A high spatio-temporal resolution mission in the Thermal Infrared : the Indian-French TRISHNA project

ECOSTRESS Science & Applications Team meeting - February 11-13, 2020 – Ventura, CA

TRISHNA Project, Scientific Objectives and Specifications

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OUTLINE

TRISHNA

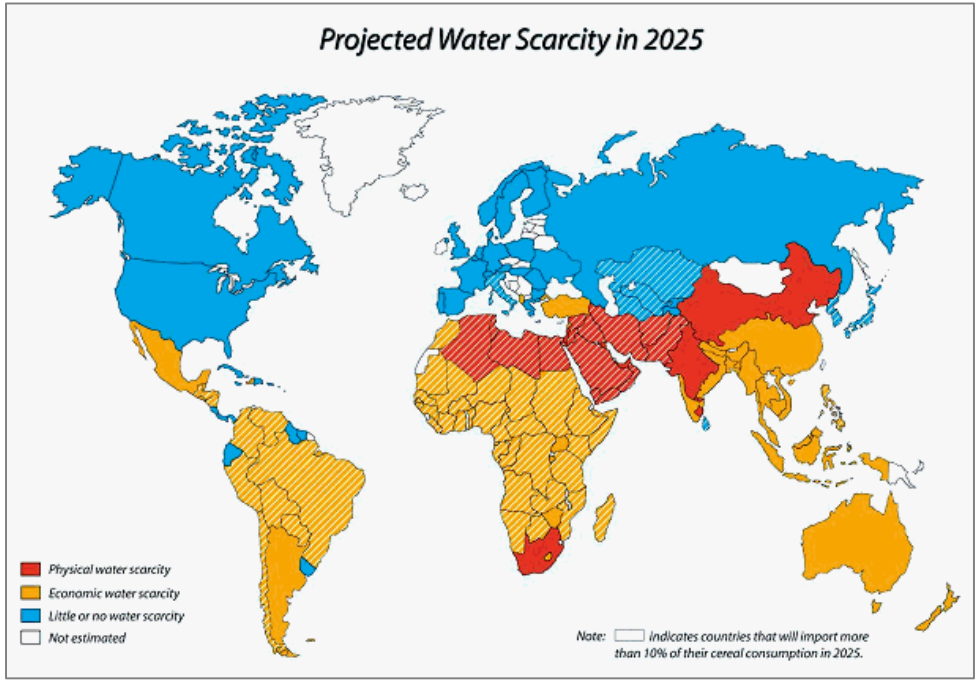
Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment

- ❑ Global context
- ❑ Presentation of the program and cooperation ISRO/CNES
- ❑ TRISHNA scientific objectives
- ❑ Main mission specifications and justification
- ❑ TRISHNA products
- ❑ TRISHNA science groups

