Jet Propulsion Laboratory
California Institute of Technology

ECOSTRESS, SBG and HyTES

Status and Results

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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
- On Orbit Collaborations and Data Gaps
- The 2023 HyTES European Campaign

- The talk will mainly focus on SBG-TIR, feel free to ask for more information on ECOSTRESS and HyTES during the week.

ECOSTRESS Data: Quick Facts and Stats

As of 3/21/2022, 256,000+ scenes have been acquired since launch, an area over several hundred times the area of the Earth's land surface

In the last quarter, ECOSTRESS surface temperature and evapotranspiration were among top 20 of most requested products from LP DAAC AppEEARS which hosts MODIS and Landsat products

We originally planned to acquire an average of 74 scenes per day but have now acquired an average of 216 scenes per day.

Highest spatial resolution multispectral thermal infrared radiometer NASA has ever built

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

We originally planned to acquire ~27,000 scenes over a 1-year Mission and have now acquired 256,000+ scenes.

ECOSTRESS WORKING WELL BUT SCHEDULED FOR DECOMMISSIONING IN LATE 2023

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

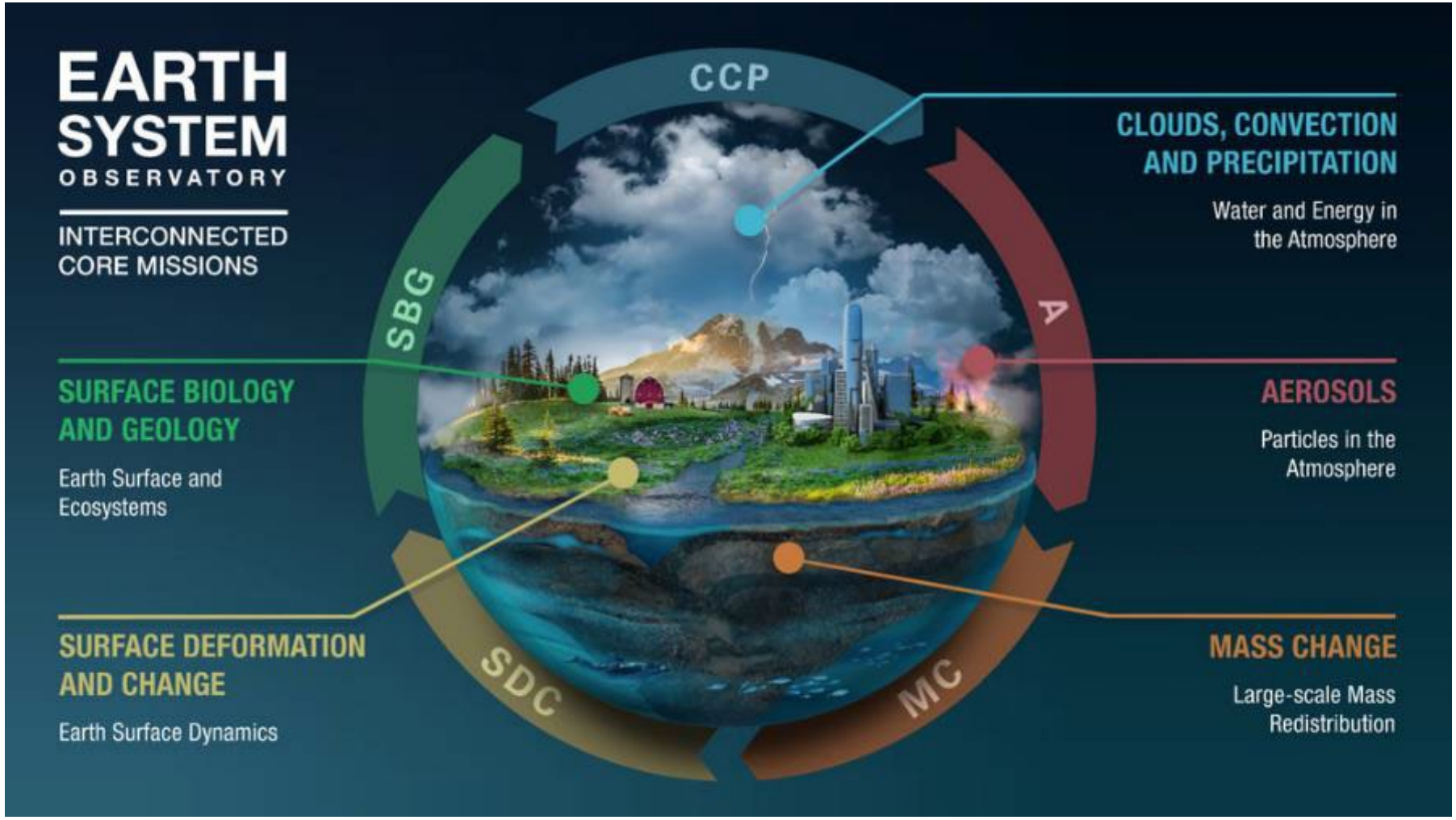
Science

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)



