TRISHNA : UNE NOUVELLE MISSION SATELLITAIRE À HAUTE RÉSOLUTION SPATIO-TEMPORELLE POUR LE SUIVI DE L'ENVIRONNEMENT

TRISHNA : A NEW HIGH RESOLUTION THERMAL INFRARED INDO-FRENCH MISSION CONCEPT

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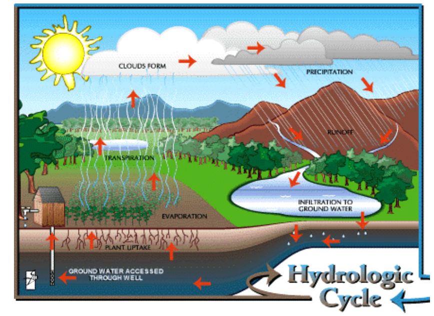
General context

Global change (climate, population growth, land use, urbanization, deforestation…)

⇒ increasing scarcity and deteriorating quality of the water resource

⇒ monitoring of the water cycle more and more crucial

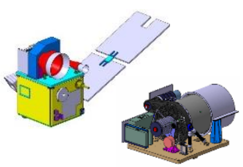


FEW Resources.org

Thermal infrared ⟶ AET, EB (evapotranspiration réelle, bilan d'énergie)

Variability of processes at local scale ⇒ Need of Spatial systems combining both high spatial resolution and revisit capacities, not existing today

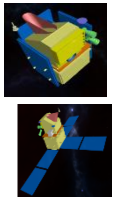
Several projects from the mid 90's (since **IRSUTE**, CNES *Seguin et al., 1999*)…



…MISTIGRI (CNES)

- **4 LWIR + 3-4 VNIR**
- **1 day / 32 km swath**
- **Microbolometers**

Lagouarde et al., 2013



…THIRSTY (CNES/NASA JPL)

- HyspIRI (**7 LWIR+1MWIR) + 3-4 VNIR**
- **3 days / Global coverage**
- **Cooled detector**

Crebassol et al., 2014

CNES-ISRO project TRISHNA

Seguin et al. (1999), Rem. Sens. of Environ., 68, 357-369
Lagouarde et al. (2013), Int. J. of Remote Sensing, 34 (9-10), 3437-3466
Crebassol et al. (2014), IGARSS Symposium, July 13th-18th, Québec City, Canada

TRISHNA scientific objectives

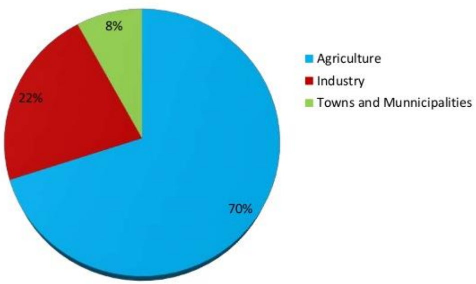
Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment

1) Ecosystem stress and water use *design driver*
2) Coastal and inland waters *design driver*

3) Urban
4) Solid Earth
5) Cryosphere
6) Atmosphere

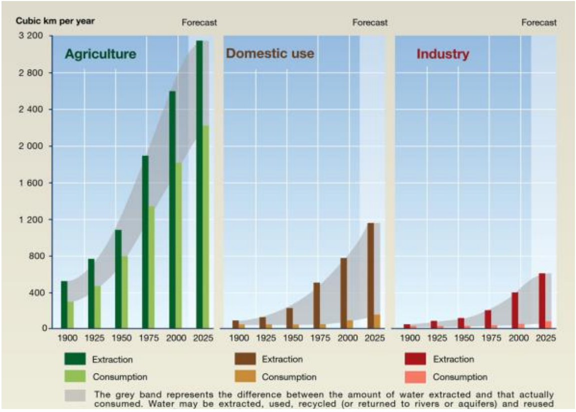
Scientific objectives - Ecosystem stress and water use

70% of world water used for agriculture



Source: World Bank, World Development Indicators, 2012

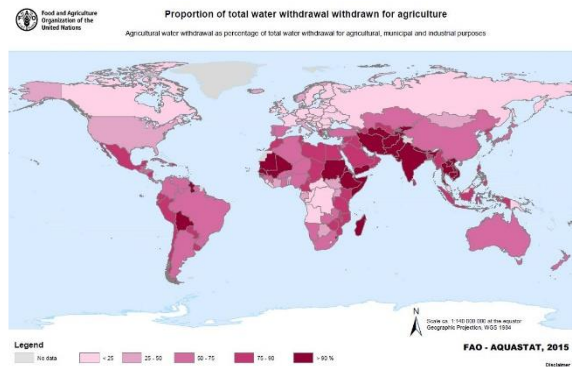
Rapid increase of water consumption



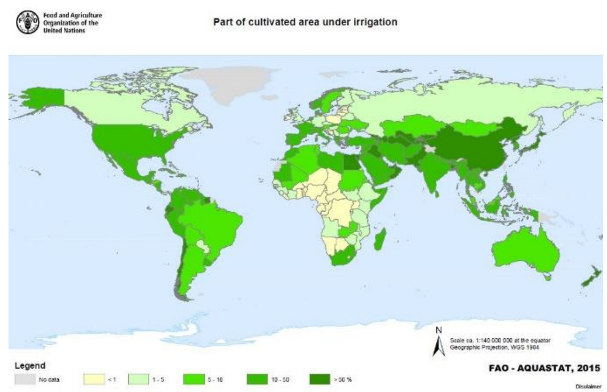
Trends in water use by sector (UNEP)

(http://www.unep.org/dewa/vitalwater/article43.html)

Proportion of total water withdrawal withdrawn for agriculture

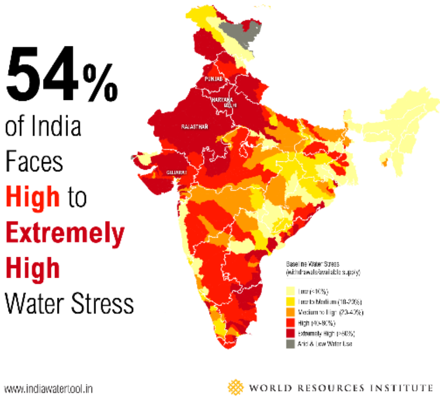


Part of cultivated area under irrigation



20% arable land irrigated → 45% food production (FAO)

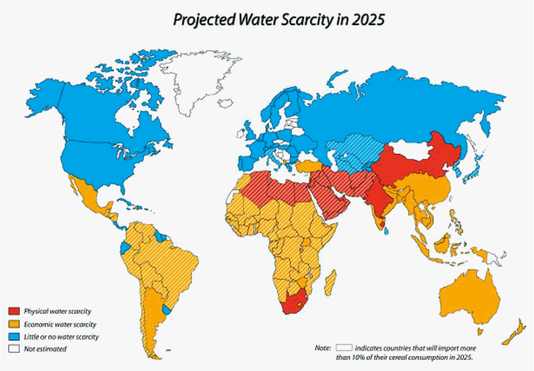
Severe water stress in many parts of the world



Scientific objectives - Ecosystem stress and water use

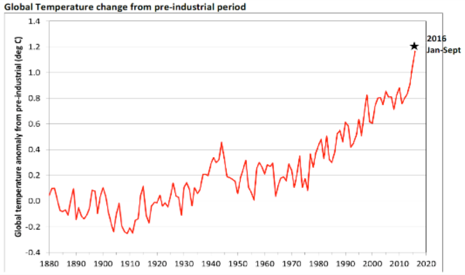
● Agriculture/forestry

- *water stress detection / water needs / irrigation optimisation*
- *water resources management*
- *growth/ crop production, food security (see 2011 G20)*
- *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*



