HyTES, ECOSTRESS and SBG Imaging in the Thermal Infrared

Simon J. Hook, Kerry Cawse-Nicholsen and Glynn E. Hulley

and the HyTES, ECOSTRESS, and SBG Teams

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

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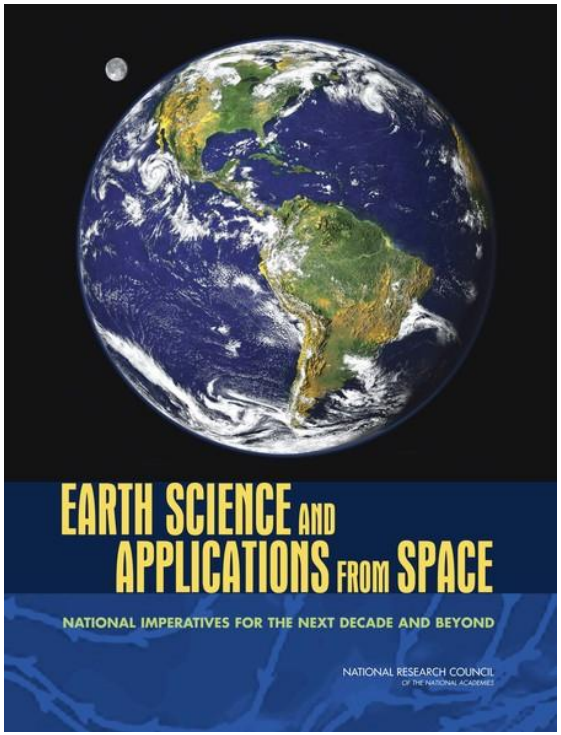
Starting in 2007!

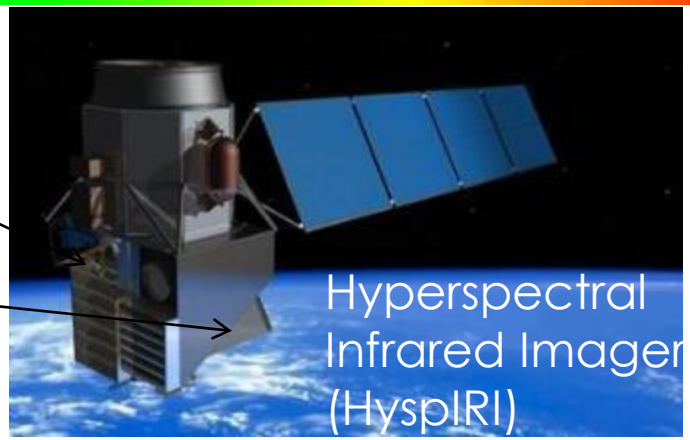
HyspIRI
Free-flyer



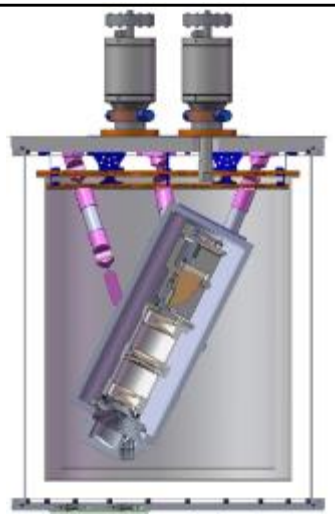
2007

VSWIR

TIR



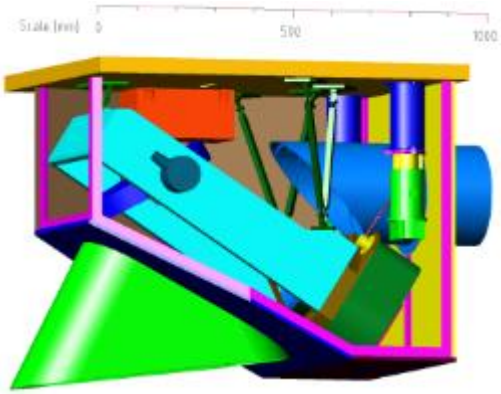
Science Risk Reduction



2008

Airborne Hyperspectral Thermal Emission Spectrometer (HyTES)

Engineering
Risk Reduction

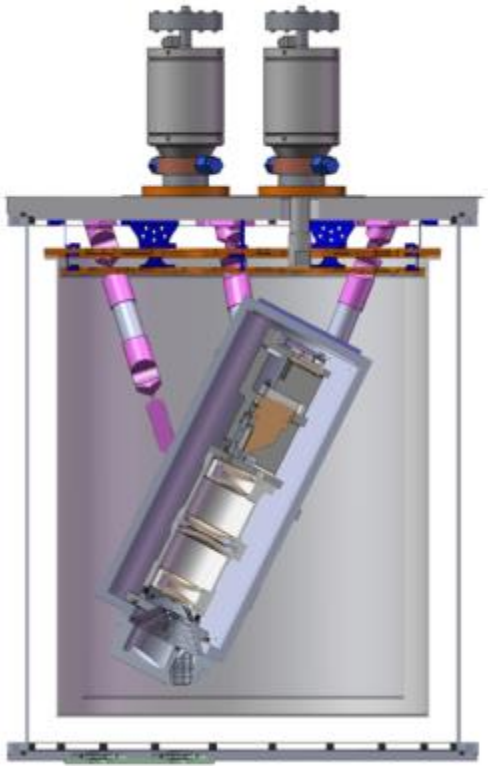


Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)

2010

Hyperspectral Thermal Emission Spectrometer (HyTES)

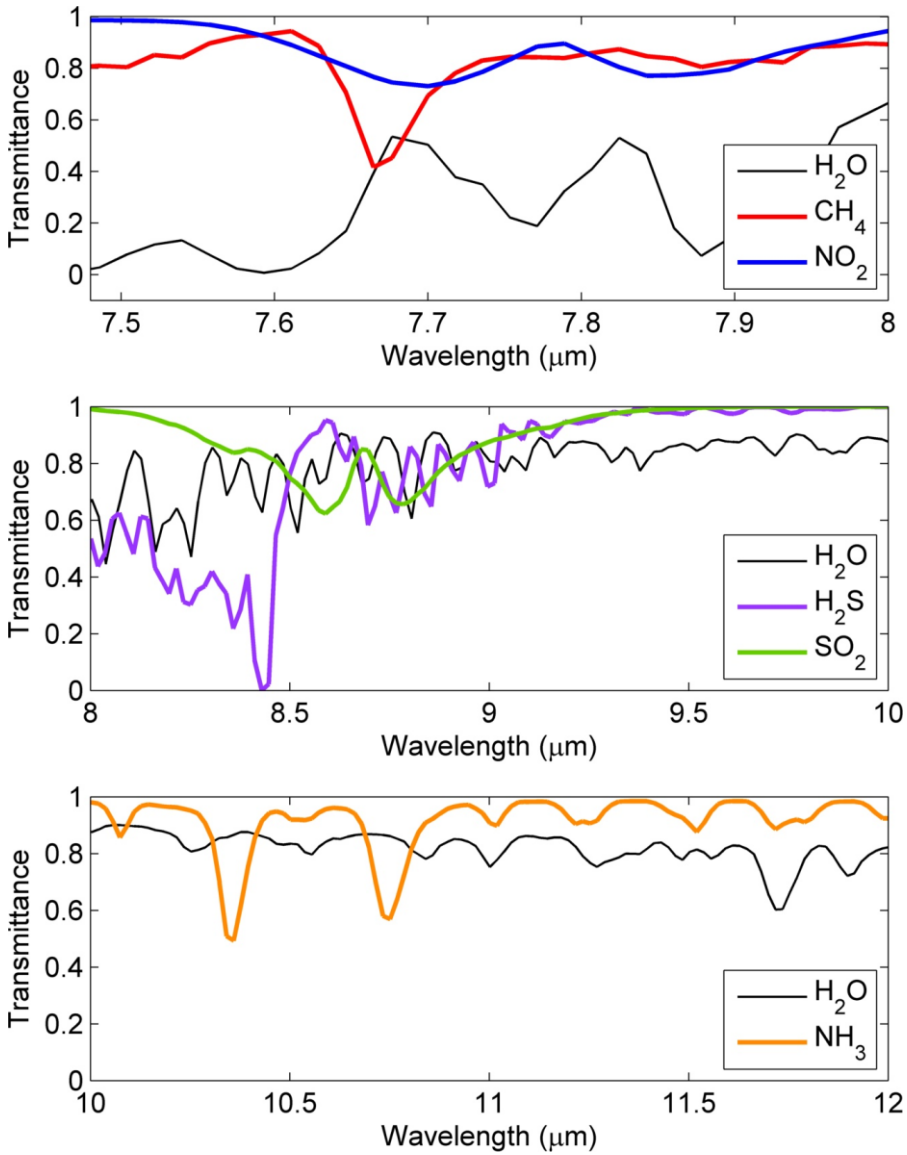
First Flights in 2012



Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 µm
Frame speed	35 or 22 fps
Integration time (1 scanline)	28 or 45 ms
Total Field of View	50 degrees
Calibration (preflight)	Full aperture blackbody
Detector Temperature	40K
Spectrometer Temperature	100K
Slit Length and Width	20 mm x 39 µm
IFOV	1.7066
Pixel Size/Swath at 2000 m flight altitude[2]	3.41m/1868.33m
Pixel Size/Swath at 20,000 m flight altitude[2]	34.13m/18683.31m