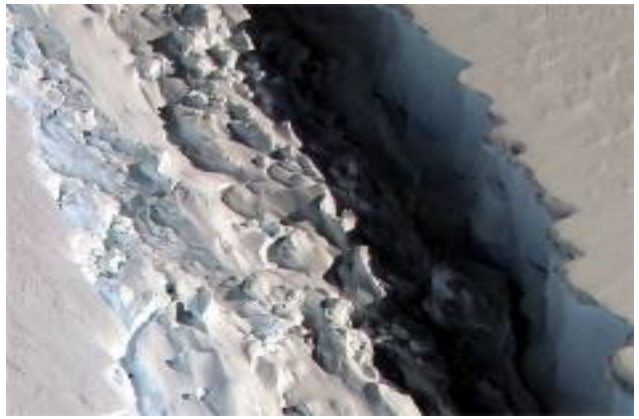
[Credit: National Aeronautics and Space Administration (NASA)]

ESO was created in May 2021

SCIENCE

EARTH SYSTEM OBSERVATORY






Surface Biology and Geology

An Observing System for Climate Impacts and Earth System Dynamics

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

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?

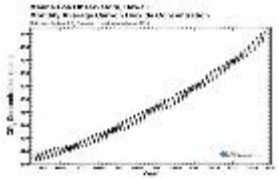
SOLID EARTH

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

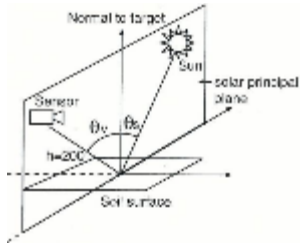
S-2. How do geological disasters directly impact the Earth system and society following an event?

KEY RESEARCH AND APPLICATIONS MEASUREMENT REQUIREMENTS

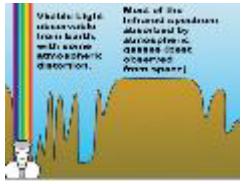
COVERAGE: The system must provide **global coverage** to address the global scope of the science including the coastal ocean and inland waters.



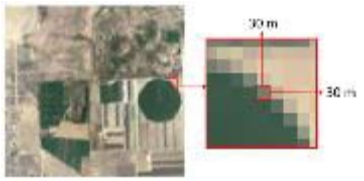
STABILITY AND DURATION: Measurements must be able to detect **long term changes** for addressing dynamics of the Earth System.



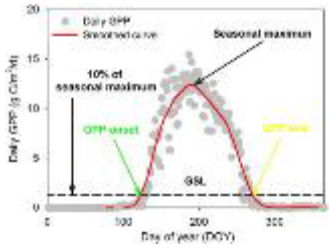
GEOMETRY: The system's orbit must allow for **consistent sun-sensor geometry** for consistency in retrievals and for calibration and validation, and provide for global coverage, as above (polar orbit).



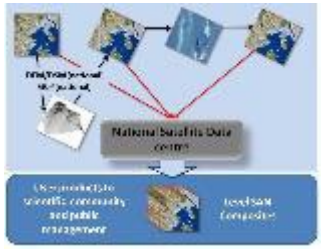
RANGE, RESOLUTION AND SENSITIVITY: Visible to Shortwave Infrared **(VSWIR; 400-2500 nm)** imaging spectroscopy and multi-spectral thermal infrared **(TIR; 4 - 12 μm)** measurements to observe "diversity" in ecosystem function. Radiometric performance driven by aquatic targets.



SPATIAL RESOLUTION: The observing system must provide **high spatial resolution** (30 and 60 m for VSWIR and TIR)