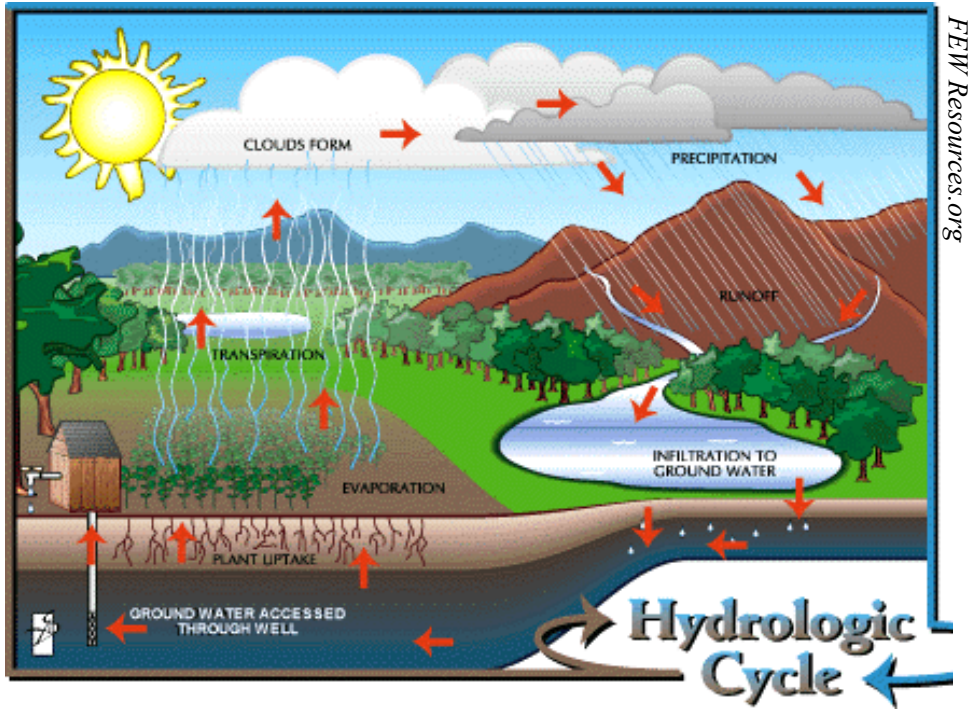
Global context

Global change (climate, population growth, land use, urbanization, deforestation…)
⇒ increasing scarcity and deteriorating quality of the water resource

Monitoring of the water cycle is becoming more and more crucial



Mcgranahan, Gordon. (2002). Demand-Side Water Strategies and the Urban Poor.



FEW Resources.org

Physical water scarcity | Economic water scarcity | Little or no water scarcity

Global context

Land and sea surface temp. (LST and SST) are key signatures of water and energy budgets

- ❑ evaluate the current drifts and assess their impacts on surface
- ❑ calibrate and validate the models predicting the evolution of ecosystems → adapting the mitigation methodologies for a sustainable development

Measurements in the Thermal Infrared (TIR) domain → LST, SST

Spatio-temporal variability of the surface :

- ❑ Complexity of physical and biological processes → access to local scale needed for decision and management policies
- ❑ Short-time scale variability (meteo forcing, human activities…)

Need for Spatial systems in the TIR with:

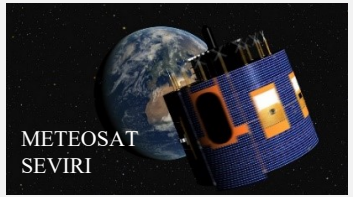
❑ high spatial resolution ❑ high revisit capacities

SUCH A SYSTEM DOES NOT EXIST TODAY

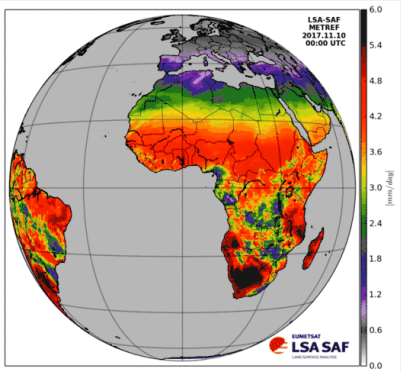
Need for a high spatio temporal resolution TIR mission

Current satellite TIR data : a resolution/revisit dilemna

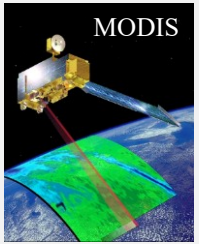
Geostationary satellites
(MSG/SEVIRI, GOES, INSAT, GMS…)

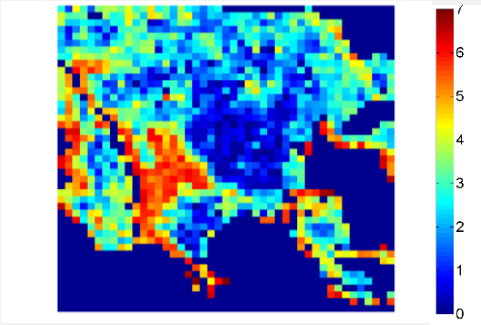


Daily AET → Nov 10, 2017 EUMETSAT

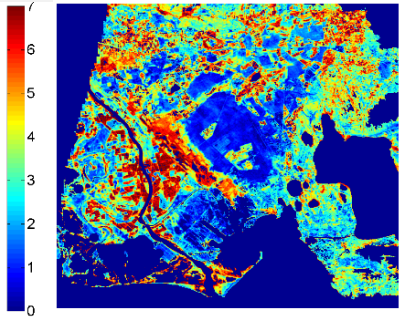


Polar meteo satellites 1km
(MODIS, SUOMI NPP VIRSS…)