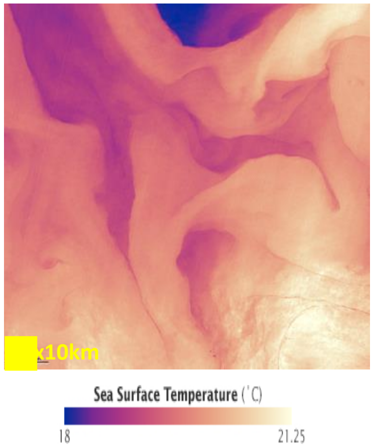
● Hydrology

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

● Ecosystem monitoring, ecology

- *microclimates, biodiversity*
- *natural vegetation droughts*

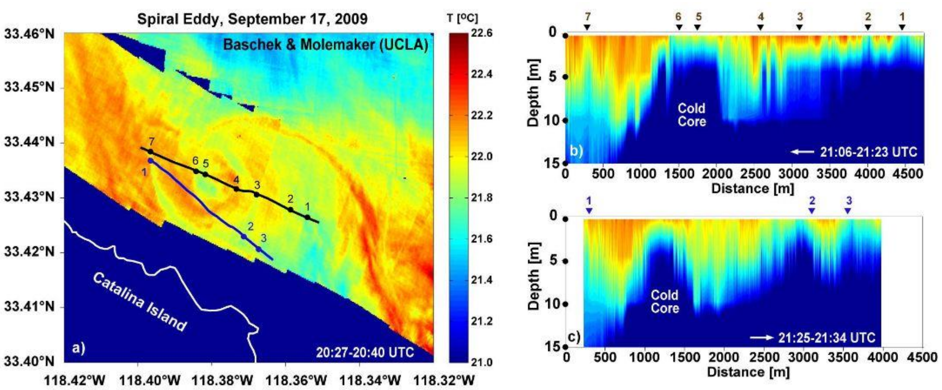
Scientific objectives - Coastal and inland waters

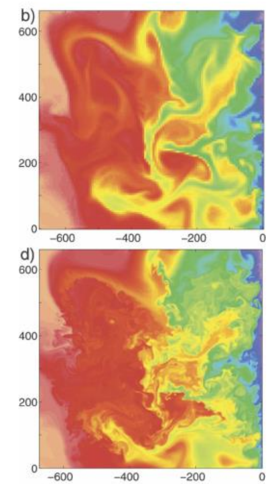


Gulf Stream portion seen by the TIRS sensor, Landsat 8, April 9, 2013

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…)





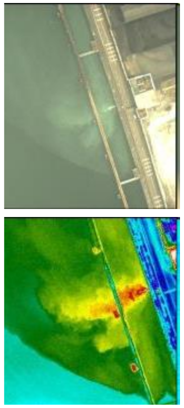
res=6 km

res=0.75 km

Modelled SST fields in the California Upwelling System: zooms of the black box at 6 and 0.75 km resolutions (Capet et al., 2008)

2.5 km diameter eddy adjacent to Catalina Island (CA): airborne SST image (left) with in situ temperature transects from two boat tracks (right). (after Holt et al., 2012)

Scientific objectives - Coastal and inland waters

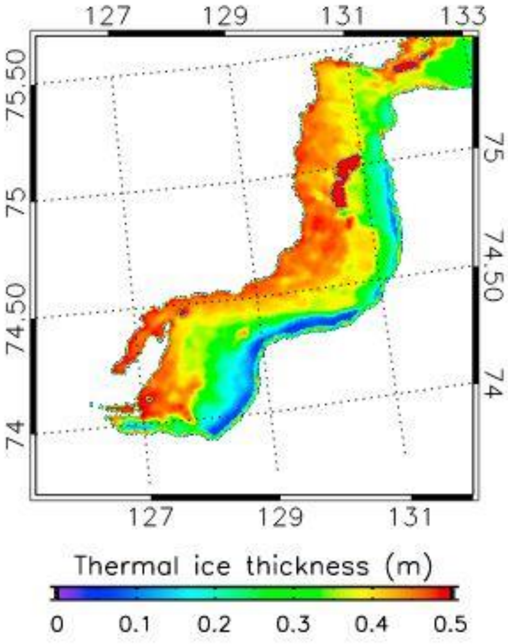


Inland waters (lakes and rivers)

- 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

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



Thermal ice thickness as derived from AVHRR surface temperatures (18 Feb 2004, 1200 UTC) in the eastern Laptev Sea (After Krumpen et al., 2011)

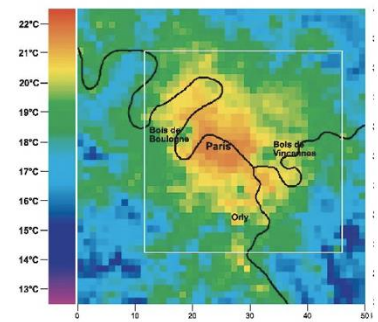
Scientific objectives - Secondary objectives

URBAN

Urban population
(10^9 inhabitants)

2008	2050
3.3	~5

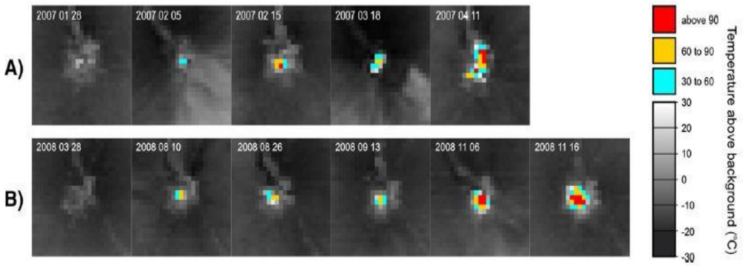
- **Urban heat island and comfort** *(welfare of inhabitants, health…)*
- **Urban vegetation**
- **Urban and peri-urban hydrology** *(run-off, urban planning)*
- **Urban meteorology and atmospheric flow** *(dispersion of pollutants…)*
- **Anthropogenic fluxes and energy consumptions** *(heating, air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



AVHRR Aug. 9, 2003 UHI over Paris (Dousset, 2007)

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...)



Thermal precursors to lava flow at Kliuchevskoi: anomalies in the crater, ASTER data (Murphy et al., 2013)

Scientific objectives - Secondary objectives

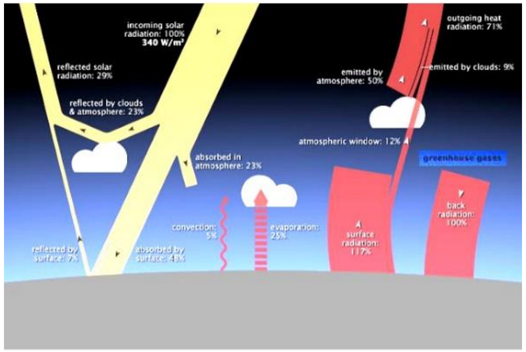
CRYOSPHERE

Himalaya-Karakoram-Hindukush (HKH), virtually a 'third pole'

- snow and glacier melt runoff
- debris detection in glaciers
- dynamics of glacial lakes

ATMOSPHERE

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



(from NASA Earth Observatory)