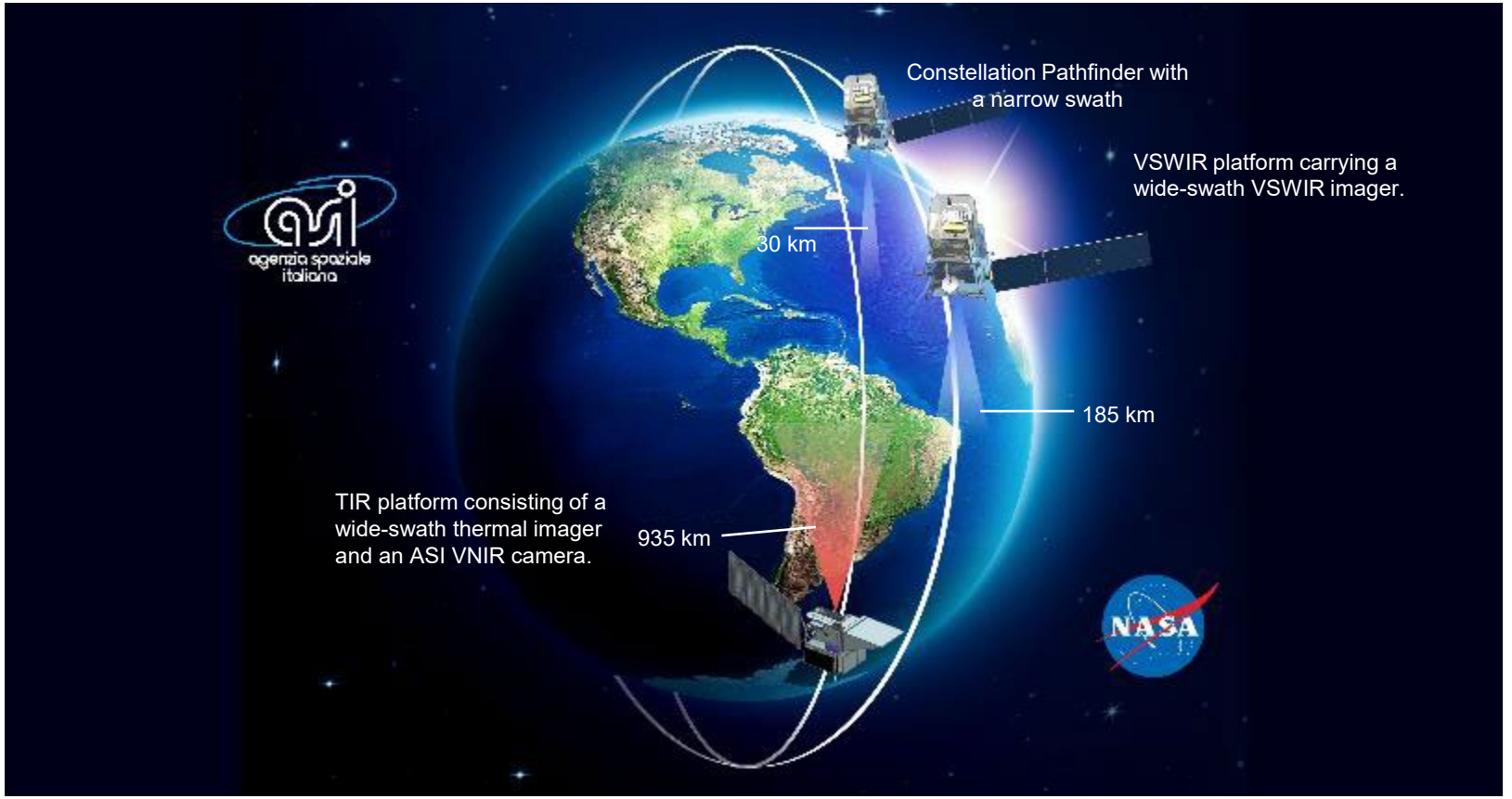


REVISIT: The SBG observing system temporal resolution must be adequate to capture **synoptic weekly and seasonal variation** as well as observe **rapid or transient changes** related to Earth system events such as fires, landslides, volcanic activity and anthropogenic incidents.



LATENCY: **Low latency,** the time between an event and data access, must be low enough to support time-sensitive applications, ≤ 24 hours.

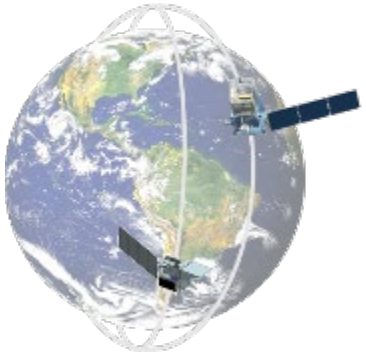
SBG Architecture and Instrumentation



Each platform/instrument has very different swaths and revisits

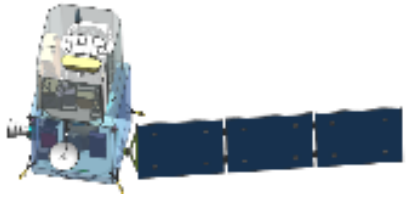
Pre Phase A Architecture Description: Two Primary Platforms and separate Constellation Pathfinder

- Two vehicles in SSO
  - TIR 665 km, 12:30 equatorial crossing time descending node
  - VSWIR 632 km, 10:45 local time
- VSWIR on a NASA spacecraft
  - Launches aboard ISRO-contributed PSLV
- TIR hosted on an ASI-provided spacecraft with an ASI-provided VNIR camera
  - Launches aboard ASI-contributed VEGA-C

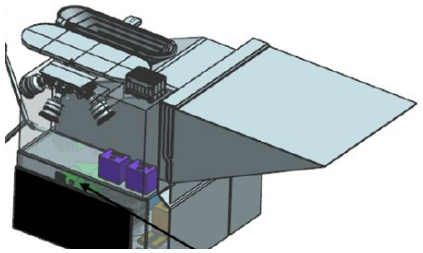


- NASA VSWIR
  - FoV: 25.5°
  - Spatial Res: 30 m
  - Swath: 185 km
  - Spectral Res: 10 nm
  - Range: 0.38 – 2.5 µm
  - Bands: 220

- NASA TIR
  - Spatial Res: 60 m
  - Swath: 935 km
  - Range: 1.6 – 12 µm
  - Bands: 8
- ASI VNIR
  - Spatial Res: 30 m
  - Range: 665, 834 nm centers
  - Bands: 2



