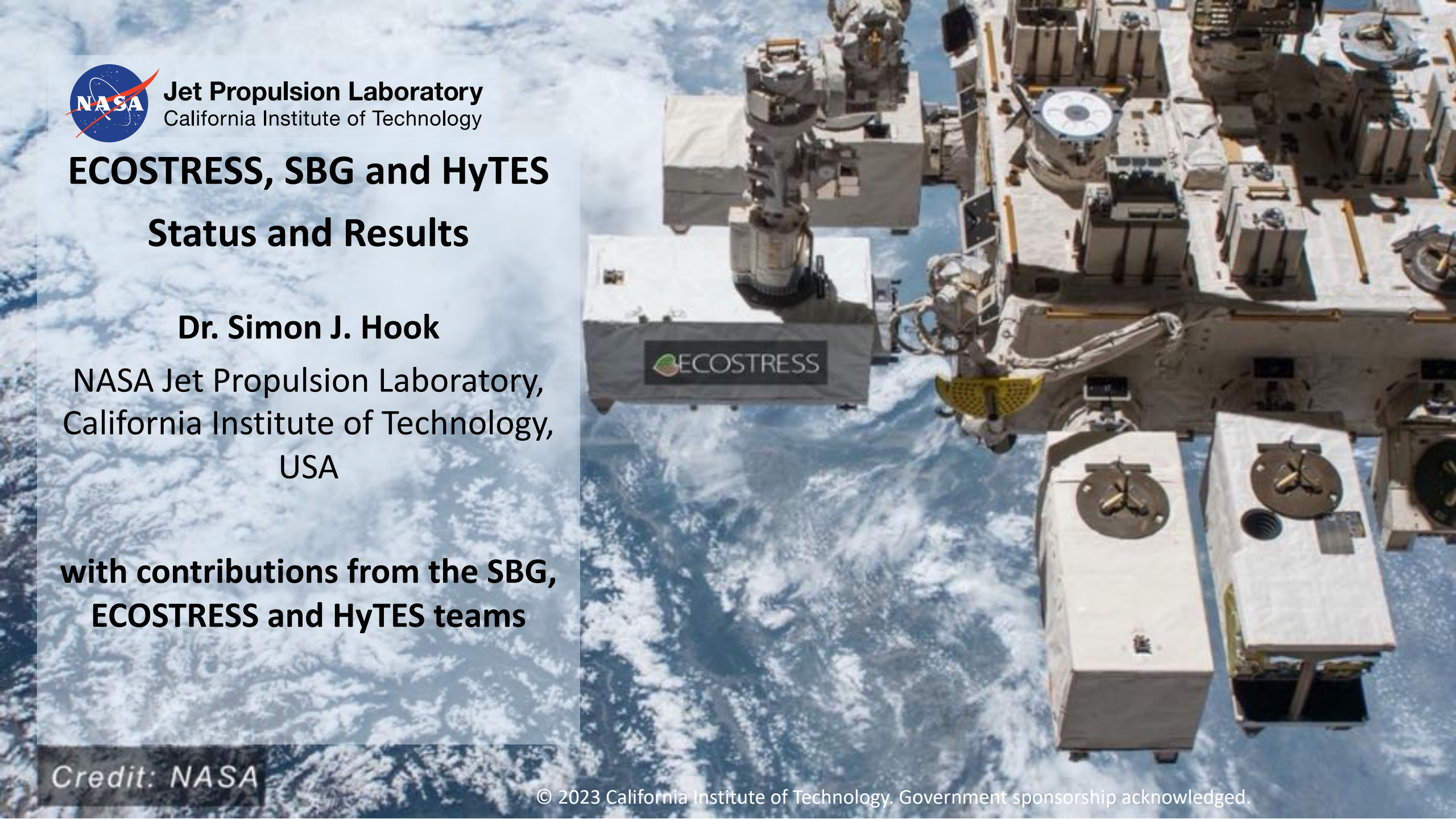


Jet Propulsion Laboratory
California Institute of Technology

ECOSTRESS, SBG and HyTES

Status and Results

Dr. Simon J. Hook

NASA Jet Propulsion Laboratory,
California Institute of Technology,
USA

with contributions from the SBG, ECOSTRESS and HyTES teams

Credit: NASA

Outline

- ECOSTRESS Update
- SBG Update
  - Science
  - The Earth System Observatory
  - The SBG Decadal Observable and its elements
  - Measurement requirements
  - Instrumentation
  - The ASI-JPL SBG-TIR element
- The 2023 HyTES European Campaign

The talk will cover a lot of material, feel free to ask for more information on any of the topics during the week.

ECOSTRESS Project Overview

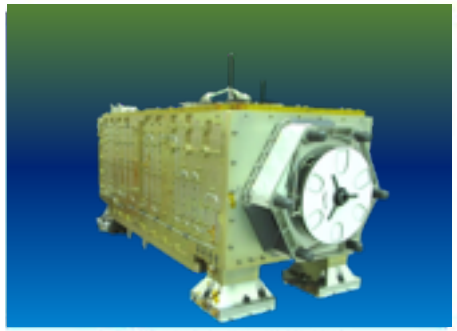
Salient Features

- *Category: 3, Risk Class: D*
- *8–12.5 µm radiometer with a 400km swath, 69 x 38 m resolution*
- *Measure brightness temperatures of Earth in 5 spectral bands*
- *Launched on SpX-15 on June 29, 2018*
- *Deployed on the ISS on JEM-EFU 10*
- *Baseline Operations: 1 year after 30 days on-orbit checkout*
- *Prime Mission Completed August 19, 2019*
- *In 2019 Phase E extended until September 2023*
- *In 2023 Phase E extended until 2029*

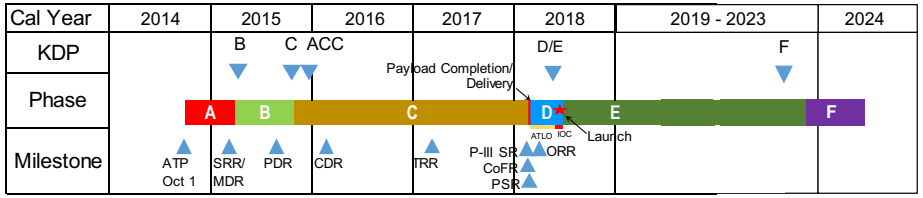
Original Science Goals

- *ECOSTRESS will measure the temperature of plants and use that information to better understand how much water plants need and how they respond to stress via high spatiotemporal resolution thermal infrared measurements of evapotranspiration from the International Space Station (ISS).*
- *ECOSTRESS will:*
  - *Identify critical thresholds of water use and water stress in critical plant 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*

ISS JEM-EF


ECOSTRESS


Falcon-9



ECOSTRESS Mission Lifecycle

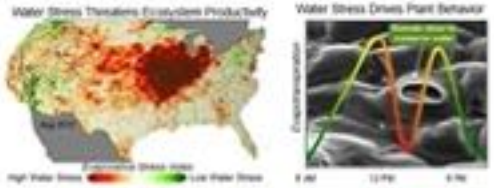
Radiometer Instrument

Payload

Dragon-Trunk Falcon-9 LV

Installation on JEM-EF

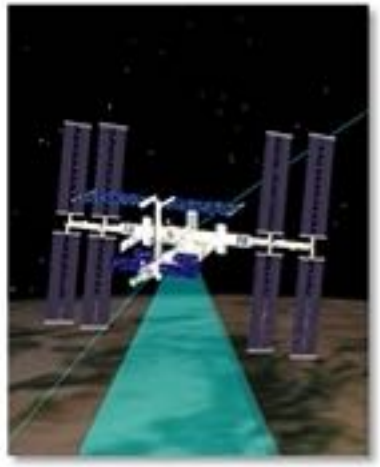
Science Data Processing and Archive



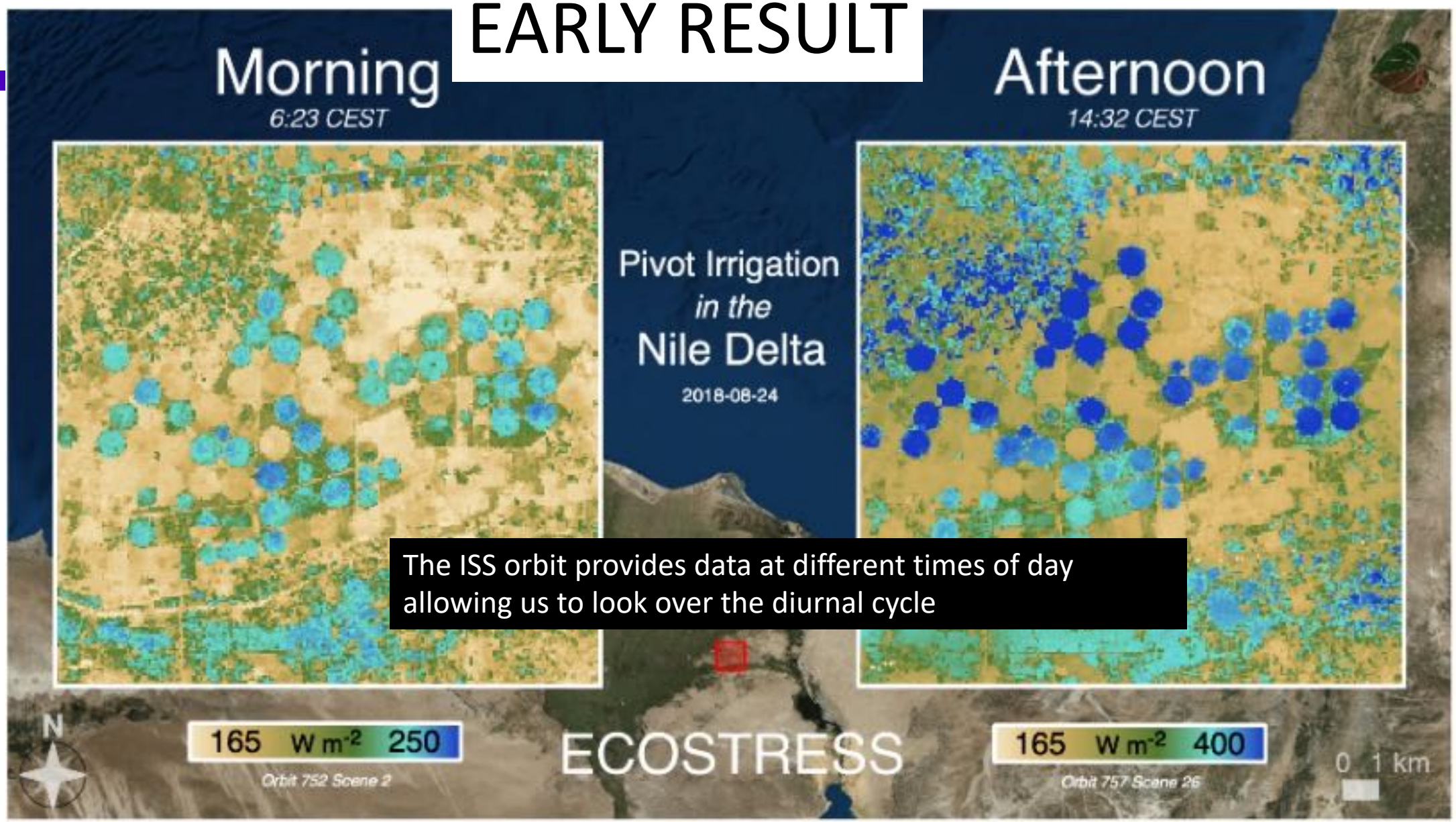
EOL Payload disposal via Dragon Trunk re-entry