0verview on recent research for defining mission specifications

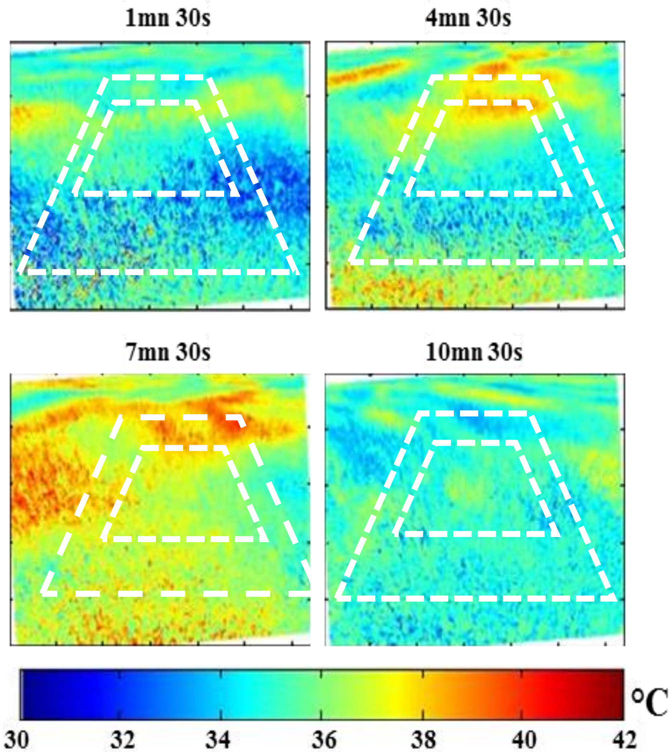
Recent attention paid on particular topics :

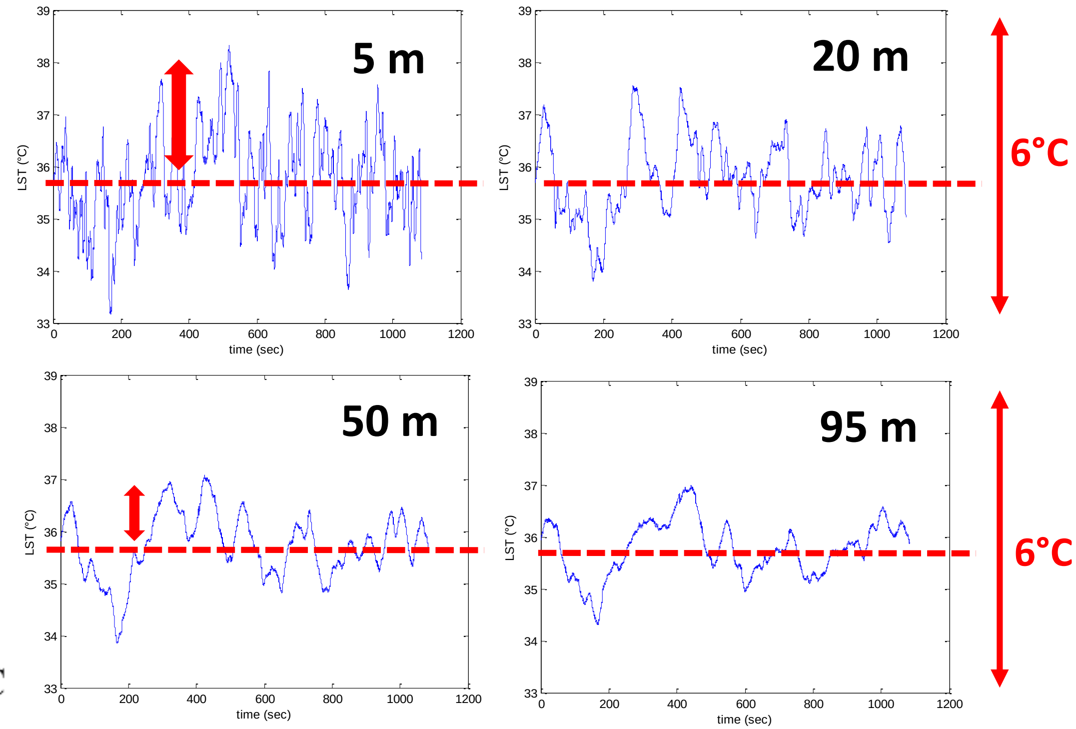
- Impact of atmospheric turbulence on LST measurements accuracy
- Analysis of TIR directionnal anisotropy
- Development of models and methodologies for estimating surface fluxes

… reveals crucial for determining the mission specifications

Impact of atmospheric turbulence on LST measurements

Experimental measurements of LST temporal fluctuations over a dry maize field





Similar fluctuations are observed over a bare dry smooth soil

Low frequency ↔ Planetary BL (PBL), high frequency ↔ Surface BL (SBL)

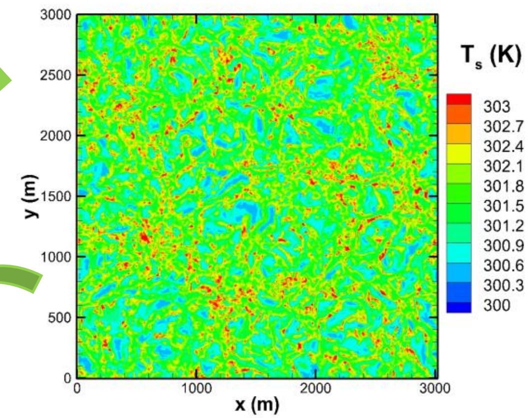
Impact of atmospheric turbulence on LST measurements

Experimental characterization of the uncertatinty on Ts

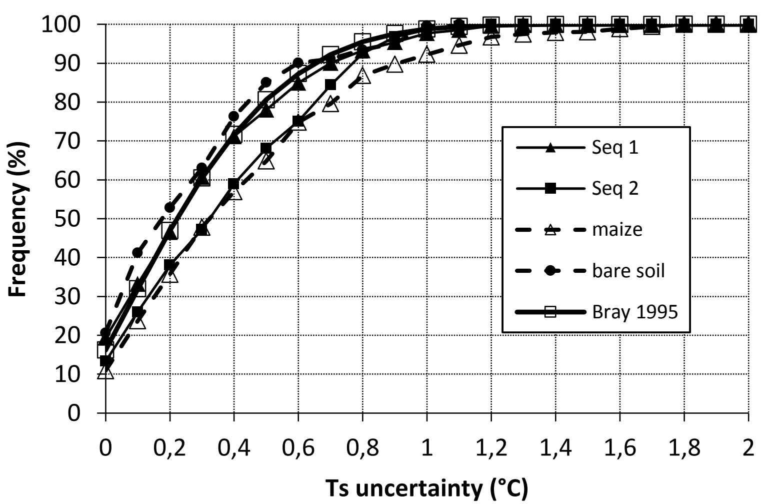
±0.6 °C for ~60% measurements
±0.8 °C for ~80% measurements
at 50m resolution

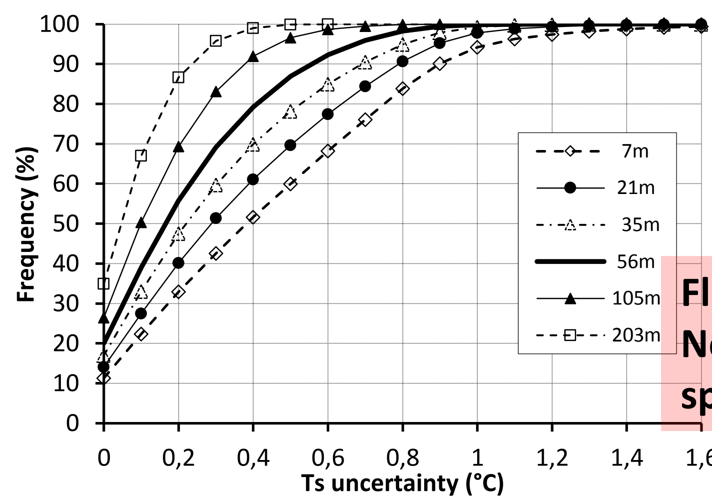
Lagouarde et al., RSE 2013
Lagouarde et al., RSE 2015