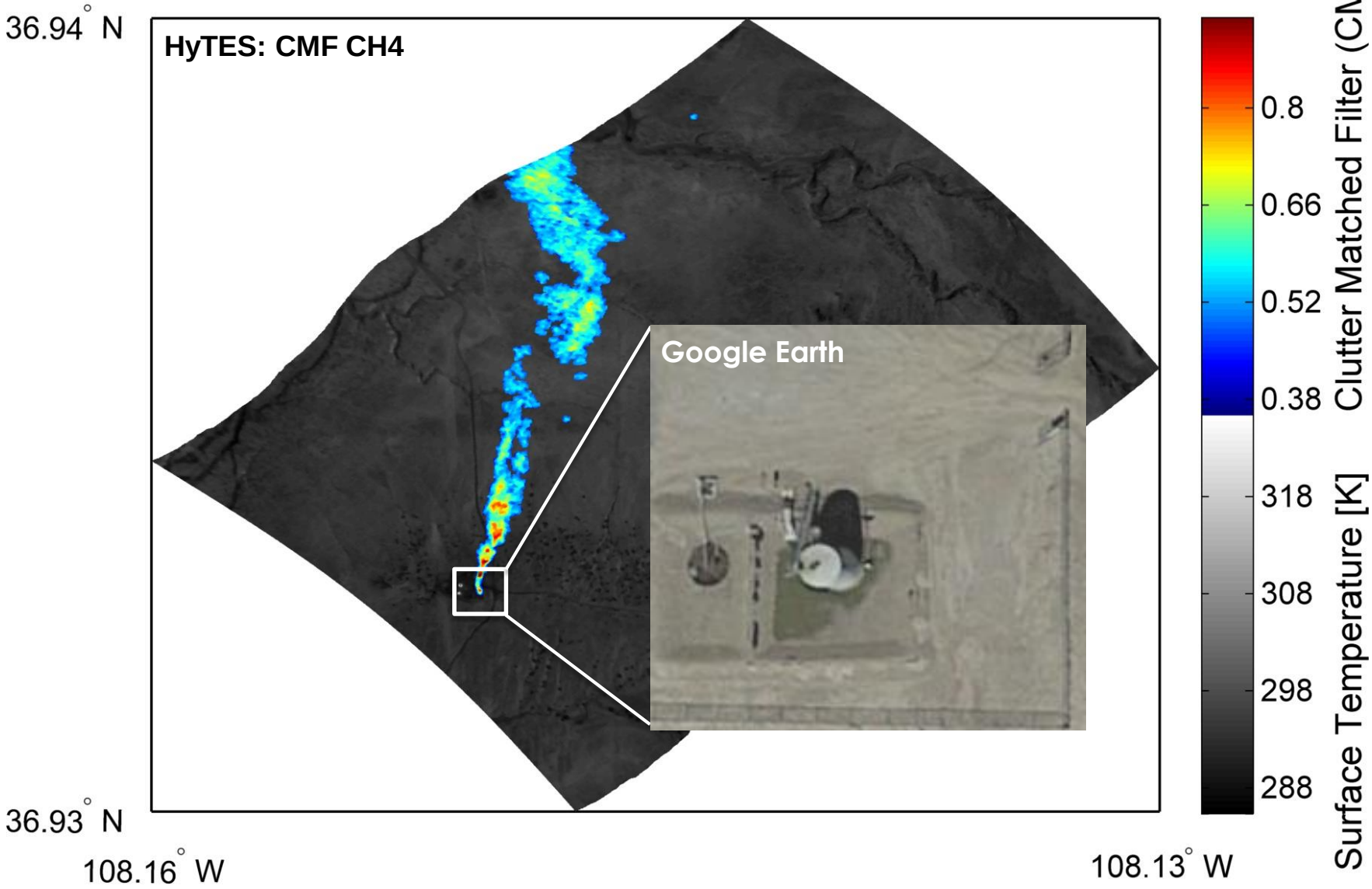
1. Does not include 1 rack of electronics to operate instruments; 2. Includes ~27 calibration pixels

HyTES Gas Species

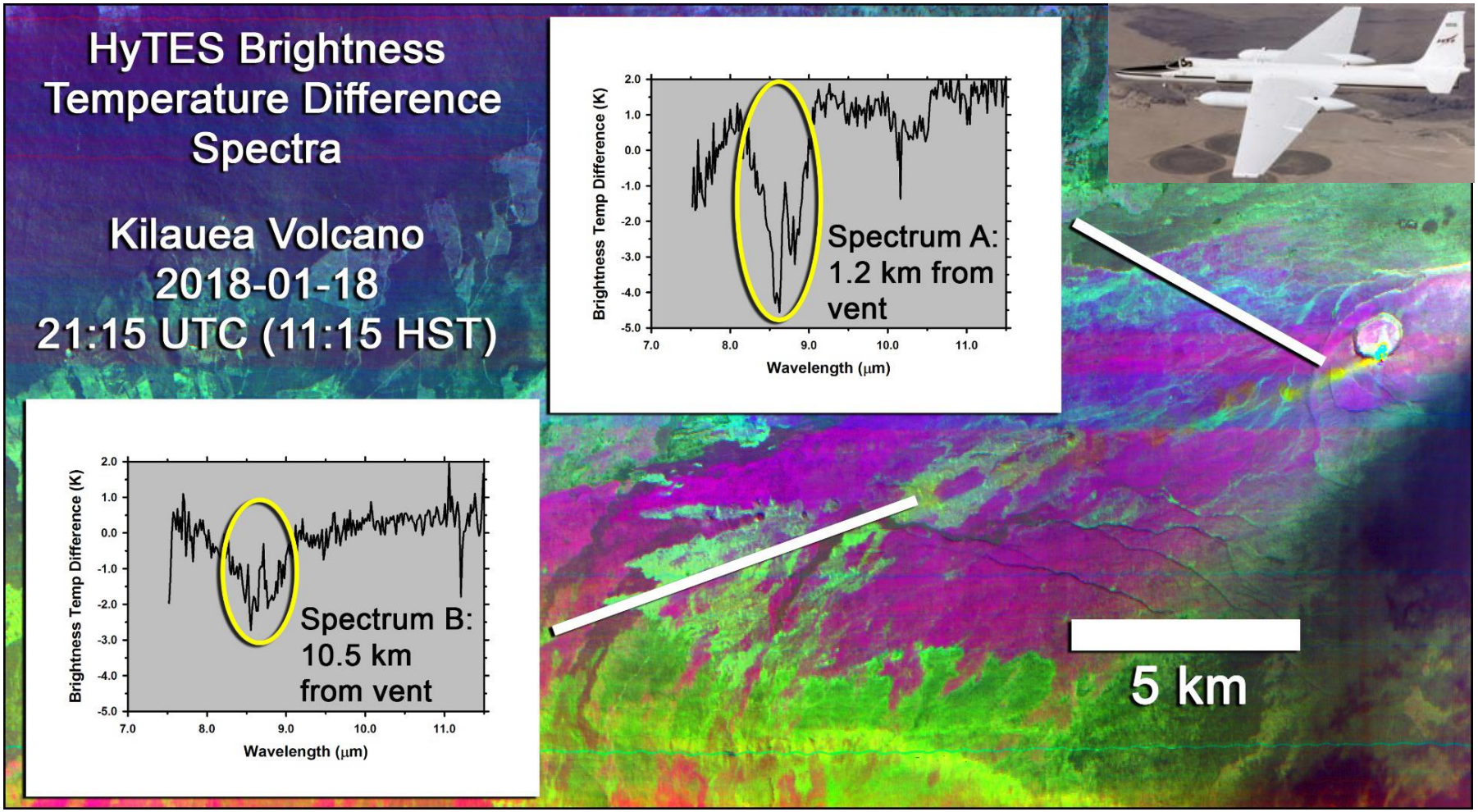


Los Angeles Gas Storage Facilities

HyTES: Methane Plume from a Storage Tank



2018 HyTES Deployed on ER to Hawaii



Slide courtesy of V. Realmuto

Hyperspectral Thermal Emission Spectrometer (HyTES) – 2019 European Campaign

- Joint science campaign in Europe with ground teams, satellite observations and NASA/JPL HyTES imaging spectrometer
- Planned duration: Install in May in UK, flights in June-July, return early July.
- Supports thermal imaging of agricultural sites and relevant current and future European space missions (Sentinel-3 B and Sentinel-LSTM).
- HyTES to be installed on British Antarctic Survey Twin Otter.
- Will collect data for 120 hours over 4 weeks in England, Spain, Italy and Germany.
- Space Act Agreement (SAA) between Kings College London (KCL) and NASA OIIR signed May 1st 2019. KCL will provide aircraft and shipping and interface with ESA. NASA will provide instrument and operational staff.

British Antarctic Survey Twin Otter

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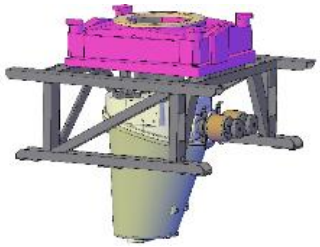
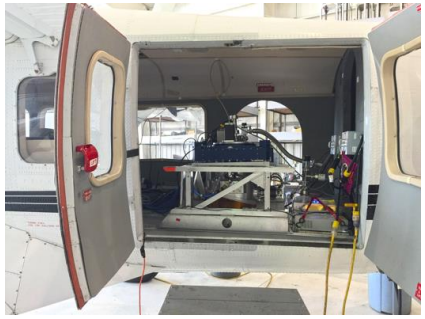