MOS and Ground and Space Network

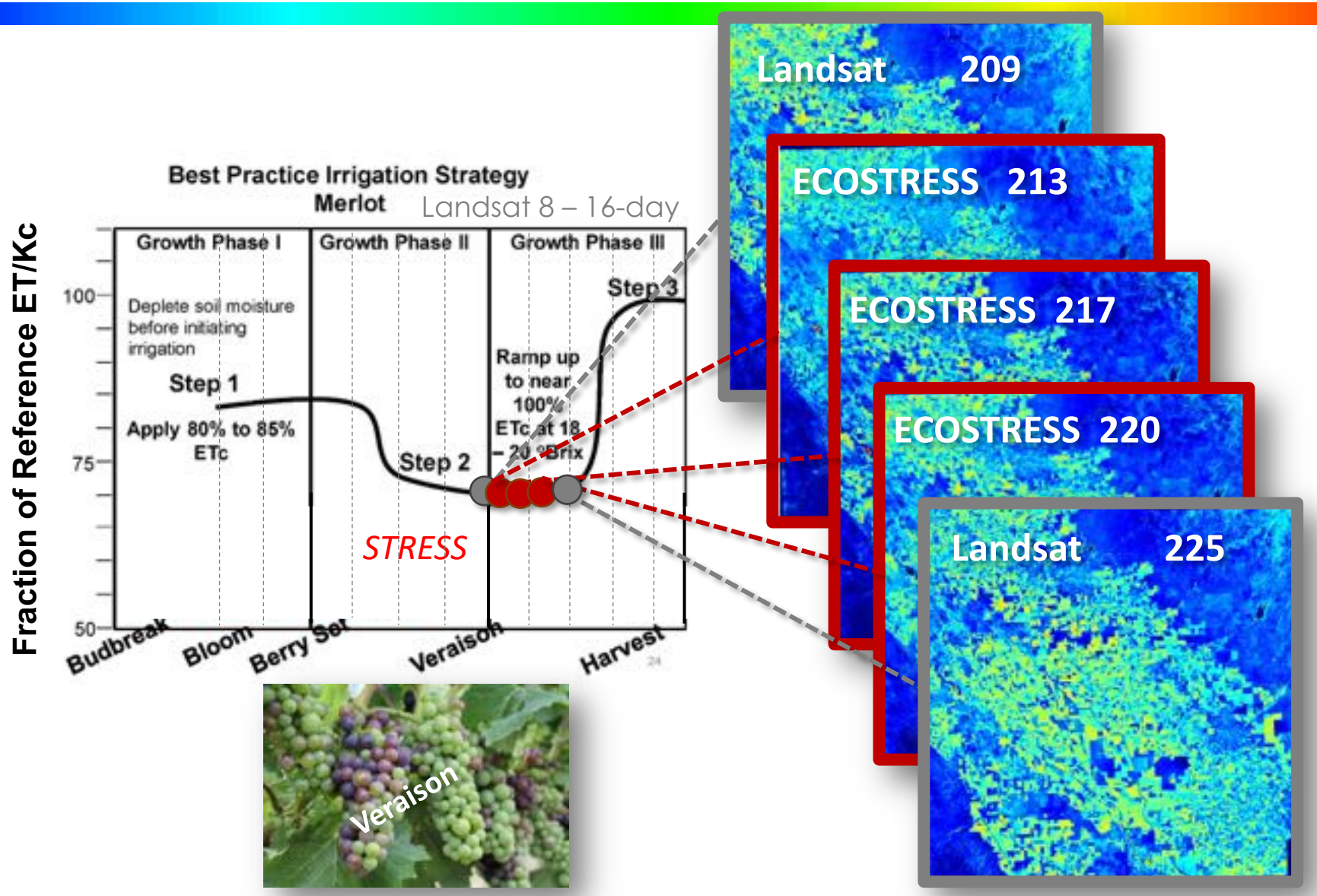
Data Collection



EARLY RESULT



ECOSTRESS enables precision irrigation for high quality Merlot



Credit: M. Anderson

ECOSTRESS used to deliver irrigation advisories to farmers

"Bringing ECOSTRESS Information to farmers" - Irriwatch CEO Wim Bastiaanssen

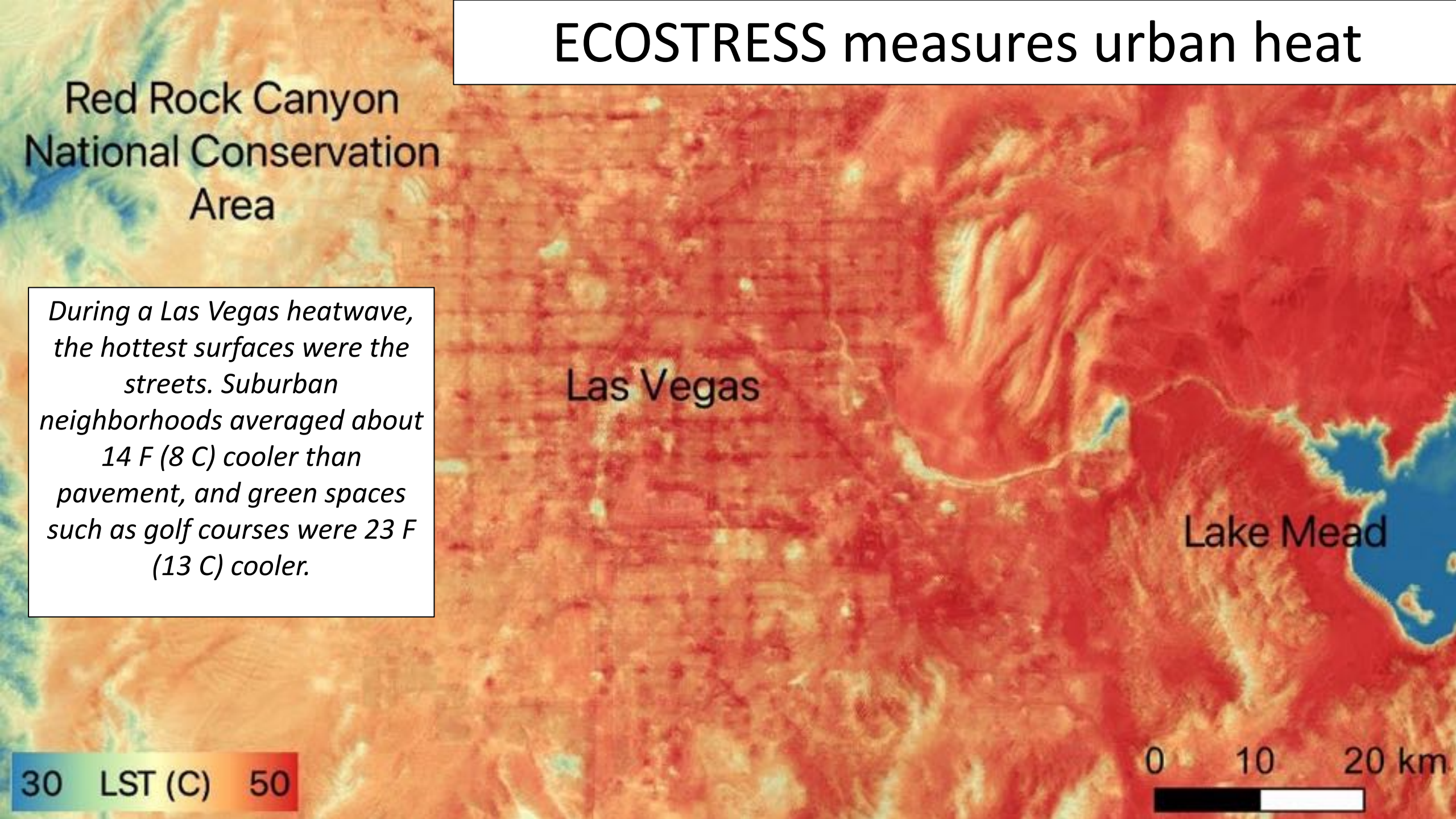
Irriwatch integrates ECOSTRESS data into high quality estimates of water use and delivers irrigation advisories to over 18,000 fields in 25 countries around the world.

Pixel: Min Adviced Water (mm/d)