VSWIR-1 on NASA Bus

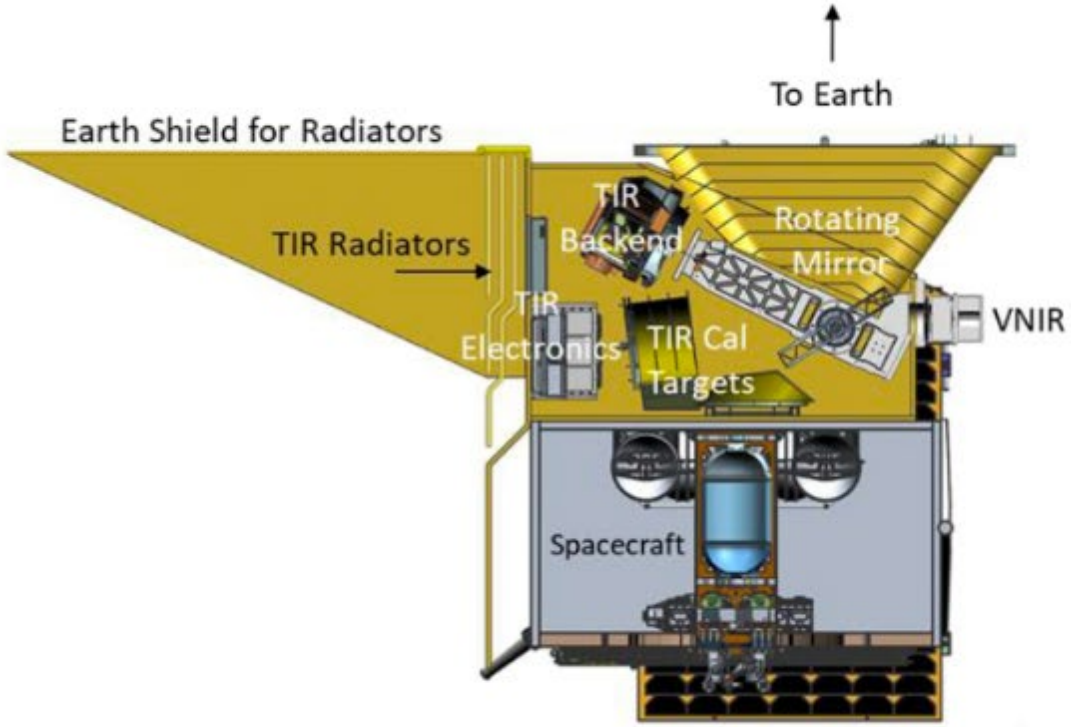


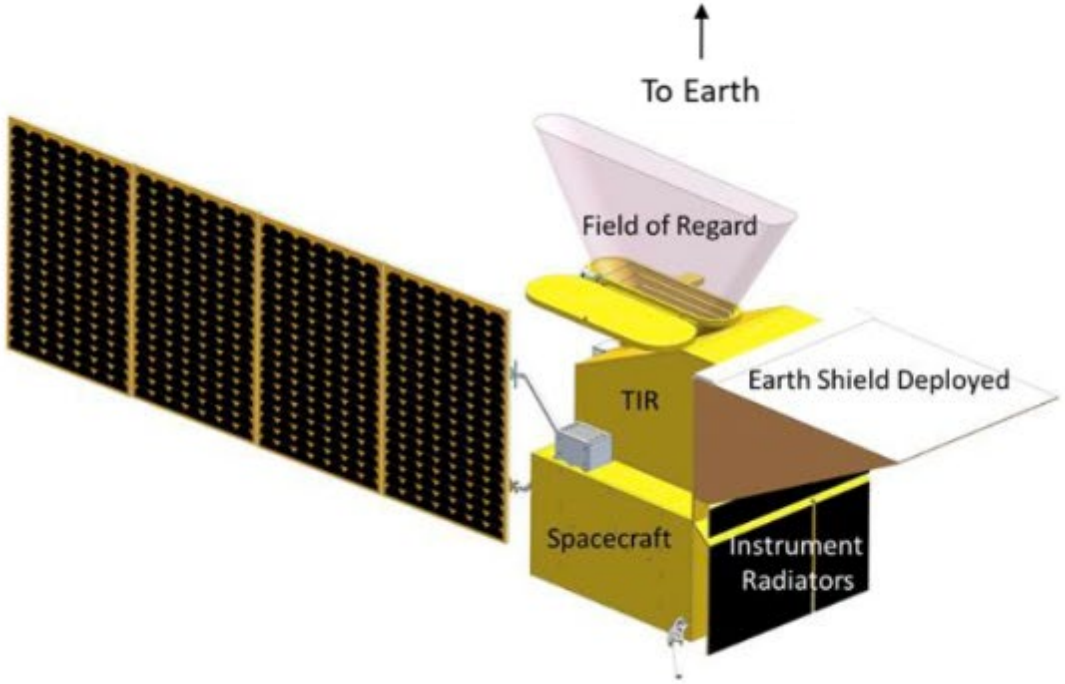
TIR on ASI PLATiNO+ Bus

- Science valuation
  - Two-Platform solution allows orbits to utilize optimum observing time coordinate with international efforts
    - VSWIR orbit can be coordinated with CHIME for reduced revisit
    - TIR orbit can be coordinated with CNES-ISRO TRISHNA and ESA-LSTM for daily revisit
  - ASI contributed VNIR provides full coincidence with NASA TIR and improved performance
- Estimated LRDs:
  - VSWIR: 2028
  - TIR: 2027

SBG Thermal Infrared (TIR) Free-Flyer Concept

- **The TIR Free-Flyer is one of three different and complementary SBG flight elements**
- **The concept was jointly developed by ASI, INGV, INAF and NASA/JPL,**