HyTES in Zeiss Mount

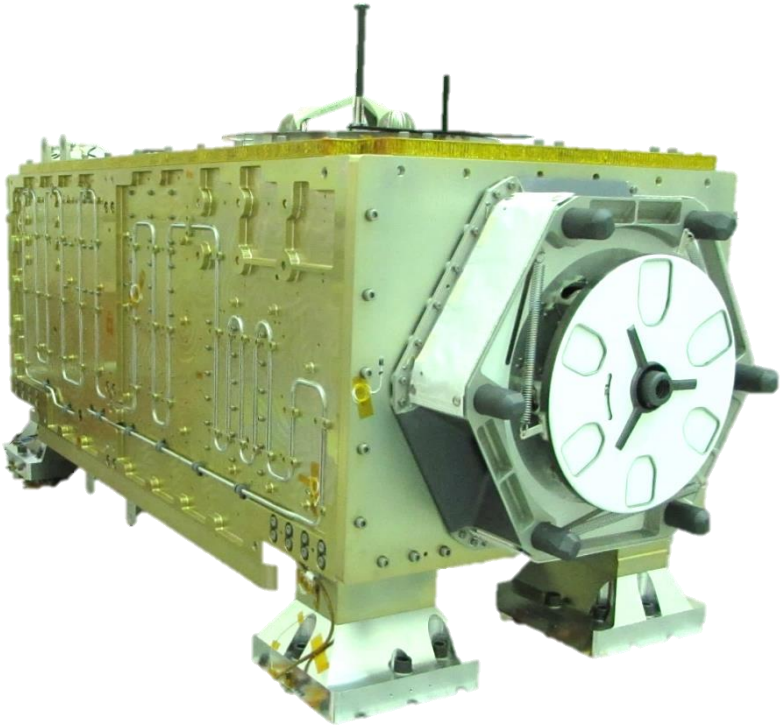


ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

ECOSTRESS

Simon J. Hook and the ECOSTRESS Team

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

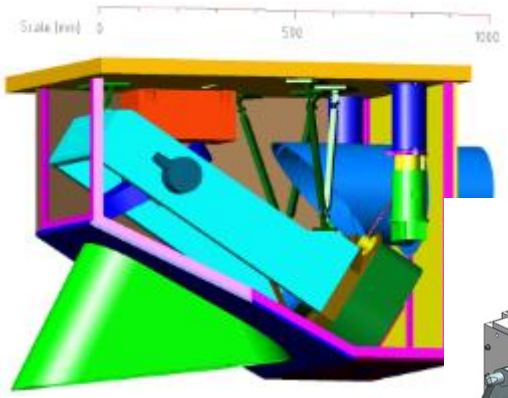


Path to Space

Hyperspectral Infrared Imager (HyspIRI)

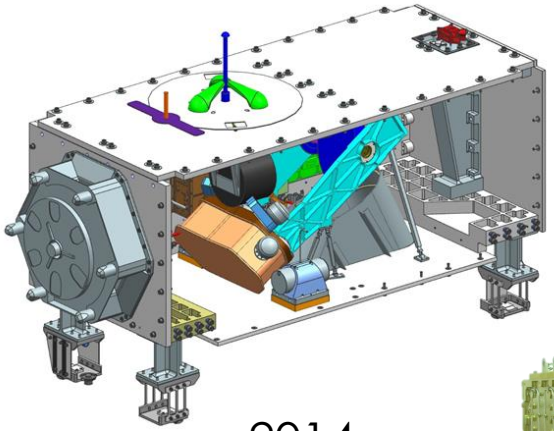
2007

Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)

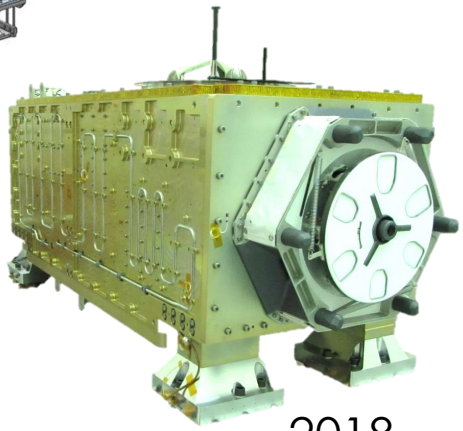


2010

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station



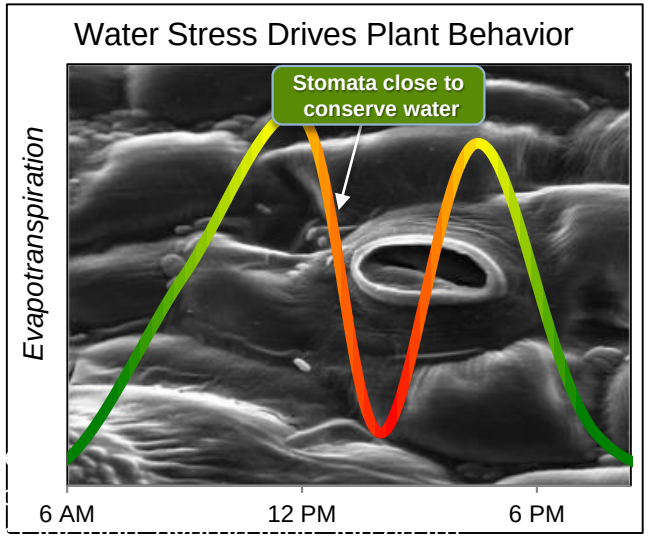
2014

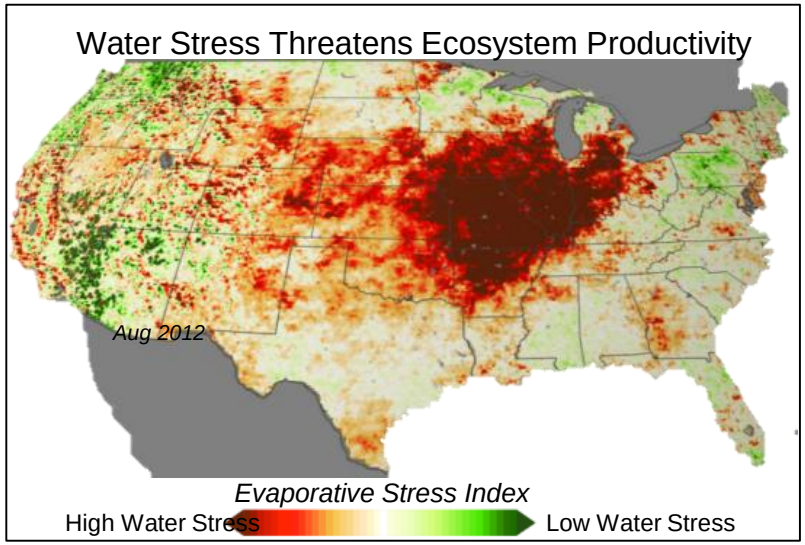


2018

Time

*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).*

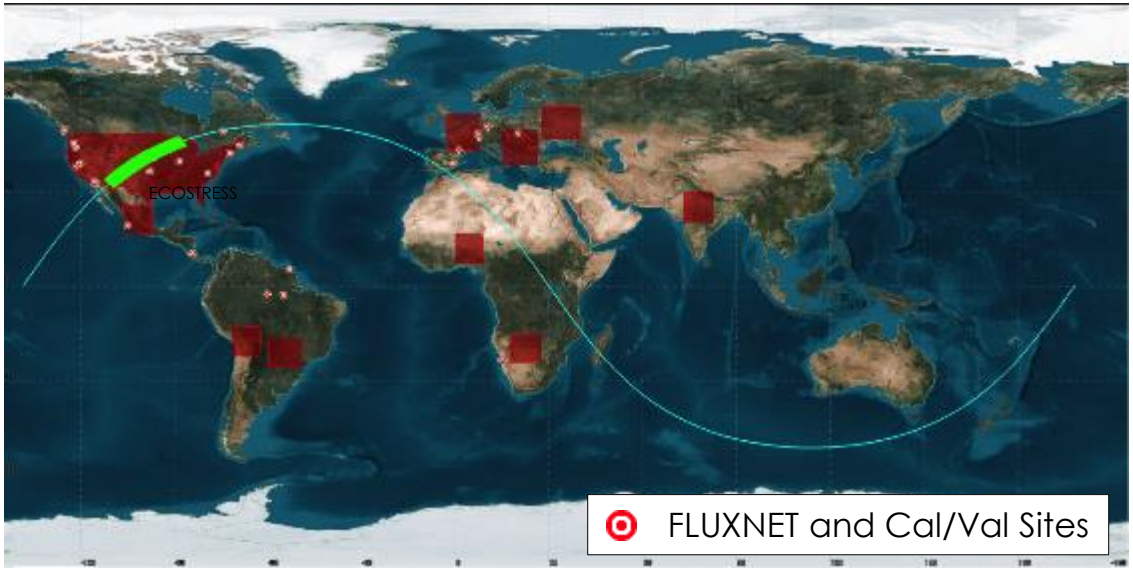




Science Objectives

- 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

ECOSTRESS Target List

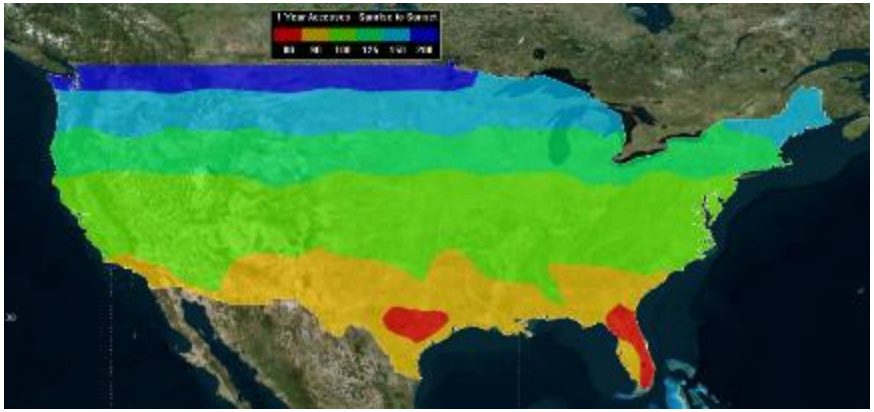


Operational Phases per Orbit

- **Science Collection Mode**
  - **Science Data**
  - **Calibration Data**
- **Scanning Mode**
  - **Data discarded**

ECOSTRESS Targets:

- CONUS + Canada
  - Day-time data only
- Climate hotspot and agricultural regions
  - 12 predefined 1000km x 1000km regions
  - Day-time data only
- FLUXNET sites
  - 400km x 400km images at 23 sites
  - Day-time data only (~120 visits/year)
- Calibration/Validation sites
  - 400km x 400km images at 4 sites
  - Day-time and night-time data (~180 visits/year)