0.00
6.00
12.00
18.00
24.00
30.00

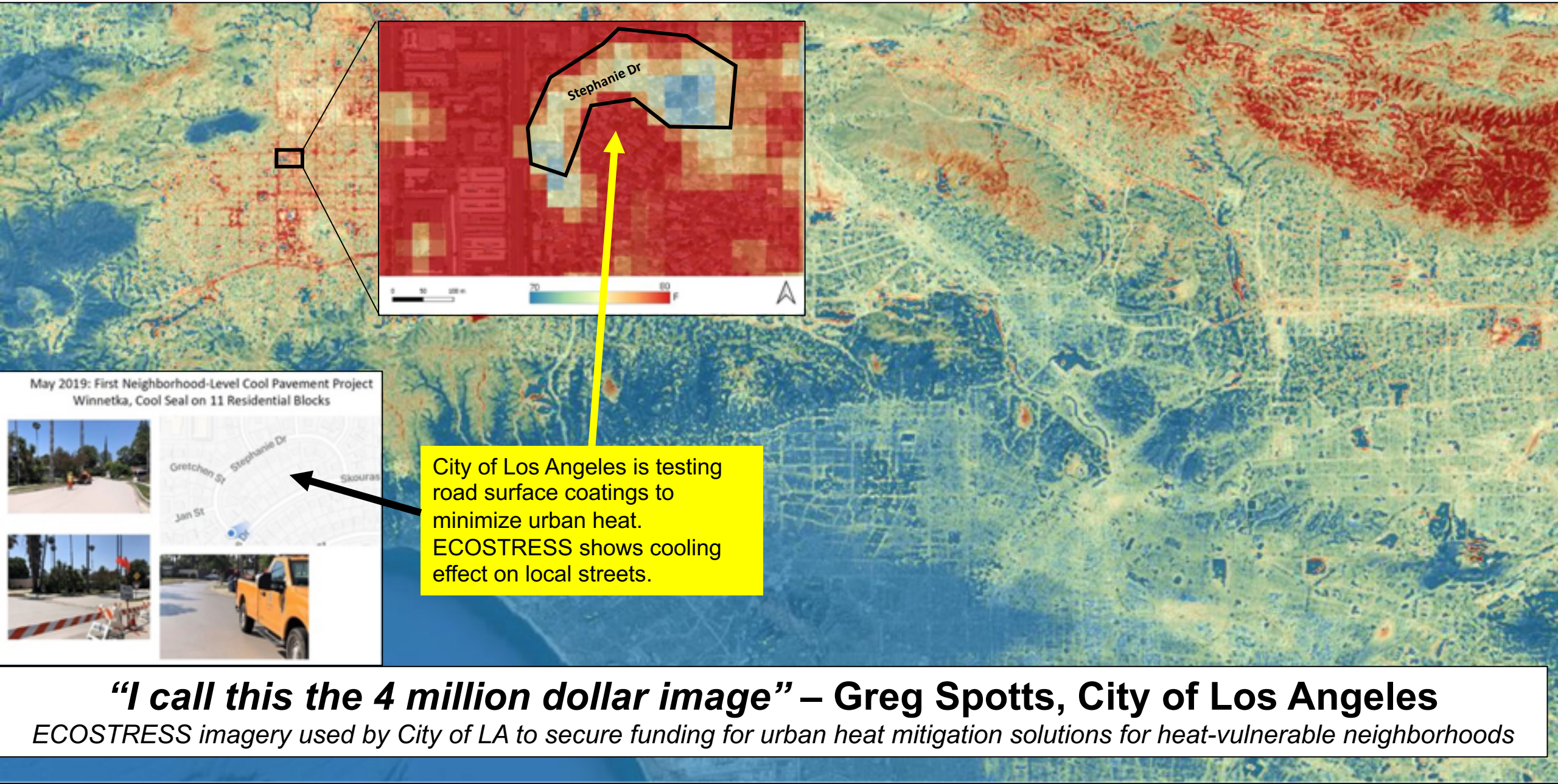
IrriWatch

ECOSTRESS measures urban heat



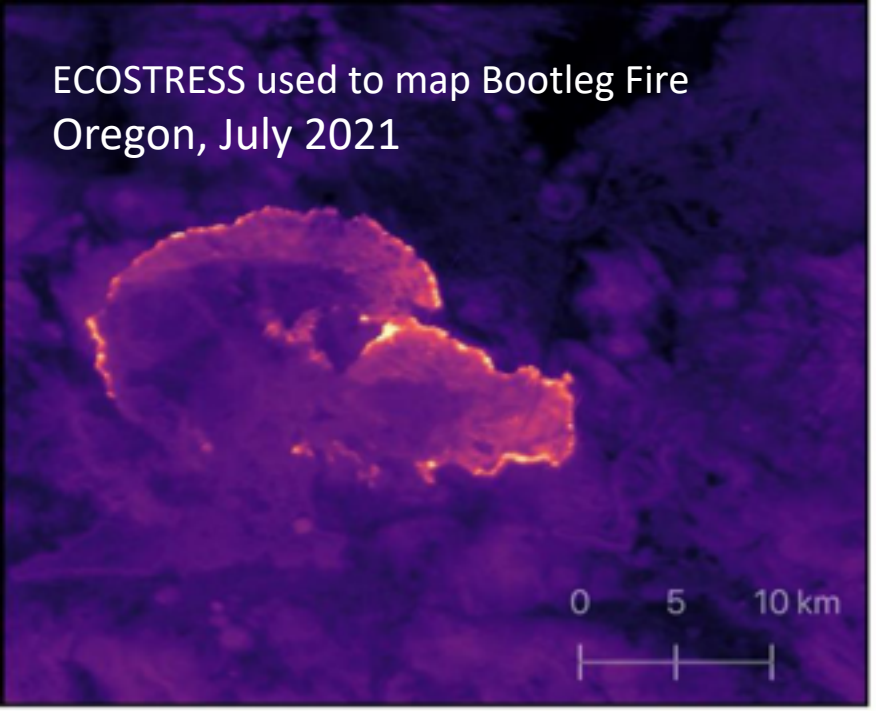
During a Las Vegas heatwave, the hottest surfaces were the streets. Suburban neighborhoods averaged about 14 F (8 C) cooler than pavement, and green spaces such as golf courses were 23 F (13 C) cooler.

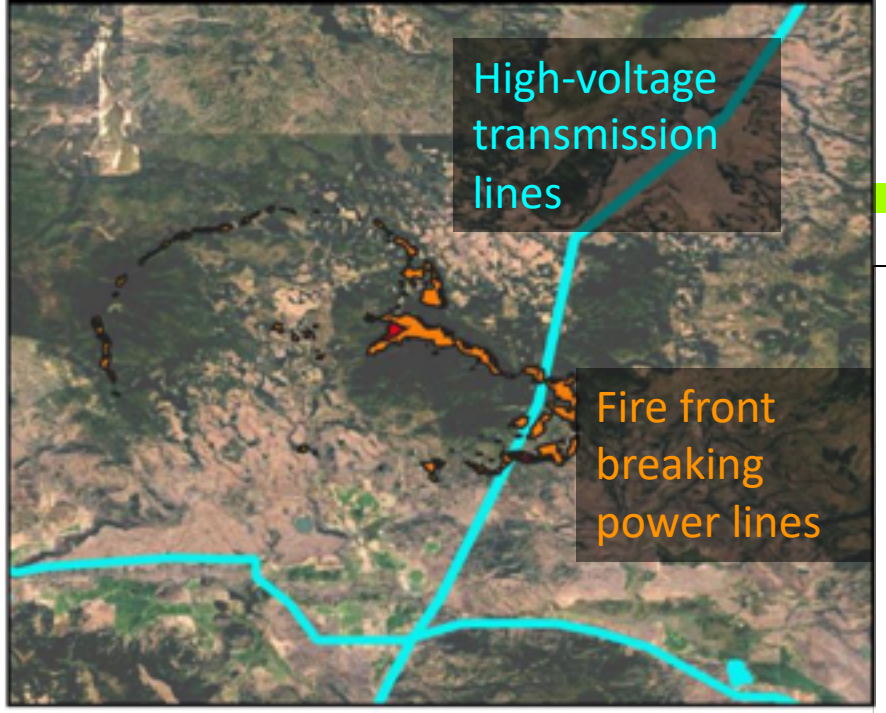
The City of Los Angeles is using ECOSTRESS to identify hotspots and quantify the effects of heat mitigation strategies such as cool roads

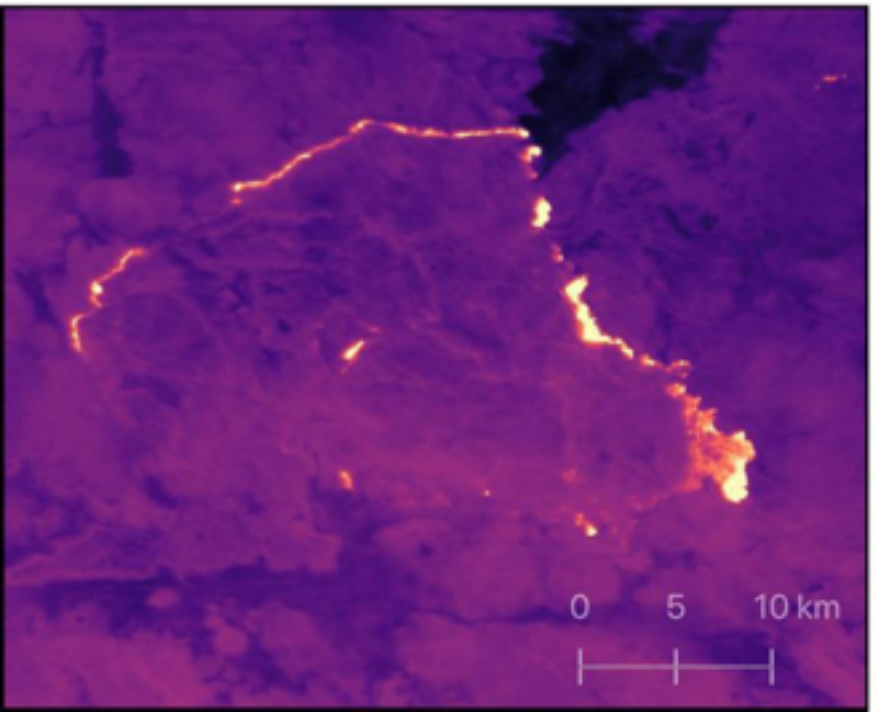


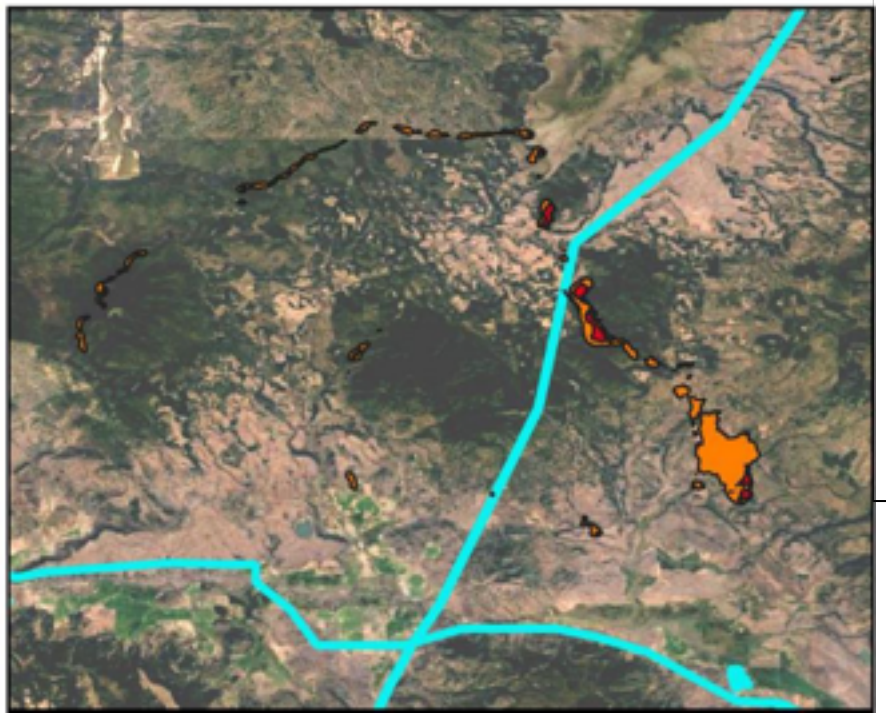
***"I call this the 4 million dollar image"* – Greg Spotts, City of Los Angeles**

ECOSTRESS imagery used by City of LA to secure funding for urban heat mitigation solutions for heat-vulnerable neighborhoods









"ECOSTRESS allows us to use the [fire maps] from last night in the morning…this is what's required if you're going to put data into the hands of incident commanders." -- USGS podcast with PNNL and USFS

ECOSTRESS imagery is integrated into an operational active fire response tool by PNNL to support USFS fire operators and responders.

10

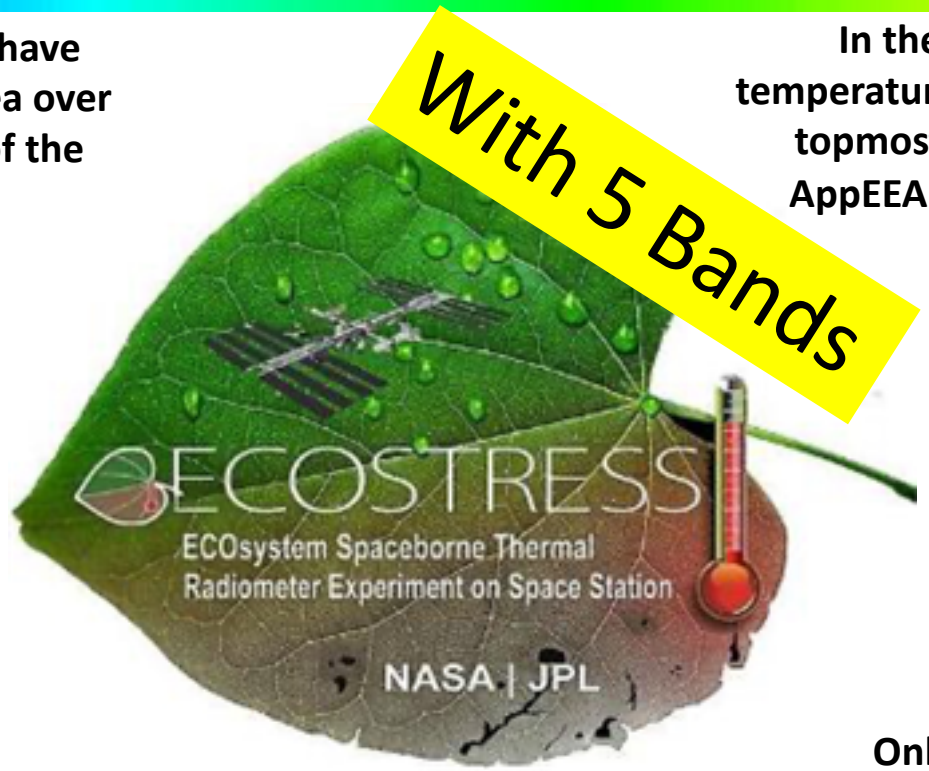
ECOSTRESS Data: Quick Facts and Stats

As of 4/2/2023 350,000+ scenes have been acquired since launch, an area over several hundred times the area of the Earth's land surface

ECOSTRESS now has 350+ science publications

We originally planned to acquire an average of 74 scenes per day but have now acquired an average of 221 scenes per day.

We originally planned to acquire ~27,000 scenes over a 1-year Mission and have now acquired 300,000+ scenes.



ECOSTRESS is on the ISS manifest through 2028!

In the last quarter, ECOSTRESS surface temperature and evapotranspiration were among topmost requested products from LP DAAC AppEEARS which hosts MODIS and Landsat products

Highest spatial resolution multispectral thermal infrared radiometer NASA has ever built

Highest temporal resolution of high spatial resolution thermal infrared sensors

Only spaceborne instrument capable of providing data suitable for evaluating data for the Decadal Survey SBG TIR mission.

