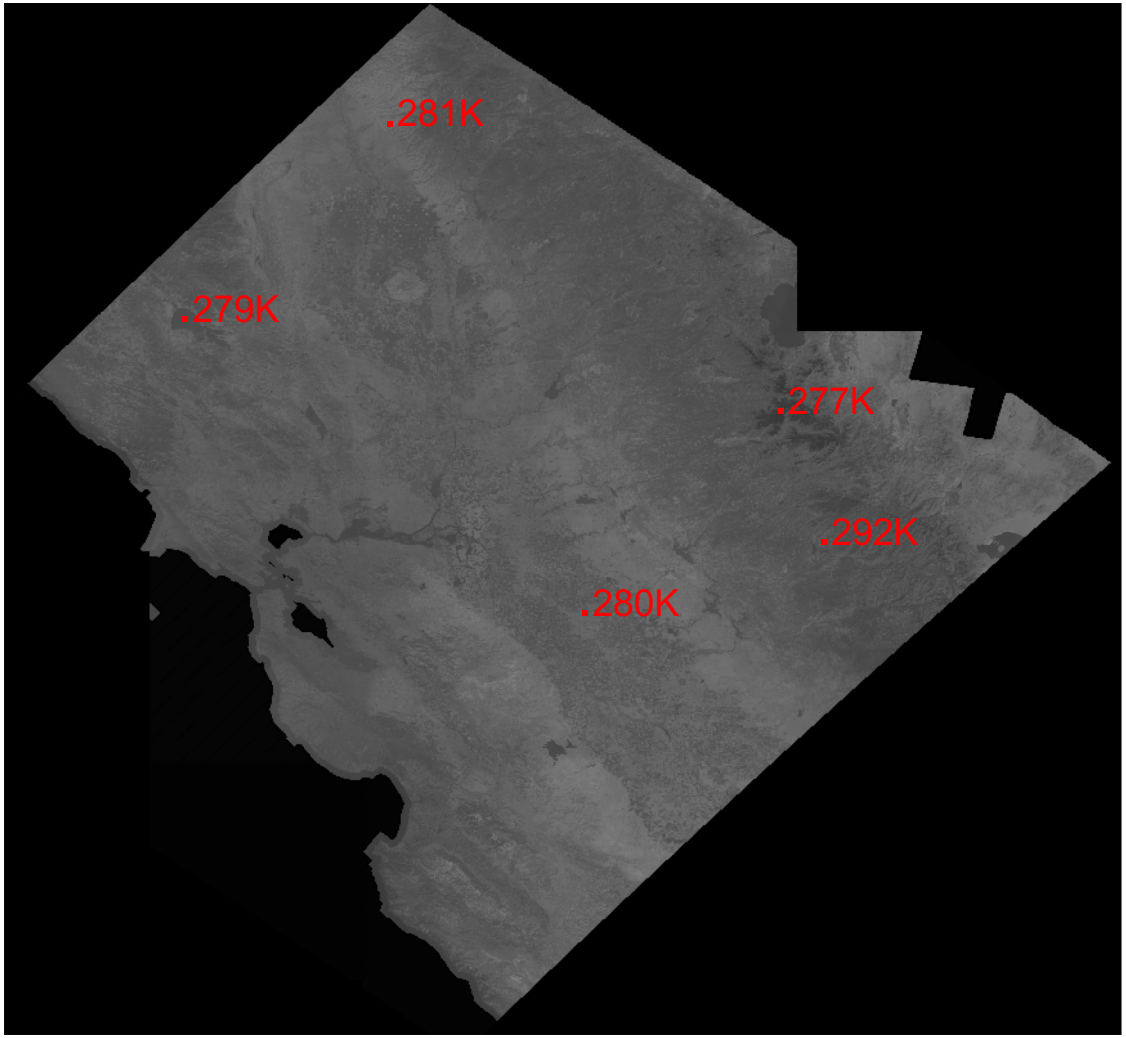
Correcting/Filling Missing Data

A Neural Network Machine Learning tool is used to predict missing data in the TIR 8.3 and 12.0u bands from existing data in the TIR 8.8, 9.1, and 10.5u bands.

The algorithm was designed and implemented by Hai Nguyen and Glynn Hulley.

Simulated Data

L1B Radiance PGE



TIR 8.3u Simulated Radiance Image

L1B_GEO
Product generated during End-to-End processing test.

1) Product is in “Orbital Frame Projection.”
2) Latitude and Longitude coordinates are provided as separate files.
3) Lat/Lons represent the center of the pixel (not upper left corner).
4) Geolocation over Oceans/Seas is interpolated from orbital path data with corrections from clear land images.

