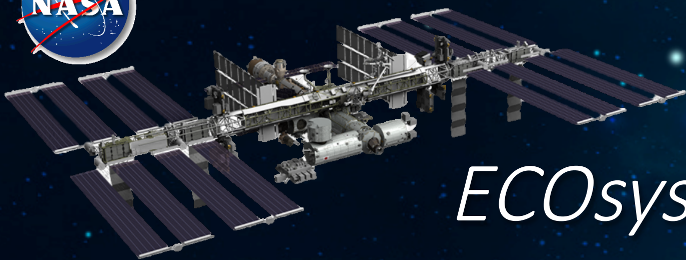
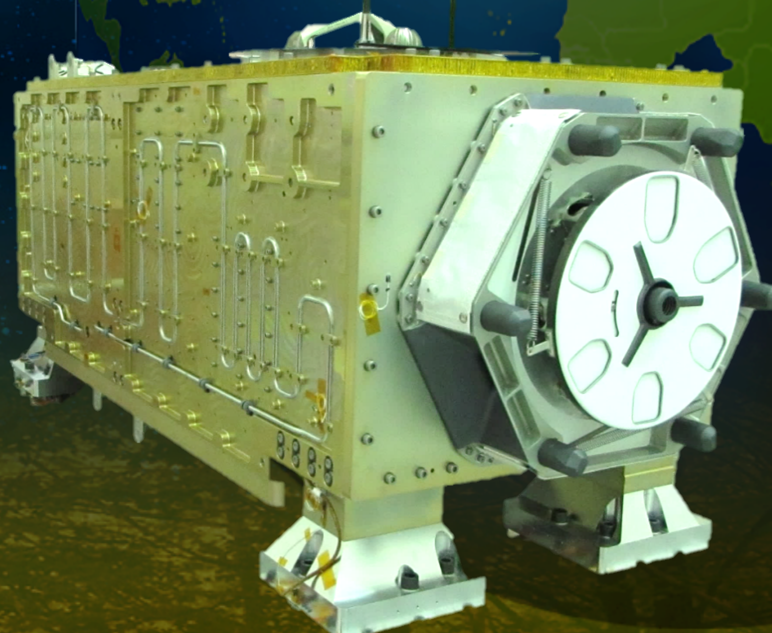


ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

ECOSTRESS

Simon J. Hook and the HyspIRI and ECOSTRESS Teams

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA



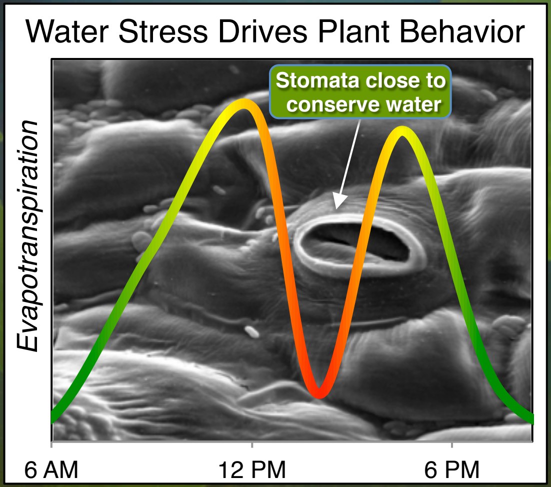
ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

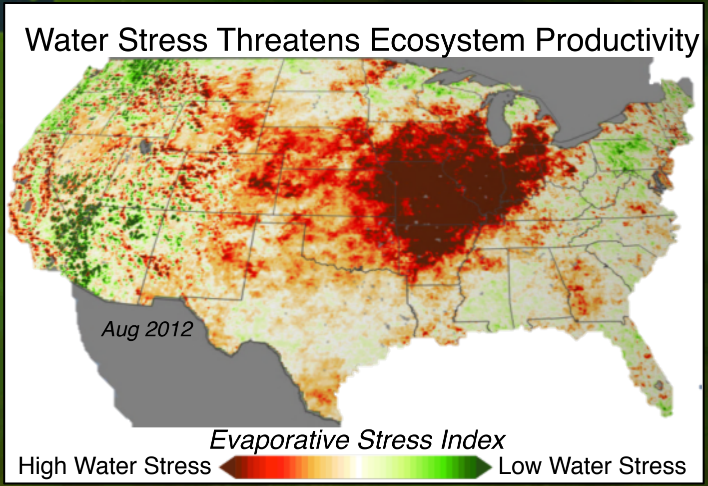
Dr. Simon J. Hook, JPL, Principal Investigator

Science Objectives

- Identify **critical thresholds of water use and water stress** in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant **water uptake decline** and/or cessation over the **diurnal cycle**
- Measure **agricultural water consumptive use** over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy



When stomata close, CO_2 uptake and evapotranspiration are halted and plants risk starvation, overheating and death.



Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

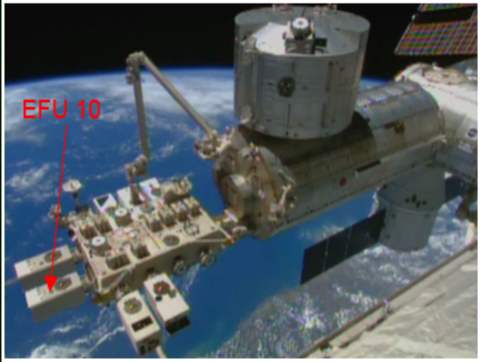
*ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration from the International Space Station (ISS).*

Project Overview

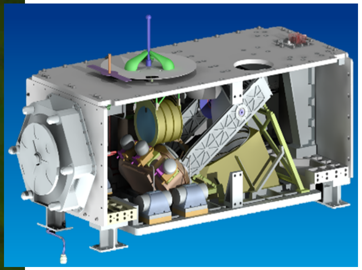
ECOSTRESS is an Earth Venture Instrument-2 on the ISS

Overview:

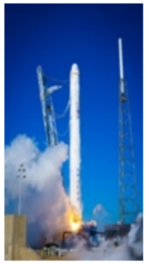
- Cost-Capped, $29.942M Cat 3/Risk class D per NPR 7120.5E/ NPR 8705.4
  - Type II project with tailoring of the JPL flight practices, single string with limited redundancy using COTS hardware
- 8–12.5 μm radiometer with a 400km swath, 69 x 38 m resolution
- Measure brightness temperatures of Earth at selected locations
- June 2018 planned launch date
- Launch on SpX-15 and deployed on the ISS on JEM-EFU 10
- Baseline operations: 1 year after 30 days on-orbit checkout



ISS JEM-EF

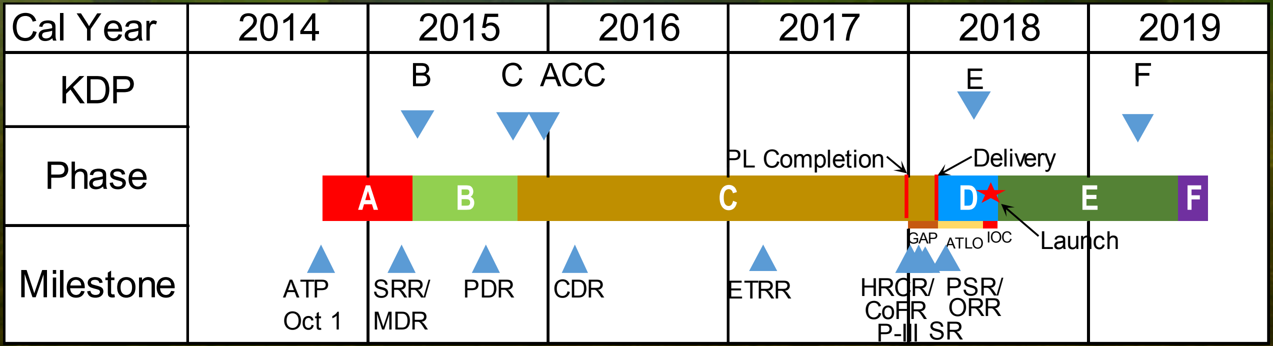


ECOSTRESS

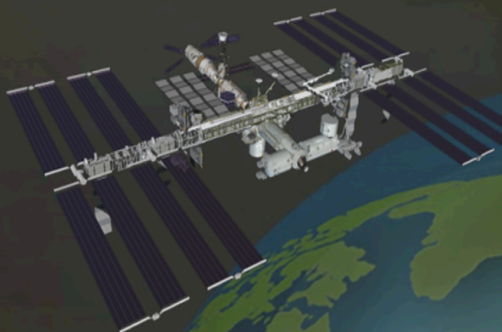


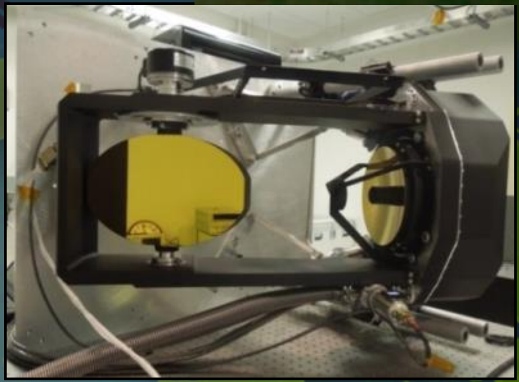
Falcon-9

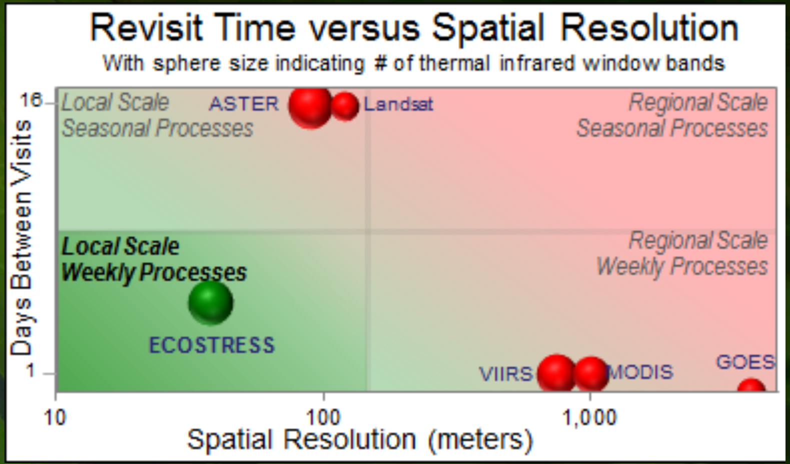
Timeline:



ECOSTRESS







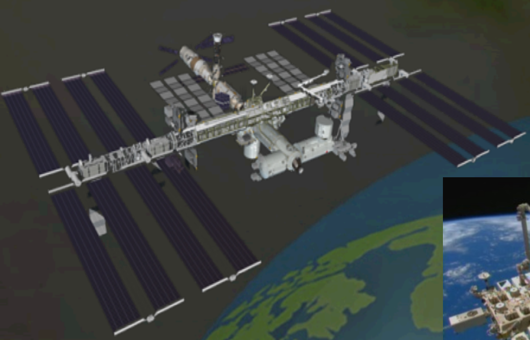
Mission

- Class D $30M cost cap
- 31-months from project start to delivery
- JPL implementation and management
- 69-month project duration (Phase A-F)
- On ISS-JEMS Module
- 12-month Science Operations (Phase E)

The inclined, precessing ISS orbit enables ECOSTRESS to sample the diurnal cycle in critical regions across the globe at spatiotemporal scales missed by current instruments in Sun-synchronous polar and high-altitude geostationary orbits.