ECOSTRESS IS WORKING WELL WE ARE READY TO CONTINUE THROUGH 2029

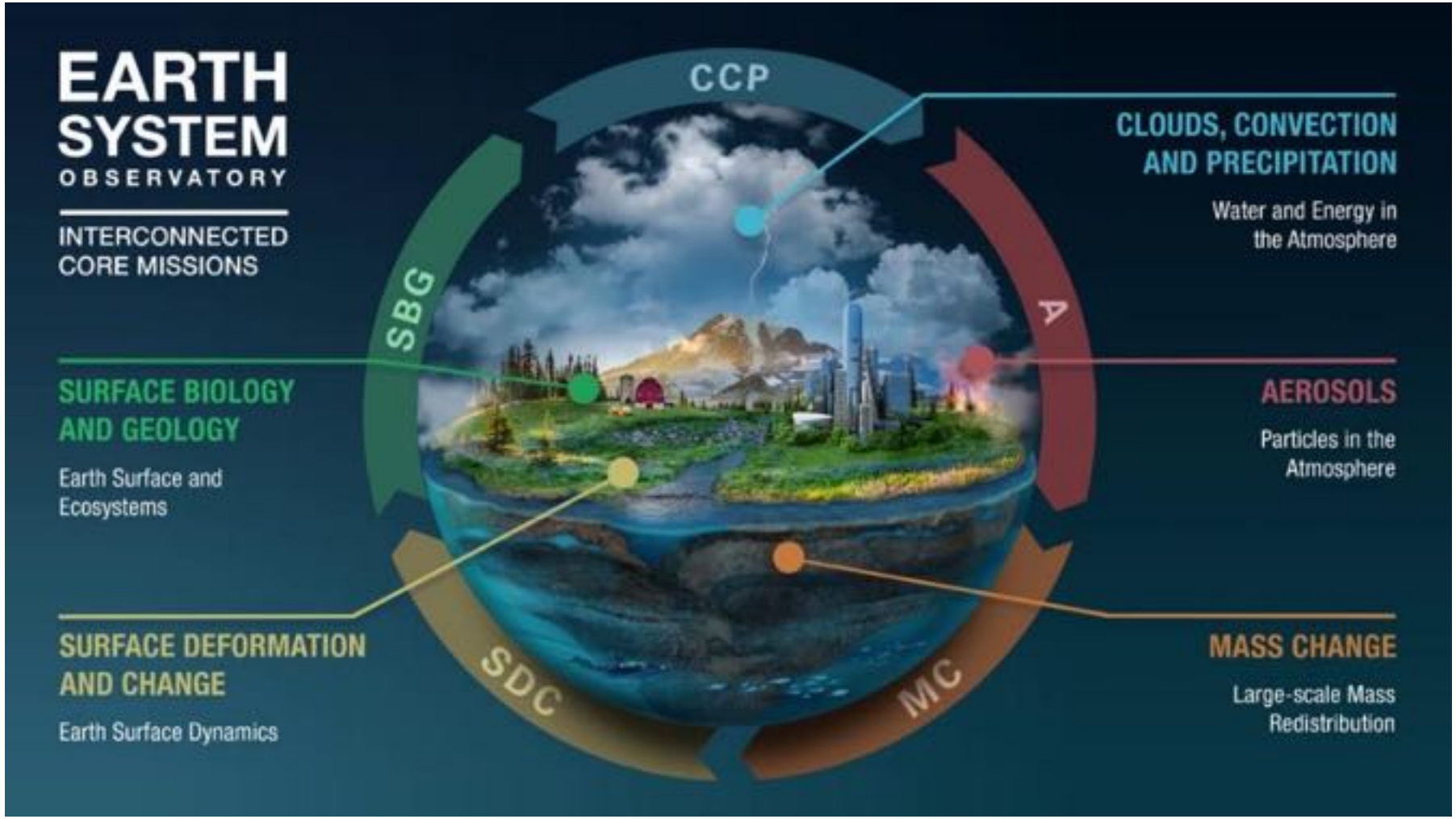
Science

In 2017 Earth Science Decadal Survey Recommends Decadal Observables:

- Aerosols-Clouds, Convection &Precipitation (ACCP)
- Surface Biology and Geology (SBG)
- Mass Change (MC)
- Surface Deformation and Change (SDC)
  - Expected to begin development later in decade

In June 2021 NASA announced the new Earth System Observation with 4 main anchor tenants: NISAR, A-CCP, **SBG** and MC

Earth System Observatory (ESO)



[Credit: National Aeronautics and Space Administration (NASA)]

ESO was created in May 2021

Research Objectives and Priorities

HYDROLOGY

H-1. How is the water cycle changing?

H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally and globally.

H-4. Hazards, extremes, and sea level rise. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events.

WEATHER

W-3. How do special variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia and water) modify transfer between domains?

ECOSYSTEMS AND NATURAL RESOURCES

E-1. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space?

E-2. What are the fluxes of carbon, water, nutrients, and energy between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?

E-3. Fluxes within ecosystems. What are the within ecosystems, and how and why are they changing?

CLIMATE

C-3. How large are the variations in the global carbon cycle and what are the associated climate and ecosystem impacts?

SOLID EARTH

S-1. How can large-scale geological hazards be accurately forecast in a socially relevant time frame?

S-2. How do geological disasters directly impact the Earth system and society following an event?

SBG: DECADAL SURVEY MOST AND VERY IMPORTANT RESEARCH OBJECTIVES ACROSS ALL FIVE DS FOCUS AREAS

Applications Objectives and Priorities

AGRICULTURE, FOOD SECURITY AND SURFACE WATER MANAGEMENT

Improve "crop per drop" by assessing vegetation water stress over irrigated agriculture

Improve water supply management through better characterization of snow properties and estimated reservoir inflows

Reduce the impacts of drought, such as crop loss and famine, on global scales

WATER QUALITY AND COASTAL ZONES

Support early detection of and response to harmful algal bloom formation

Protect sensitive aquatic habitats by monitoring/reducing water pollutant loading, particular in coral reefs and other sensitive ecosystems

Water surface temperature and impacts on marine biodiversity

CONSERVATION

Support biodiversity understanding and protections by mapping invasive species composition, structure, distribution; support removal and restoration efforts

Monitoring of endangered species habitat; provide alerts of disease mortality of impacted vegetation, including insect infestation

Biodiversity hotspots and priority conservation areas, 30 x 30 plans

WILDFIRE RISK AND RECOVERY

Fuel mapping (cover type, extent, status) for wildfire danger management

Post fire severity assessment and recovery, including prediction of areas with higher likelihood of debris flows

DISASTERS AND NATURAL HAZARDS

Detect and track oil spill events and

Support active fire mapping and response

Improve mitigation of heat wave events for vulnerable populations

GEOLOGY APPLICATIONS

Mineral mapping for exploration efforts and reduction of environmental hazards

Forecast aviation hazards and support emergency response for volcanic eruptions

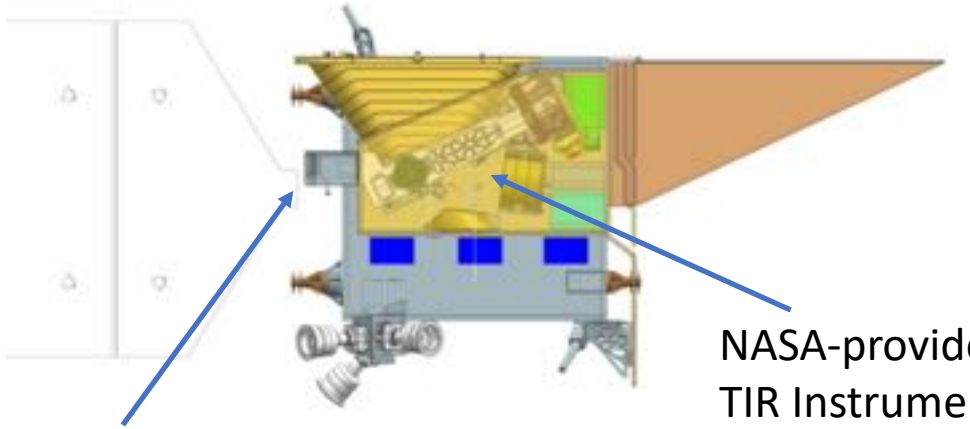
Landslide risk assessment with improved substrate map land cover maps

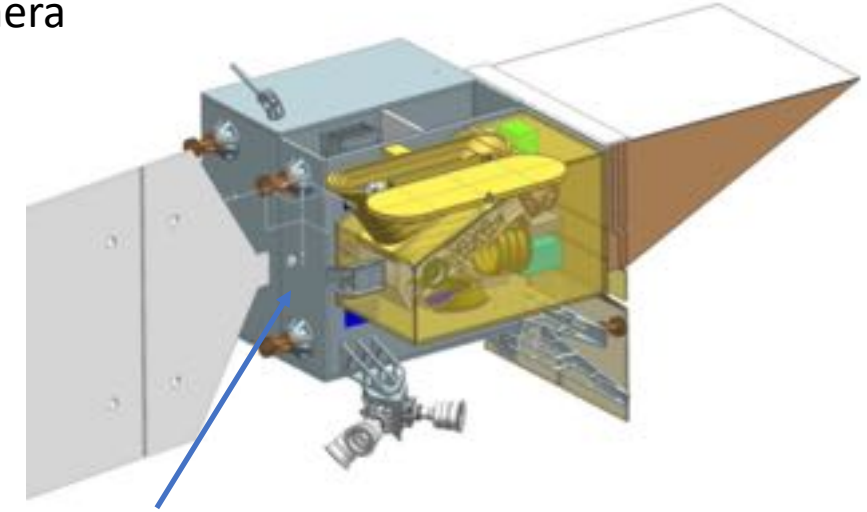
SBG: DECADAL SURVEY APPLICATION OBJECTIVES ACROSS ALL FIVE DS FOCUS AREAS

SBG TIR Key Instrument Parameters

Key Parameters	SBG-TIR
Number of satellites	1
Combined revisit (days)	≤ 3 (different obs. angles)
Nominal Altitude (km)	665
Orbit cycle (days)	3
GSD (nadir/edge of scan) (m)	TIR: ≤60 /93, VNIR: ≤30 /52*
FOV (degrees)	± 34.4
Swath (km)	935
Coverage	Land and Coastal
Day/Night	Day + Night
LTDN	12:30
LWIR bands (8-12 µm)	6
VNIR/SWIR/MWIR	2/0/2
Accuracy (K)	0.5
NeDT (K)	<0.2
Data latency (hours)	<24

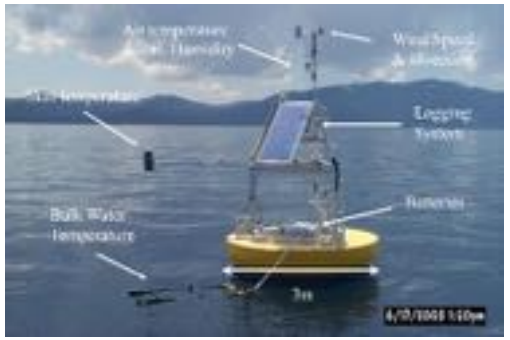
* Based on angle will be less when combine with mask

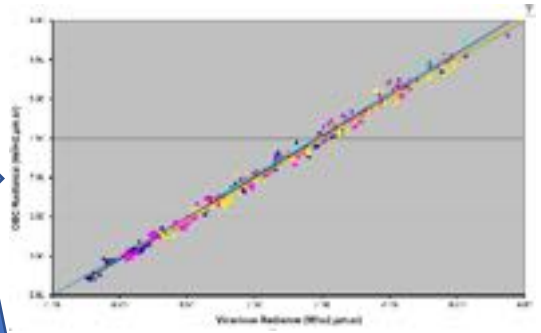


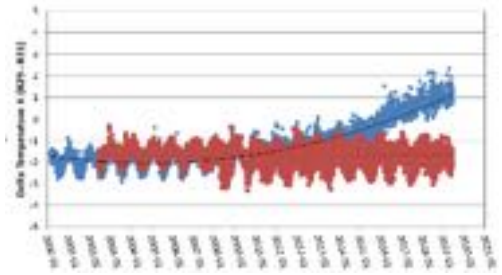


Calibration and Validation

- Developing a suite of sites with the necessary instrumentation to calibrate and validate the data and products for SBG based on existing sites.
- Existing sites are used as reference standards for numerous domestic and international aircraft and satellite hosted instruments.