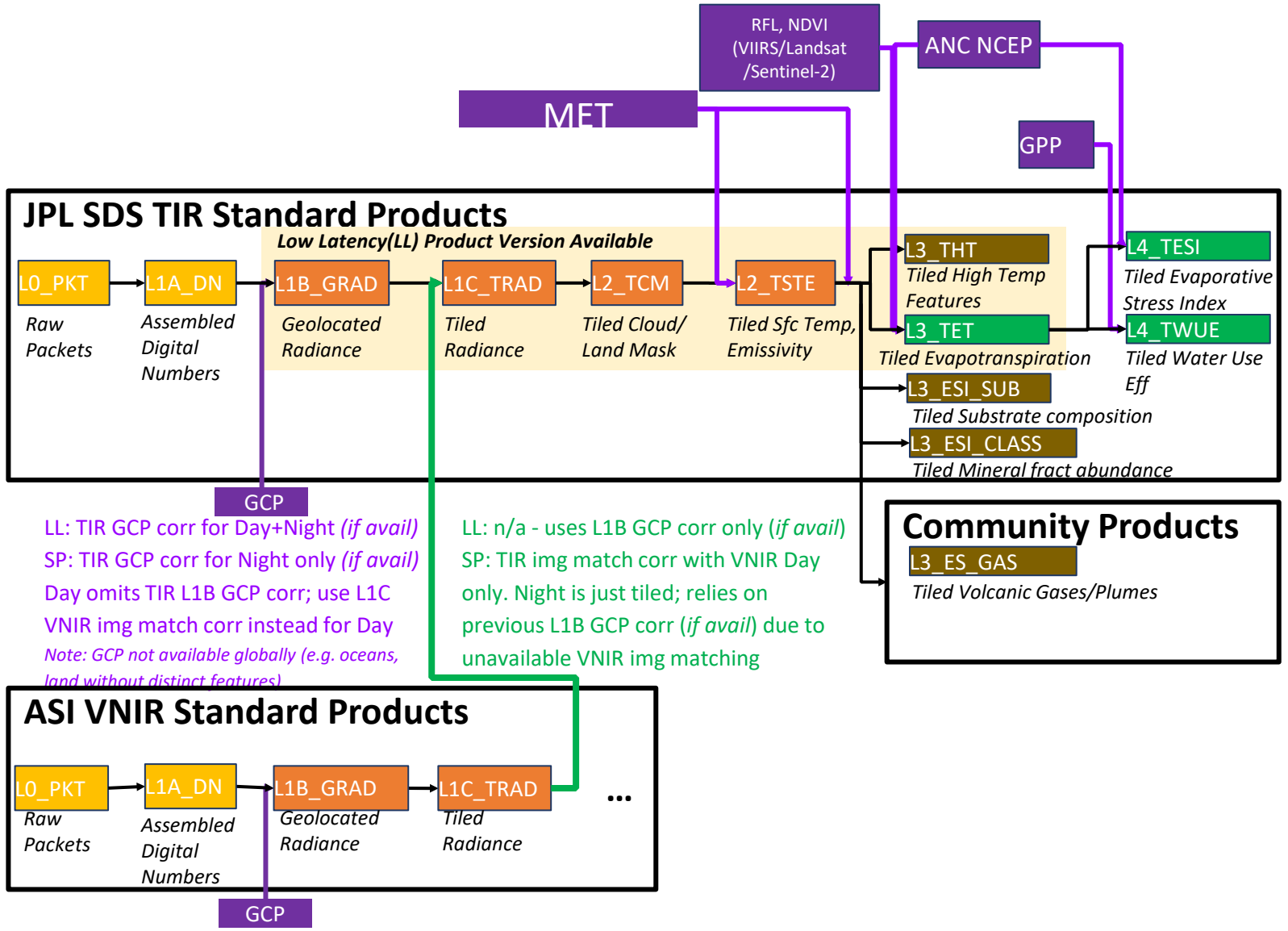


[Credit: NASA/Jet Propulsion Laboratory (JPL) and the Agenzia Spaziale Italiana (ASI)]