LES simulation, Pine forest



Statistics of the satellite LST departure from its mean value



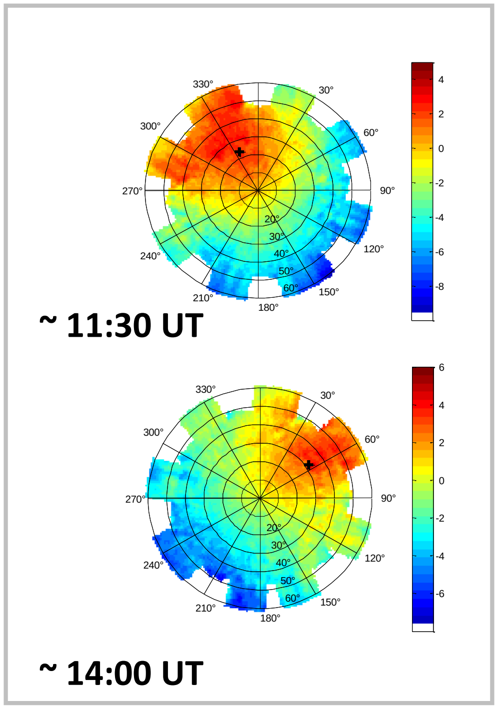


Flexibility on NeDT specification?

Directional anisotropy

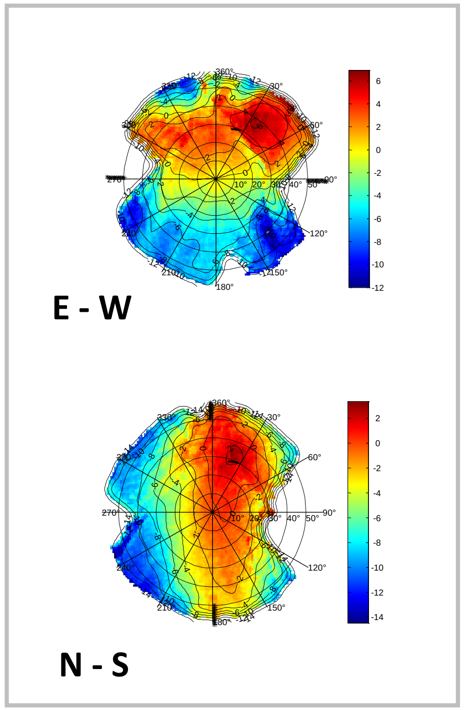
LST prone to important directional anisotropy effects and hot spot

Urban



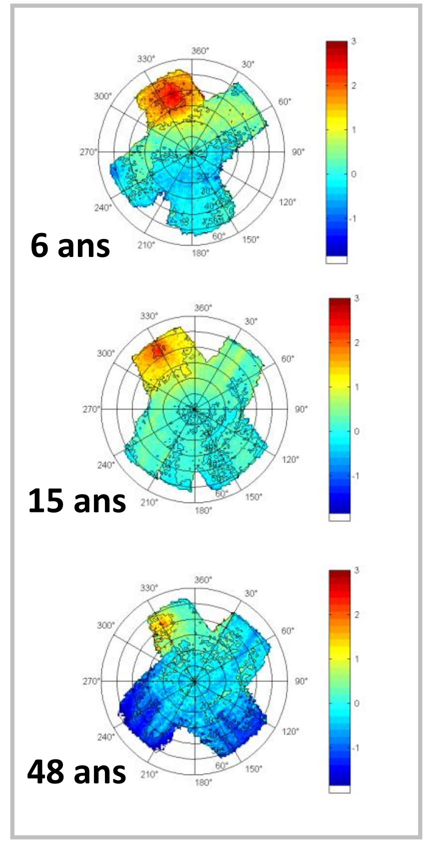
Lagouarde et al., RSE 2004, 2010

Impact of rows (vineyard)



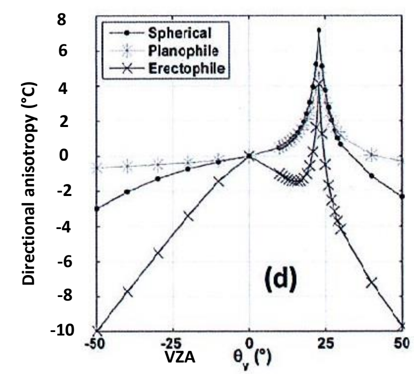
Lagouarde et al., IEEE, 2013

Impact of pine stand structure



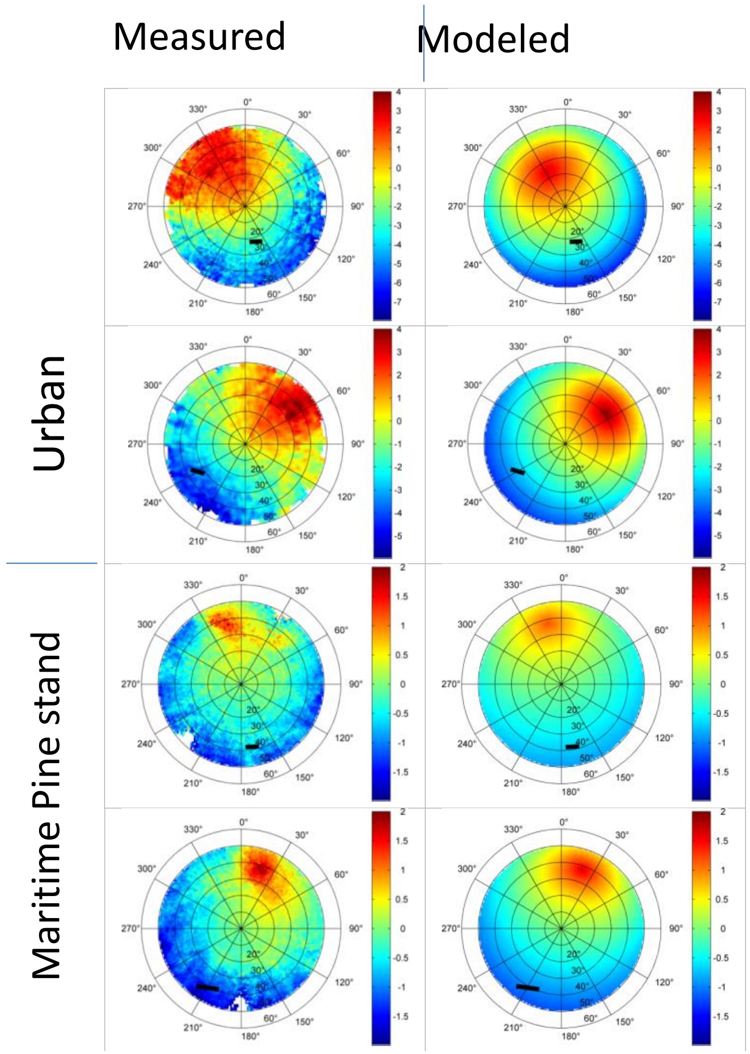
Lagouarde et al., RSE 2000

Impact of structure (SCOPE simulated)