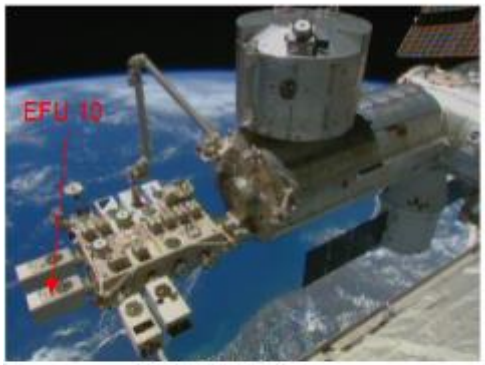


Project Overview

ECOSTRESS is an Earth Venture Instrument-2 on the ISS

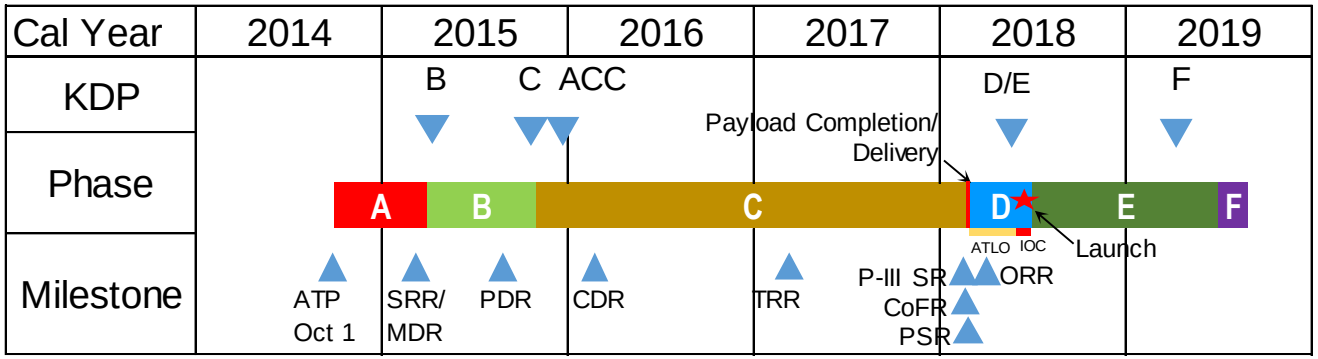
Overview:

- 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
- Launched June 29, 2018 on SpaceX Falcon 9 (CRS15)
- Deployed on the ISS on JEM-EFU 10
- Baseline operations: 1 year after in-orbit checkout



ISS JEM-EF

Timeline:

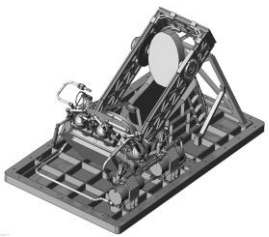


ECOSTRESS

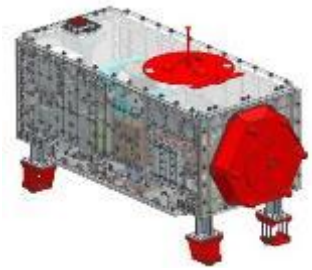
Falcon-9

Mission Concept

Radiometer Instrument



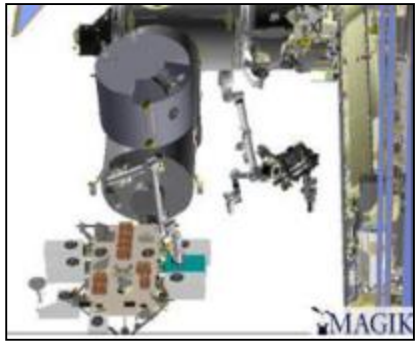
ECOSTRESS Payload



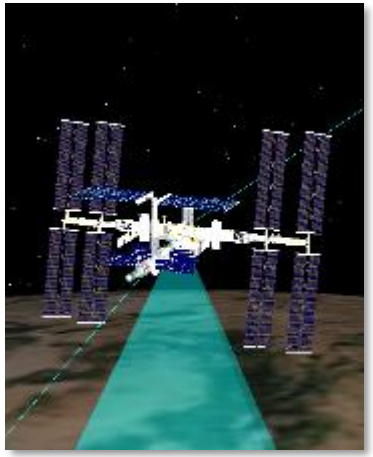
Dragon-Trunk

Falcon-9 LV

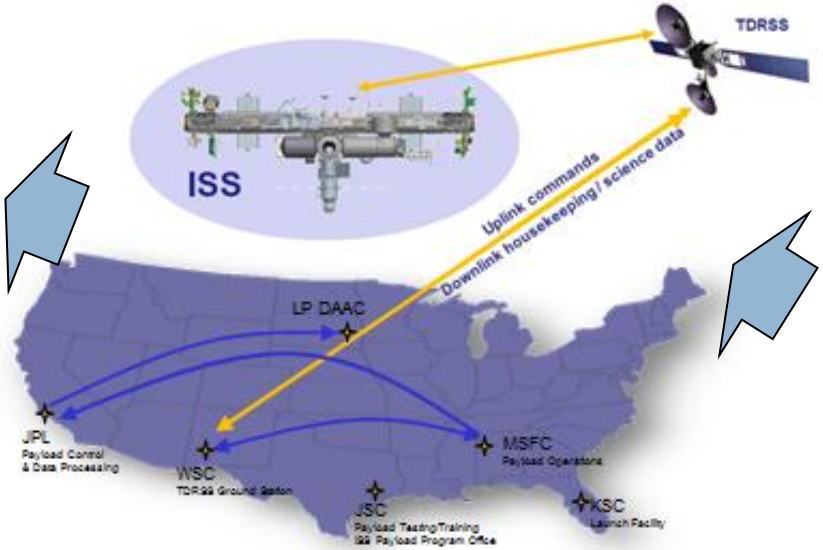
Installation on JEM-EF



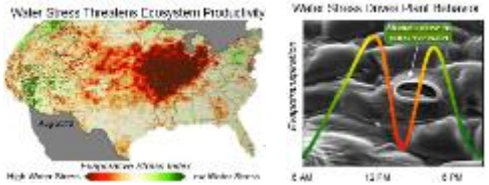
Data Collection



MOS and Ground and Space Network



Science Data Processing and Archive



ECOSTRESS Science Data Products

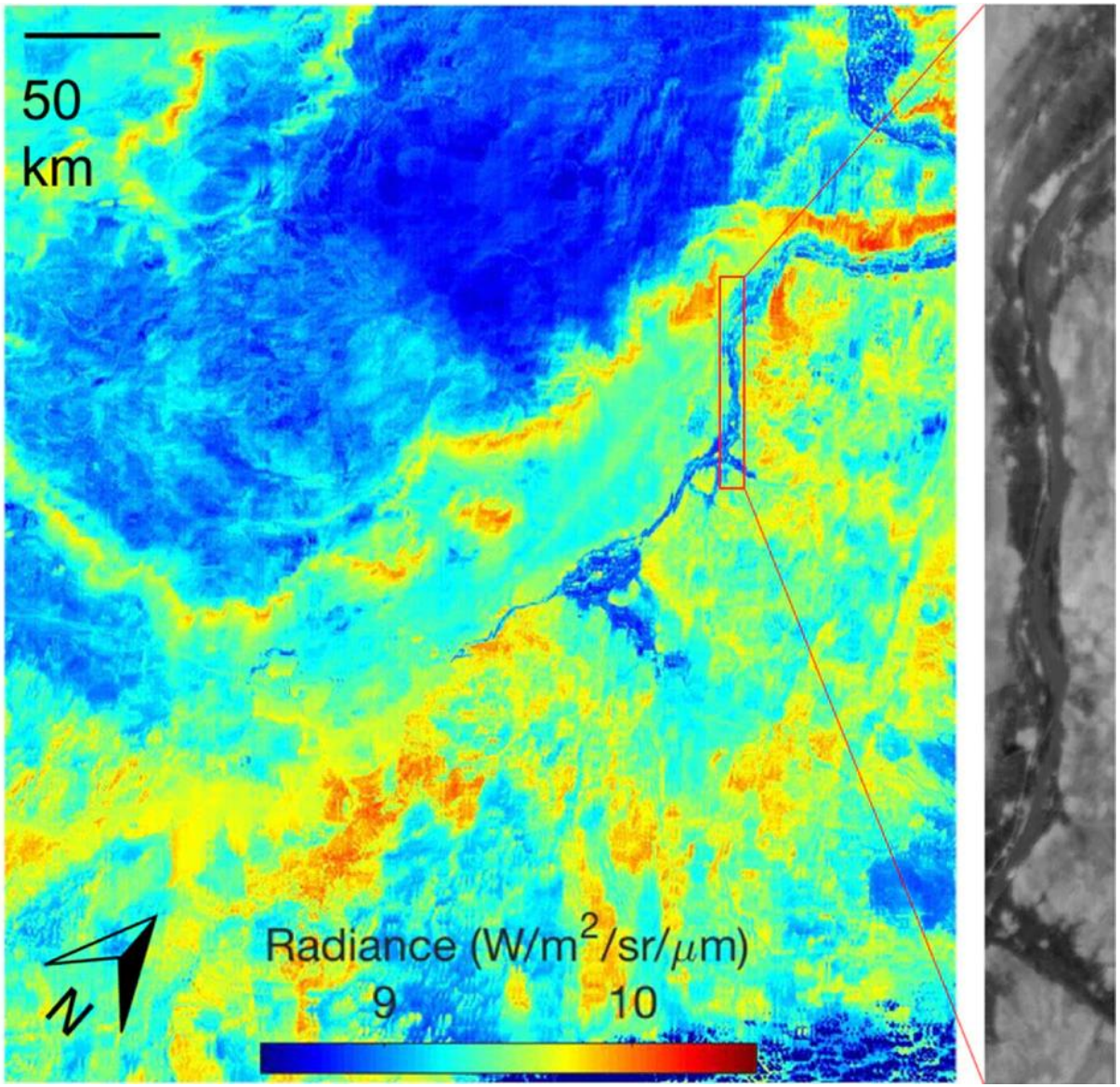
Data Product	Description	Initial Availability to NASA DAAC	Median Latency in Product Availability to NASA DAAC after Initial Delivery	NASA DAAC Location
Level 0	Raw collected telemetry	6 months after IOC	12 weeks	LP DAAC
Level 1	Calibrated Geolocated Radiances	6 months after IOC	12 weeks	LP DAAC
Level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