EO satellites
(TIR on LANDSAT, ASTER)



← ET (mm/day), July 8, 2008, Crau region (S-E France)

Resolution	**> 3 km**	**1 km**	**60 - 120m**
Revisit	15 min	1 day	18 days

Program background history

Mission recommended during the last Scientific Prospective Seminar in 2004, 2009, 2014, 2019.
High priority confirmed by the French Scientific Committee

MISTIGRI (2008/2011) CNES

- Mission Design Review
- Preliminary Requirements Review
- **Cooperation to be found for program decision**

THIRSTY (2013 /2014) CNES / JPL

- Mission Design Review
- JPL decision to fly onboard ISS

But we mean: good for you, of course

SOIF (2015) CNES

- Mission Design Review
- **Cooperation to be found for program decision**

TRISHNA (2016 / 2019) CNES/ISRO

- Mission Design Review
- **Preliminary Requirements Review October 2019**

With the long-term and constant involvment of Jean Pierre Lagouarde (INRA) → Jean Louis Roujean (CESBIO)

Cooperation between ISRO and CNES

Cooperation Agreement between CNES and ISRO for a reinforced cooperation in space activities - signed in April 2015

To set up the terms and conditions of a favorable cooperative framework for the implementation of any future joint mission

Implementing Arrangement for Trishna - signed January 24, 2016

To conduct definition studies for a potential joint thermal-infrared (TIR) Earth Observation mission

Phase 1

- Finalisation of the mission requirements and associated data policy principles
- Definition of work share and responsibilities

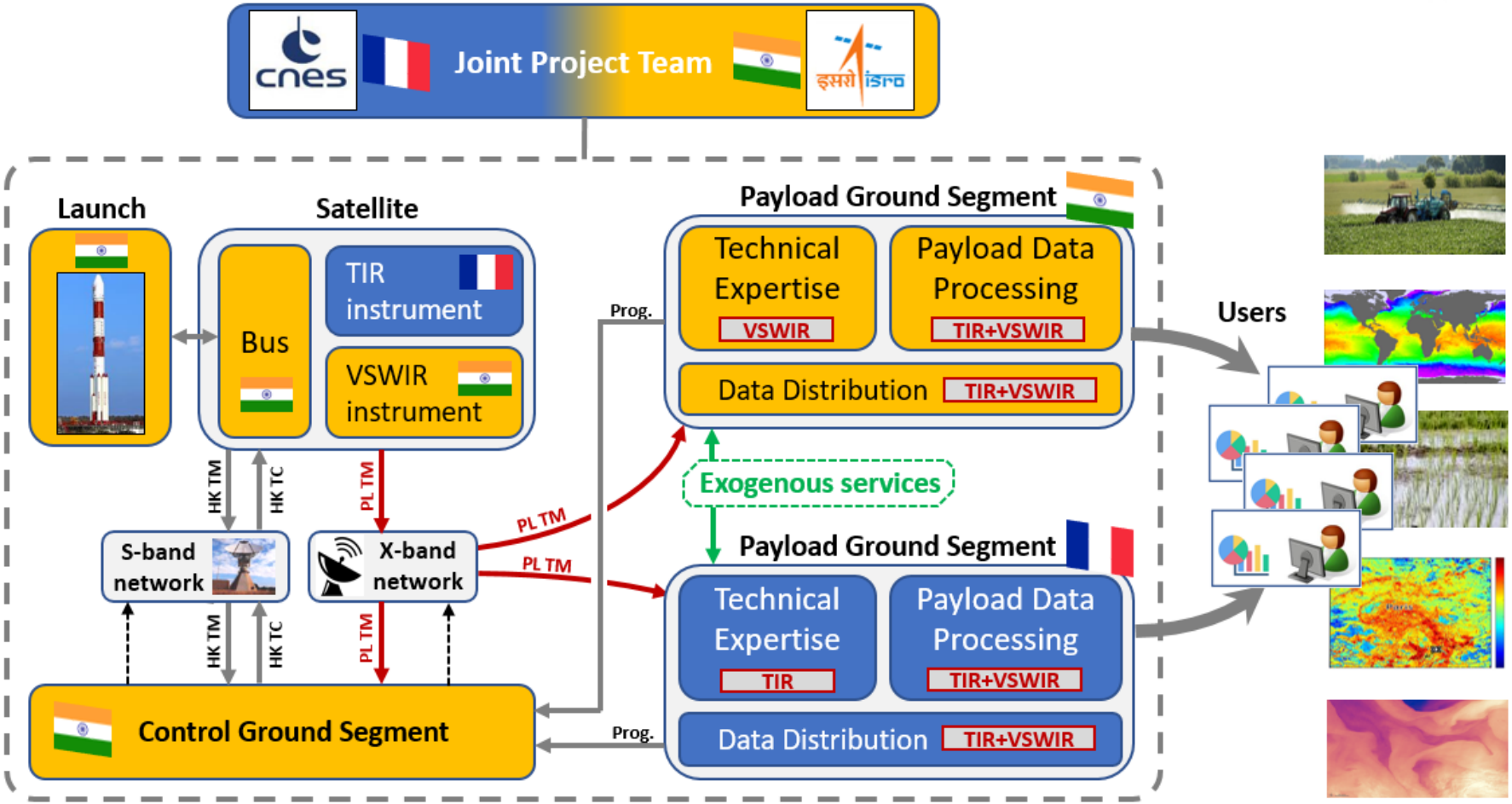
→Closed in november 2017 (Mission Definition Review)