Comparison of HS in principal solar plane for 3 crop structures (spherical, planophile, erectophile)

Directional anisotropy (modelling)



Modelling directional anisotropy:

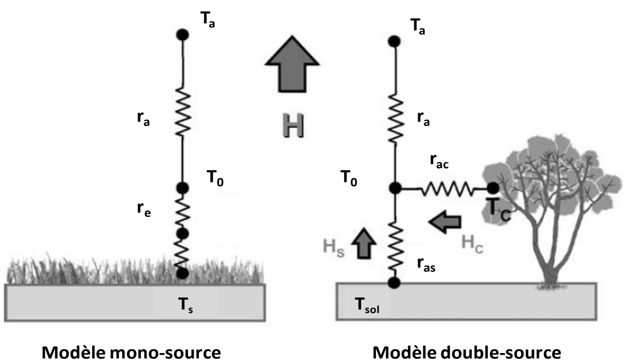
- ❑ 3D models (urban daytime and nighttime
  [Lagouarde et al., RSE 2010 and 2012]
- ❑ SCOPE multilayer model
  [Duffour et al., 2015 and 2016a]
- ❑ Parametric approach
  [Duffour et al., 2016b]

Research currently conducted to improve parametric approaches by combining TIR with VNIR anisotropy
→ See **Zunjian Bian**'s Poster

Duffour et al. / RSE, 158 (2015) 362–375
Duffour et al. / RSE, 177 (2016a) 248–264
Duffour et al. / RSE, 186 (2016b) 250–261

Modelling surface fluxes

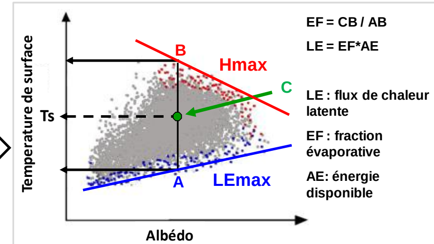
Different approaches are followed within the TRISHNA SWG group :



***1 source- and 2 source-models** based on resistive schemes (Kustas et al.)*

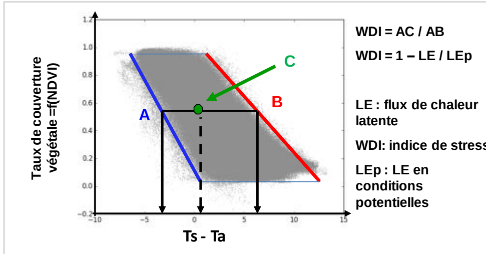
SEBAL (Bastiansen, 1998)

S-SEBI (Roerink et al., 2000)

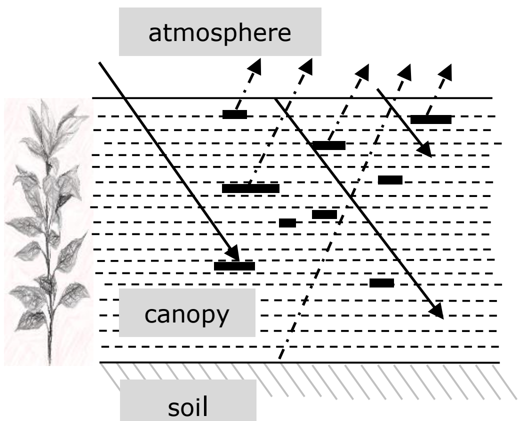


WDI (Water Deficit Index)
(Moran et al 1994)

METRIC (Allen et al., 2007)



***Contextual approaches** (S-SEBI, WDI,…)*

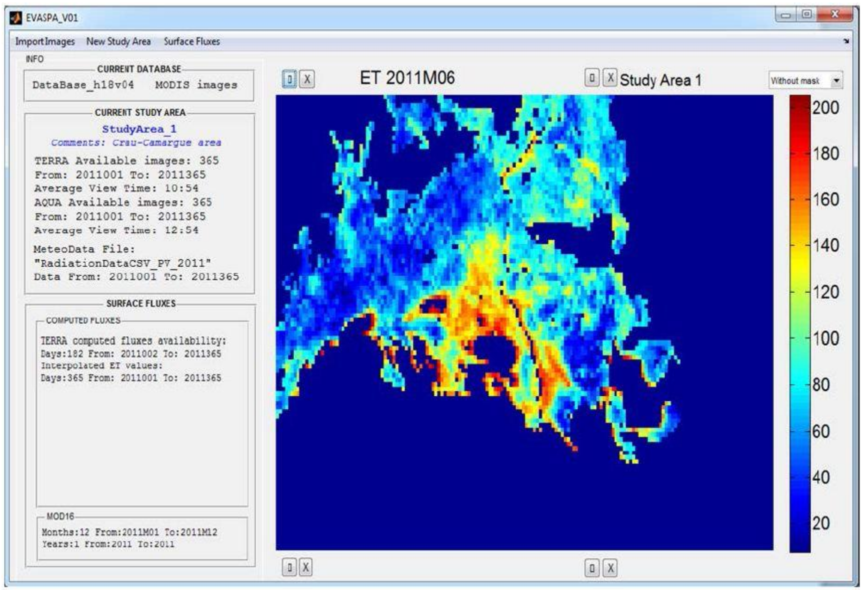


***Multi-layers TSVA models** (MuSICA, SCOPE…)*
Ogée et al., 2003; Van der Tol et al., 2009; Duffour et al, 2015

Lagouarde and Boulet, 2016. Land Surface Remote Sensing in Continental Hydrology (chapter 10)

Modelling surface fluxes

Important methodological know-how → Efforts to develop practical tools for ET mapping