Data distributed by Land Processes Distributed Active Archive Center (*LP DAAC*)

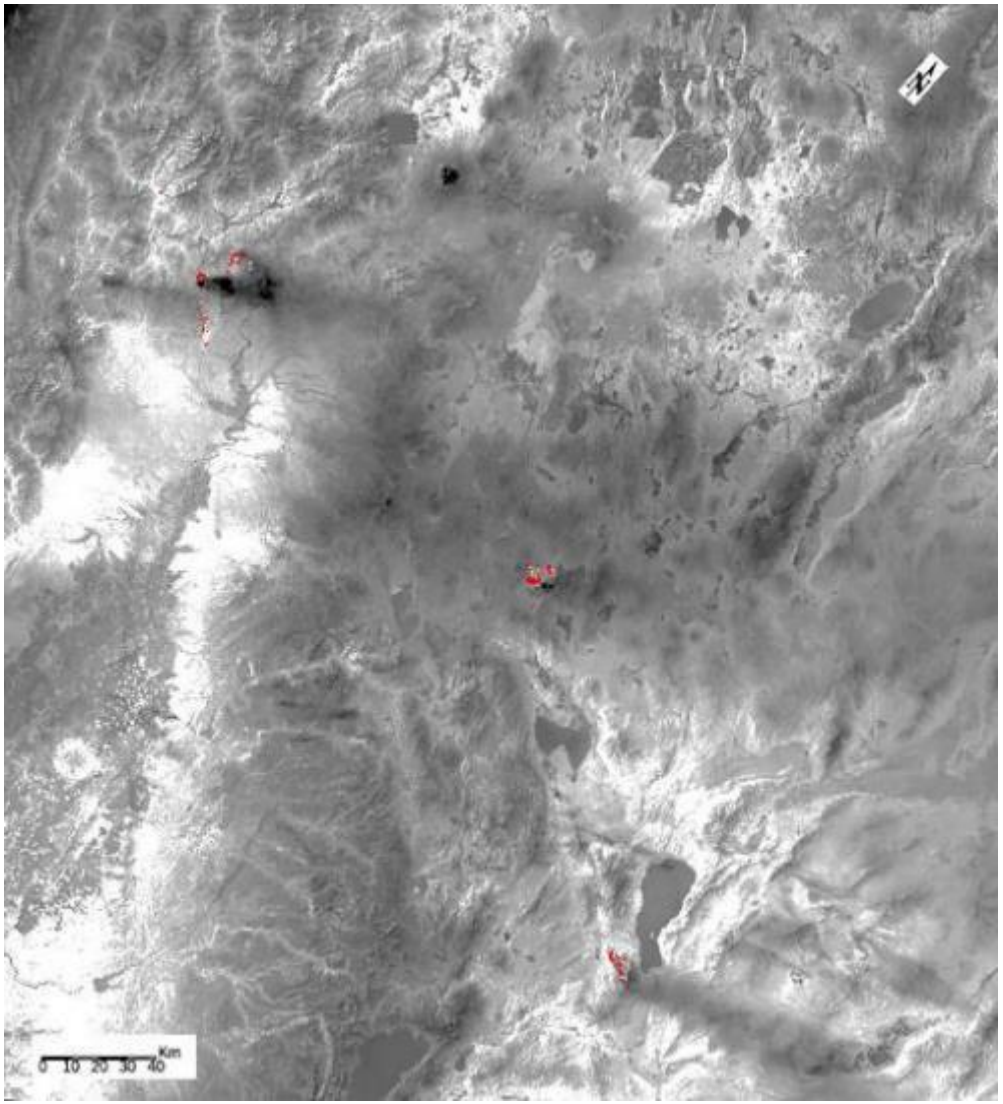
Launch

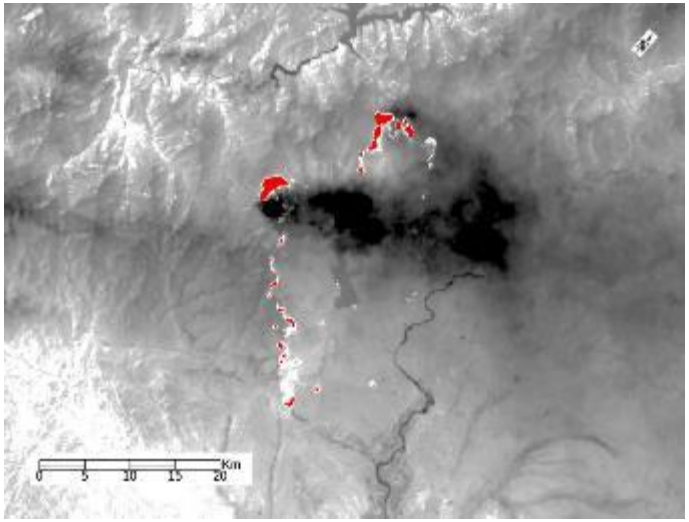
June 29th, 2018

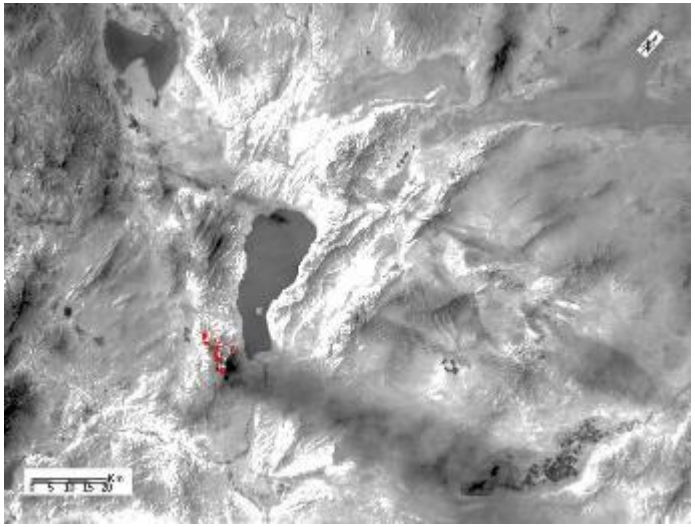
ECOSTRESS First Light



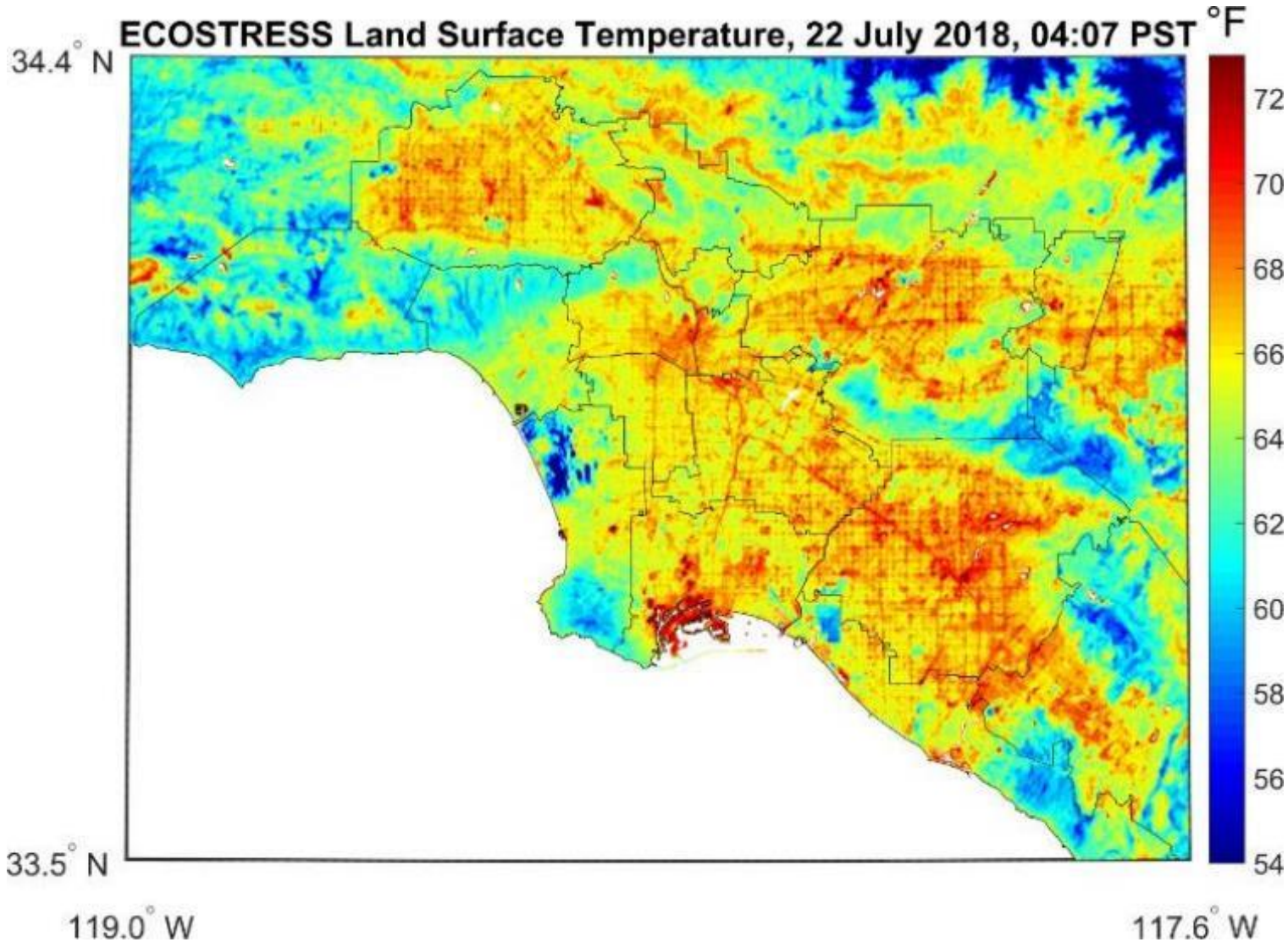
NASA's 'Space Botanist' Observes California, Nevada Wildfires