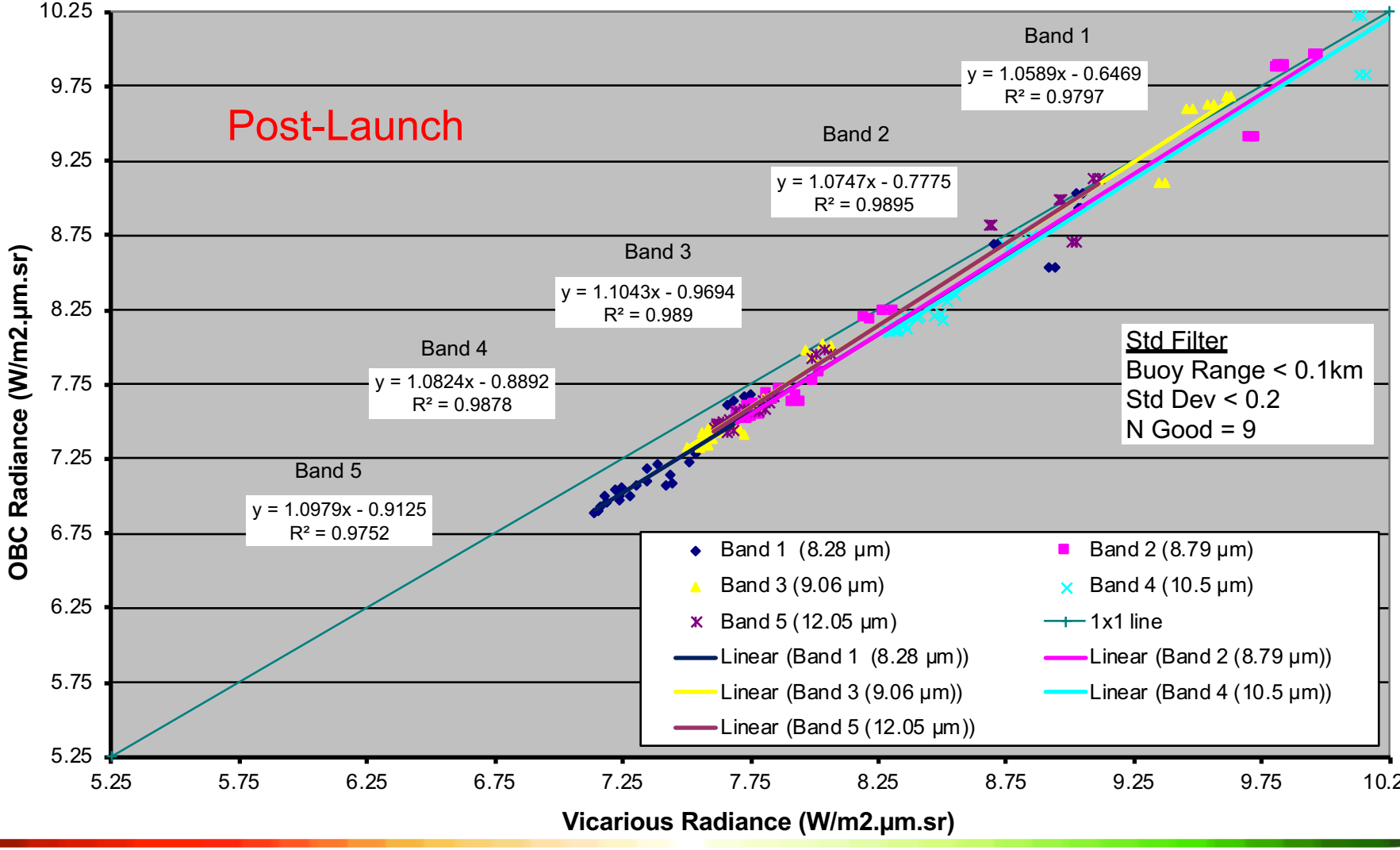
ECOSTRESS Launch 29JUN2018

Space X Falcon 9 rocket launch at 5:42am EDT

Space X

TIR Radiance Verification and Validation

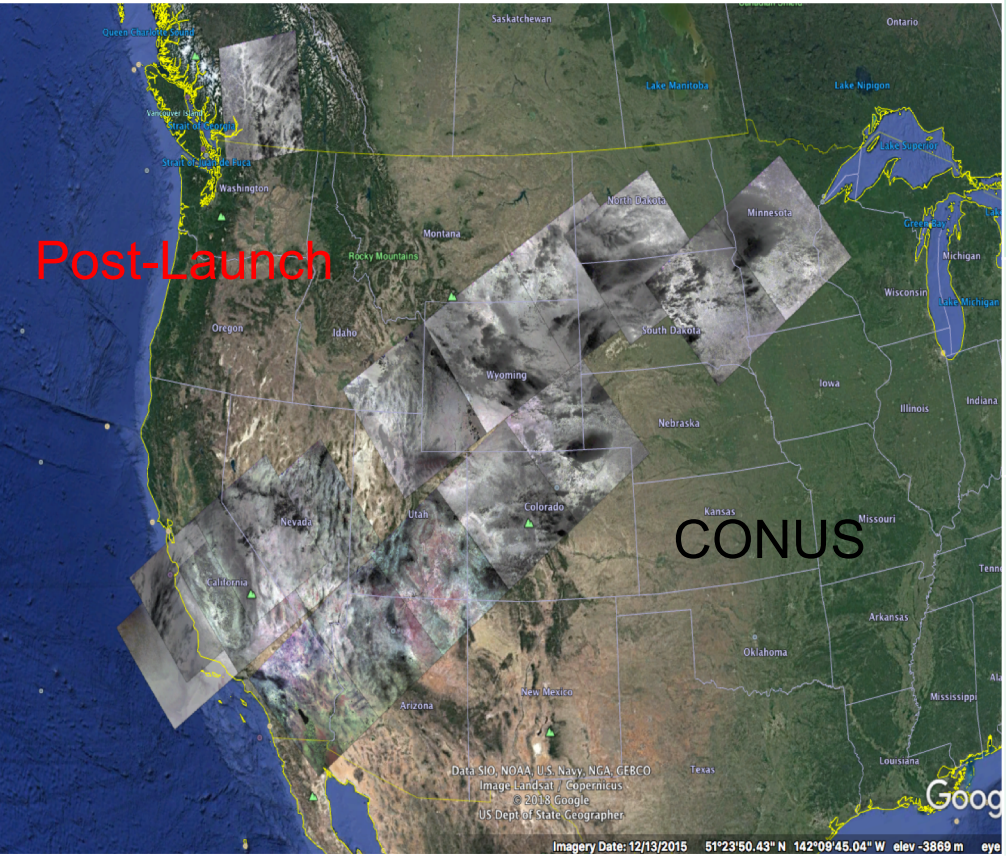
ECOSTRESS Vicarious and OBC Thermal Infrared Derived Radiances at L. Tahoe and Salton Sea, CY2018, Std Filter, v1



Slide from: K. Cawse-Nicholson and R. Radocinski

Geolocation Accuracy Verification Examples