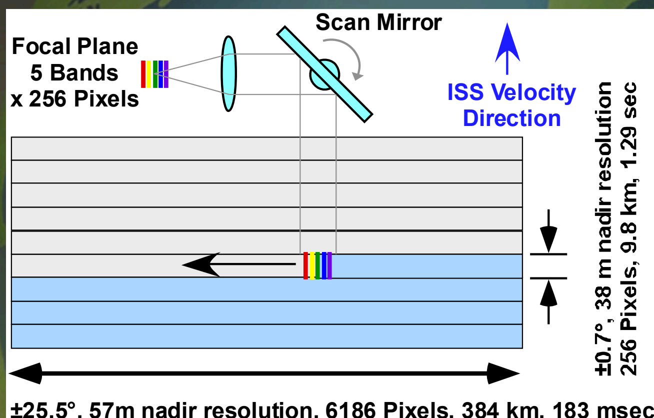
Instrument

- Leverages functionally-tested PHyTIR space-ready hardware developed under the NASA Instrument Incubator Program:
  - — Spectral resolution: 5 bands in the thermal infrared window (8-12.5 μm) part of the electromagnetic spectrum
  - — Noise equivalent delta temperature: ≤ 0.3 K
  - — Spatial resolution: 38 m x 69 m
  - — Swath width: 400 km @ 400 km altitude (51°)
- *Well understood measurement and algorithms based on prior missions, such as ASTER, MODIS, and Landsat*



ECOSTRESS

Push-whisk System



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

Science Team

Principal Investigator

Simon Hook, JPL

Co-Investigators

Rick Allen, Univ. of Idaho

Martha Anderson, USDA

Joshua Fisher, JPL

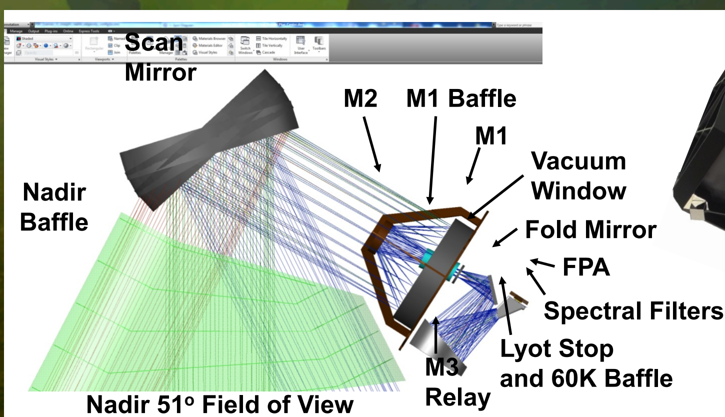
Andrew French, USDA

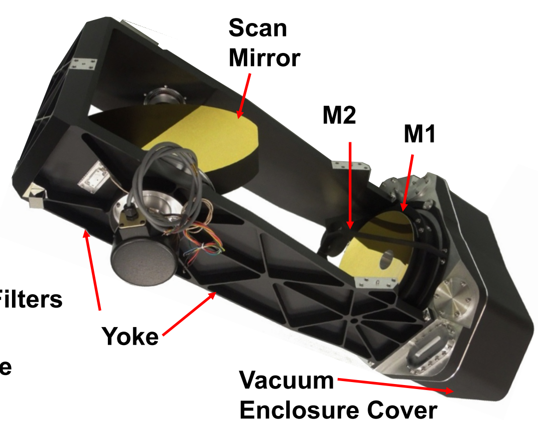
Glynn Hulley, JPL

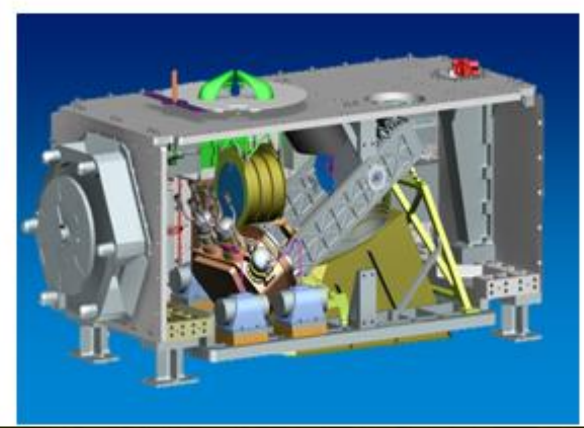
Eric Wood, Princeton Univ.

Collaborators

Christopher Hain, Univ. Maryland

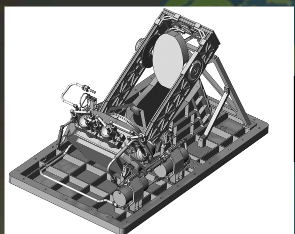




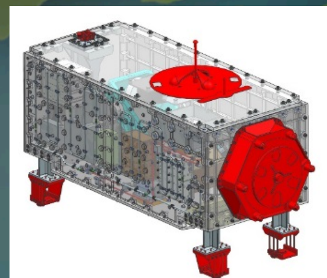


Mission Concept

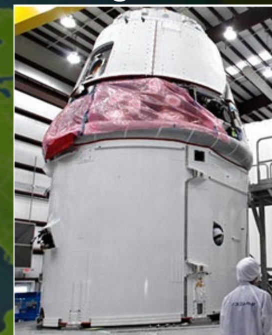
Radiometer Instrument



ECOSTRESS Payload

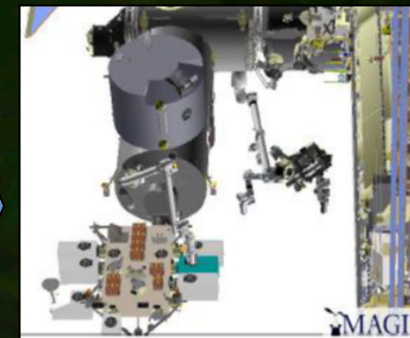


Dragon-Trunk

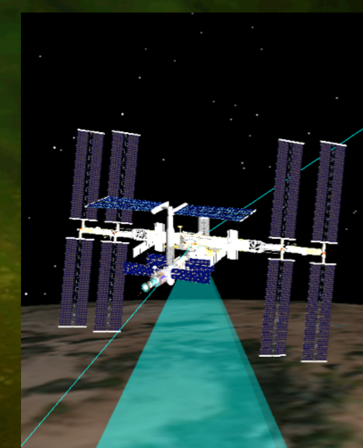


Falcon-9 LV

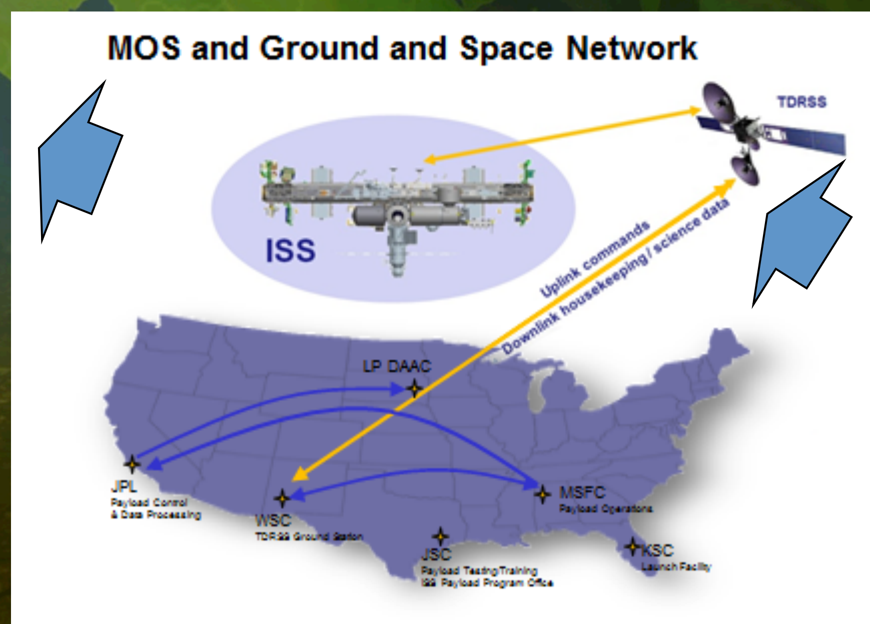
Installation on JEM-EF



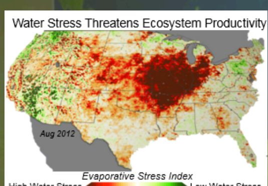
Data Collection

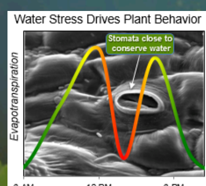


MOS and Ground and Space Network



Science Data Processing and Archive





Current Events

- 01/31/18 Phase III Safety Review
- 01/24-31/18 C&DH Test at JSC SDIL
- 10/17-19/17 POIWG #42 meeting
- ~~10/06/17 HRS Redesign Peer Review~~
- ~~10/03/18 Contamination Cover Design Review (SpaceX)~~
- ~~08/17/17 LatchX 2.0 CDR part~~
- ~~07/20/17 HRS failure during RV testing~~
- ~~07/18/17 Start of Random Vibration testing~~
- ~~06/29/17 Start of EMI-EMC testing~~
- ~~05/15-17 Science team meeting~~
- ~~04/25-26 POIWG~~
- ~~04/26/17 TRR~~
- ~~03/27/17 pFSE 2.0 CDR~~
- ~~01/30-31 ECOSTRESS Ops TIM at Marshall~~
- ~~11/29-30 JAXA TIM at Caltech~~
- ~~09/27/16 RT validation test~~
- ~~07/26-28 POIWG~~
- ~~04/14/16 Post-CDR Briefing to DPMC~~
- ~~03/29/16 Post-CDR DMC~~
- ~~03/08-09 Project CDR~~
- ~~02/11/16 SpaceX Interface Telecom~~
- ~~02/10/16 ISS Interface CDR~~
- ~~02/09/16 Phase II Safety Review~~
- ~~01/27/16 POIWG~~
- ~~01/26/16 Payload I&T and ATLO Peer Review~~
- ~~01/25/16 V&V Peer Review~~
- ~~01/20/16 Firmware Peer Review~~
- ~~01/12/16 Fracture Control Board Review 4~~
- ~~01/07/16 Radiometer Mechanical Peer Review~~
- ~~01/04/16 Phase II Safety Data Package due~~
- ~~12/17/15 Thermal Peer Review~~
- ~~12/16/15 Electronics Peer Review~~
- ~~12/15/15 Telecom Peer Review~~
- ~~12/14/15 Optics, Detector & Calibration Peer Review~~
- ~~12/10/15 Accommodation Confirmation Briefing to DPMC~~
- ~~12/07/15 Fracture Control Board Review 3~~
- ~~12/07/15 FSW Peer Review~~
- ~~12/04/15 MOS, GDS, and SDS Peer Review~~
- ~~12/02/15 Radiometer I&T Peer Review~~
- ~~12/02/15 Science Peer Review~~
- ~~11/18/15 Payload Enclosure Peer Review~~
- ~~11/16/15 Fracture Control Board review 2~~
- ~~11/05/15 Science Team Meeting #2~~
- ~~10/29/15 Scan Mechanism Peer Review~~
- ~~10/23/15 KDP-C~~
- ~~10/20/15 Fracture Control Board review 1~~
- ~~10/05/15 DMC~~
- ~~07/28/15 PDR~~
- ~~07/23/15 JAXA Face to Face meeting~~
- ~~07/14/15 Phase I Safety Review~~
- ~~07/01/15 Science Peer Review~~
- ~~06/30/15 Telecom SS Peer Review~~
- ~~06/24/15 JAXA Technical Exchange Meeting~~
- ~~06/23/15 ISS Interface PDR~~
- ~~06/19/15 Thermal Peer Review~~
- ~~06/18/15 Optics and Detector Peer Review~~
- ~~06/16/15 Scan mechanism Peer Review~~
- ~~06/15/15 Radiometer structure Peer review~~
- ~~06/11/15 Enclosure tabletop review~~
- ~~06/10/15 Electronics Peer Review~~
- ~~06/10/15 MOS/GDS and SDS Peer Review~~
- ~~06/05/15 FSW Peer Review~~
- ~~05/27/15 II&T and ATLO Peer Review~~
- ~~05/26/15 Firmware Peer Review~~
- ~~05/21/15 Motor Control Peer Review~~
- ~~05/21/15 WAP Downselect~~
- ~~05/20/15 Wi-Fi Tabletop Review~~
- ~~05/06/15 Heat Exchanger Design Review~~
- ~~04/30/15 Cold Panel Peer Review~~
- ~~04/16/15 Cryocooler thermal analysis Tabletop~~
- ~~04/16/15 Signal Chain/Flex Peer Review~~
- ~~04/15/15 KDP-B~~
- ~~03/25/15 Wi-Fi WG at JSC~~
- ~~03/24/15 Safety TIM/phase 0 at JSC~~
- ~~03/17/15 JAXA Briefing~~
- ~~03/05/15 Inheritance Review~~
- ~~02/10/15 SRR/MDR~~
- ~~01/12/15 Baseline Walkthrough~~
- ~~12/14/14 ECOSTRESS Science Team Meeting~~
- ~~11/06/14 ISS Kickoff Meeting~~
- ~~11/04/14 ESSP/SMD Meeting~~
- ~~10/01/14 Authority To Proceed (ATP)~~