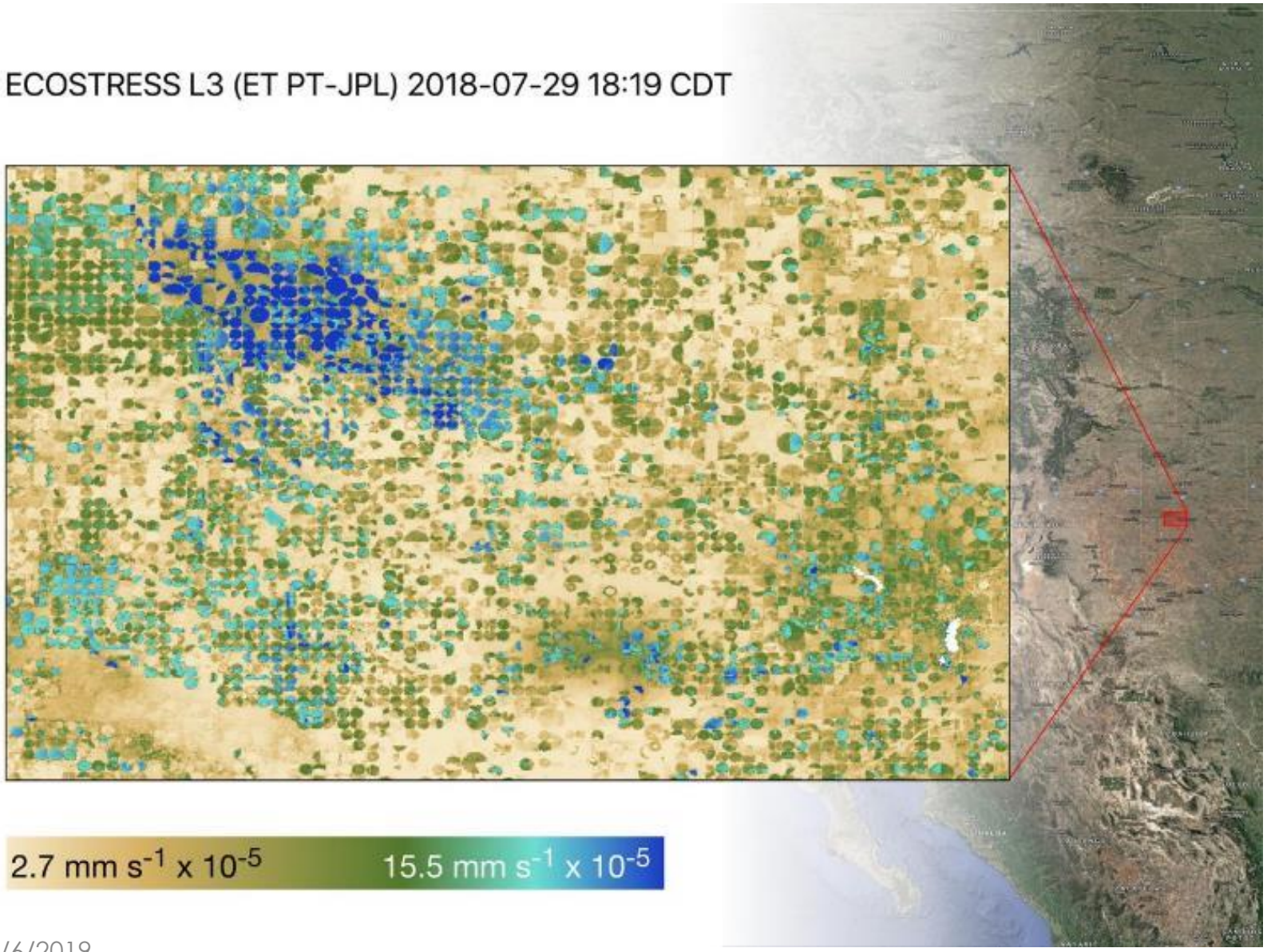




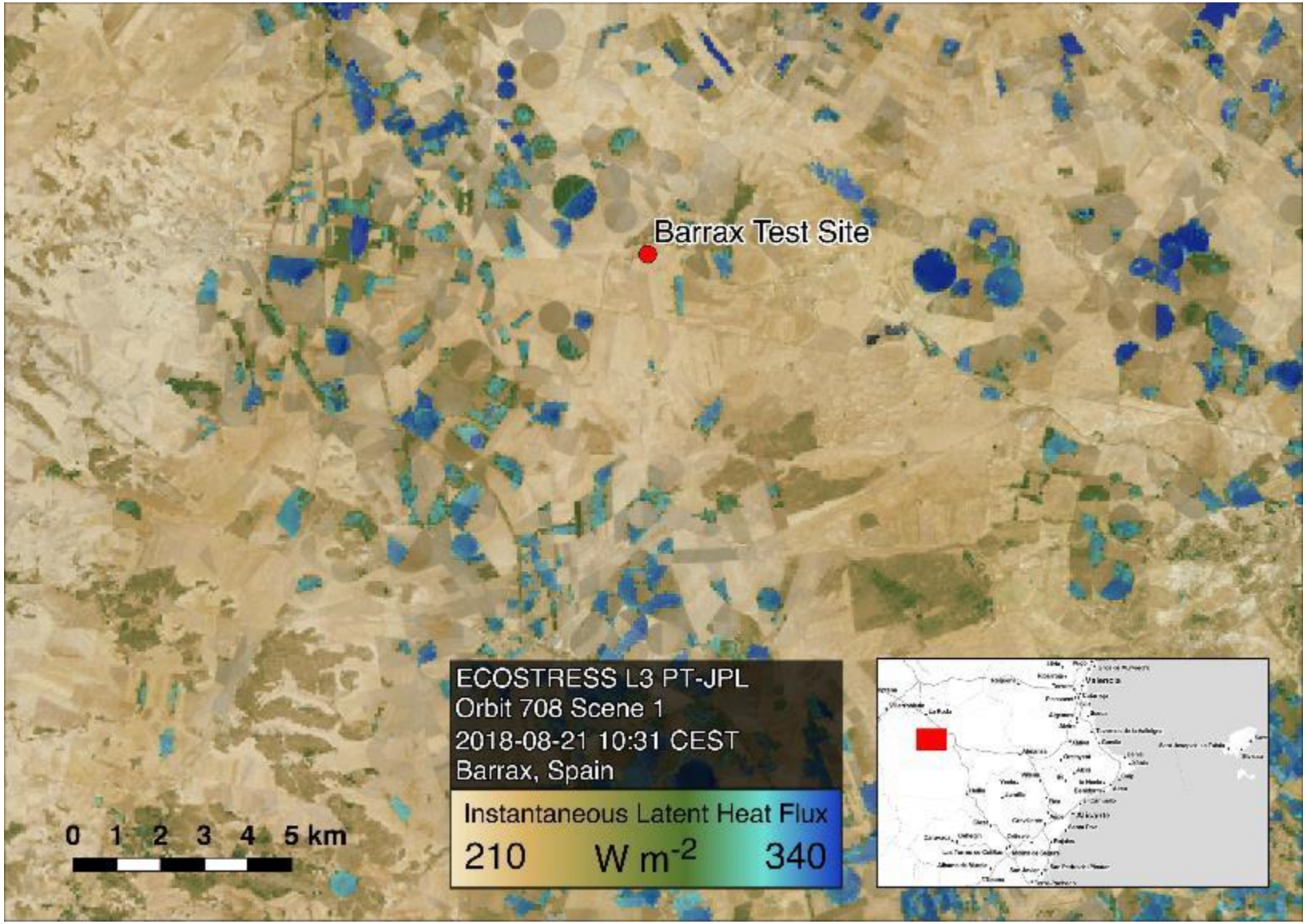
NASA's 'Space Botanist' Takes the Temperature of Los Angeles



First ET Maps!