Quality Images (Minimal Clouds & Ocean) Meet Geolocation Requirements



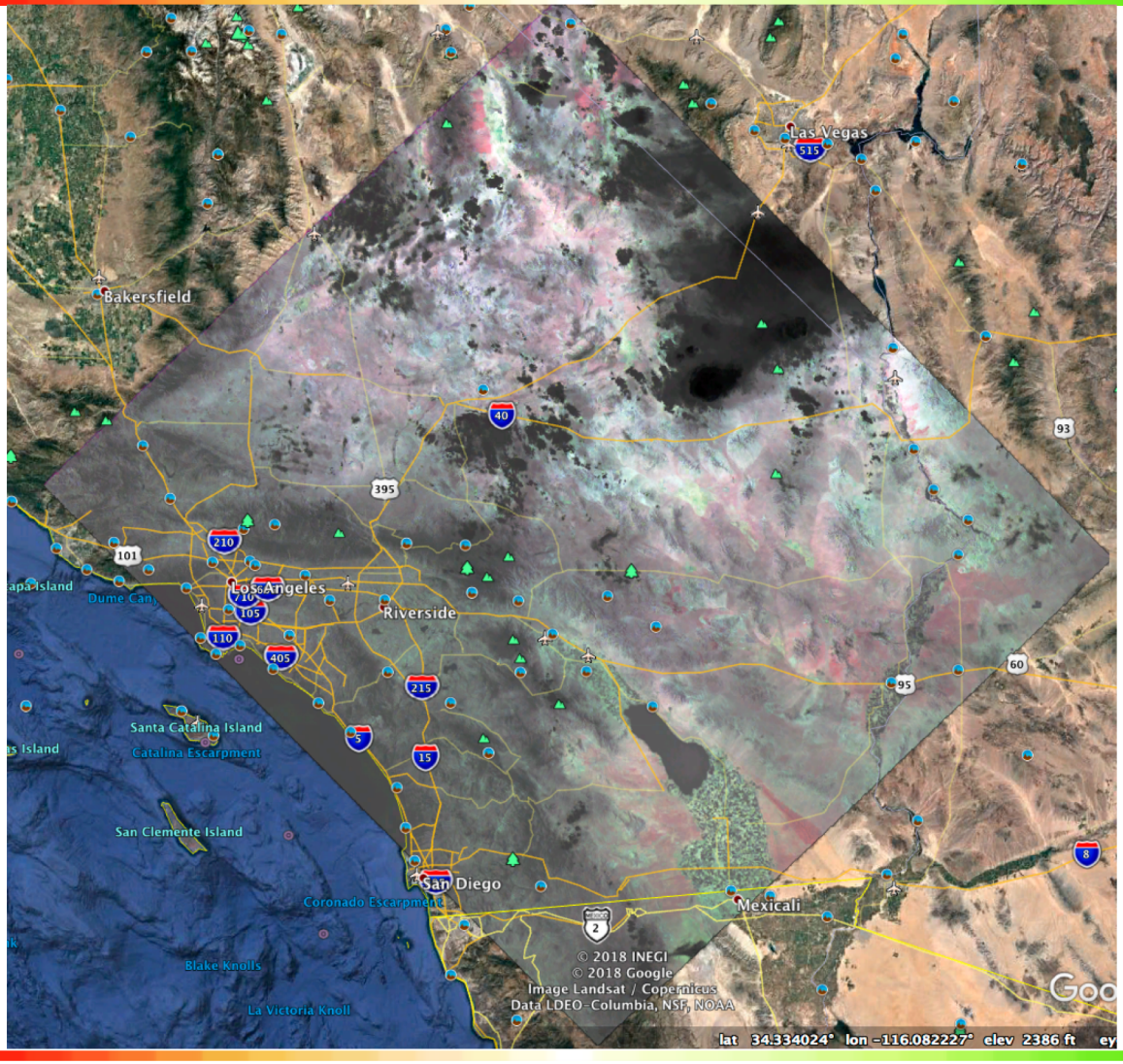
Orbit	Scene	Initial Error (m)	Estimated Final Geolocation Accuracy (m)
361 CONUS	004	23.8	50.9
	005	259.7	58.0
	007	84.3	29.8
	008	107.7	26.6
	009	163.7	23.9
468 CONUS	006	4193.1	45.5
	007	4089.2	47.9
	008	4151.8	69.6
	012	4091.4	31.6
483 CONUS	003	2395.1	43.6
	004	2364.5	48.5
	005	2346.4	33.6
	006	2349.4	49.9
	007	2344.4	29.0
	009	2353.9	21.4
	010	2344.4	17.2