From ECOSTRESS October 2017 Monthly Status Report

Project Status Summary

Technical			Schedule			Programmatic			Resources		
JUL	AUG	SEP	JUL	AUG	SEP	JUL	AUG	SEP	JUN	JUL	AUG
R	R	R	Y	Y	Y	G	G	G	G	G	G

Detailed Description: **(for items identified as yellow or red)**

Technical: Experienced at least two failures during Y-axis random vibration full level test on July 20th, 2017. The failures were found in Heat Rejection System (HRS) bimetallic tubing fittings and a missing data channel in the FPA.

SpX has provided new coupled loads analyses (CLA) because of a manifest change on SpX-15 (ACES payload schedule slip). Need to evaluate impact.

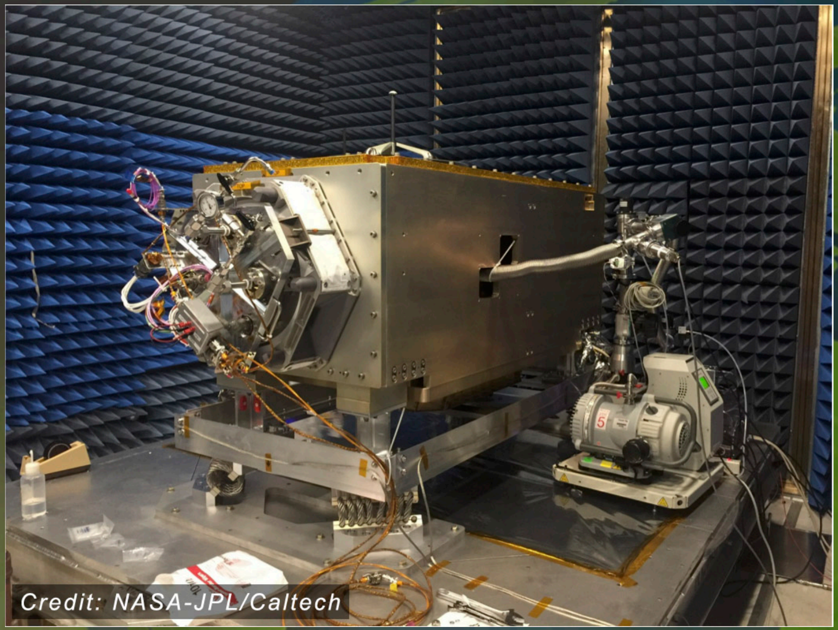
Schedule: The repair of the failures during Y-axis random vibration full level test will shorten or eliminate the Storage period in Phase C

What Happened !!!

G	No Current Problem All commitments can be met	
Y	Significant problem Identified solution	
R	Major Problem No identified solution	

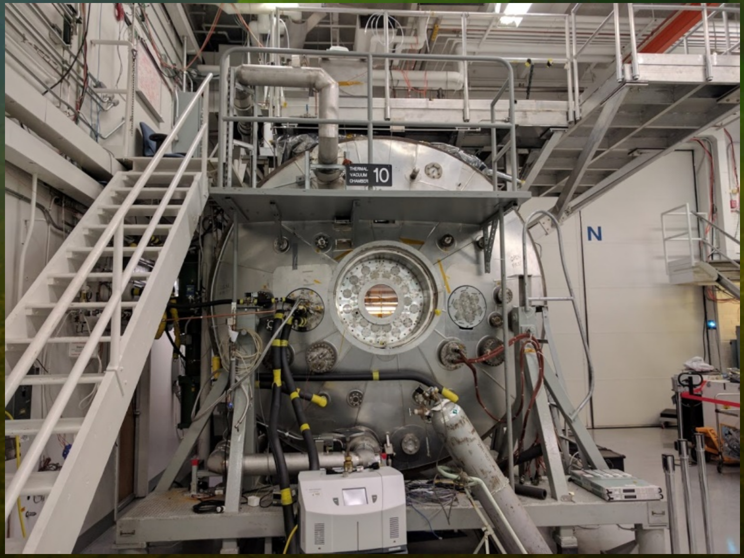
Final Tests

EMC/EMI



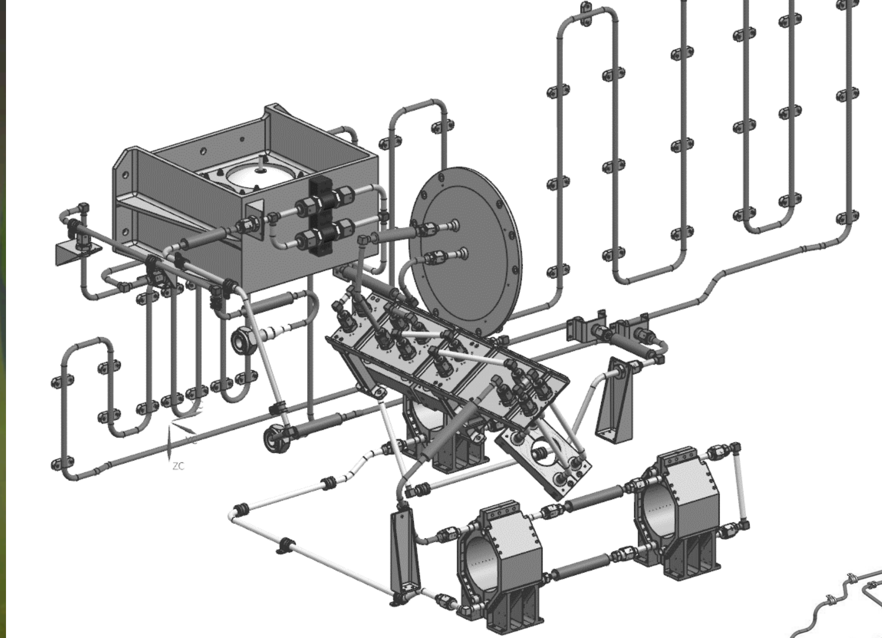
Vibration

Thermal Vacuum



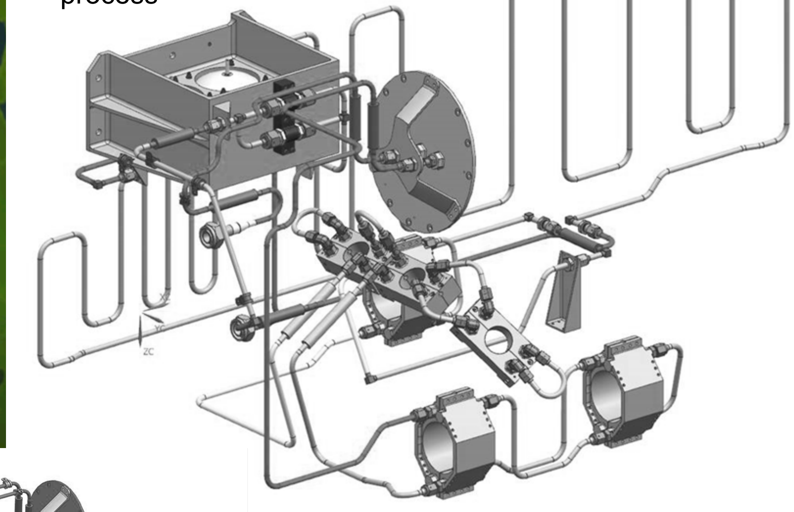
Heat Rejection System (HRS)

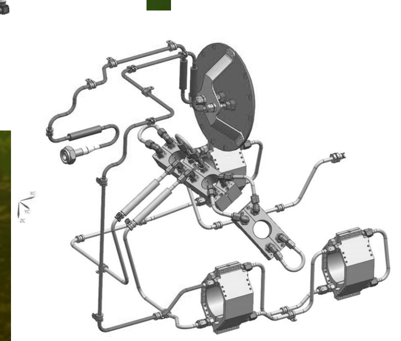
WAS



RE-DESIGN

- All static load cases run with results showing margin
- ATA random vibration analysis in process

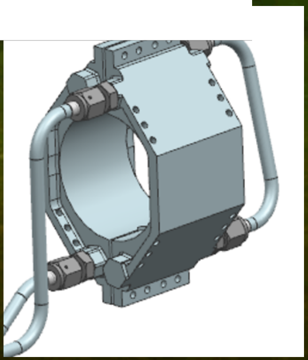




P-clamps supports

Bimetallic Fitting

Threaded port on all heat exchangers

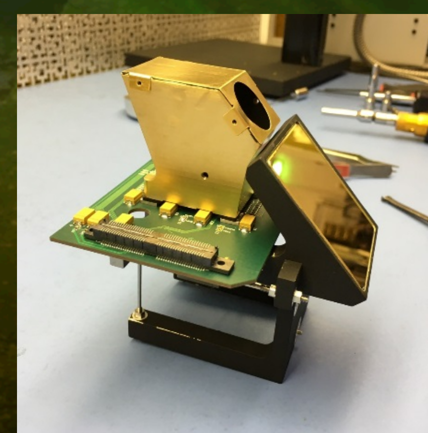


Stainless Steel fitting with O-ring

Missing Data Channel Investigation

- The entire signal chain has been tested from the FPA to the FPIE
  - No anomalies found
- Most likely issue is a wire-bond between the ROIC and PWA
  - A wire-bond may have been damaged in handling that was not noticed during repair
  - A repaired wire-bond may have not been adequately repaired
  - There is no way to know for certain if a wire-bond failed unless detector is removed and disassembled
- L1 requirement is met with just 3 bands
- Minimum impact to geolocation accuracy
- If no issues are observed in remaining environmental tests (Random vibe and TVAC), risk is low that further damage to the FPA would occur on launch or orbit