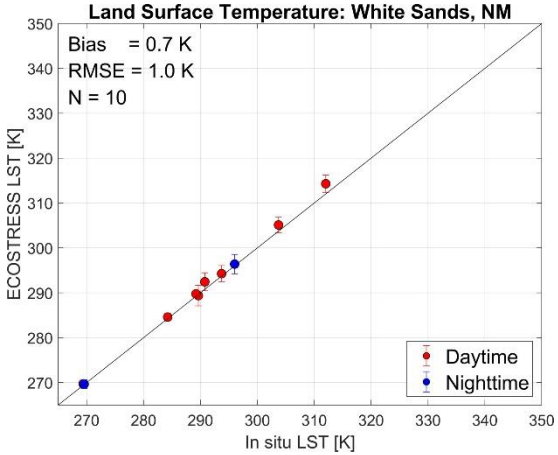


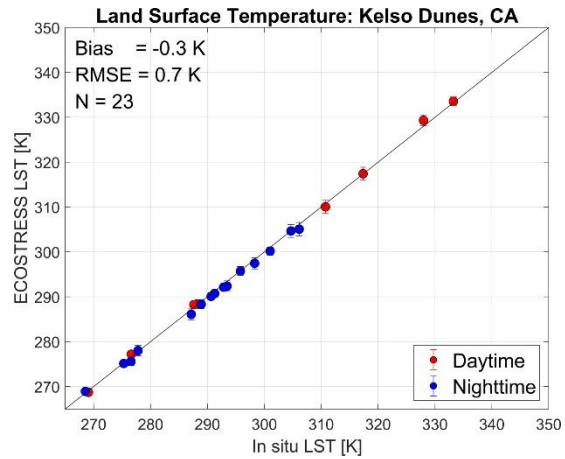
Barrax Test Site, Spain

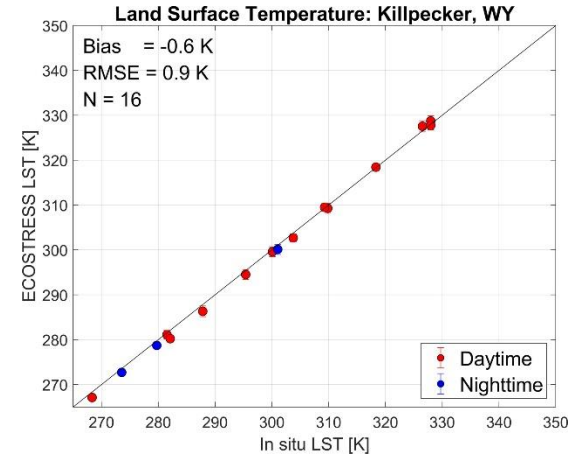


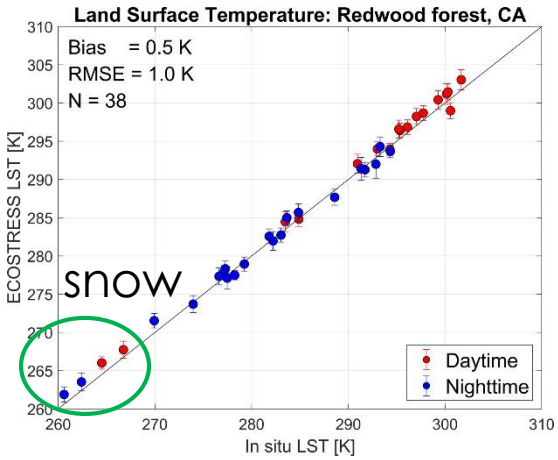
ECOSTRESS – Some Science Facts

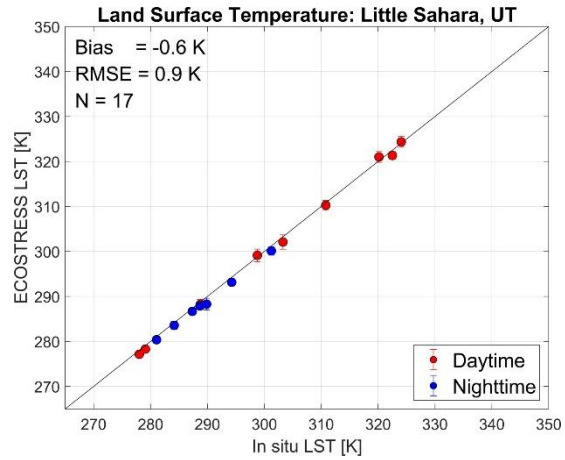
- ECOSTRESS was proposed to have an average operating daily acquisition rate of 72 scenes. It has had an operating daily acquisition rate of 118 scenes.
- ECOSTRESS has operated for 150 days.
- ECOSTRESS has acquired 17,705 400 km x 400 km scenes, 18 times the total land surface of the Earth.
- ECOSTRESS has the largest early adopter program ever, with 234 early adopters, larger projects typically get less than 50 early adopters.
- All data products (L1-L4) were delivered ahead of schedule, via the early adopter program.
- L1 data were publicly released on schedule.
- The NASA ECOSTRESS science team call was heavily oversubscribed with about 120 Notice of Intents for ~10 selections. Over 70 final proposals were received.
- Work has already begun on validating the data products, see the next 2 slides. Results indicate the instrument is well calibrated with excellent product quality.
- **ECOSTRESS <u>is</u> the highest spatial resolution multispectral thermal infrared radiometer NASA has <u>ever</u> built. It is the only spaceborne instrument capable of providing data suitable for evaluating data for the Decadal Survey SBG TIR mission.**