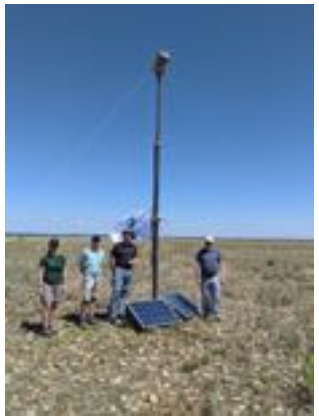






Tonzi Ranch

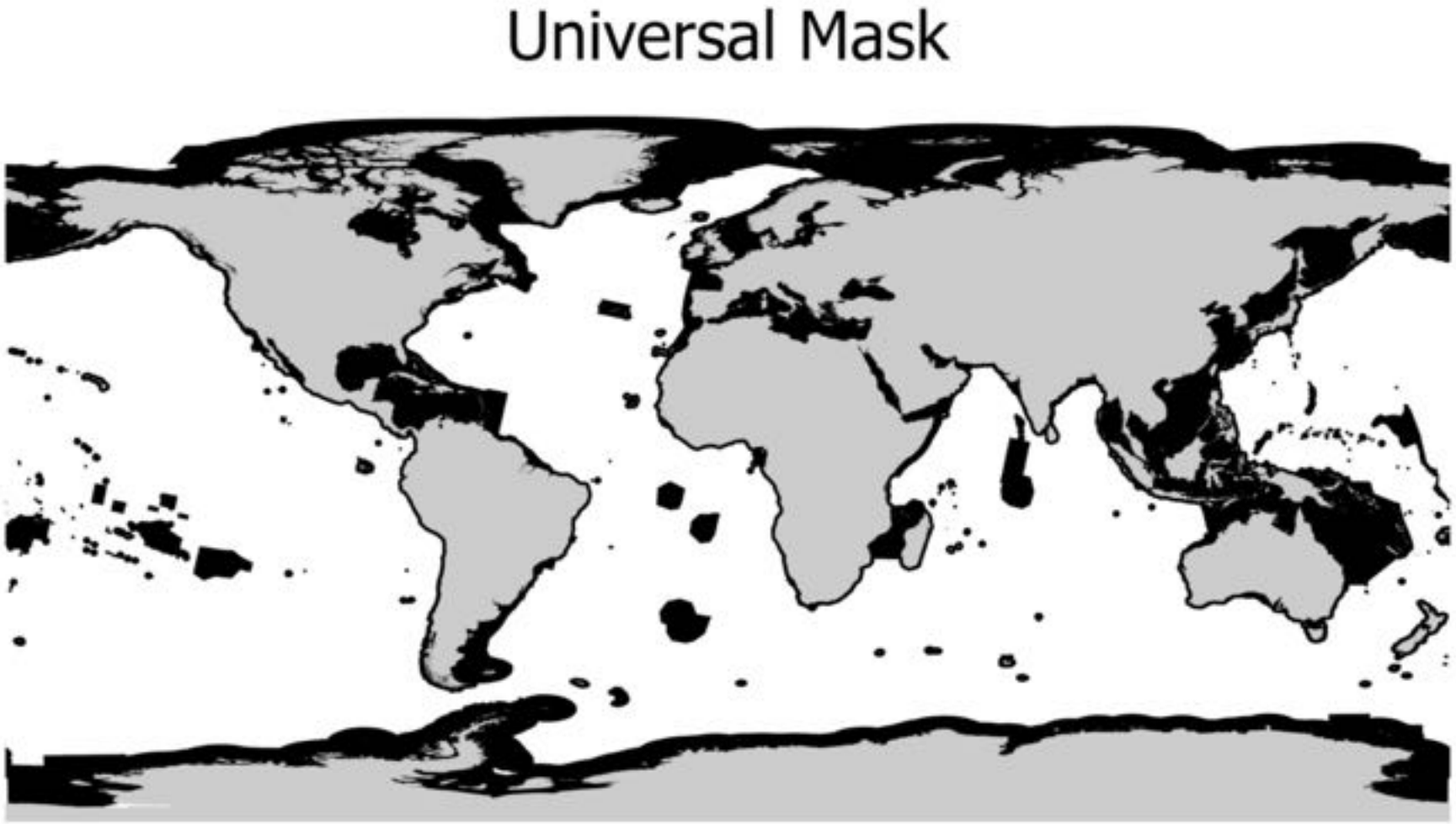
Russell Ranch



La Crau

Venice Lagoon

Developed Universal Mask – Combination of SBG, TRISHNA and LSTM Masks

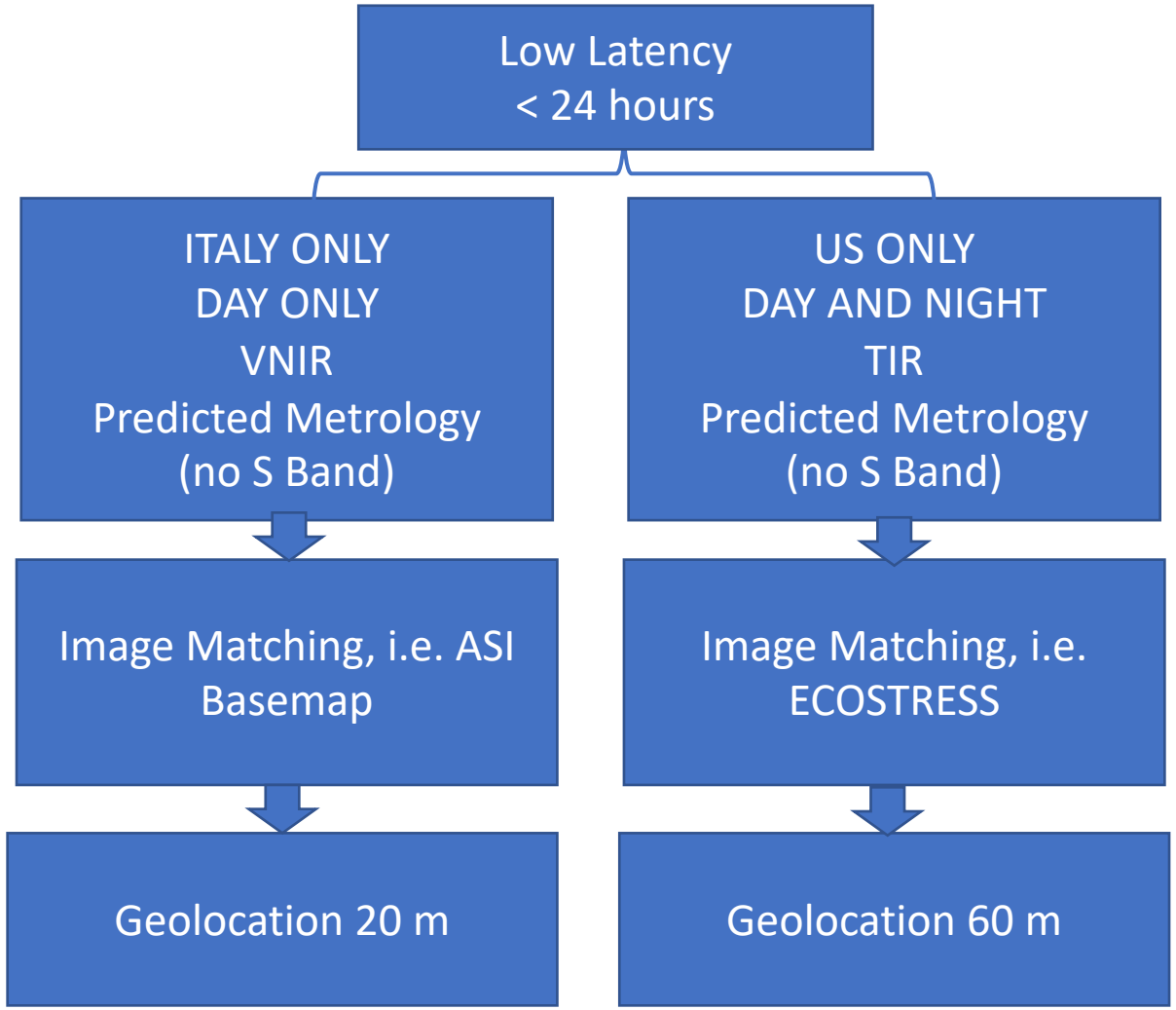


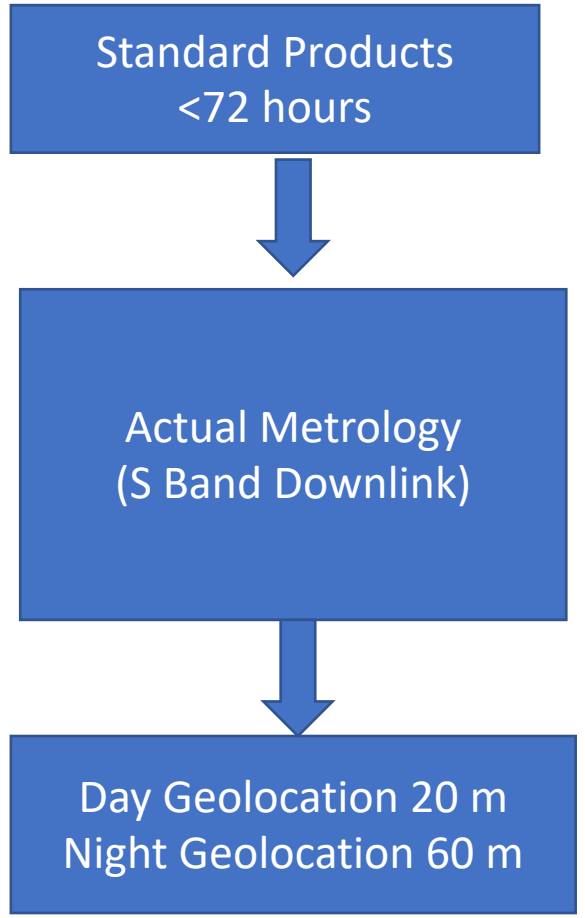
Masks and Downlinks – MCR

Can be tuned as needed

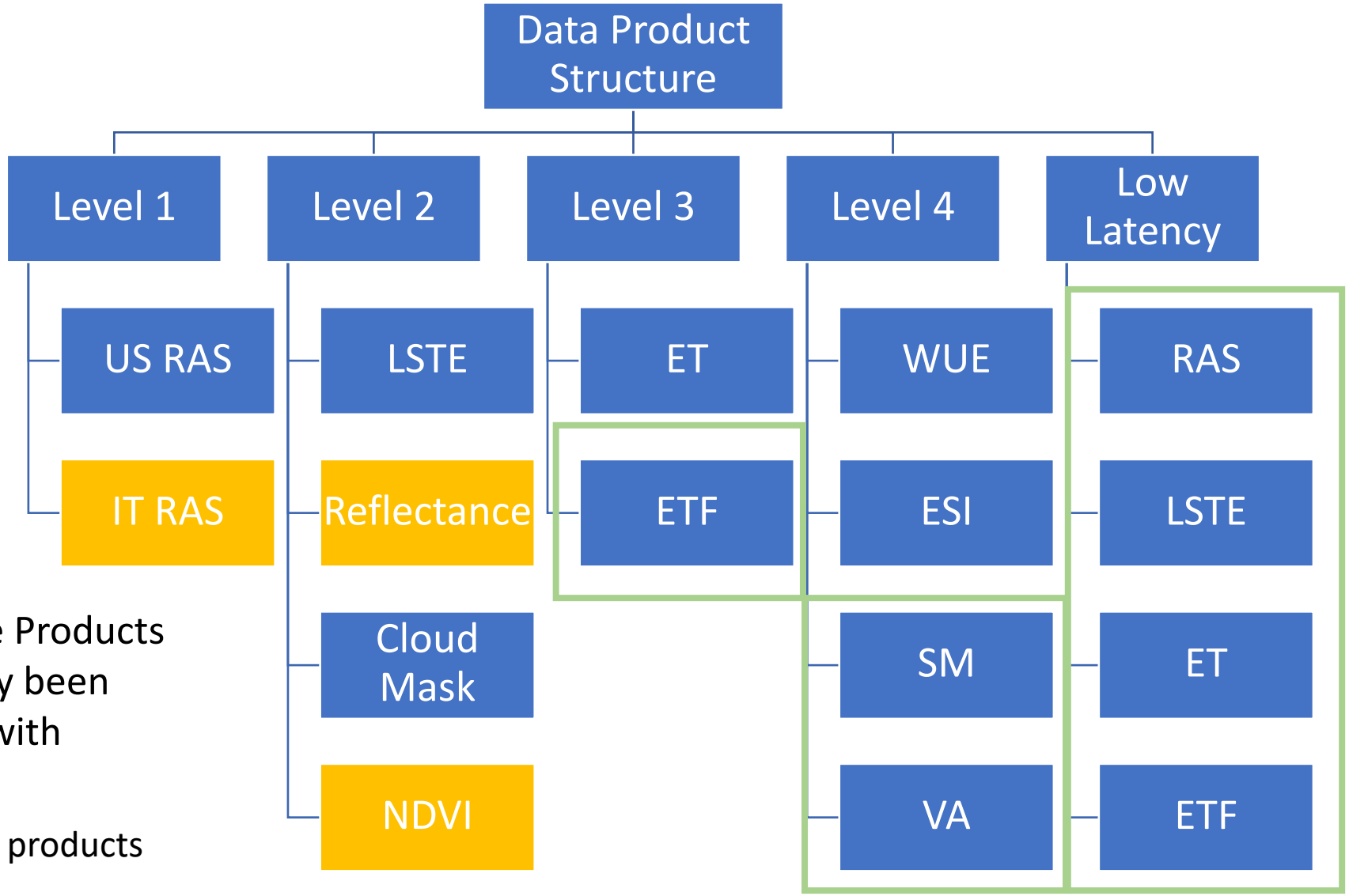
Assumptions / Considerations	
Mask	Universal mask, same mask for VNIR and TIR but can use different masks
Culling	Only collect every other pass over poles. Apply above 60 N and below 60 S.
Compression	VNIR – 3:1 lossy, TIR 2.3:1 lossless (proven with ECOSTRESS)
Solar elevation	Daytime = greater than 20 degrees
Number of bands	Download 8 TIR bands day and night. Download 2 VNIR bands during day
Ocean resampling	Included, currently set at 1 km
Minimum strip length	2 seconds
Stations	Exact number of stations to be determined
Recorder	2 Terrabit
Spacecraft downlink	Spacecraft can downlink and record at the same time

Data Products and Latency





TIR Science Product Organization



Many of the Products have already been developed with ECOSTRESS

Italian products

New products

ACRONYMS

RAS – Radiance at Sensor

LSTE – Land Surface Temperature and Emissivity

NDVI – Normalized Difference Vegetation Index

STiC – Surface Temperature Initiated Closure

ETF – Elevated Temperature Features

WUE – Water Use Efficiency

ESI – Evaporative Stress Index

VA – Volcanic Activity

SM – Surface Mineralogy

VNIR and TIR Standard Products

Product Name	Joint Product	Product Level	Tiled	Requires TIR and VNIR	Day/Night
SBG Swath Top of Atmosphere TIR Calibrated Radiance Instantaneous L1B Global 60 m**	N	L1B	N	N	D and N
SBG Tiled Top of Atmosphere VNIR/TIR Calibrated Radiance Instantaneous L1C Global 30/60 m	Y	L1C	Y	Y	D and N(night does not require VNIR)
SBG Tiled Surface Temperature and Emissivity Instantaneous L2 Global 60 m	Y	L2	Y	Y	D and N (night does not require VNIR)
SBG Tiled Cloud Mask Instantaneous L2 Global 60 m	Y	L2	Y	Y	D and N(night does not require VNIR)
SBG Tiled Elevated Temperature Features L3 Global 60 m	Y	L3	Y	Y	D and N
SBG Tiled ET Suite L3/4 Global 60 m (Joint product)	Y	L3/4	Y	Y	D
SBG Tiled Volcanic Activity L4 Global 60 m	Y	L4	Y	Y	D and N
SBG Tiled Surface Composition L3/L4 Global 60 m	Y	L4	Y	Y	D and N

TOA Calibrated Radiance in cartographic geometry - 30 m	N	L1C	Y	N	D