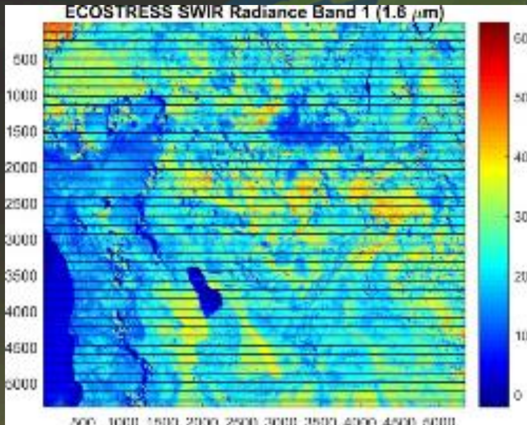
Wire-bond between ROIC and PWA



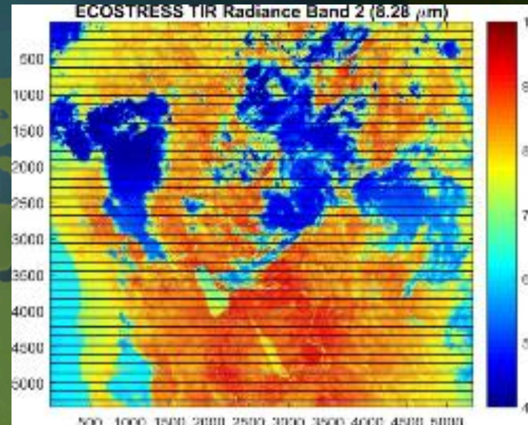
Focal Plane Assembly

Simulated Dataset with Missing Scans

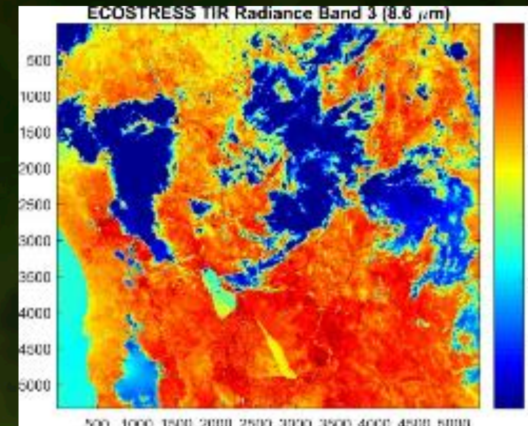
Band 1 – 1.6 µm (Geolocation)



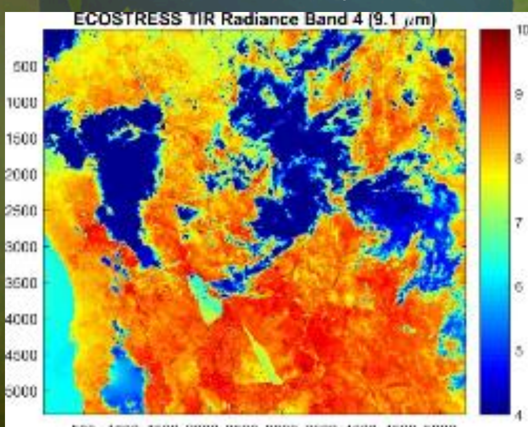
Band 2 – 8.28 µm



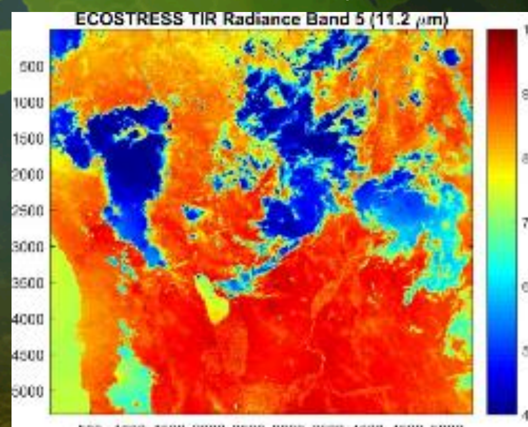
Band 3 – 8.68 µm



Band 4 –9.05 µm



Band 5 – 10.52 µm



Band 6 – 12.05 µm

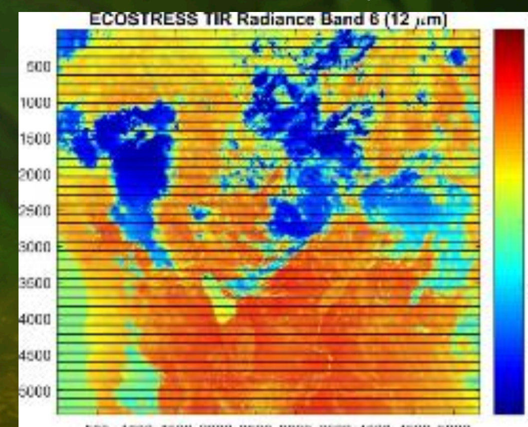


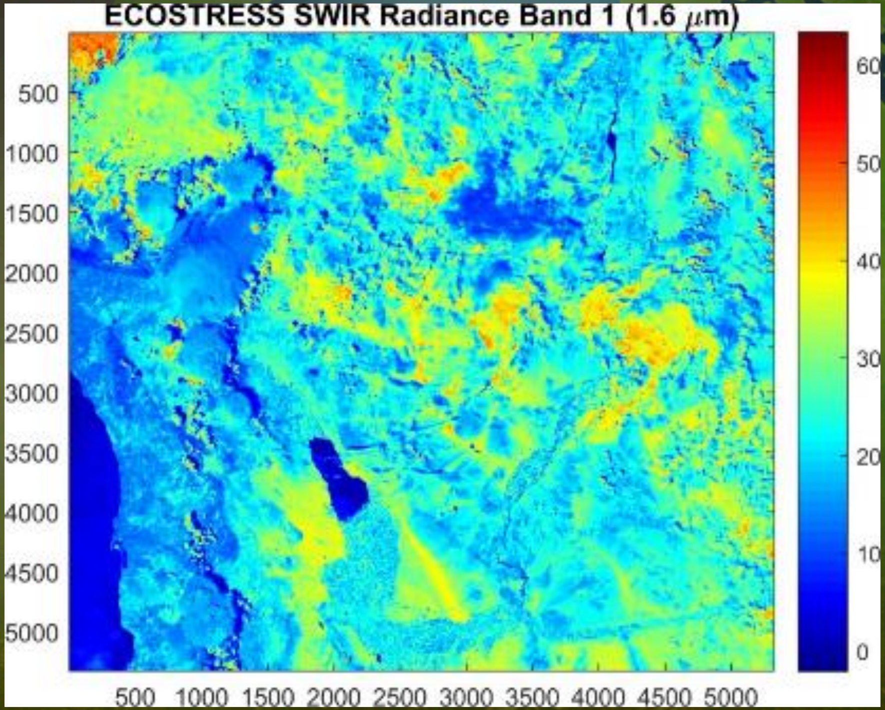
Image Row #

Image Column #

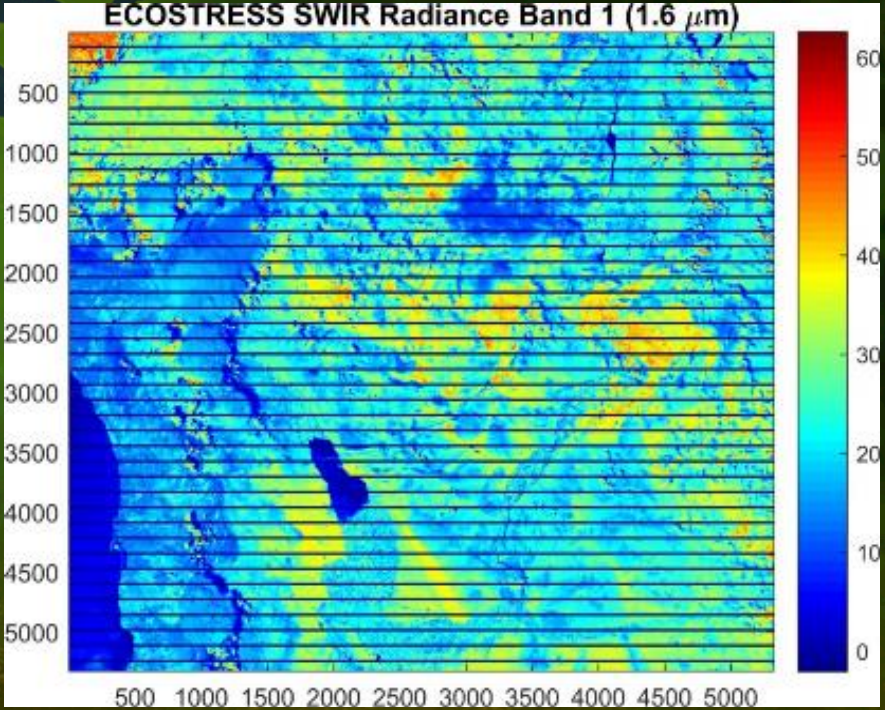
A 400km x 400km (5400 x 5632 Pixels) image built up after scanning would have approximately 44 equally spaced stripes. Each stripe would be approximately 400 km wide x 600m long. Spacing between stripes would be 9km.

Simulated Dataset with Missing Scans

SWIR Band 1 (1.6 μm)



Pre Random Vibration

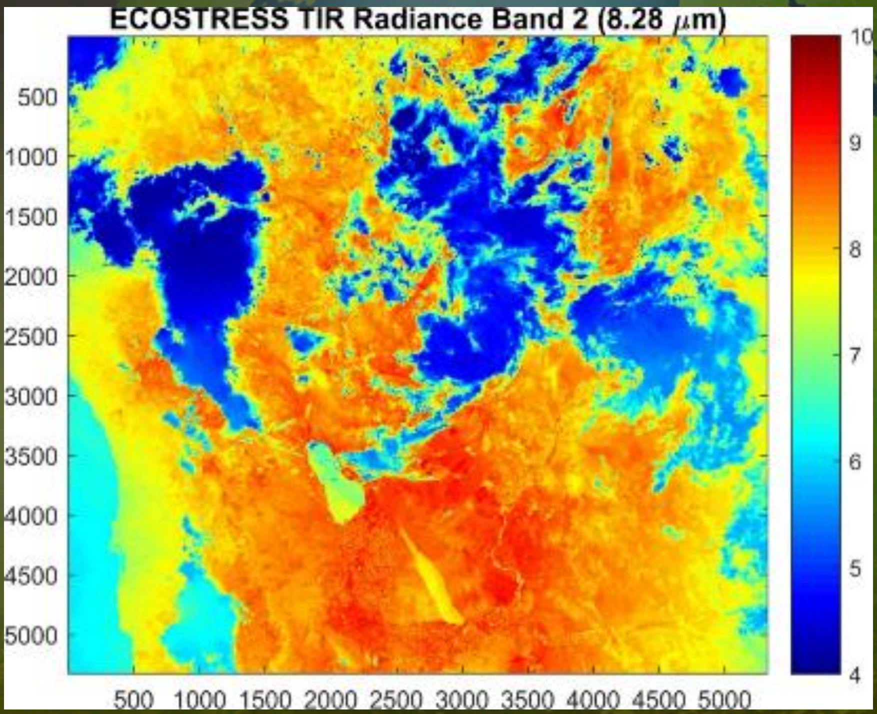


Post Random Vibration

Simulated Dataset with Missing Scans

TIR Band 2 (8.28 µm)

Standard Level 1 Product



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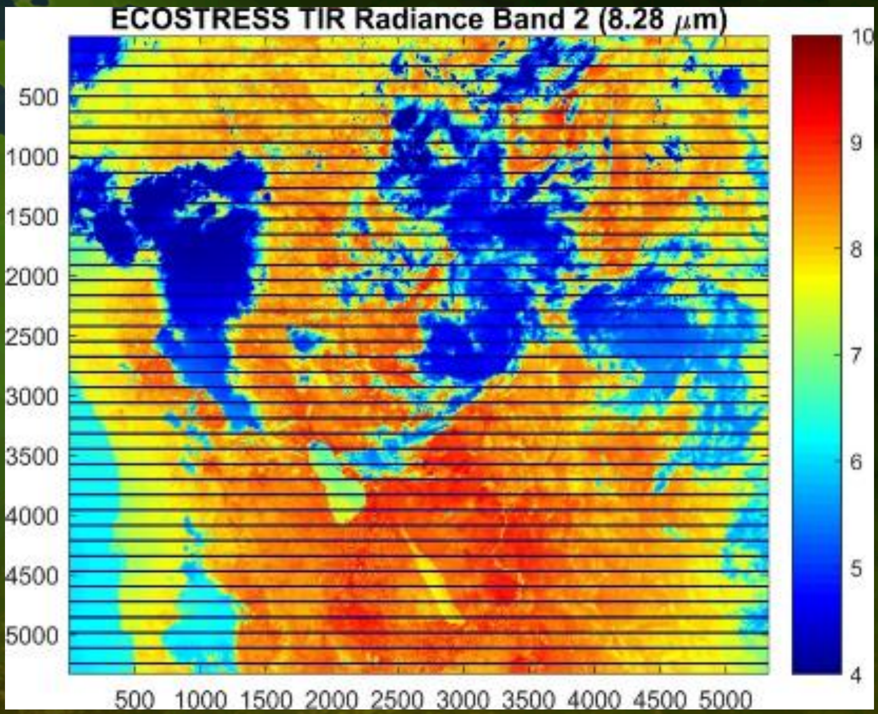