Requirement: 50m (For Quality Images)

Geolocation Verification

Using Google Earth

Post-Launch

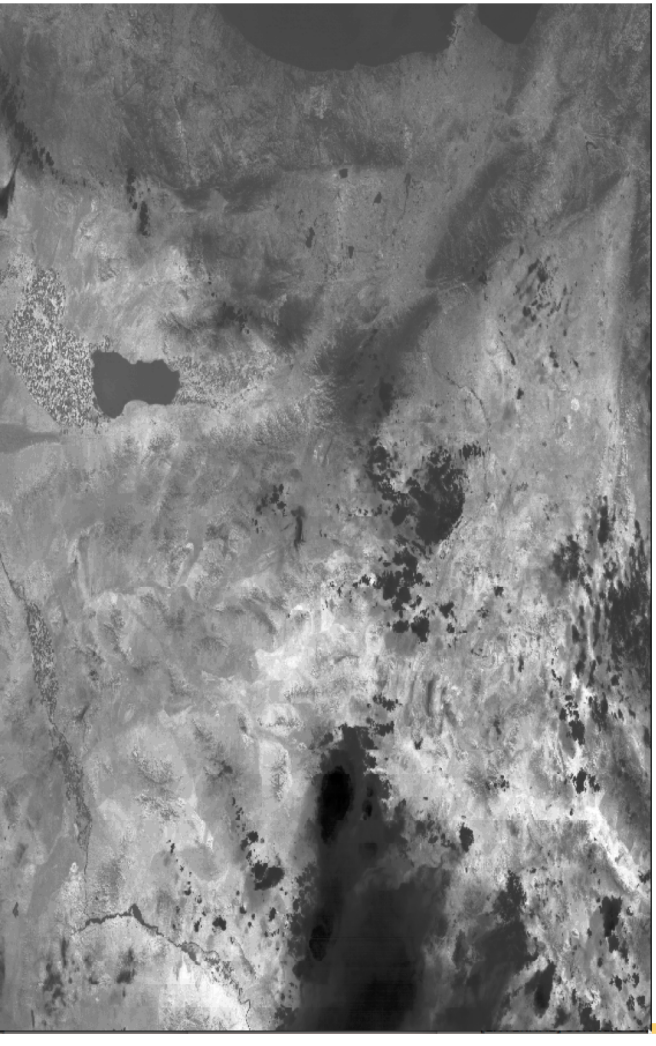


Salton Sea
00376_001
2018073

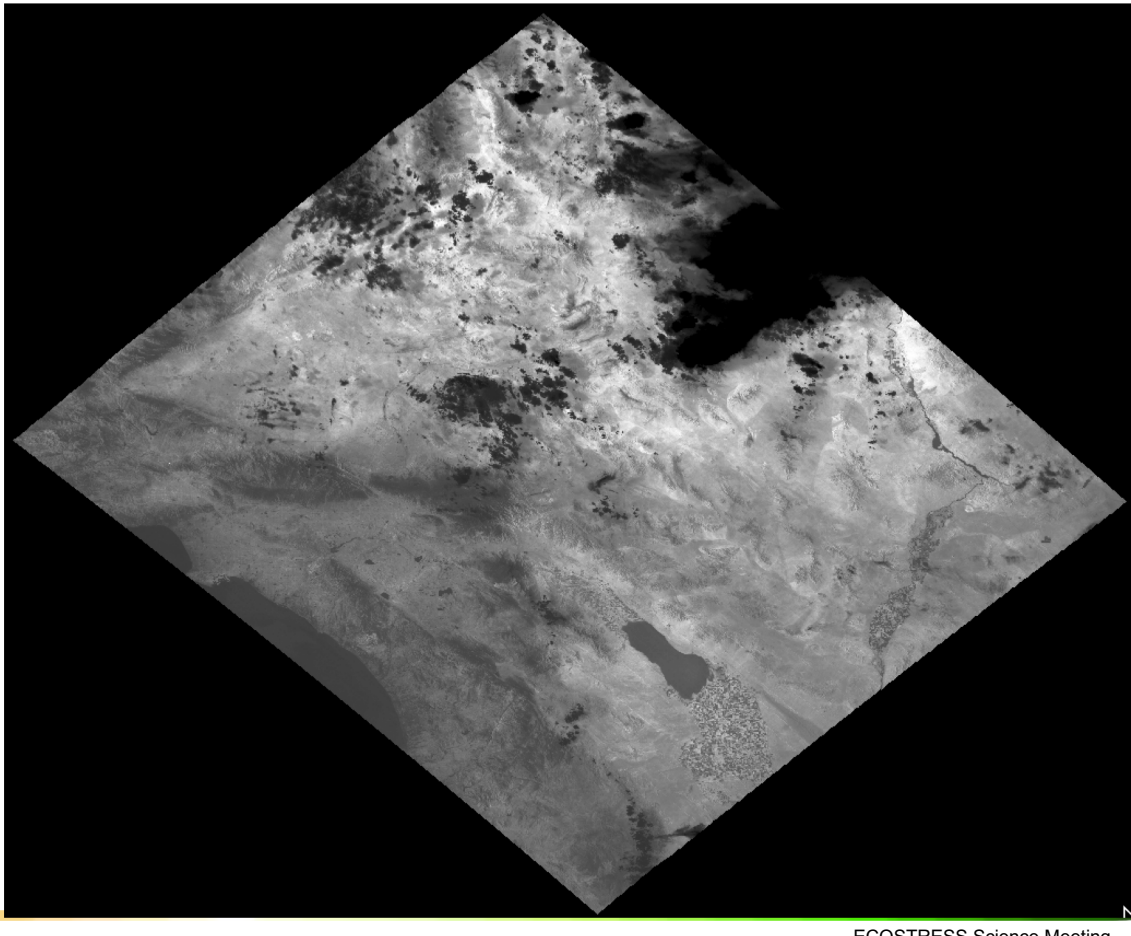
L1B_RAD and L1B_MAP_RAD Product Verification