TOA Reflectance in cartographic geometry (from L1C) - 30 m	N	L2	Y	N	D
BOA Reflectance in cartographic geometry (from L1C) - 30 m	N	L2	Y	N	D
NDVI (from BOA Reflectance) - 30 m	N	L2	Y	N	D

- A Joint Product is one that includes the VNIR data
- ** These products will also be provided as geolocated swath products
- Low latency and Standard data products and always generated by project.
- Low latency products require only data from one of the SBG TIR or VNIR cameras, with no ancillary data. We will demonstrate the capability to make low latency available in 24 hours. Low latency LST uses GMAO meteorology.

VNIR and TIR Low Latency Products

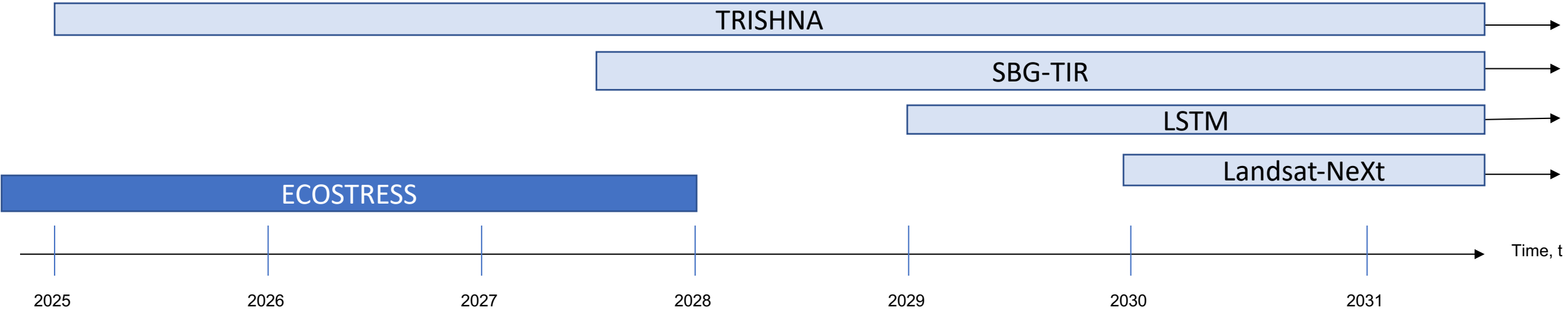
Product Name	Joint product	Product Level	Tiled	Requires TIR and VNIR	Day/Night
Swath Top of Atmosphere TIR Calibrated Radiance Instantaneous L1 Global 60 m**	N	L1	Y	N	D and N
Tiled Surface Temperature and Emissivity **Low Latency** Instantaneous L2 Global 60 m	N	L2	Y	N	D and N
Tiled Cloud Mask **Low Latency** Instantaneous L2 Global 60 m	N	L2	Y	N	D and N
Tiled Elevated Temperature Features **Low Latency** Instantaneous L3 Global 60 m	N	L3	Y	N	D and N
Tiled ET **Low Latency** Instantaneous L3 Global 60 m	N	L3	Y	N (uses LL STARS)	D only

TOA Calibrated Radiance - 30 m	N	L1B	Y	N	D
TOA reflectance (from L1B) - 30 m	N	L2	Y	N	D
NDVI (from L1B) - 30 m	N	L2	Y	N	D

- A Joint Product is one that includes the VNIR data
- ** These products will also be provided as geolocated swath products
- Low latency and Standard data products and always generated by project.
- Low latency products require only data from one of the SBG TIR or VNIR cameras, with no ancillary data. We will demonstrate the capability to make low latency available in 24 hours. Low latency LST uses GMAO meteorology.

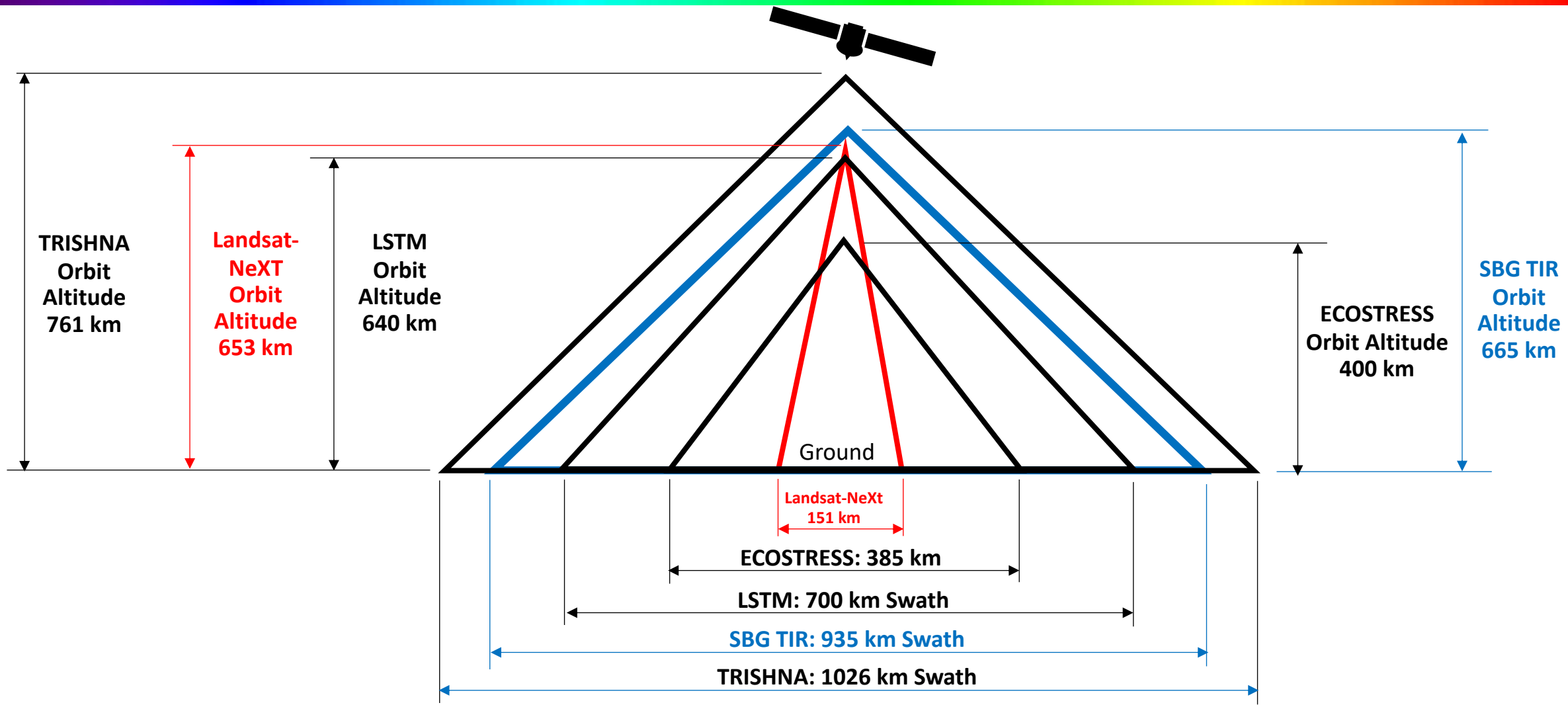
International Partnerships and Data Continuity

TRISHNA, SBG-TIR and LSTM are staggered in order to produce a continuous record for climate studies and applications. TRISHNA launches in 2025, SBG-TIR in 2027 and LSTM in 2029. This allows for a **continuous record** and possibly some periods when all 3 satellites are available **which would allow daily coverage**. The current earliest launch for Landsat-N is the end of the decade, so SBG-TIR will be operating in a period when Landsat-N data is not yet available.