Image Column #

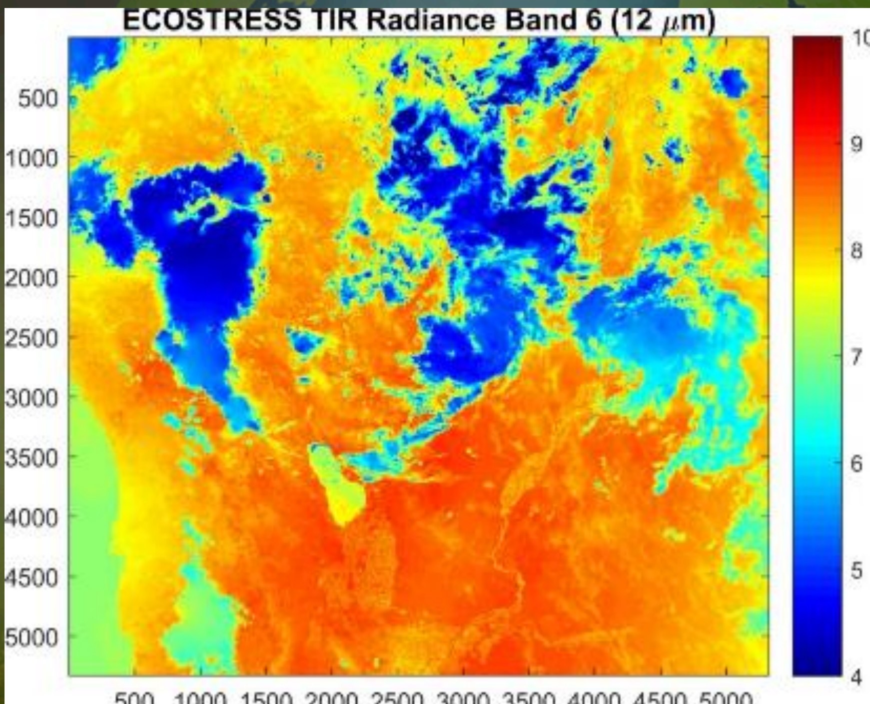
Pre Random Vibration

Post Random Vibration

Simulated Dataset with Missing Scans

TIR Band 6 (12.05 µm)

Standard Level 1 Product



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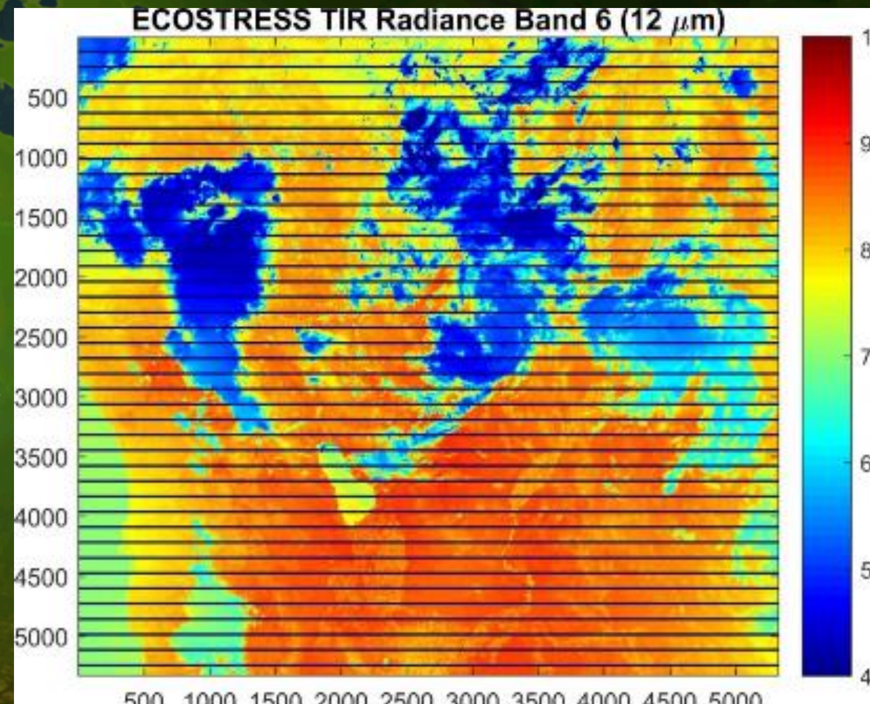


Image Column #

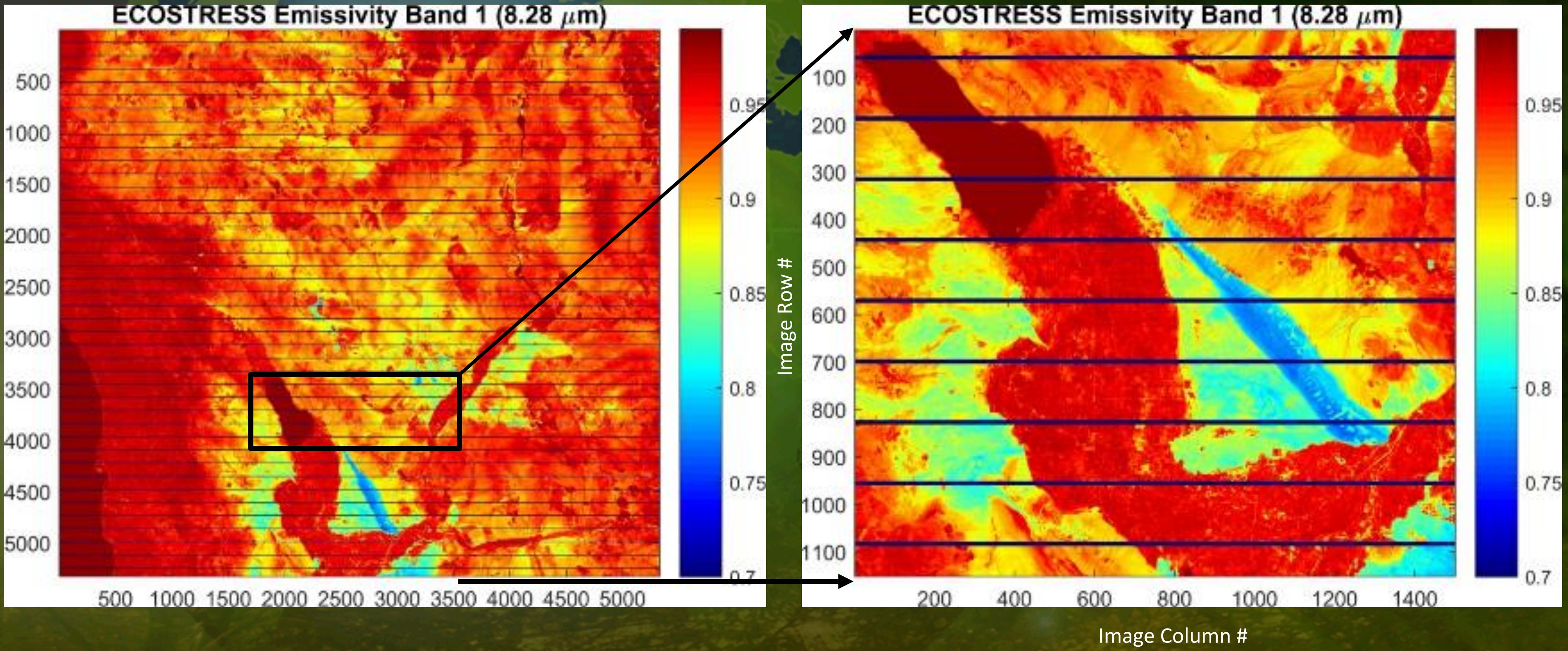
Pre Random Vibration

Post Random Vibration

Simulated Dataset with Missing Scans

TIR Band 1 Emissivity (8.28 µm)

Standard Level 2 Product



The Level 2 Standard Emissivity product for the 8.28 and 12.05 µm bands will be affected

Science Impact

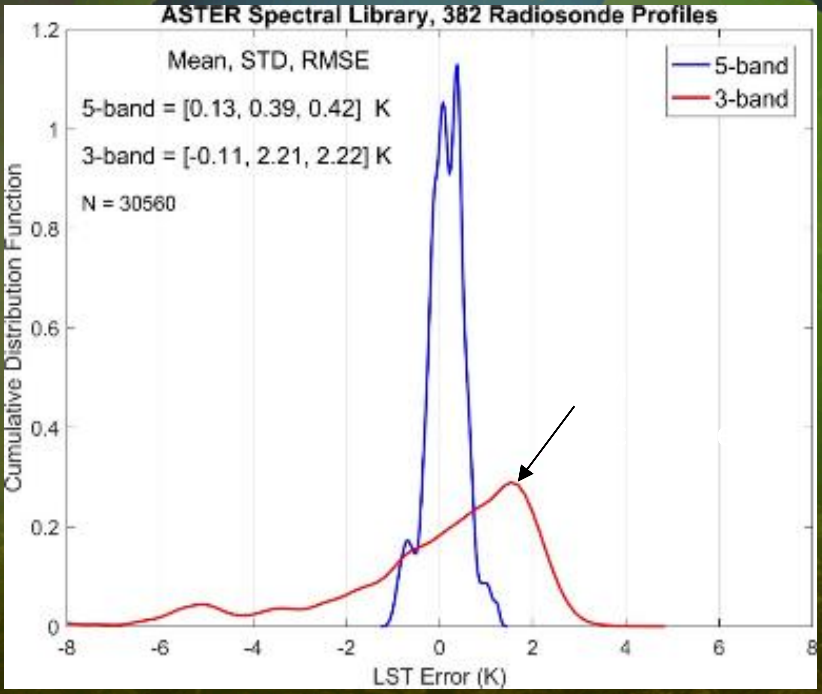
- The missing scanlines will impact the followings areas:

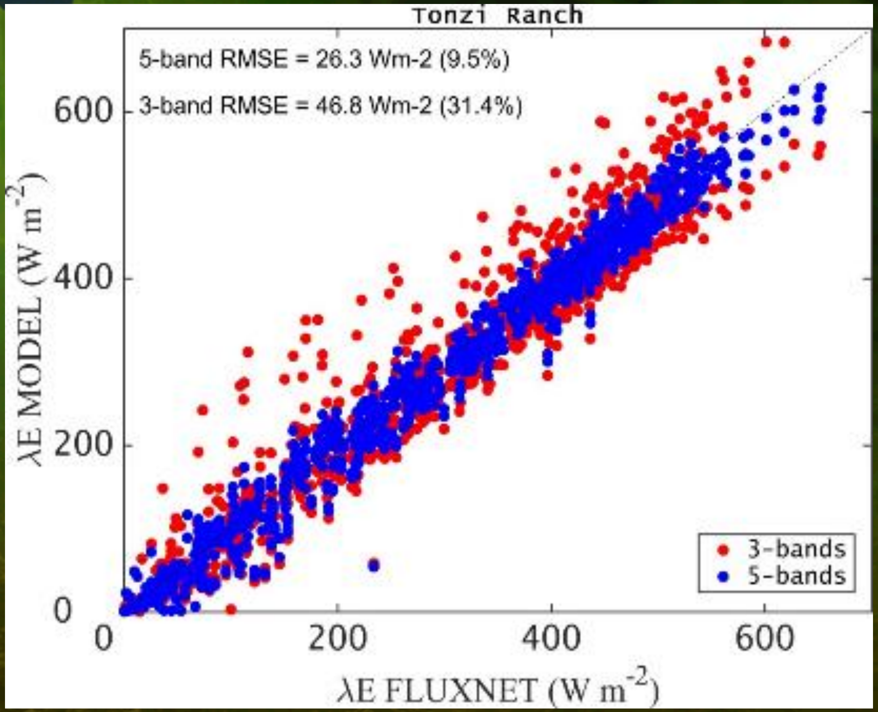
- The accuracy of the surface temperature retrieval over the bad data stripes where there are only 3 fully functional bands would be reduced. This would then impact the retrieval of Evapotranspiration (ET) over the bad data stripes. ET is critical product for this mission, which provides the foundation for the higher level products.