Phase 2

- Finalization of the system requirements
- Definition of the satellite configuration, the payload concept, the launch strategy
- Development plan and costs definition
- Preparation of the Arrangement for realization Phase

→ Closed in October 2019 (Preliminary Requirement Review)

TRISHNA system architecture and workshare between ISRO and CNES

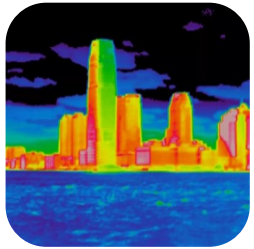


TRISHNA Thermal Infrared instrument datasheet

Mass	195 kg
Power	265 W
Optics	Three-mirror anastigmat telescope
Number of spectral bands	4
Band names	TIR1 – TIR2 – TIR3 – TIR4
Specified central wavelengths	8.65µm – 9.0µm – 10.6µm – 11.6µm
Specified FWHM per band	0.35µm – 0.35µm – 0.7µm – 1.0µm
Radiometric accuracy	0.5K at 300K
Radiometric precision	0.2K at 300K
Dynamic range	250K – 400K
Aperture size	150mm
Focal length	400mm
Focal plane temperature	60K
On-board calibration	1 blackbody + 1 cold space view
Scan cycle	5 sec

TRISHNA Scientific objectives






1) *Ecosystem stress and water use* — *design driver*
2) *Coastal and inland waters* — *design driver*
3) *Urban ecosystems monitoring*
4) *Solid Earth*
5) *Cryosphere*
6) *Atmosphere*

TRISHNA Scientific objectives: design drivers

From *TRISHNA User Requirement Document*

Ecosystem stress and water use

Agriculture/forestry

- water stress detection / water needs / irrigation optimisation
- water resources management
- growth/ crop production, food security
- impact of agricultural practices on water use, climate change adaptation
- forest fire risks, frost detection…

Biogeochimical cycles

- carbon cycle ↔ global warming processes
- water quality
- soil pollution
- arctic permafrost

Hydrology

- link with meteorology (mesoscale circulation)
- water budgets and biogeochimistry at watershed scale

Ecosystem monitoring, ecology

- microclimates, biodiversity
- natural vegetation droughts

Coastal and inland waters

Coastal waters

- Submesoscale activity (mixing processes) ↔ ecosystems productivity (phytoplankton)
- Gaz fluxes (CO_2, CH_4) at the air-sea interfaces
- Coastal zone monitoring and management: water quality, algae blooms, halieutic resource, fresh water resurgences, discharges (water, pollutants, thermal plumes…)