* Earliest possible launch dates shown, may launch later

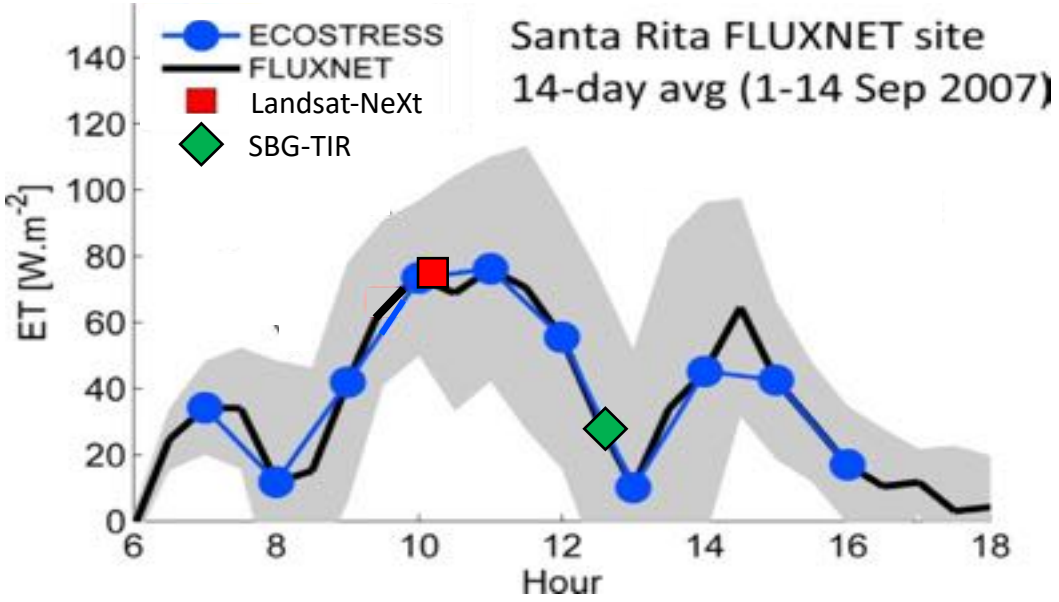
The SBG TIR, LSTM, and TRISHNA Swath Widths



TIR Overpass Time

SBG-TIR overpass time is at 12:30 pm on the descending node. This is similar to LSTM and TRISHNA. It was selected to capture the peak afternoon plant stress

Representative Evapotranspiration (ET) Plot



[Stavros, N. et al., ISS observations offer insights into plant function, September 2017, Nature Ecology & Evolution 1(10), DOI:10.1038/s41559-017-0327-z]

Plant stomata close in the early afternoon (max water stress and heat stress). The observed heat signature is highest during this time period.

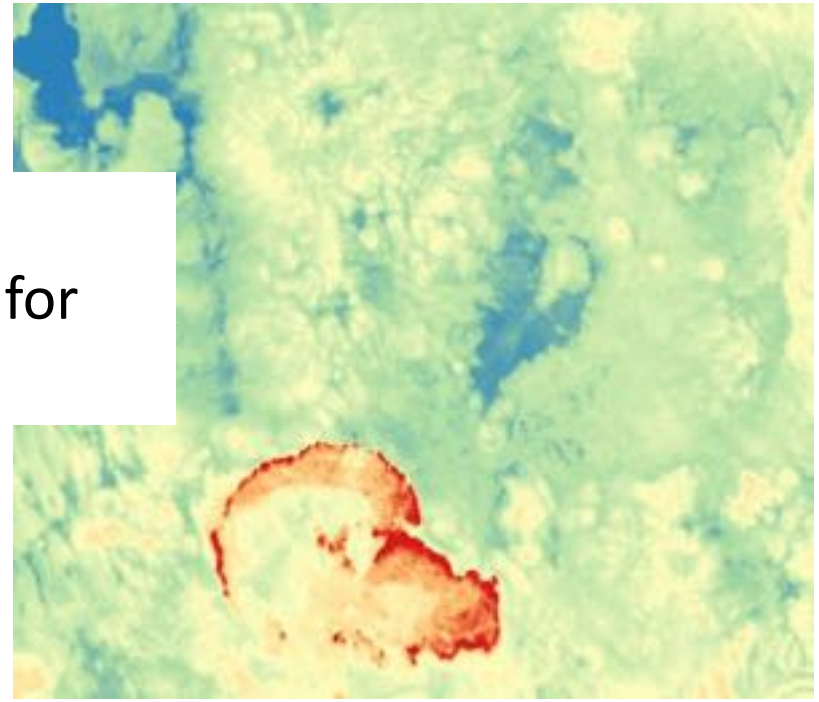
BASED ON ECOSTRESS

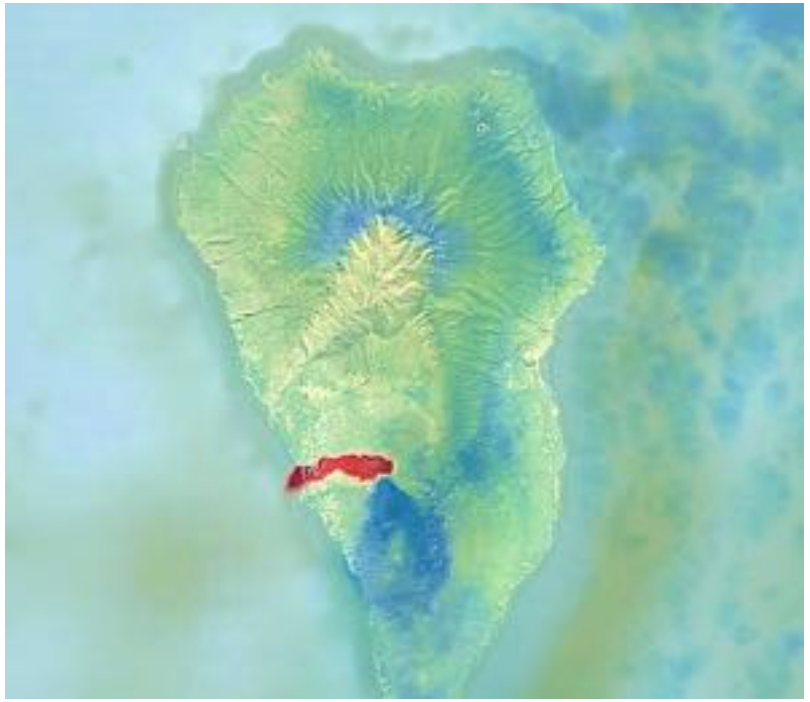
SBG-TIR Measures High Temperature Features

Ability to see hot spots and measure fire radiative power (FRP) - SBG-TIR is the **only mission out of TRISHNA, SBG-TIR, LSTM and Landsat-N that includes mid infrared (MIR: 3-5 um) bands.** These bands have been selected to address 2 critical issues:

1. **Active wildfires** - one MIR band measures FRP – critical to understanding the impact of fire on climate; and provides added utility to those actively battling wildfires
2. **Active volcanoes** - one MIR band is designed not to saturate until very high temperatures ~1200K. This is needed to detect changes in the fumarolic activity from volcanoes as well as track active fires. TRISHNA, LSTM and Landsat-N do not have MIR bands and their TIR bands will all saturate at much lower temperatures.

Unique Capability for SBG-TIR





Comparison of LSTM, TRISHNA and SBG-TIR

	LSTM	TRISHNA	SBG-TIR
Number of satellites	2	1	1
Combined revisit (days)	2 (same obs. angles)	≤ 3 (different obs. angles)	≤ 3 (same obs. angles)
Nominal Altitude (km)	649	761	665
Orbit cycle (days)	4 (for each sat.)	8	3
GSD (nadir/edge of scan) (m)	37/50	57/60	TIR: ≤60 /93, VNIR: ≤30 /52*
FOV (degrees)	± 28	± 34	± 34.4
Swath (km)	700	1000	935
Coverage	Land and Coastal	Land and Coastal	Land and Coastal
Day/Night	Day + Night	Day + Night	Day + Night
LTDN	12:30	12:30	12:30
LWIR bands (8-12 µm)	5	4	6
VNIR/SWIR/MWIR	4/2/0	5/2/0	2/0/2
Accuracy (K)	0.5	0.5	0.5
NeDT (K)	<0.15	<0.2	<0.2
Data latency (hours)	6-12	12 (demo)	<24

* Based on angle for SBG, for other instruments based on combination of angle and mask

Europe 2023 Airborne Campaign

- ESA/ NASA co-funded airborne/ ground campaign in Italy & France between May & July 2023

- Supporting multiple satellite missions:

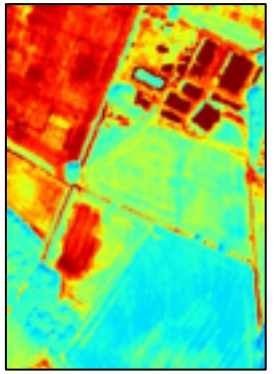
1. LSTM
2. SBG
3. TRISHNA

High-resolution future TIR satellite missions

4. NITROSAT

← EE11 candidate – monitoring nitrogen cycle

- Two intensive operation periods (IOPs) with 2 aircraft (Kenn Borek Air + British Antarctic Survey) focussing on directionality research
  - IOP1 = 21 May – 2 June IOP2 = 25 June – 2 July



- Single aircraft period (HyTES only) between these dates where data will be collected relevant to SBG, TRISHNA and NITROSAT missions

Hyperspectral Thermal Emission Spectrometer (HyTES)
2019, 2021 and 2023 European Campaigns

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

British Antarctic
Survey Twin Otter

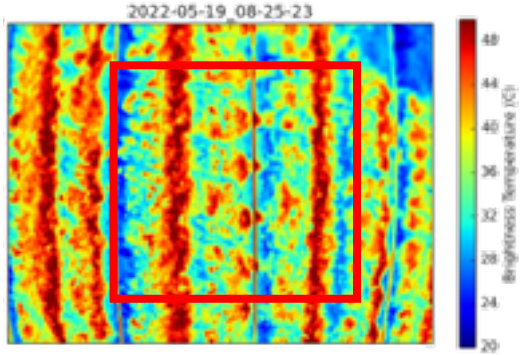
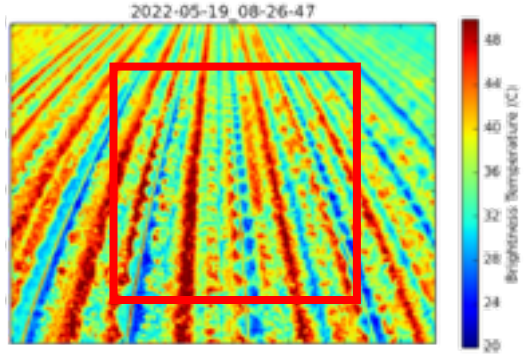
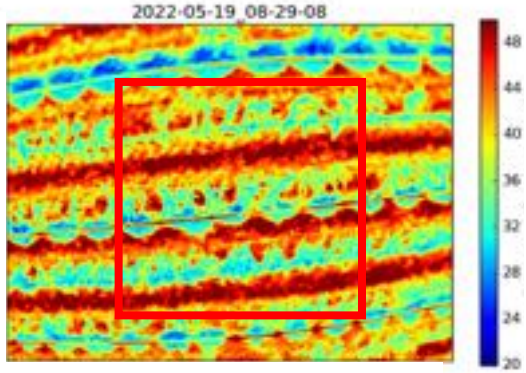
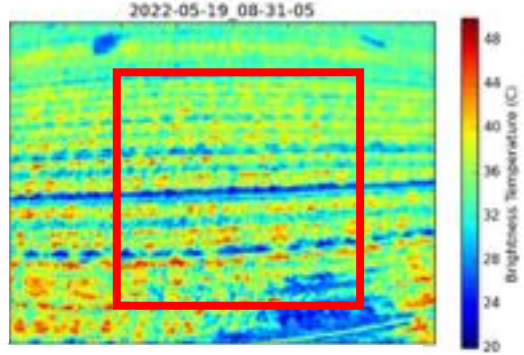
Canadian BOREK
Twin Otter