Salton Sea 00376_001 2018073

TOA Radiance Swath



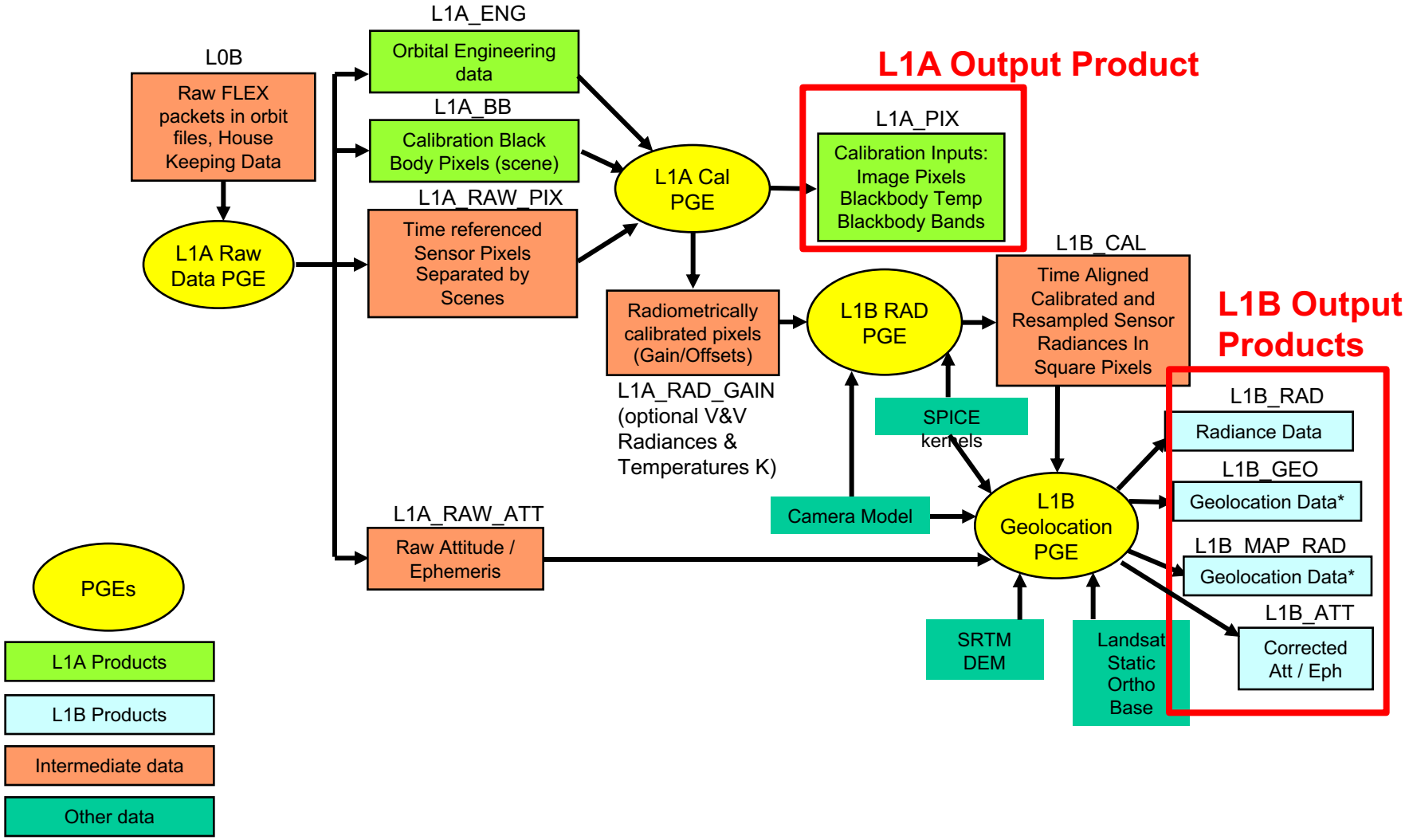
Mapped TOA Radiance*



Post-Launch

*With rotation to North/South

L1 Process Summary & Products



L1A Products

L1A_PIX: Pre-Processed Calibration Inputs

Field Name	Type	Units	Field Data	valid min	valid max	fill
Group	UncalibratedDN (Size 11264x5400 sets)					
b1_image	Int16	DN	Band 1 SWIR Raw image Pixel Data	0	32767	Table 3-7
b2_image	Int16	DN	Band 2 Raw image Pixel Data	0	32767	Table 3-7
b3_image	Int16	DN	Band 3 Raw image Pixel Data	0	32767	Table 3-7
b4_image	Int16	DN	Band 4 Raw image Pixel Data	0	32767	Table 3-7
b5_image	Int16	DN	Band 5 Raw image Pixel Data	0	32767	Table 3-7
b6_image	Int16	DN	Band 6 Raw image Pixel Data	0	32767	Table 3-7
Group	BlackbodyTemp (1 set for image frame)					
fpa_325	Float32	Kelvin	Calibrated 325 Kelvin Blackbody Focal Plane	310	330	N/A
fpa_295	Float32	Kelvin	Calibrated 295 Kelvin Blackbody Focal Plane	275	305	N/A
Group	BlackbodyBandDN (1 set for image frame)					
b1_325	Float32	DN	B1 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b1_295	Float32	DN	B1 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
b2_325	Float32	DN	B2 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b2_295	Float32	DN	B2 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
b3_325	Float32	DN	B3 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b3_295	Float32	DN	B3 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
b4_325	Float32	DN	B4 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b4_295	Float32	DN	B4 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
b5_325	Float32	DN	B5 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b5_295	Float32	DN	B5 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