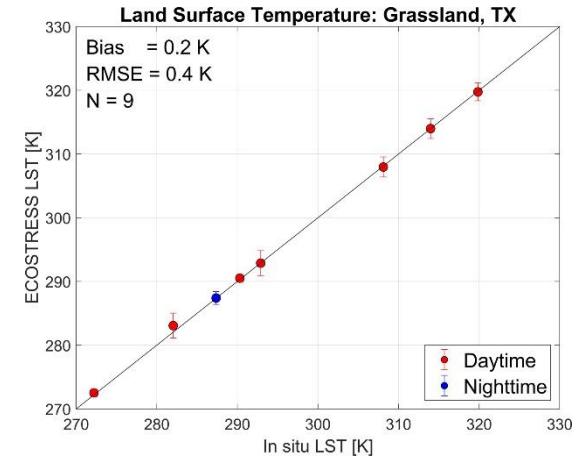


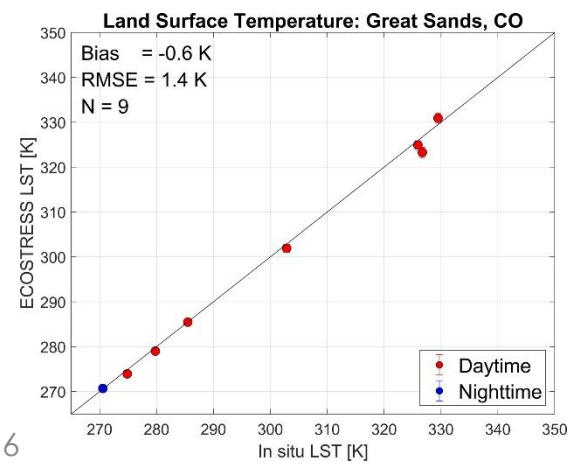


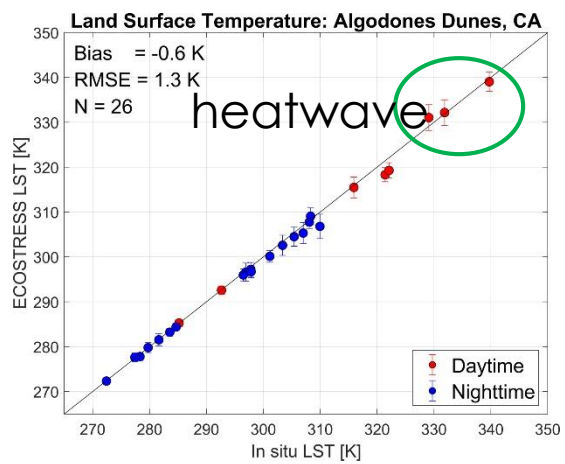










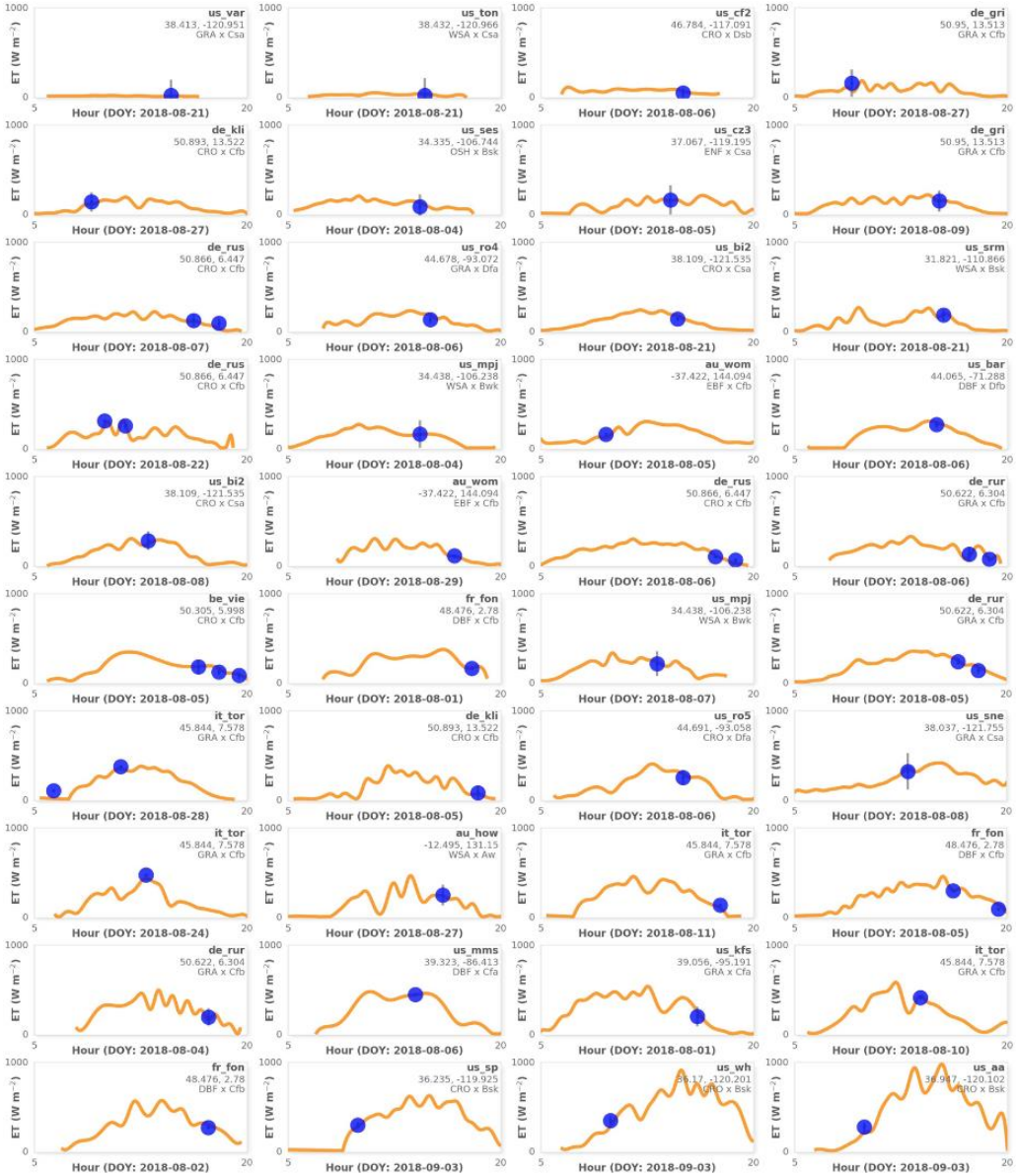


Land Surface Temperature Validation Results Against Selected Test Sites

Courtesy G. Hulley – Science Team Member

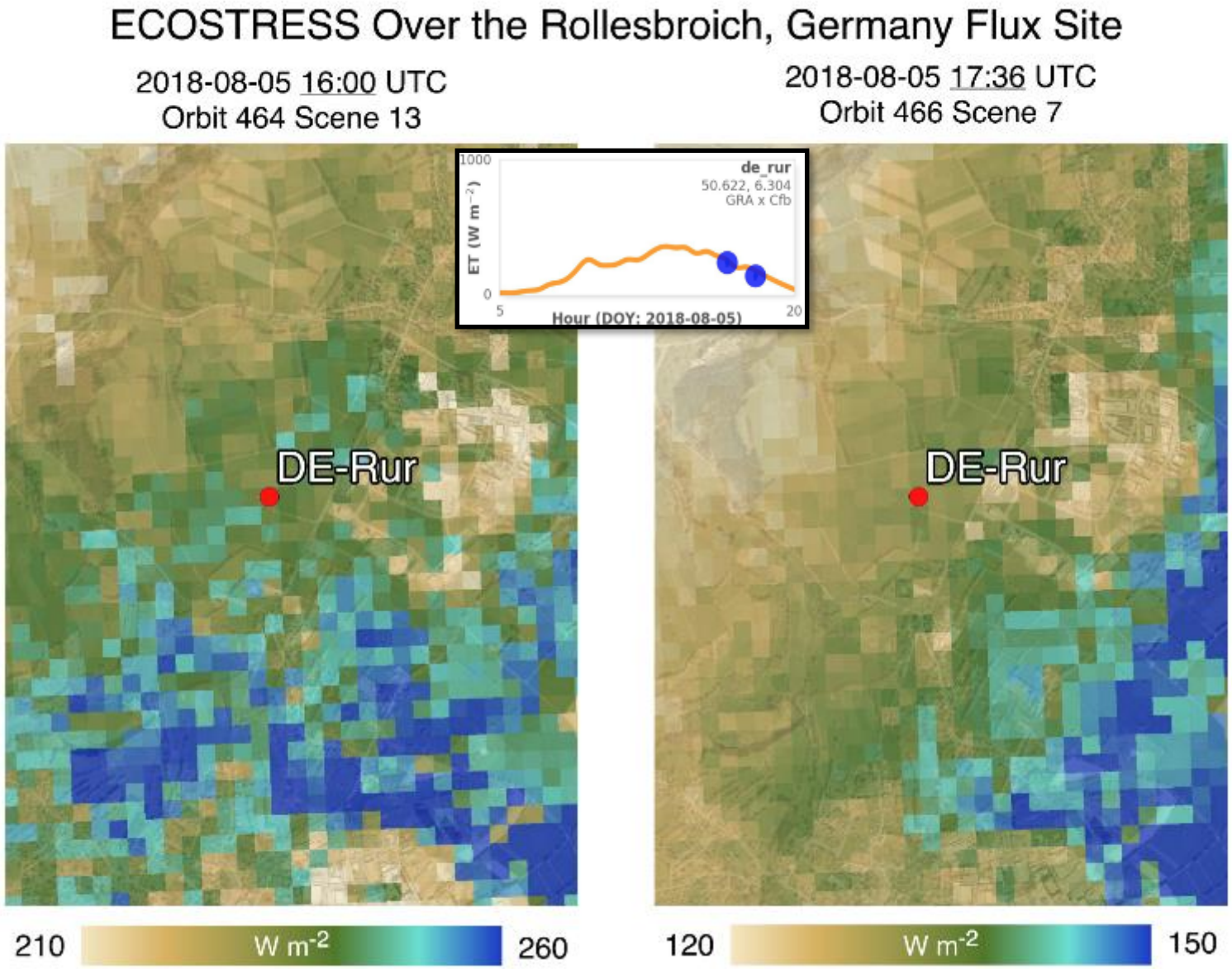
Evapotranspiration – Different times of day

ORANGE line shows measurements at ground FLUXNET sites and **BLUE** dot shows retrieved ECOSTRESS ET values throughout the day.



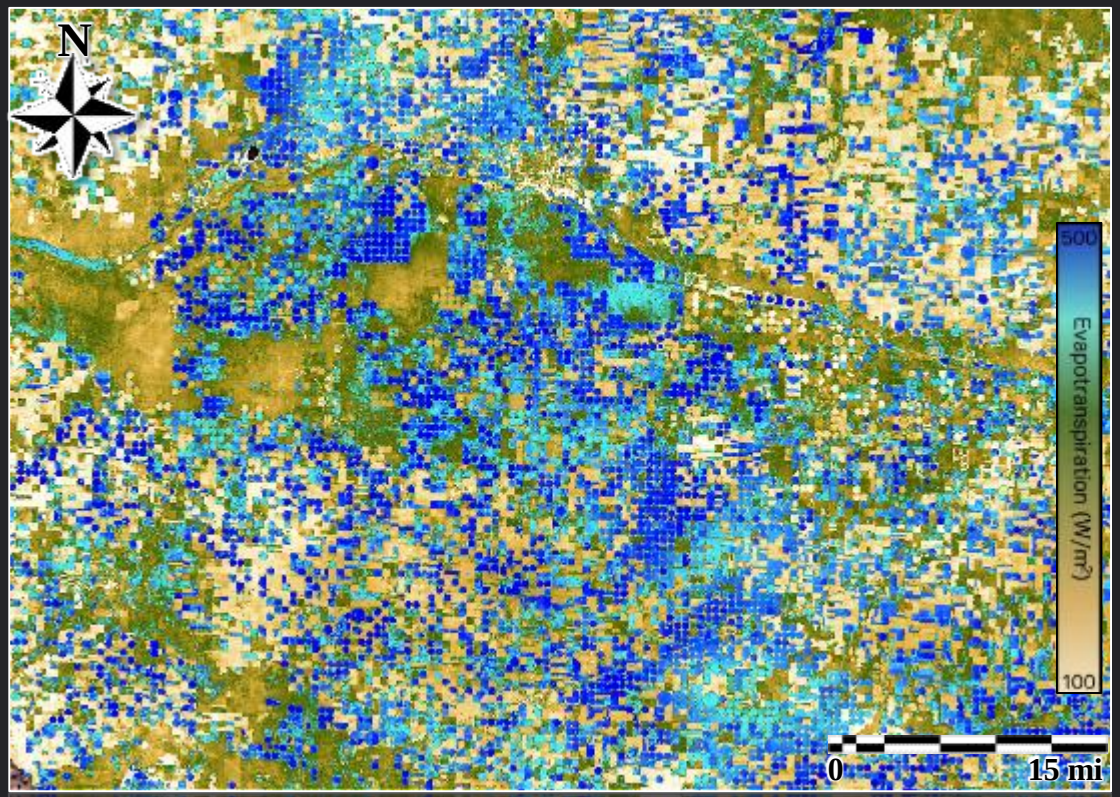
Courtesy J.B. Fisher Science Lead

Recent Results over Germany



ECOSTRESS

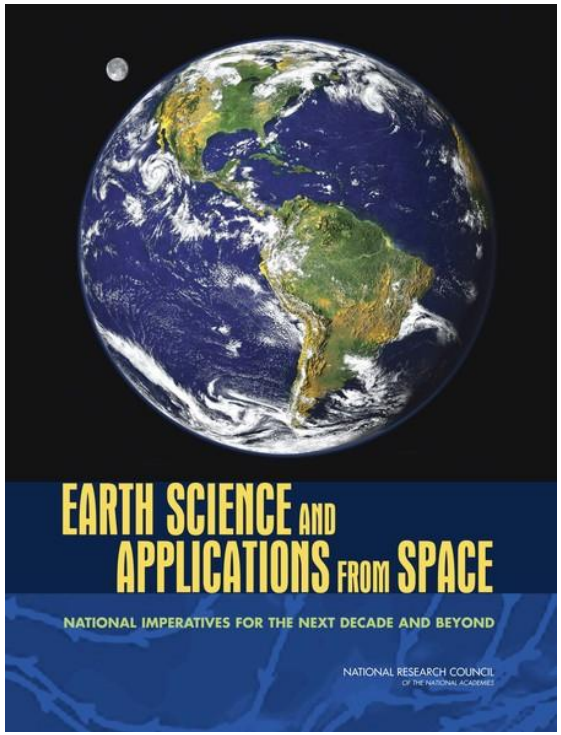
- Selected July 30, 2014
- Launched June 29, 2018 to the ISS
- Began operations August 20, 2018
- 30 M$ Cost Capped, on schedule, on budget
- Acquired 17,705 400 x 400 km scenes as of 3/14/19
- First use of WiFi for a science mission
- Delivers L1-L4 products
- More information at: https://ecostress.jpl.nasa.gov



ECOSTRESS evapotranspiration image over Garden City, Kansas USA | Center pivot irrigation dominates the landscape with circular patterns distributed across this Kansas community. Blue circles and squares indicate recently irrigated fields.

HyspIRI to SBG

HyspIRI
Free-flyer



2007

ECOSTRESS
Launched 2018

EMIT
Launch 2021

SBG
TBD

2017

Decadal Survey Implementation

TABLE S.2 Observing System Priorities

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, and Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

Summary

- 2007 First Decadal Survey released – recommended HyspIRI as Tier II mission
- 2008 and 2010 HyTES and PHyTIR developed as part of risk reduction for HyspIRI
- 2014 ECOSTRESS (using PHyTIR) selected in Earth Ventures 2 and launched on ISS in 2018
- 2017 Second Earth Science Decadal Survey released – recommended Surface Biology and Geology Mission for early implementation.
- 2018 EMIT selected in Earth Ventures 4 for launch on ISS in 2021
- 2018 NASA Hq establishes SBG team