SBG Data Product / Processing Flow: TIR

Legend

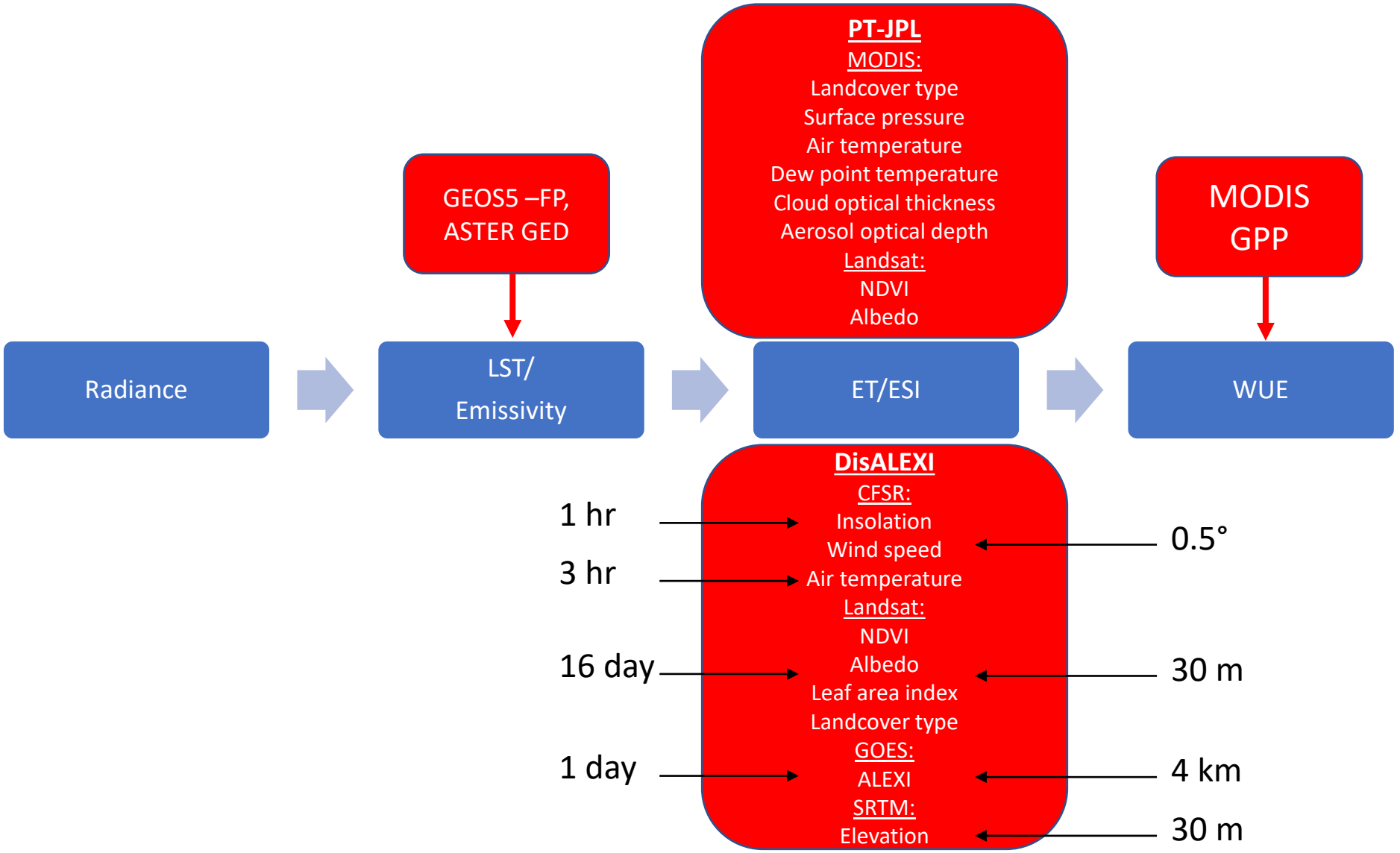
- Raw Sensor Data
- General Products
- Aquatic Products
- Terrestrial Ecosystem Products
- Geology / Earth Surface Products
- Ancillary datasets
- Low Latency(LL) Version Available



Note 1: Standard Products(SP) and Low Latency (LL) Products are intended to be generated all the time when applicable for their geographical application use-case

Note 2: Only VNIR products that have dependencies to TIR product generation shown on this chart. There are other downstream VNIR-only products

Processing pipeline – Developed with ECOSTRESS



Surface Temperature and Evapotranspiration Error Budgets

Erro budget 1K

LST

Atmospheric correction

Algorithm

Instrument noise

Error budget 1 mm/day

ET

LST

Albedo

Leaf area index

Algorithm

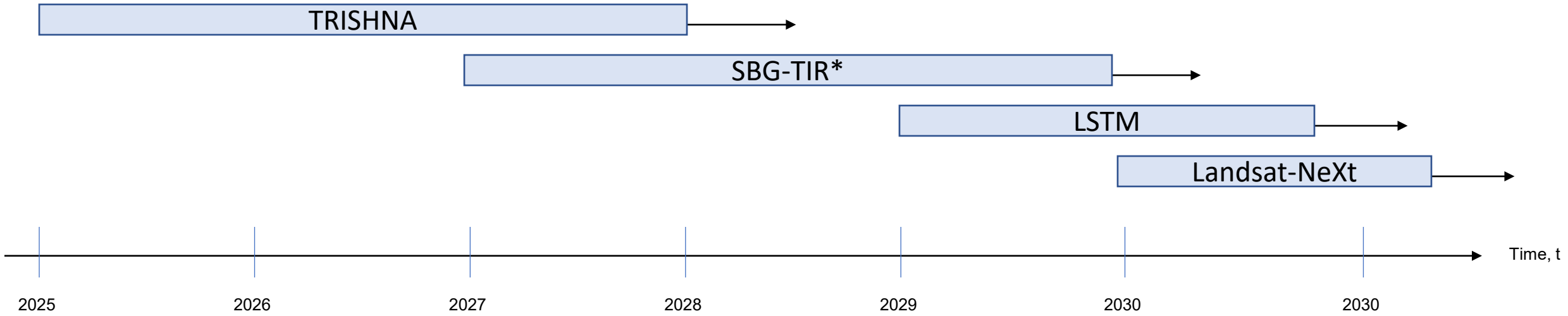
On-Orbit Collaborations

Summary Specifications for LSTM, TRISHNA and SBG

	LSTM	TRISHNA	SBG-TIRFF
Number of satellites	2	1	1
Revisit (days)	4 (both satellites) (same obs. angles)	≤ 3 (different obs. angles)	≤ 3 (same obs. angles)
Altitude (km)	649	761	665
Orbit cycle (days)	4 (for each sat.)	8	3
GSD (nadir/edge of scan) (m)	37/50	57/90	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
Equatorial Crossing time, descending node	12:30	13:00	12:30
LWIR bands (8-12 µm)	5	4	5
VNIR/SWIR/MWIR	4/2/0	5/2/0	2/1/2
Accuracy (K)	0.5	0.5	0.5
NeDT (K)	<0.2	<0.2	<0.2
Data latency (hours)	6-12	12 (demo)	<24