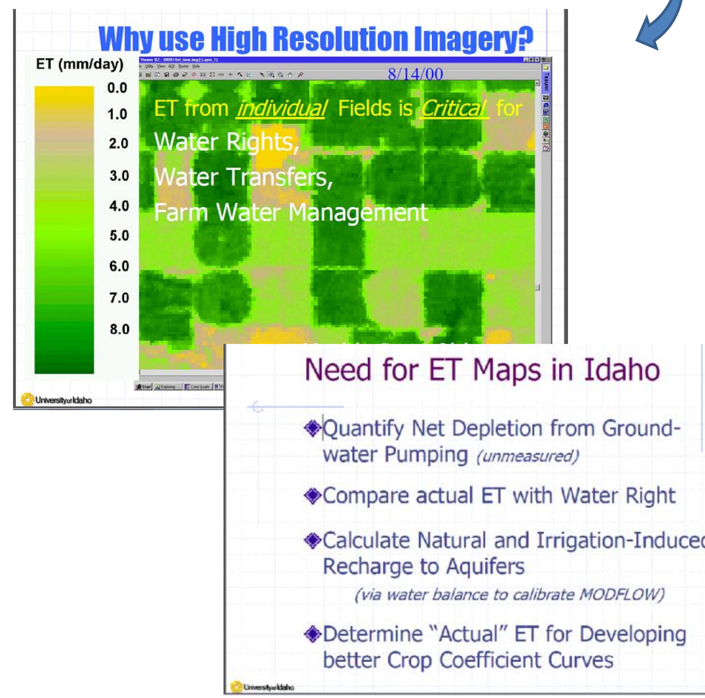


Development of EVASPA : a tool for mapping actual evapotranspiration

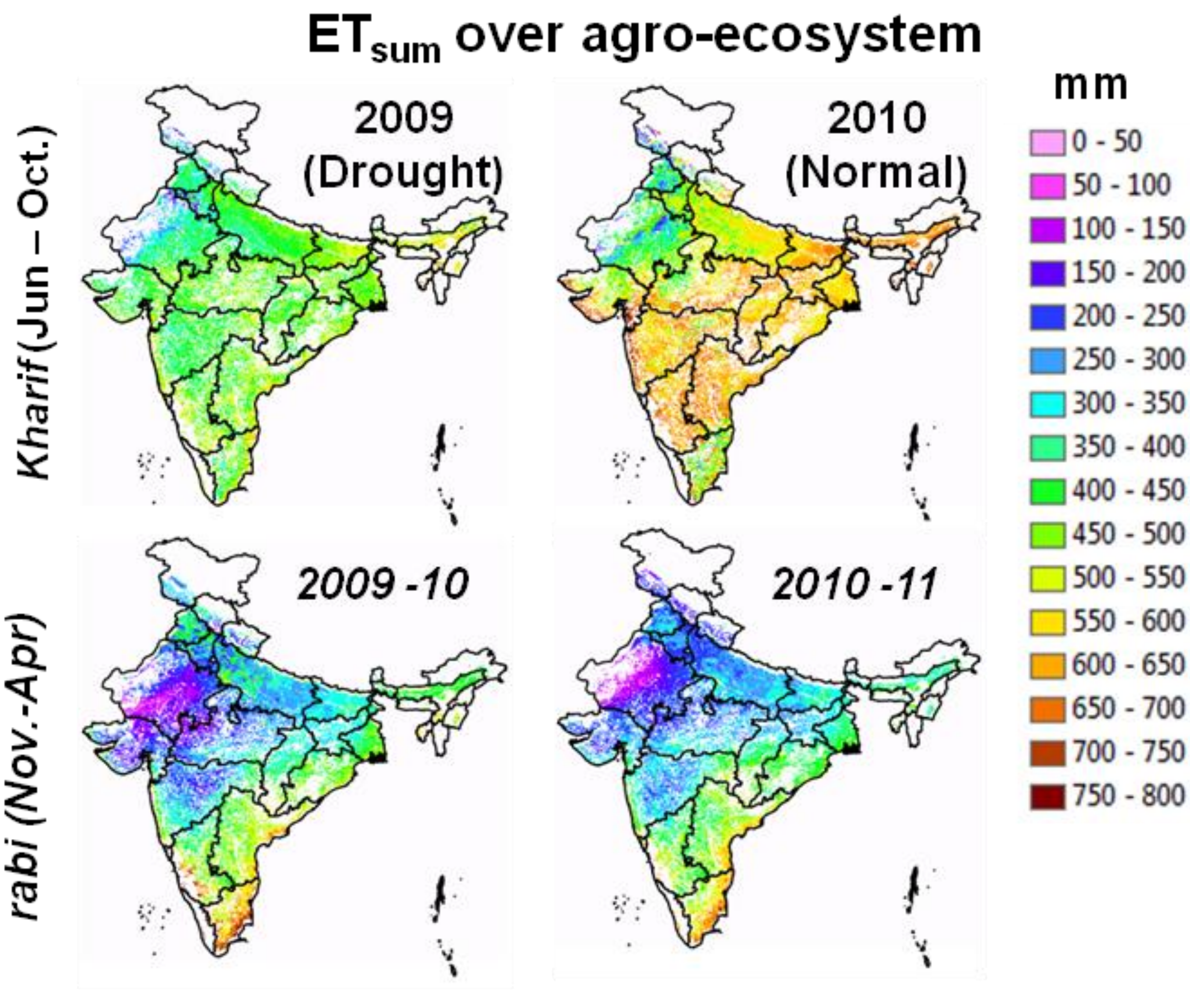
Gallego Elvira et al., DOI: 10.1016/j.proenv.2013.06.035

Operational applications to water management developed in USA

From Richard Allen (METRIC/SEBAL workshop Fort Collins, Colorado, February 7, 2005)



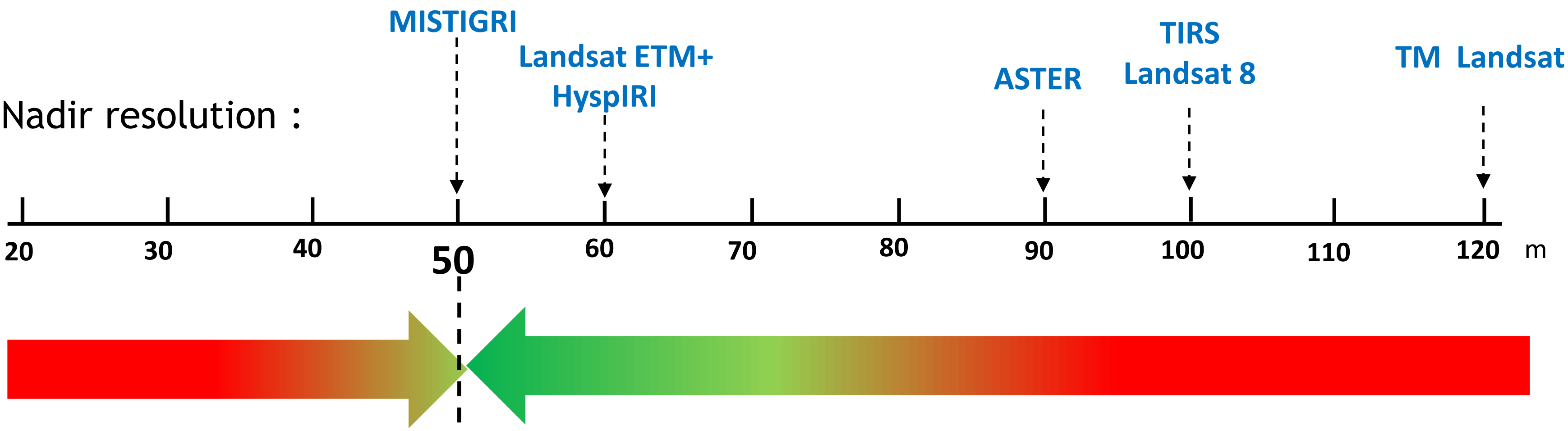
Regional-scale ET and agricultural consumptive water use from Indian Geostationary Satellites

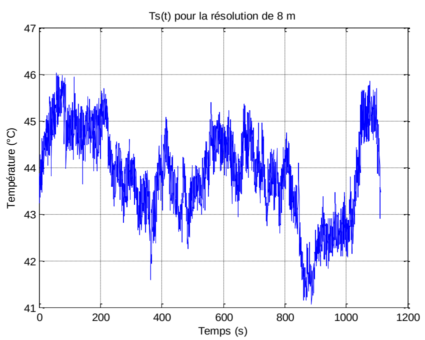


In : Bhattacharya et al, 2013; ISRO-GBP Scientific report

Main mission specifications

Mission specifications - Spatial resolution





Optimum range of resolution at nadir

Degradation of end of swath pixels

Puducherry region

SBL Turbulence limits accuracy

TRISHNA

Acces to field scale require <100m

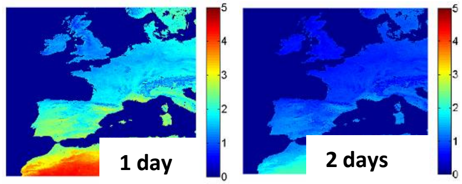
(Agam 2007, Garrigues 2006, Kustas 2004….)