Inland waters (lakes and rivers)

- GTN-L lakes (GCOS) [Essential Climate Variable Ts]
- Deltas, estuary hydrology, lagunaes
- Biological activity and productivity
- Warning of water borne diseases (application to human health)
- Thermal discharges

Sea ice (at local scale)

- Monitoring melting/freezing processes (meltponds, leads, polynyas)
- Feedbacks climate ↔ melting ice

TRISHNA Scientific objectives

From *TRISHNA User Requirement Document*

Urban microclimates

- Urban heat island and comfort *(welfare, health…)*
- Urban vegetation
- Urban and peri-urban hydrology *(run-off, urban planning)*
- Urban meteorology and atm. flow *(dispersion of pollutants…)*
- Anthropogenic fluxes and energy consumptions *(heating, air conditionning …)*

2008	2050
3.3	~5

Urban population (10^9 inhabitants)

Solid Earth

- Monitoring volcanic activity *(prediction of eruptions, mitigation of risks…)*
- Detection of peat and coal fires *(pollution, CO_2…)*
- Detection of thermal anomalies *(geothermal exploration, earthquakes precursors...)*

Cryosphere

- Melt runoff using Degree-Day and Energy Balance approach
- Identification of debris cover/thickness over glacier ice
- Snow metamorphism processes and its effect on snow reflectance
- Lake dynamics at High alt. and Basin/Sub-basin scale dynamics
- Retrieval of sea ice surface temperature in polar region

Atmosphere

- surface radiation budget
- clouds (high clouds, cirrus…)
- atmospheric water vapor

Mission specifications: revisit = 3 days, nadir resolution = 57m

Revisit guided by :

- ❑ Cloud frequency / data availability
- ❑ Technical constraints : swath, arrays detector size, view zenith angle
- ❑ Expected products (AET) accuracy

1 day is the goal

3 days is the best possible with single satellite

Puducherry region, India

Spatial resolution guided by :

- ❑ Field size
- ❑ Technical constraints : arrays detector size, swath
- ❑ LST accuracy (*vs* atmospheric turbulence induced fluctuations)

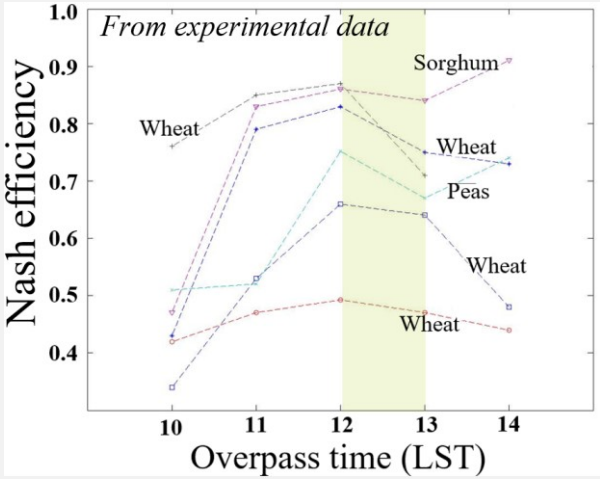
50 - 60 m (nadir)

< 100m (edge)

Brittany region, France
(© Google Earth)

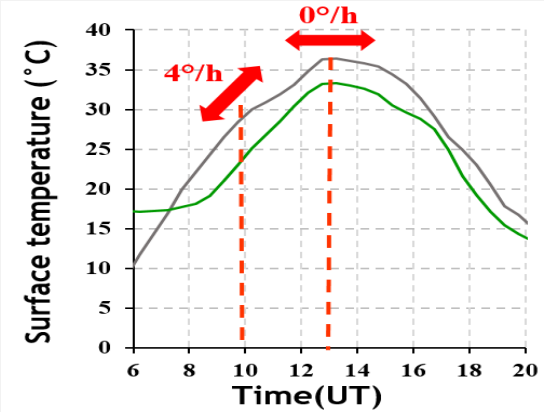
Mission specifications: overpass time = 1PM