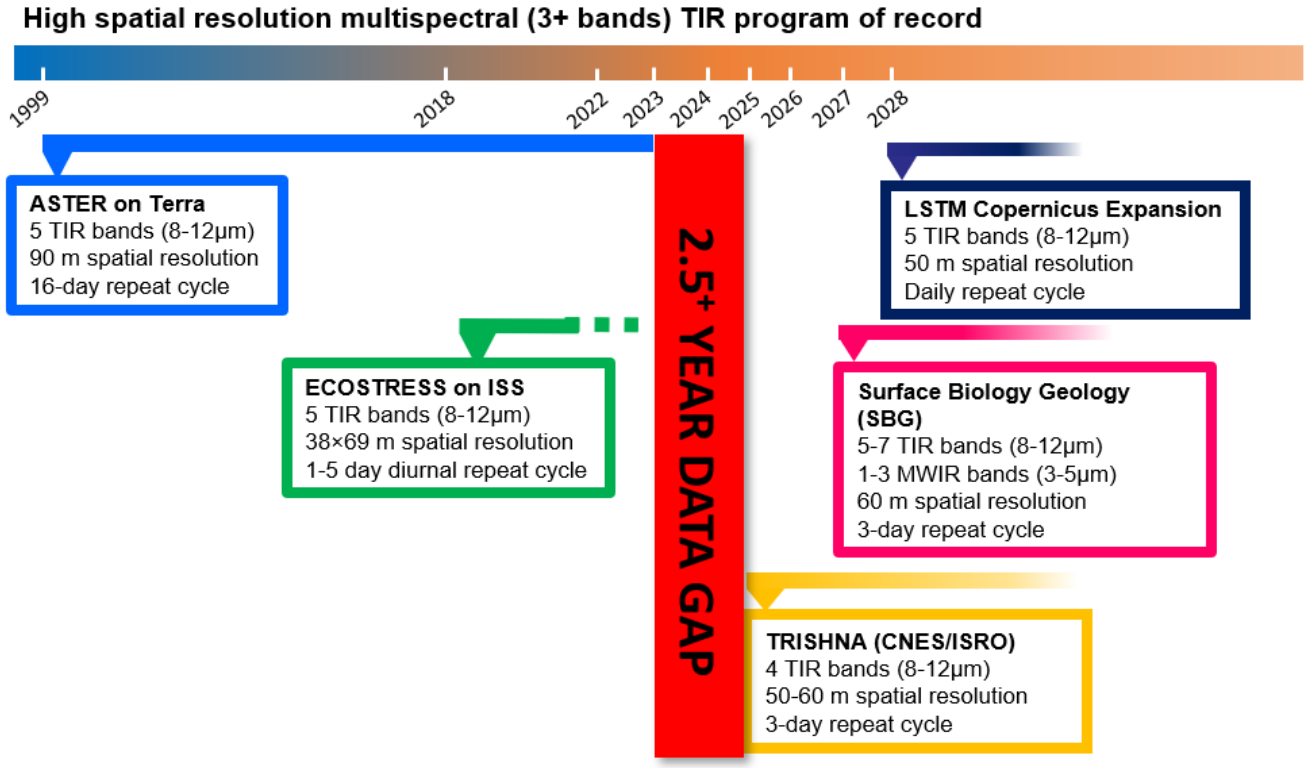
Potential Launch Schedules

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.



Ready to launch SBG-TIR in 2027

Potential multispectral TIR data gap



Exciting future with TRISHNA, SBG and LSTM; however, ECOSTRESS, while funded to provide data through Sept. 2023, with TRISHNA scheduled to launch no earlier than end of CY2025, there could be a **2.5 year data gap**. Aircraft TIR instruments will play a critical role; however they cannot fill the gap that would be left by ECOSTRESS.

ECOSTRESS is currently acquiring 216 scenes / day, amounting to 32M sq km and **nearly 3x the number of scenes originally proposed** (74 scenes / day). For reference, Landsat-8 acquires 24M sq km / day or, in ECOSTRESS terms, 162 scenes.

ECOSTRESS data continue to be in high demand – in the last 12 months, the ECOSTRESS Land Surface Temperature and Emissivity product was the 2nd most requested product in the LP DAAC AppEEARS data access tool. The MODIS Terra Land Surface Temperature/Emissivity product was the 1st. There are 120+ products in the tool

Hyperspectral Thermal Emission Spectrometer (HyTES) –2019, 2021 and 2022 European Campaigns

- Joint science campaigns in Europe with ground teams, satellite observations and NASA/JPL HyTES imaging spectrometer
- Next campaign planned for summer 2023.
- 2023 campaign is focused on Italy
- Supports thermal imaging of sites relevant for ESA LSTM mission, ASI-NASA SBG-TIR mission and CNES-ISRO TRISHNA mission.
- HyTES is installed on Twin Otter
- Work undertaken through Space Act Agreement (SAA) between Kings College London (KCL) and NASA OIIR.