Temperature and ET Retrieval

Total uncertainty in Land Surface Temperature (LST) increases from 0.4 to 2.2 K over missing scan lines

Total uncertainty in ET increases from 10% to 31% over missing scan lines using the thermal-based STIC ET model





JPL Temperature/Emissivity Uncertainty Simulator – Hulley et al. 2012

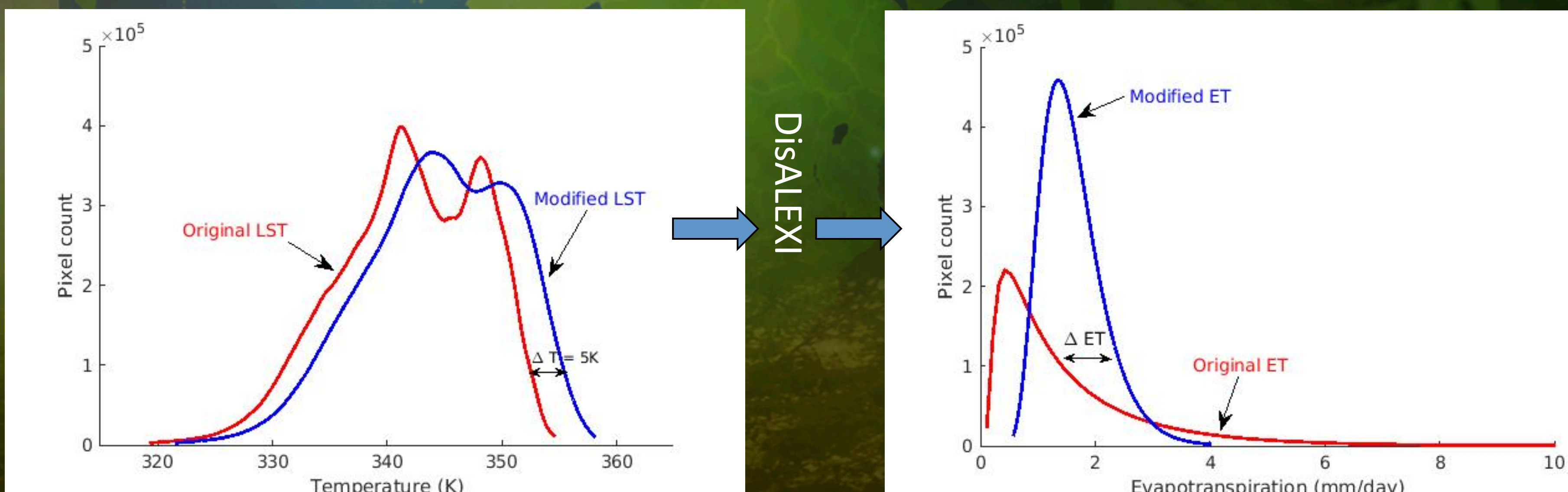
Temperature and ET Retrieval

The disALEXI disaggregation tool accepts 14 inputs, including land surface temperature (LST).

ET resulting from the simulated scene ranged from 0 to 8 mm/day.
(Cropland ET in a warm, arid area, may range from 6 to 9 mm/day.)
At 1K temperature difference, the ET difference ranged from -1 to 2 mm/day.
At 5K temperature difference (pictured), the ET difference ranged from 3 to 5 mm/day.

Temperature

Evapotranspiration



Summary of Science Impact

- The partial failure of the FPA affects 3 of the 6 ECOSTRESS spectral bands. The 3 bands affected are the geolocation band, and the 8.28 and 12.05 µm thermal bands. The affected bands are missing 8 scanlines every 128 lines.
- No data will be obtained in the 3 affected spectral bands in 8 scanlines every 128 lines.
- The critical deliverable for ECOSTRESS is EvapoTranspiration (ET). The uncertainty for ET in the area of the affected scanlines will increase from 10% to 31%.
- It will not be possible to provide L1 and L2 spectral products over the bad lines in the bad bands (8.28 and 12.05 µm), e.g. Level 1 Brightness Temperature, Level 2 Spectral Emissivity.
- While ECOSTRESS will be able to complete its mission with 3 good bands, it is likely the broader research community will want NASA to fix this problem.
- All Level 1 requirements defined in the PLRA will be met.

ECOSTRESS

- Some facts and figures
  - Focused on water use and availability
  - Selected in EVI-2
  - Class D mission on ISS
  - Uses PHyTIR developed under ESTO IIP
  - Deliver in early 2017
  - Launch in June 2018
  - Nominal mission lifetime 1 year

L1 Science Requirements and Margins

Parameter	Science Requirement (from PLRA)	Current Best Estimate @ 400 km
Ground Sample Distance (m) Crosstrack x Downtrack at nadir	≤ 100 x ≤100	68.5 x 38.5
Swath width (ISS nominal altitude range is 385 to 415 km)	≥ 360	402
Wavelength range (µm)	8-12.5	8-12.5
Number of bands	≥ 3	5 TIR + 1 SWIR
Radiometric accuracy (K @300K)	≤ 1	0.5
Radiometric precision (K @300K)	≤ 0.3	0.15
Dynamic Range (K)	270-335	200-500
Data collection	CONUS, twelve 1,000 x1,000km key climate biomes and twenty-five FLUXNET sites. On average 1 hour of science data per day.	1.5 hours per day of science data

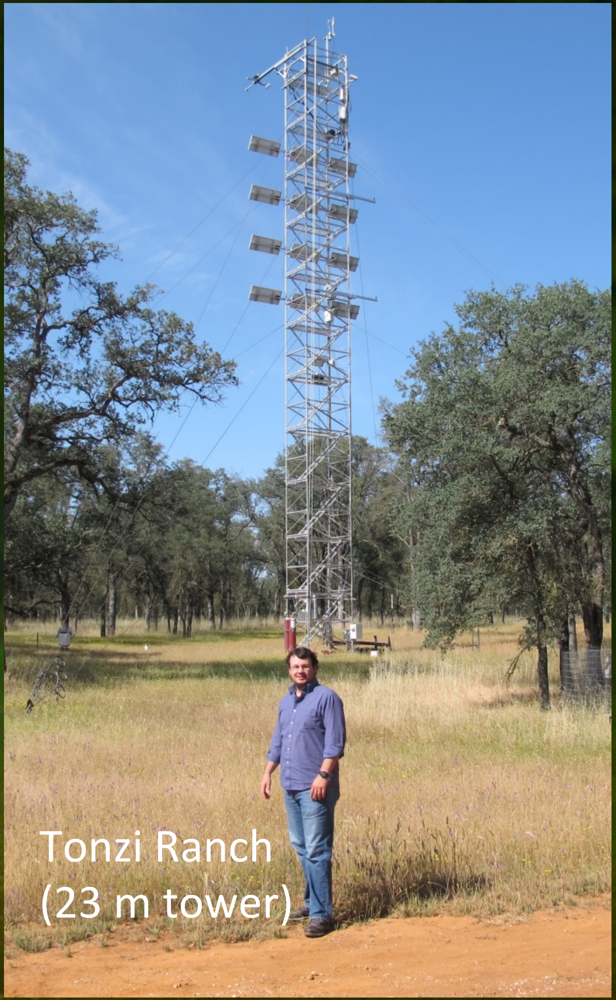
ECOSTRESS Science Data Products

Data Product	Description	Initial Availability to NASA DAAC	Median Latency in Product Availability to NASA DAAC after Initial Delivery	NASA DAAC Location
Level 0	Raw collected telemetry	6 months after IOC	12 weeks	To be assigned by NASA SMD/ESD
Level 1	Calibrated Geolocated Radiances	6 months after IOC	12 weeks	To be assigned by NASA SMD/ESD
Level 2	Surface temperature and emissivity	6 months after Level 1 data products are available	12 weeks	To be assigned by NASA SMD/ESD
Level 3	Evapotranspiration	2 months after Level 2 data products are available	12 weeks	To be assigned by NASA SMD/ESD
Level 4	Water use efficiency and evaporative stress index	2 months after Level 3 data products are available	12 weeks	To be assigned by NASA SMD/ESD

Calibration and Validation

- On-board blackbodies
- Vicarious calibration sites
- Validation sites (FLUXNET)

Lake Tahoe



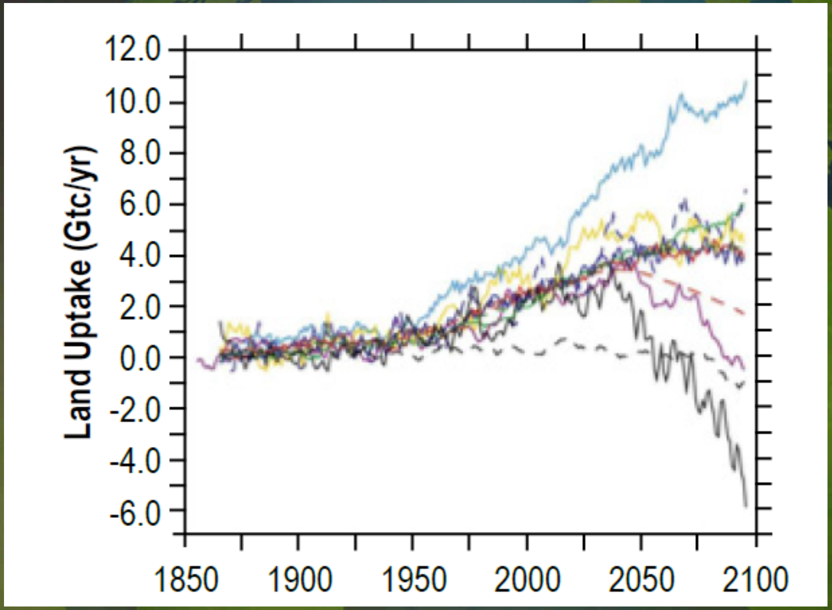
Summary

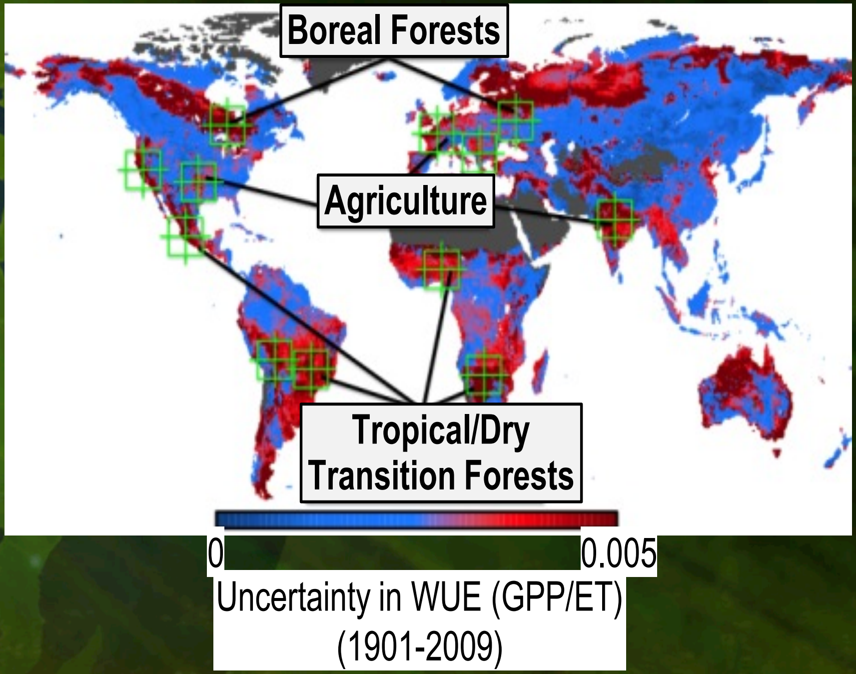
- ECOSTRESS is possible because of the development of the PHyTIR instrument for HyspIRI-TIR supported by ESTO
- ECOSTRESS will address a subset of the science associated with HyspIRI
- The ECOSTRESS mission will help answer three key science questions:
  - How is the terrestrial biosphere responding to changes in water availability?
  - How do changes in diurnal vegetation water stress impact the global carbon cycle?
  - Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?
- ECOSTRESS has a clearly defined set of data products and mature algorithms
- The FPA partial failure will impact the ECOSTRESS science, however, the L1 Requirements will be met