Overpass time must cope with max sensitivity for flux estimation



Noon to 1PM LST → max accuracy on fluxes retrieval

Minimizing the sensitivity of LST measurement to overpass time

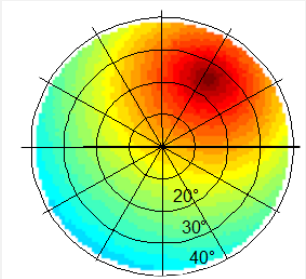


→ 1PM LST more suited to models with 30mn-1h time steps
→ 1PM LST minimizes impact of time differences (orbit)

SST measurements

1PM LST
→ 1AM nighttime overpass preferred for water surfaces temperature (no skin thermal effects)

Hot spot impact

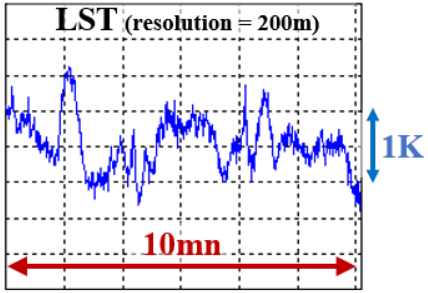


For mid-latitudes, scan perpendicular to 1PM principal plane → mitigation of hot spot effects

⚠ Not true for inter-tropical areas !

Mission specifications: NeDT = 0.2K @300K, ARA = 0.5K @300K

LST measurements are affected by **atmospheric turbulence**:



- ❑ Temporal fluctuations over dry maize field or bare soil (from experimental measurements)
- ❑ SBL turbulence effect on LST is smoothed by spatial integration on the pixel
- ❑ PBL turbulence affects LST whatever the pixel size
  → uncertainty on instantaneous LST meas. from space

Surface Boundary Layer (SBL) turbulence: meters & seconds
Planetary Boundary Layer (PBL) turbulence: kms & minutes

Experimental characterization of the uncertainty on LST, at 50m resolution:
+/-0.6K for ~60% of the measurements
+/-0.8K for ~80% of the measurements

Lagouarde et al., RSE 2013
Lagouarde et al., RSE 2015

Specifications:

- ❑ Specified NeDT at instrument level: **0.2K**
- ❑ Absolute Radiometric Accuracy: **0.5K**

Impact on level 2 products: Atmospheric correction / Temperature-emissivity separation (TES): **1K to 1.5K uncertainty on LST**

LST systematic uncertainty of 1.5 K is sufficient for acquiring a daily ET accuracy of 5%

Allen et al., 2007
Sobrino et al. 2016

Mission specifications: need for simultaneous TIR, VNIR & SWIR data

Complementarity TIR/VNIR/SWIR

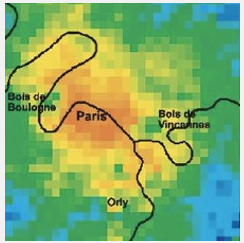
- TIR → water stress
- VNIR → vegetation status
- VNIR provides information on potential "accidents" in the temporal evolution of the vegetation status
- SWIR bands for thin cirrus cloud detection (1.38µm) and snow/cloud discrimination (1.6µm)

'Ecosystem stress' (vegetation) scientific objective

- Rapid surface changes: phenology (growth, flowering, senescence…), water stress, harvesting…
- Albedo needed for energy budget and *in fine* AET (actual evapotranspiration)
- Model constraining

'Coastal and inland waters' scientific objective

- Information on biological activity needed (chlorophylle concentration…)
- Dependence with turbulence and mixing processes (rapidly changing)



'Urban ecosystem monitoring' scientific objective

- Complexity of the structure → lots of shadows → less correlation between TIR and VNIR measurements if not acquired at the same time

Mission specifications: orbit selection

Directional anisotropy in TIR: still a research field

- A uniform viewing configuration on a given site allows minimizing its impact
- With a constant viewing configuration, the angular effect appears as a bias, and not as an error (crucial for temporal analysis)