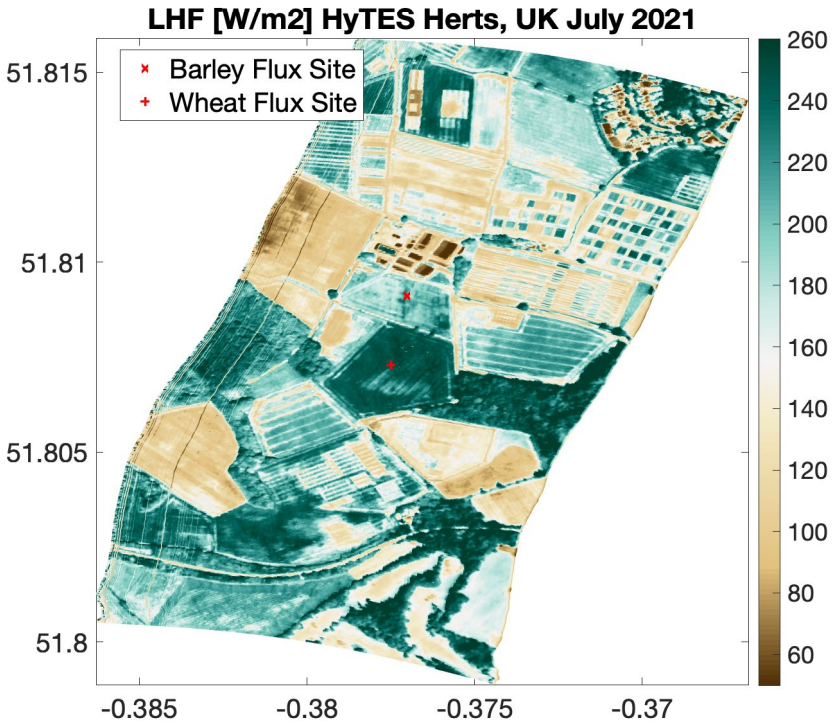
Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 μm
Frame speed	35 or 22 fps
Integration time (1 scanline)	28 or 45 ms
Total Field of View	50 degrees
Calibration (preflight)	Full aperture 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

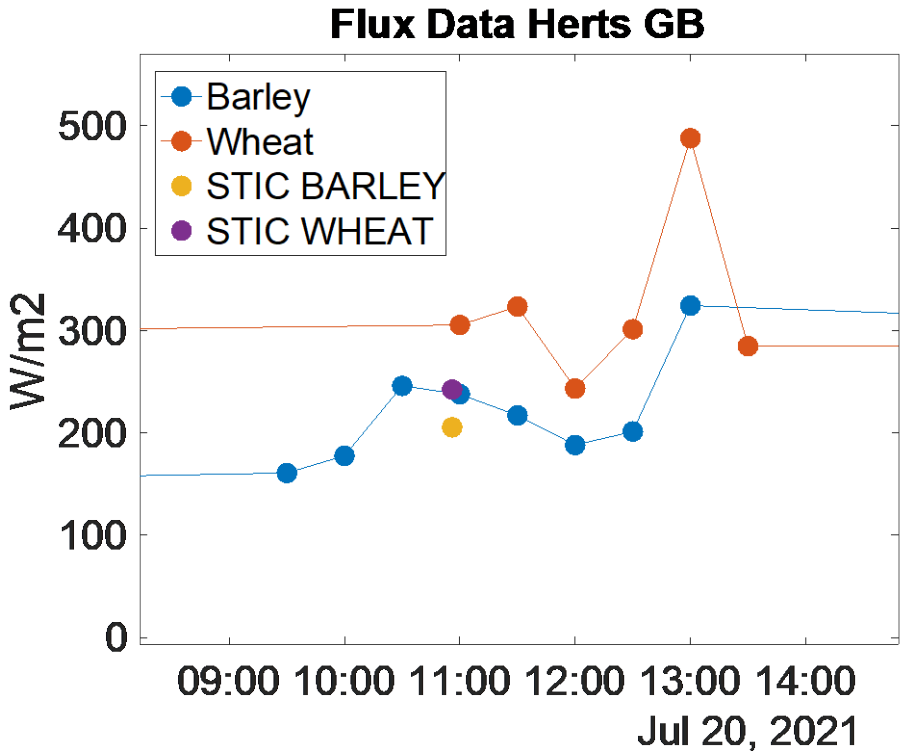
British Antarctic Survey Twin Otter

HyTES imagery acquired near Grosseto, Italy in 2019

ET Product for HyTES

- The STIC model takes surface temperature (LST) into account directly in Penman-Montieth, improving sensitivity of evapotranspiration to surface temperature.
- STIC will complement other ET algorithms, as a thermally sensitive ET estimate that can help reveal the diurnal cycle of thermal plant stress.





Preliminary validation: STIC using HyTES LST compared against flux tower eddy covariance data [Hertfordshire, UK]

- *K. Mallick et al., 2014, A Surface Temperature Initiated Closure (STIC) for surface energy balance fluxes, Remote Sensing of the Environment*

Summary

- NASA has announced the Earth System Observatory with 4 anchor tenants: NISAR, SBG, ACCP and MC.
- SBG in Pre-Phase A with MCR in June 2022
- SBG concept includes joint ASI-NASA TIR mission with components provided by ASI and NASA with potential launch date in 2027
- ECOSTRESS currently planned for decommissioning in 2023, Instrument working well but site needed for another payload leading to potential data gap between ECOSTRESS and TRISHNA
- European 2023 HyTES Campaign focused on Italy

Questions?