Mission specifications - Revisit

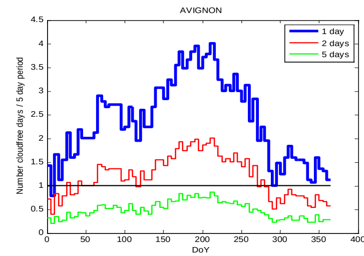
Revisit imposed by 4 combined constraints:

1 minimum availability of cloud free data

Cloud frequency analysis with criteria: 1 cloudfree day / 5 days required], RAQRS 2010

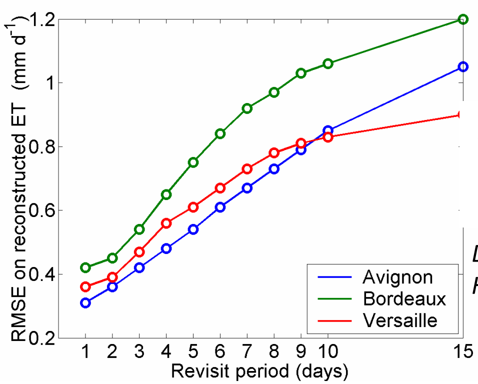


Analysis of 2000-2009 MODIS cloud masks



Statistical analysis of a hourly solar radiation dataset (1993-2009, INRA AGROCLIM) over France

2 providing sufficient accuracy on derived products (←meteo, irrigation…)

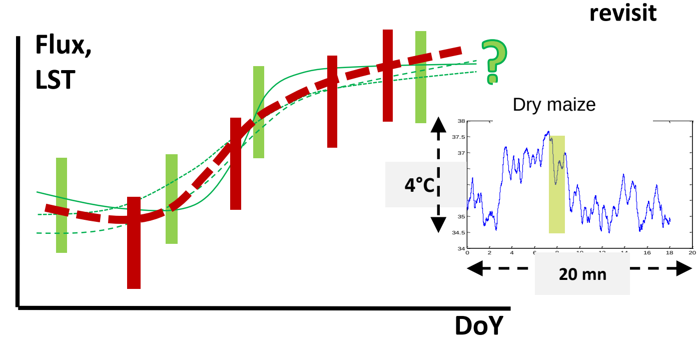


Analysis of ISBA-AGs ETR (IPCC scenario A1B, period 1950 - 2100)

Delogu, E. et al. (2012). HESS, 9, 1699-1740

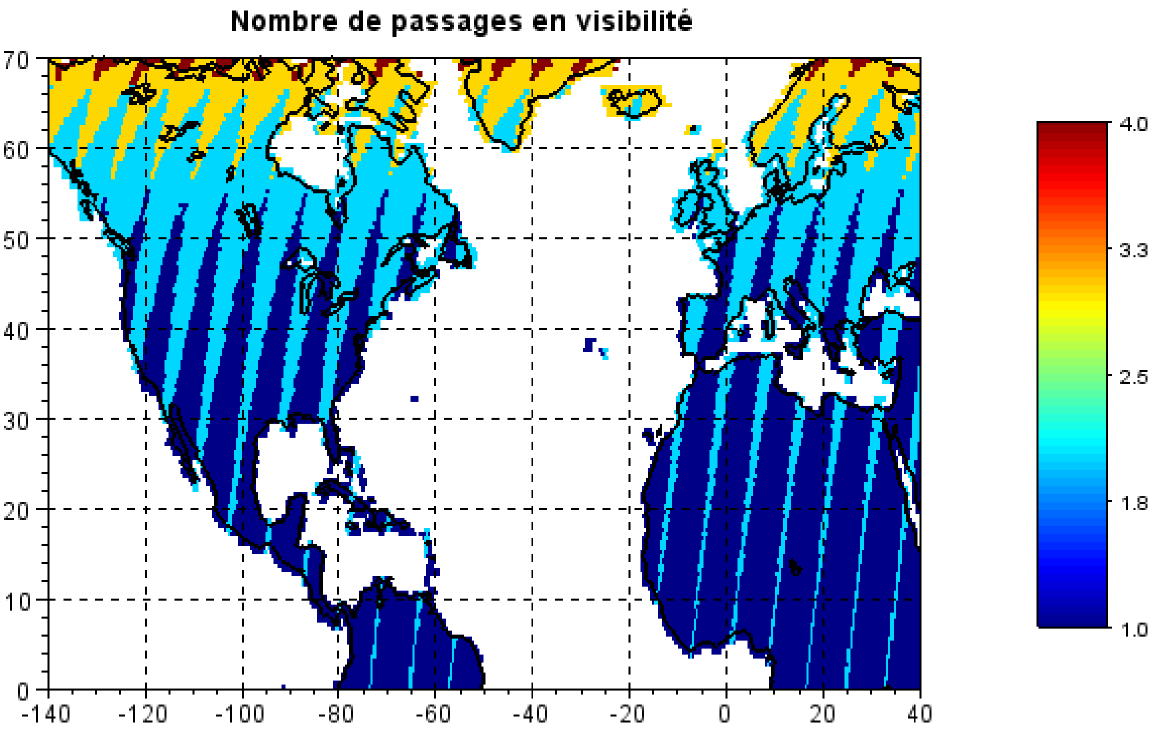
3 Necessity of reducing the impact of atmospheric turbulence uncertainty