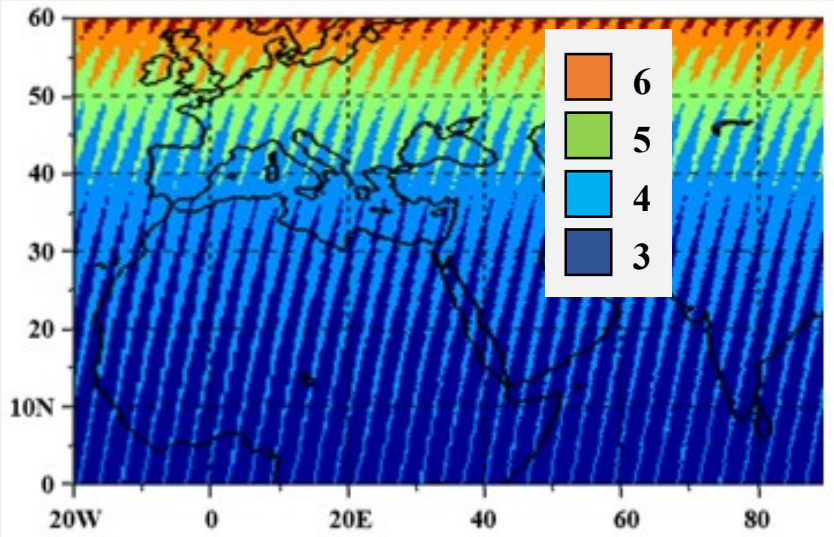
Hot-spot

- On a 3-day orbit, intertropical zones measurements can be inside hot-spot conditions, affecting seasonal-long time series
- Different viewing configurations garantee hot-spot free acquisitions, and provides valuable data for studying directional anisotropy

Selected orbit: 761 km altitude / 8 days revisit

- Repeatable geometric conditions every 8 days
- Compatible with global coverage every 3 days with extended swath (+/- 33 deg swath angle)
- Provides 2 hot-spot free acquisitions every 8 days on inter-tropical regions at any period of the year
- Drawback: swath is extended

Number of accesses in 8 days (with scan ±34 deg) →



Mission specifications: spectral bands

Band name	Wavelength Center (nm)	FWHM (nm)	Purpose
Blue	485	70	Detection of low clouds
Green	555	70	Coastal, sediments, snow
Red	670	60	Vegetation (LAI, fCOVER, NDVI, …)
NIR	860	40	Vegetation (LAI, fCOVER, NDVI, …)
Cirrus	1380	30	Detection of thin cirrus clouds
SWIR	1610	100	AOD, snow/cloud discrimination, vgt stress, burnt areas

+ 910nm band for water vapor content estimation (under study)

Band name	Wavelength Center (µm)	FWHM (µm)	Purpose
TIR 1	8.65	0.35	Temperature/emissivity separation
TIR 2	9.0	0.35	Temperature/emissivity separation
TIR 3	10.6	0.7	Split-window
TIR 4	11.6	1.0	Split-window

Source: TRISHNA SMRD V3.0

Mission specifications: spectral bands

Band name	Wavelength Center (nm)	FWHM (nm)	L_{typ} ($W/m^2/sr/\mu m$)	L_{max} ($W/m^2/sr/\mu m$)	Required SNR @ L_{typ} (*)
Blue	485	70	30	663.5	50
Green	555	70	30	600.5	100
Red	670	60	20	486.1	100
NIR	860	40	30	325.3	100
Cirrus	1380	30	6	55.0	25
SWIR	1610	100	4	77.9	100

(*) expressed at native GSD (57m)

Band name	Wavelength Center (µm)	FWHM (µm)	$NeDT_{threshold}$ @300K (K)	$NeDT_{goal}$ @300K (K)	$T_{saturation}$ (K)
TIR 1	8.65	0.35	0.3	0.25	400
TIR 2	9.0	0.35	0.3	0.25	400
TIR 3	10.6	0.7	0.25	0.2	400
TIR 4	11.6	1.0	0.25	0.2	400

Source: TRISHNA SMRD V3.0

TRISHNA products (under definition)