b6_325	Float32	DN	B6 Focal Plane Averaged DN for 325k BB	0	32767	Table 3-7
b6_295	Float32	DN	B6 Focal Plane Averaged DN for 295k BB	0	32767	Table 3-7
Group	FPIEncoder (Size 44x5400)					
EncoderValue	Uint32	None	Mirror encoder value of each focal plane in each scan	0	1749247	0xffffffff
Group	Time (Size 11264x1, 44 scans, 256 repeated values per scan)					
line_start_time_j2000	Float64	Second	J2000 time of first pixel in line	N/A	N/A	N/A

HDF5 Format

Source:
L1 PSD D-94634
Table 3-5

L1B Products

L1B_RAD: Resampled TOA Radiance Images

Field Name	Type	Units	Field Data	valid min	valid max	Fill	
Group	Radiance (Size 5632x5400 sets)						
radiance_1	Float32	Watt/m2/sr/um	TIR 8.285 microns.	N/A	N/A	Table 3-10	
radiance_2	Float32	Watt/m2/sr/um	TIR 8.785 microns	N/A	N/A	Table 3-10	
radiance_3	Float32	Watt/m2/sr/um	TIR 9.060 microns	N/A	N/A	Table 3-10	
radiance_4	Float32	Watt/m2/sr/um	TIR 10.522 microns	N/A	N/A	Table 3-10	
radiance_5	Float32	Watt/m2/sr/um	TIR 12.001 microns	N/A	N/A	Table 3-10	
data_quality_1	Int8	None		0	4	N/A	
data_quality_2	Int8	None		0	4	N/A	
data_quality_3	Int8	None		0	4	N/A	
data_quality_4	Int8	None		0	4	N/A	
data_quality_5	Int8	None		0	4	N/A	
Group	SWIR (Size 5632x5400)						
swir_dn	Int16	DN	Uncalibrated SWIR data with Dark Current subtracted	N/A	N/A	Table 3-7	
Group	FPIEncoder (Size 44x5400)						
EncoderValue	Uint32	None	Mirror encoder value of each focal plane in each scan	0	1749247	0xffffffff	
Group	Time (Size 5632, 44 sets of 128 repeated values)						
line_start_time_j2000	Float64	Second	J2000 time of first pixel in line	N/A	N/A	N/A	
Group	L1B_RADMetadata						
RadScanLineOrder	String	None	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.	N/A	N/A	N/A	