HyTES imagery acquired
near Grosseto, Italy in 2019

Angular Effects at Ground Scale (2022)

Corn (mapping mode) 19/5 : early in growing cycle

Large BT difference for 90° boom azimuth as can't see soil between rows at high VZA when VAA is perpendicular to row orientation

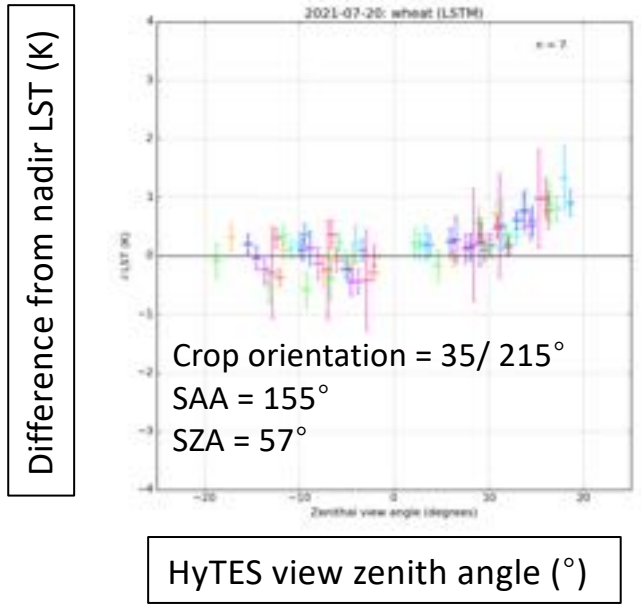
	Nadir	60 °
Boom Azimuth 0°	 Mean BT = 37.8 °C	 Mean BT = 38.7 °C
Boom azimuth 90°	 Mean BT = 41.2 °C	 Mean BT = 34.9 °C

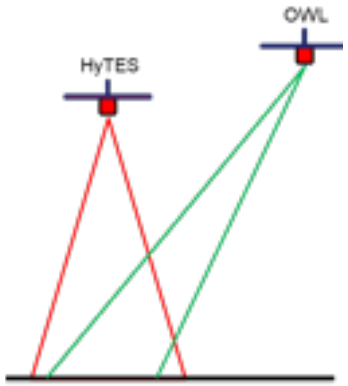
TIR Directionality (LSTM)

- Previous campaign in 2021 using a single aircraft indicated differences between nadir & non-nadir surface temperatures within the view angle & orientation of LSTM satellite
- Time or directionality – what is the cause?

- This year will mitigate this through **simultaneous acquisition** with different LWIR sensors on **two aircraft**
  - Advantage = isolate directional component by reducing the temporal component of surface temperature change
- Measurements focussed in Grosseto (Italy) over agricultural & urban sites (with additional nighttime flight over Milan)
- In-situ instrumentation for cal/val as well as for dedicated ground-scale directional experiments

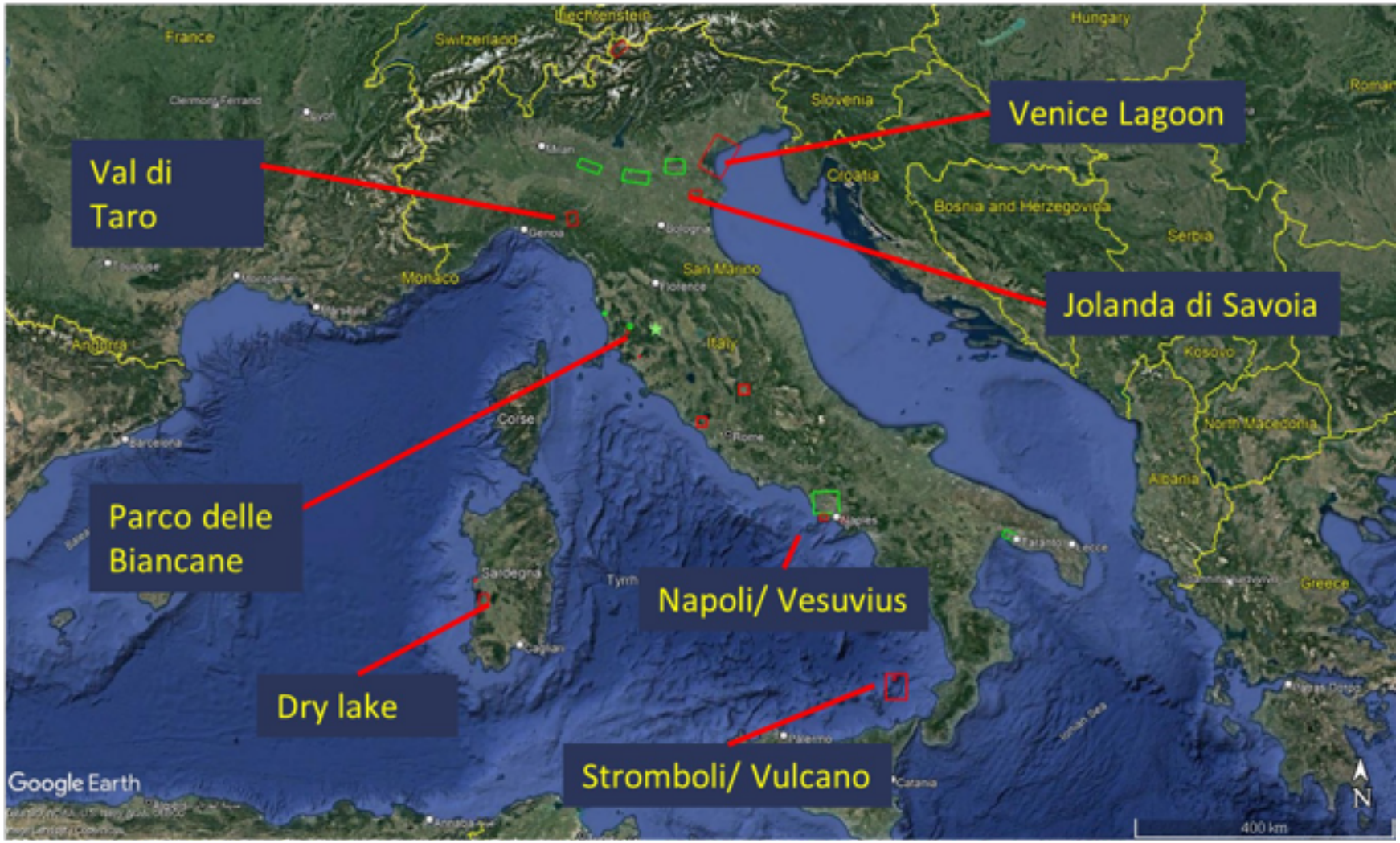
LSTM orientation (25°)





SBG Target Sites (HyTES-only)

Siena airport



Target sites in France - (HyTES-only)

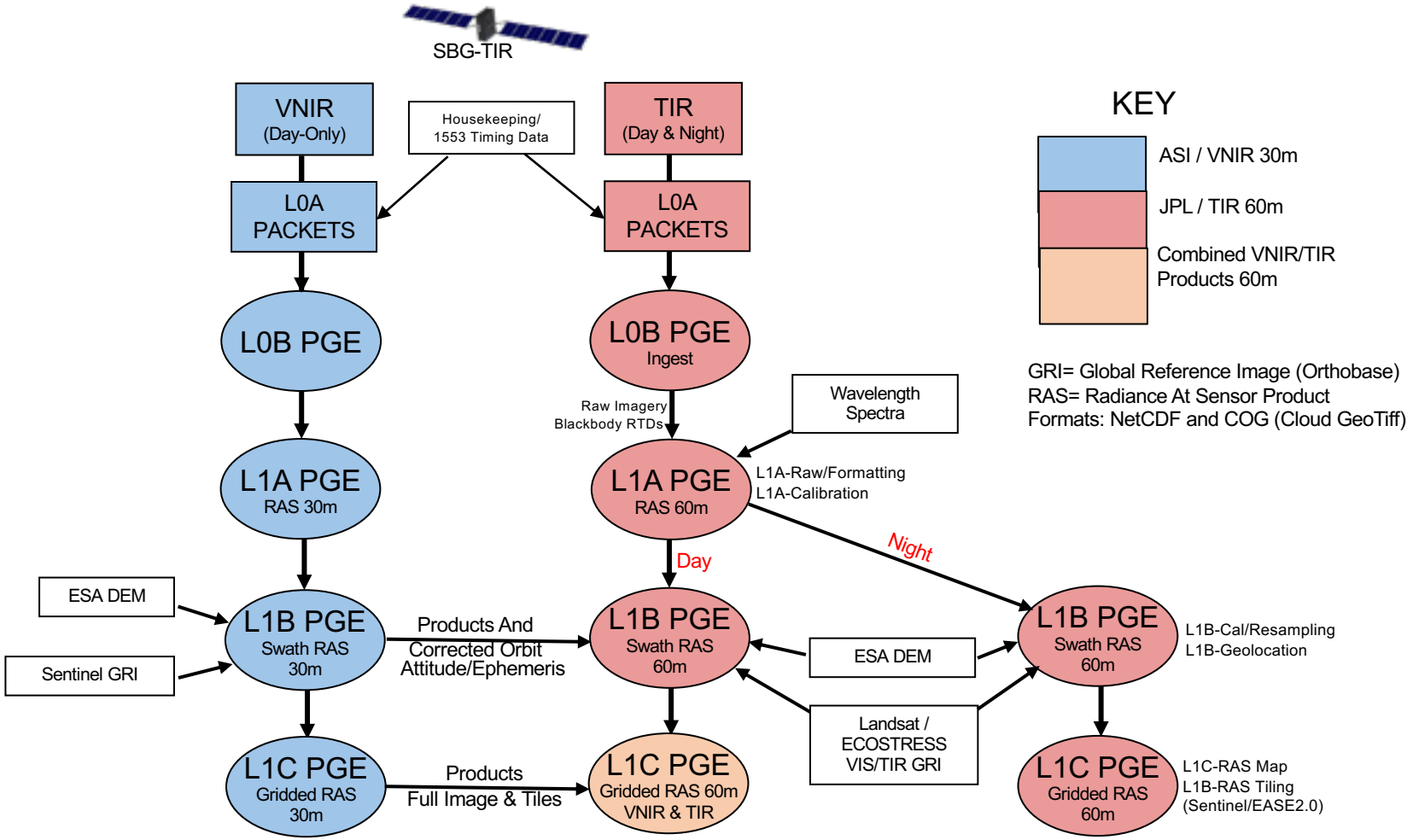
Summary

- ECOSTRESS has now been manifest until 2029 and extended until next Senior Review (2026)
- NASA has announced the Earth System Observatory with 4 anchor tenants: NISAR, SBG, ACCP and MC
- SBG has completed MCR and KDP-A and moved into Phase A
- SBG concept includes joint ASI-NASA TIR mission with components provided by ASI and NASA with potential launch date in 2027
- Planning for European 2023 HyTES campaign underway. Campaign will be focused on acquiring data to better understand effects of view angle in satellite data. Campaign is complex and involves 2 aircraft.

Questions?

Backup

SBG Data Flow - Standard Products



SBG Data Flow - Low Latency Products