ECOSTRESS will launch in 2018 and provide highest spatial resolution thermal infrared data ever from the International Space Station. HyspIRI is planned for the 2023+ timeframe unless the Decadal Survey increases the priority !!

BACKUP

Q1. How is the terrestrial biosphere responding to changes in water availability?

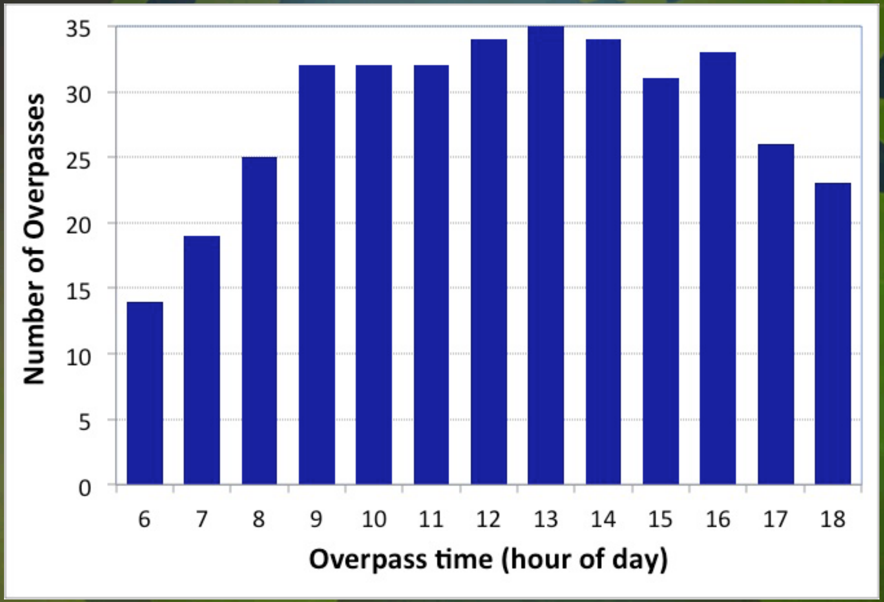




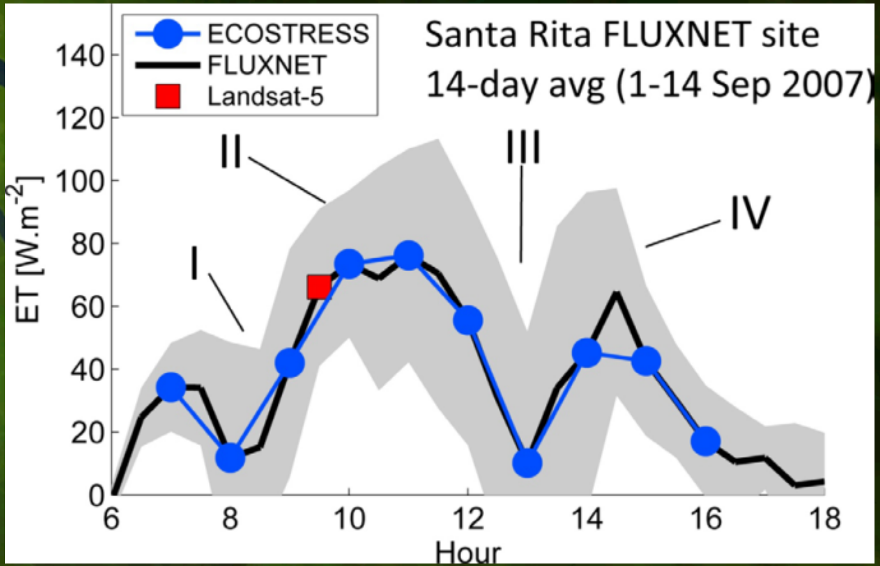
Uncertainty in our knowledge of carbon response is directly dependent on water response uncertainty and how plants use water under drying conditions.

Red areas ("hotspots") are where global models disagree on water use efficiency (WUE) based biome changes with climate change. ECOSTRESS will reduce this uncertainty with measurements for WUE (GPP/ET).

Q2. How do changes in diurnal vegetation water stress impact the global carbon cycle?



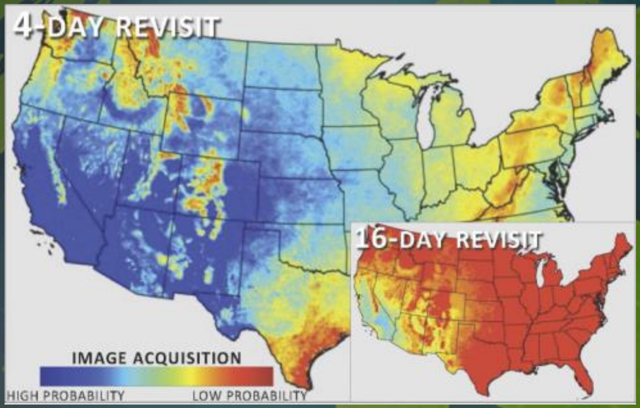
ECOSTRESS acquires numerous samples throughout the day over 1 year (at 50o latitude shown, for example).



ECOSTRESS's diurnal sampling measures the shape of the daily ET cycle. The afternoon decline in ET is related to water stress (clear day).

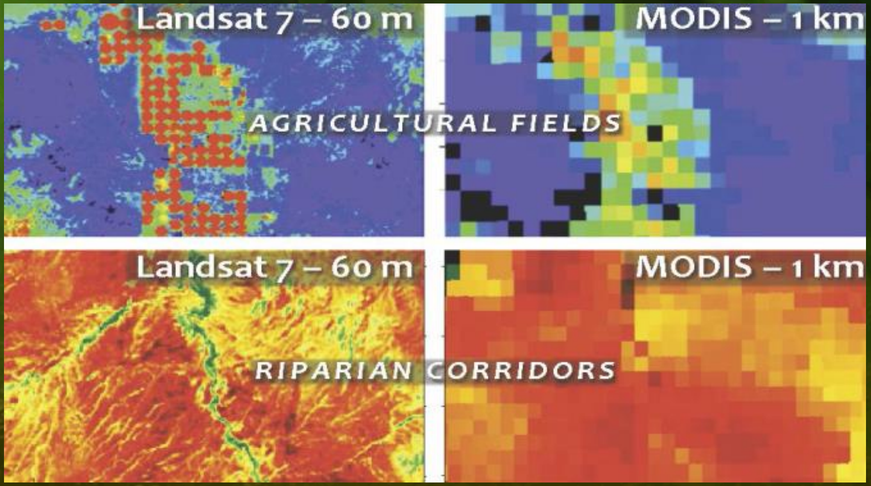
I: Xylem refilling after initial water release.
II: ET at maximum/potential rate in the morning.
III: Stomata shut down water flux in the afternoon.
IV: ET resumes at maximum/potential in early evening when demand is reduced

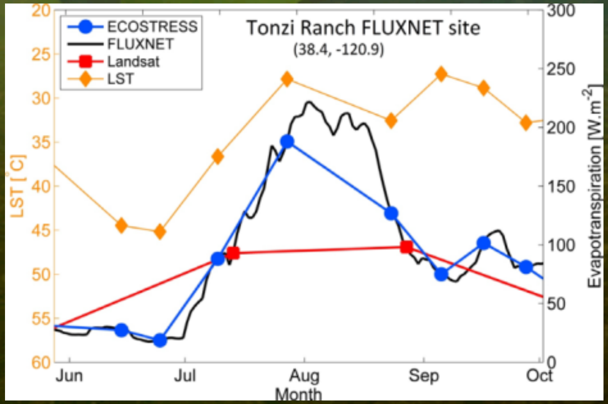
Q3. Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?



ECOSTRESS's spatial resolution will distinguish fine-scale landscape heterogeneity such as agricultural systems (top) and riparian corridors (bottom) similar to Landsat (left), whereas MODIS (right) does not.

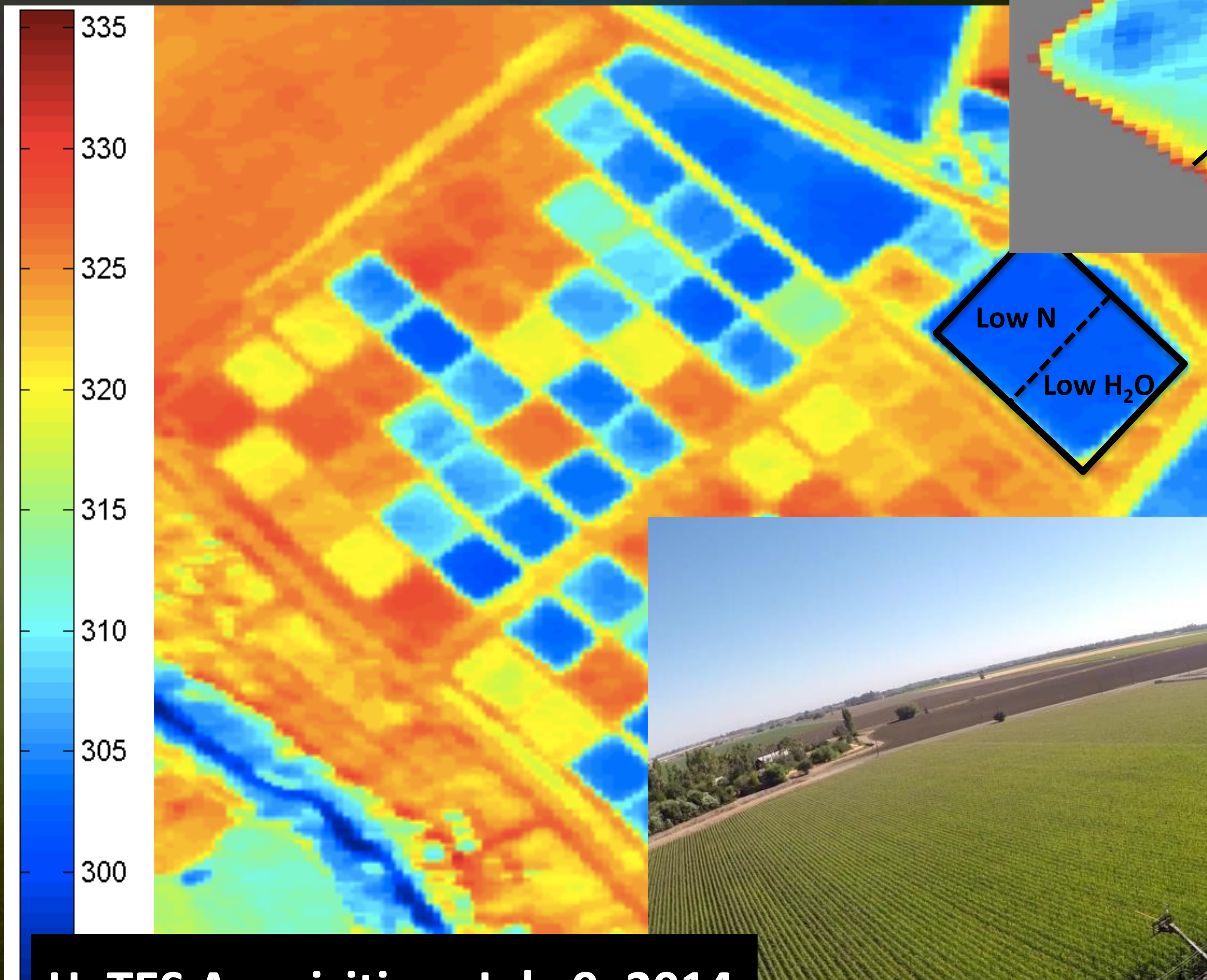
Probability of producing valid ET estimates when satellite revisit time is 16 days (lower-right inset) vs. 4 days