See Next Page For Data Quality Codes

HDF5 Format

Source:
L1 PSD D-94634
Table 3-8

L1B_RAD: Data Quality Codes and 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

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

Source:
L1 PSD D-94634
Tables 3-9 and 3-10

L1B_GEO: Output Geolocation Metadata

(Provided for Each Pixel)

Field Name	Type	Units	Field Data	valid min	valid max	fill
Group	Geolocation (Size 5632x5400 sets)					
height	Float32	Meter		N/A	N/A	N/A
land_fraction	Float32	%	Percentage of pixel that is land	0	100	-9999
latitude	Float64	Degrees		-90	90	N/A
line_start_time_j2000	Float64	Second	J2000 time of first pixel in line	N/A	N/A	N/A
longitude	Float64	Degrees		-180	180	N/A
solar_azimuth	Float32	Degrees		-180	180	N/A
solar_zenith	Float32	Degrees		-90	90	NA
view_azimuth	Float32	Degrees		-180	180	N/A
view_zenith	Float32	Degrees		-90	90	N/A
Group	L1GEOMetadata			-90	90	N/A
AverageSolarZenith	Float64	Degrees	Average solar zenith angle for scene			
OrbitCorrectionPerformed	String	None	One of “True” or “False”. If “True”, we were able to use image matching with our global orthobase to correct the reported navigation. If false, we are using uncorrected navigation data.	N/A	N/A	N/A
OverAllLandFraction	Float64	%	Overall land fraction for scene	0	100	N/A

HDF5 Format

Source:
L1 PSD D-94634
Table 3-12

L1B_MAP_RAD: Map Projected TOA Radiance

HDF5 Format

Field Name	Type	Units	Field Data	valid min	valid max	fill
Group	Mapped/MapInformation			N/A	N/A	N/A
CoordinateSystem	String	None	Well Known Text (WKT) describing coordinate system			
GeoTransform	Float64	None	Affine GeoTransform	N/A	N/A	N/A
Group	Mapped					
data_quality_1	Int8	None		0	4	NA
data_quality_2	Int8	None		0	4	NA
data_quality_3	Int8	None		0	4	NA
data_quality_4	Int8	None		0	4	NA
data_quality_5	Int8	None		0	4	NA
height	Float32	Meters		N/A	N/A	N/A
latitude	Float64	Degrees		-90	90	NA
longitude	Float64	Degrees		-180	180	NA
radiance_1	Float32	Watt/m2/sr/um	TIR 8.285 microns	N/A	N/A	Table 3-10
radiance_2	Float32	Watt/m2/sr/um	TIR 8.785 microns	N/A	N/A	Table 3-10
radiance_3	Float32	Watt/m2/sr/um	TIR 9.060 microns	N/A	N/A	Table 3-10
radiance_4	Float32	Watt/m2/sr/um	TIR 10.522 microns	N/A	N/A	Table 3-10
radiance_5	Float32	Watt/m2/sr/um	TIR 12.001 microns	N/A	N/A	Table 3-10
solar_azimuth	Float32	Degrees		-180	180	N/A
solar_zenith	Float32	Degrees		-90	90	N/A
swir_dn	Int16	DN	Uncalibrated SWIR data with Dark Current subtracted	NA	NA	Table 3-7
view_azimuth	Float32	Degrees		-180	180	N/A
view_zenith	Float32	Degrees		-90	90	N/A
Group	L1GEOMetadata					
OrbitCorrectionPerformed	String	None	One of “True” or “False”. If “True”, we were able to use image matching with our global orthobase to correct the reported navigation. If false, we are using uncorrected navigation data.	N/A	N/A	N/A

Source:
L1 PSD D-94634
Table 3-13

L1B_ATT: Spacecraft Ephemeris and Attitude

(Orbital Data at One Second Intervals)