Product level	VNIR & SWIR	TIR
0	Raw observation data	Raw observation data
1	Ortho-rectified image Coarse cloud mask Top-of-atm. reflectance	Ortho-rectified image Coarse cloud mask Top-of-atm. Radiance Brightness temperature
2a	**Radiative variables :** ▪ Scene classification (Cloud, Shadows, Water, Snow, Land) ▪ Surface reflectance after atm. correction ▪ Atmospheric variables (water vapour, AOT) ▪ Albedo	**Radiative variables :** ▪ Scene classification (Cloud, Shadows, Water, Snow) ▪ Surface radiance after atm. Correction ▪ Surface temperature ▪ Surface emissivity
2b	**Biophysical variables** *(ecosystem stress and water use)***:** ▪ leaf area index, fractional vegetation cover, fAPAR ... ▪ net radiation, evapo-transpiration, water stress index ...	
3a	Periodic Syntheses (decadal, monthly) of radiative variables (see Level 2A)	
3b	Periodic Syntheses (decadal, monthly) of biophysical variables (see Level 2B) + - land cover - mask of irrigated crops	

TRISHNA science groups

Mission sub-groups:

- Ecosystem stress and water use
- Coastal and inland waters
- Urban microclimate monitoring
- Solid Earth
- Cryosphere
- Atmosphere

- CAL/VAL
- Definition of the products

Organization:

- French / Indian mirror organization involving local research entities
- Objectives: definition of the expected variables and associated precision, products, algorithms, cal/val strategy

→ joint Indo-french ATBDs

- Synergies to develop with ECOSTRESS, SBG, LSTM science teams

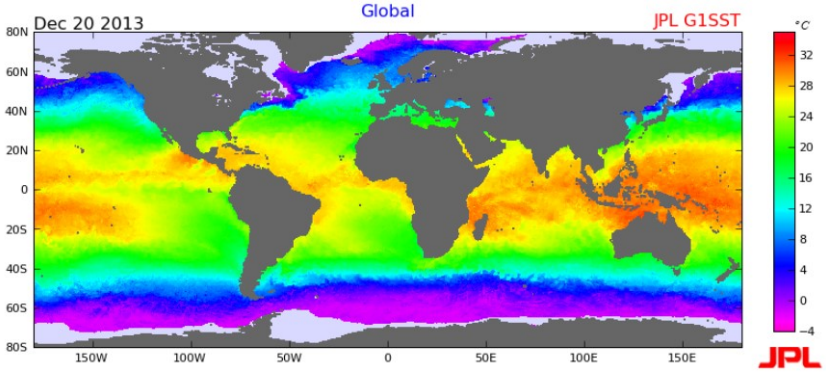
Next milestones:

- TRISHNA session at RAQRS 2020 *(ipl.uv.es/raqrs)*
- TRISHNA science workshop in Bangalore (Nov 2020)
- TRISHNA symposium in Toulouse (End 2021 / Beg 2022)

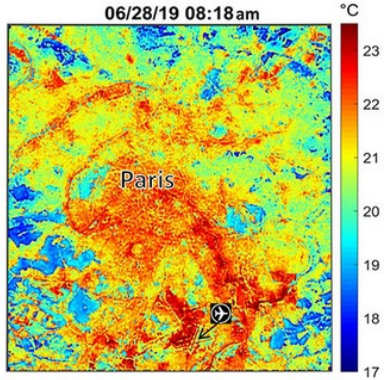
TRISHNA Mission at a glance

From *TRISHNA Science Mission Requirement Document*

- ISRO/CNES cooperation, launch in 2025
- Focus on ecosystem stress and water use
- Global coverage
- 4 TIR bands + 4 VNIR bands + 2 SWIR bands
- Revisit : 3 acquisitions per 8 days period
  761km-8day orbit reducing hot spot constraints in intertropical zone
- ± 34° scan angle, 1030km swath
- Nadir spatial resolution (VNIR-SWIR-TIR):
  57 m for continental and coastal areas, binned at 1 km over open ocean
- Overpass time : 1 PM ± 15 mn
- NeDT 0.2K
- Indo-French(*) science mission group, synergies to develop with ECOSTRESS, SBG, LSTM science & application teams
  (*) with european contributors



Daily global Sea Surface Temperature data (Dec 20, 2013) 1-km resolution
Credit: JPL Regional Ocean Modeling System group



Heat Wave over Paris (June 28, 2019) mapped by NASA's ECOSTRESS
Credit: NASA/JPL-Caltech

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