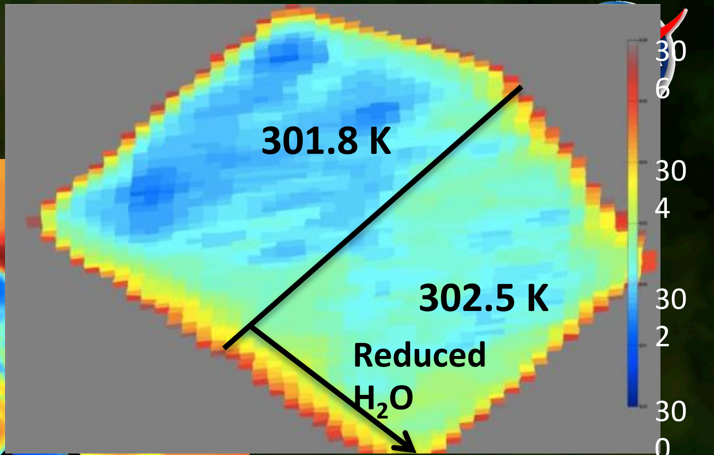




ECOSTRESS's temporal resolution provides a *9-fold* decrease in ET error relative to Landsat.

Using JPL Airborne Instruments for Precursor Studies:



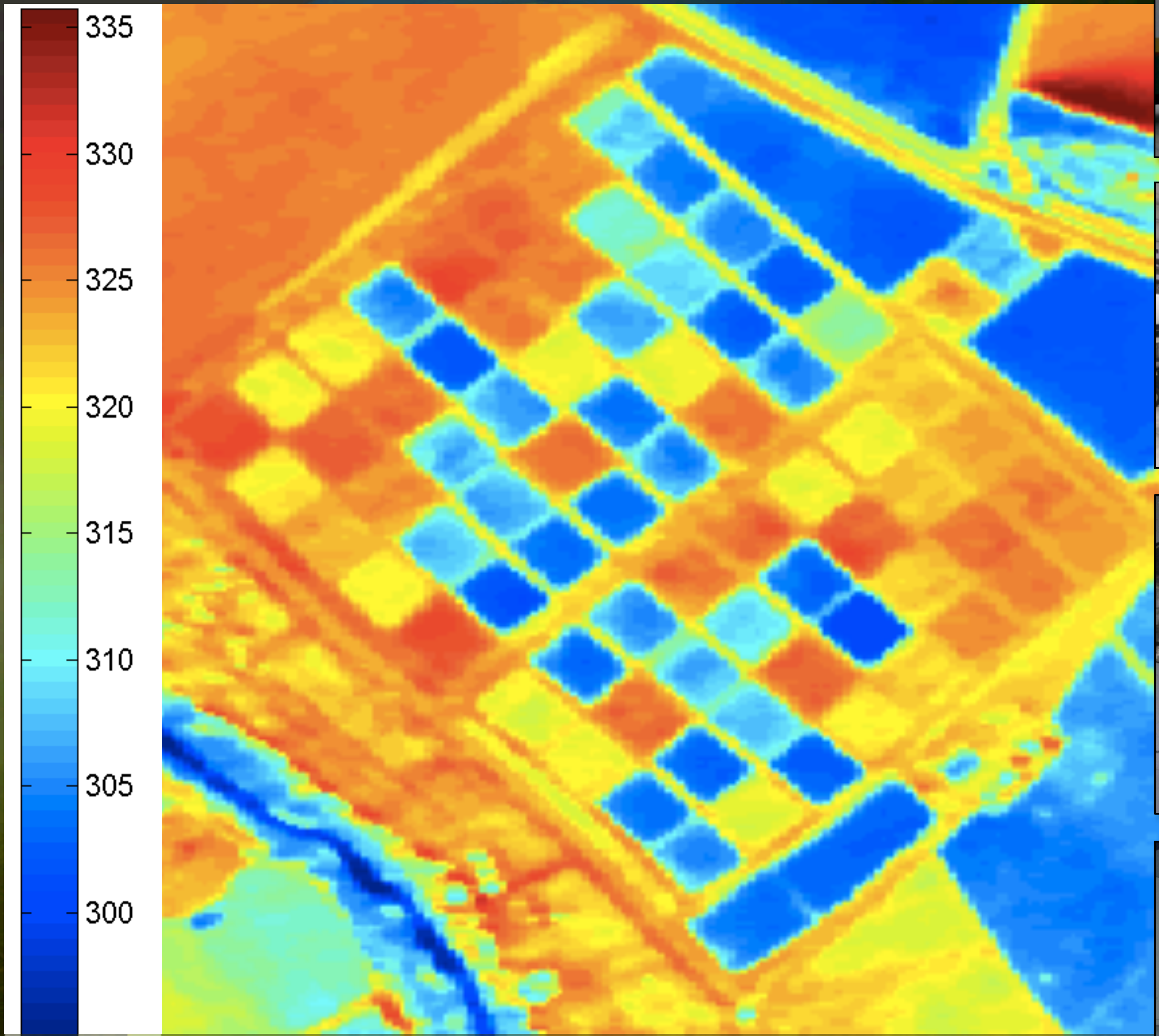


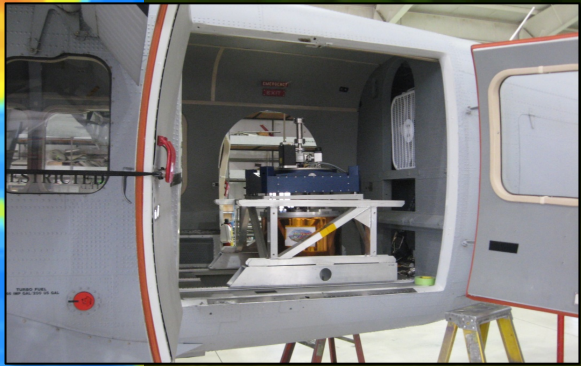
<u>HyTES Acquisition: July 9, 2014</u>

HyTES: Hyperspectral Thermal Emission Spectrometer

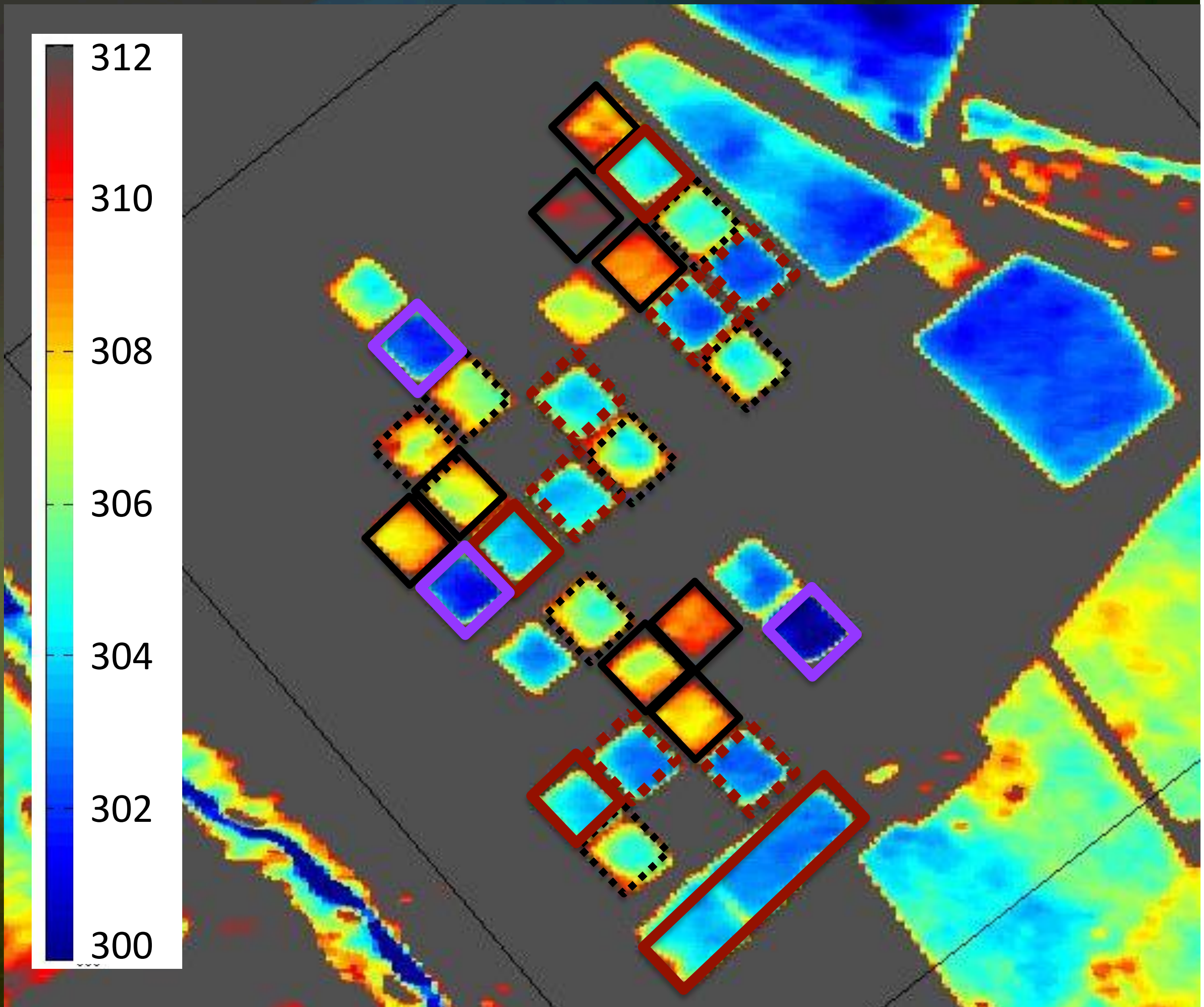
JPL Airborne Capability

Image Acquisition: 9 JUL 2014





HyTES Acquisition: July 9, 2014



Irrigated July 7-8:

Organic Tomato

→ **Mean LST = 309 K**

Conventional Tomato

→ **Mean LST = 306 K**

Irrigated July 2-3:

Organic Corn

→ **Mean LST = 304 K**

Conventional Corn

→ **Mean LST = 303 K**

Alfalfa

→ **Mean LST = 301.5 K**