Field Name	Type	Units	Field Data	valid min	valid max	fill
Group	Ephemeris (Size unlimited, once per second for entire orbit)					
time_j2000	Float64	Seconds	Seconds from J2000 epoch	N/A	N/A	N/A
eci_position	Float64	Meters	X, Y, Z Position in ECI coordinate	N/A	N/A	N/A
eci_velocity	Float64	m/s	X, Y, Z Velocity in ECI coordinates	N/A	N/A	N/A
Group	Attitude (Size unlimited, once per second for entire orbit)					
time_j2000	Float64	Seconds	Seconds from J2000 epoch	N/A	N/A	N/A
quaternion	Float64	None	Attitude quaternion (I, j, k, theta)	N/A	N/A	N/A
Group	Uncorrected Ephemeris (Size unlimited, once per second for entire orbit)					
time_j2000	Float64	Seconds	Seconds from J2000 epoch	N/A	N/A	N/A
eci_position	Float64	Meters	X, Y, Z Position in ECI coordinate	N/A	N/A	N/A
eci_velocity	Float64	m/s	X, Y, Z Velocity in ECI coordinates	N/A	N/A	N/A
Group	Uncorrected Attitude (Size unlimited, once per second for entire orbit)					
time_j2000	Float64	Seconds	Seconds from J2000 epoch	N/A	N/A	N/A
quaternion	Float64	None	Attitude quaternion (I, j, k, theta)	N/A	N/A	N/A
Group	L1GEOMetadata					
OrbitCorrectionPerformed	String	None	One of “True” or “False”. If “True”, we were able to use image matching with our global orthobase to correct the reported navigation. If false, we are using uncorrected navigation data.	N/A	N/A	N/A

HDF5 Format

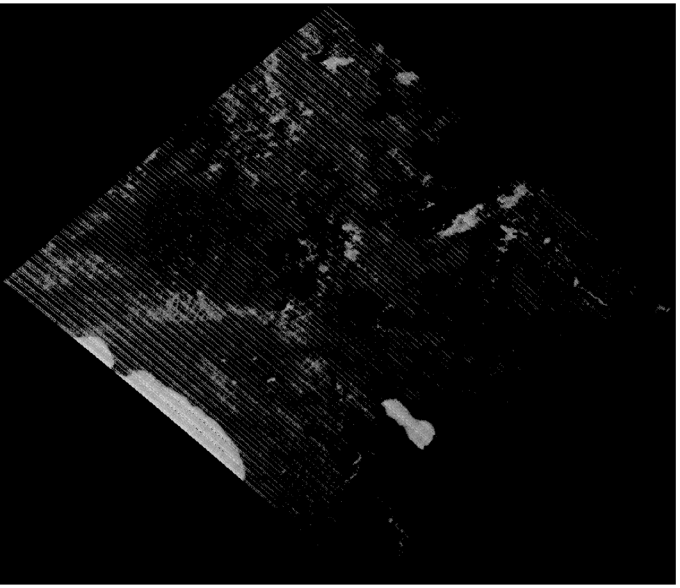
Source:
L1 PSD D-94634
Table 3-13

Backup

Salton Sea 00376_001 20180731 SWIR

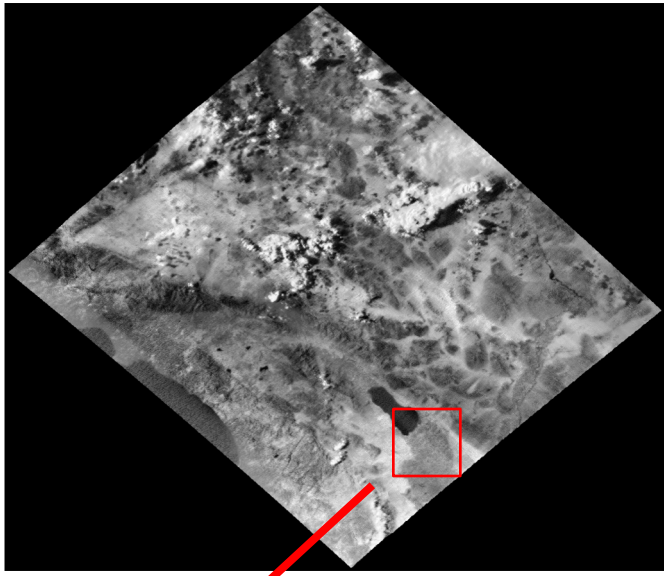
31JUL2018 6:45pm Local Time

Post-Launch

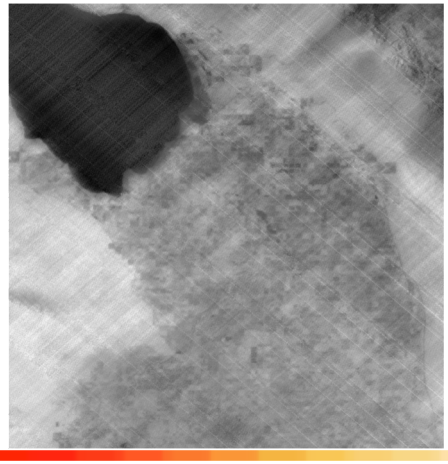


Initial Product

“Visual” Product



Zoom Detail



SWIR Visual

TIR Composite