Assimilation and/or interpolations more robust with higher revisit



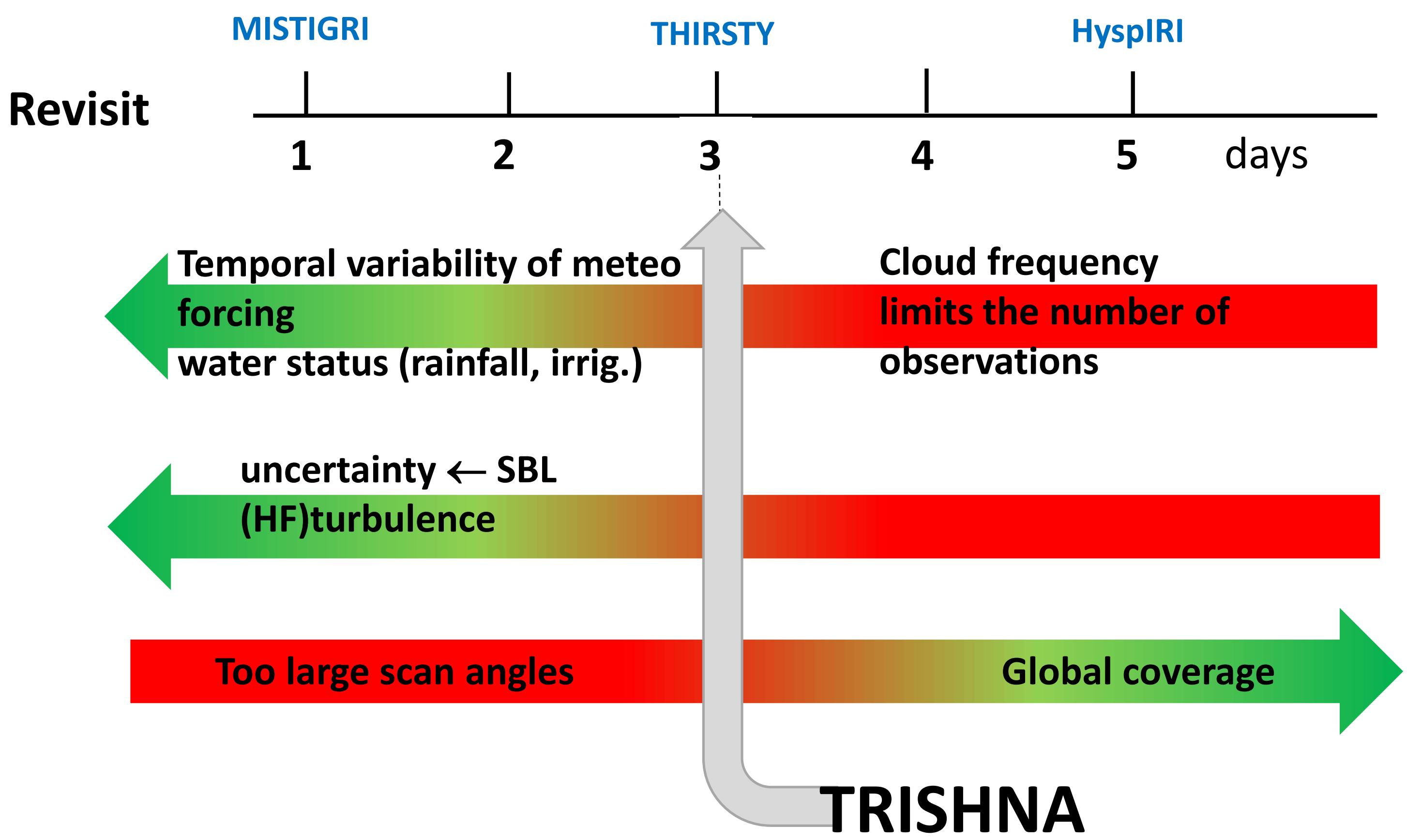
Mission specifications - Revisit

4 global coverage requirement ← orbit/revisit/swath/scan angle



THIRSTY
666 km orbit

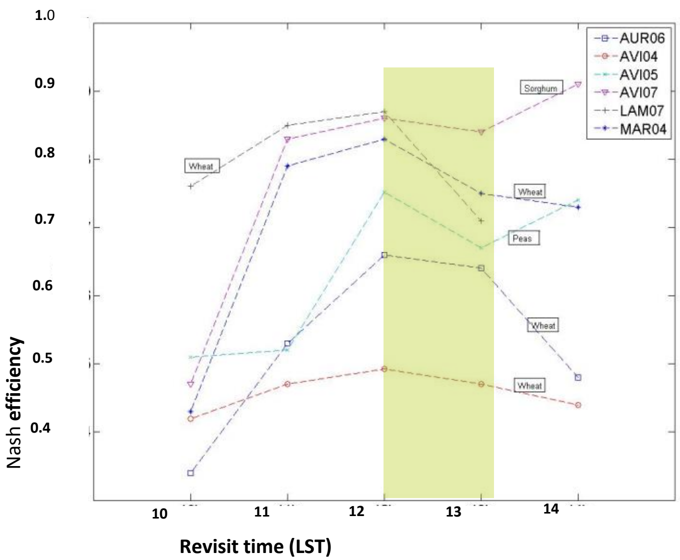
Mission specifications - Revisit



Also refer to Anderson et al., 2012

Mission specifications - Overpass time

1 **Overpass time must cope with maximum sensitivity for flux estimation**

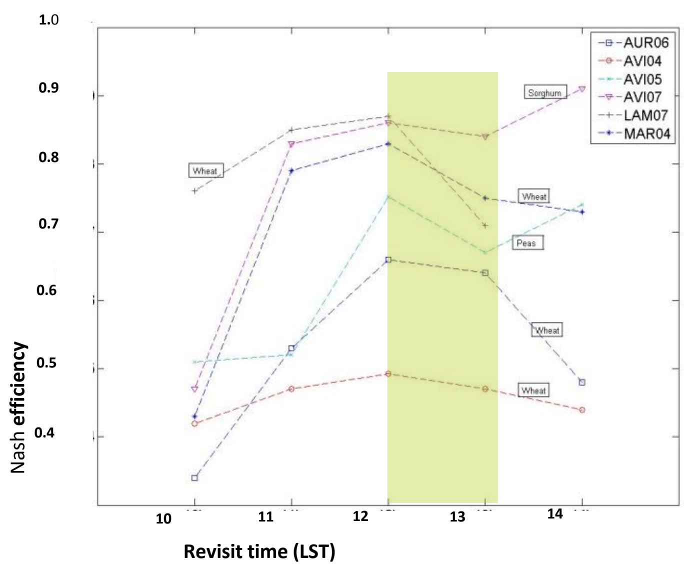


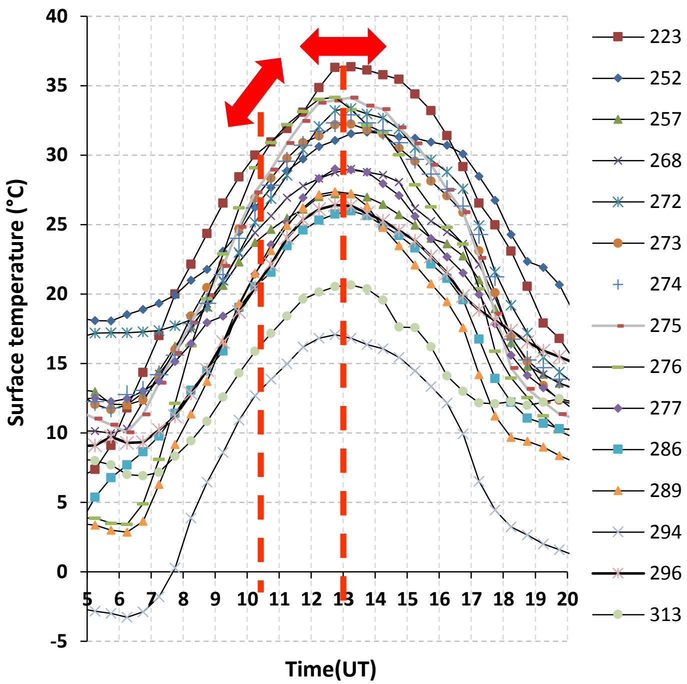
→ ~12:00 - 13:00 UTC overpass time providing maximum accuracy on fluxes retrieval

Mission specifications - Overpass time

1 **Overpass time must cope with maximum sensitivity for flux estimation**

2 Minimizing the sensitivity of LST measurement to overpass time





LST at different dates along the year (pine stand)

~ 4°C/h

→ ~12:00 - 13:00 UTC overpass time providing maximum accuracy on fluxes retrieval

→ 13 LST minimises possible errors due to variation in acquisition time

→ 13 LST more suited to models having 30mn-1hour time steps

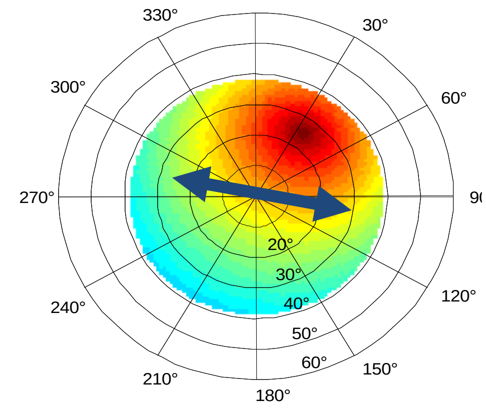
Mission specifications - Overpass time

3 **SST measurements**

13:00 LST daytime
⇒ 01:00 nighttime overpass

1:00 AM preferred for ST measurements over water surfaces (by avoiding remaining skin thermal effects)

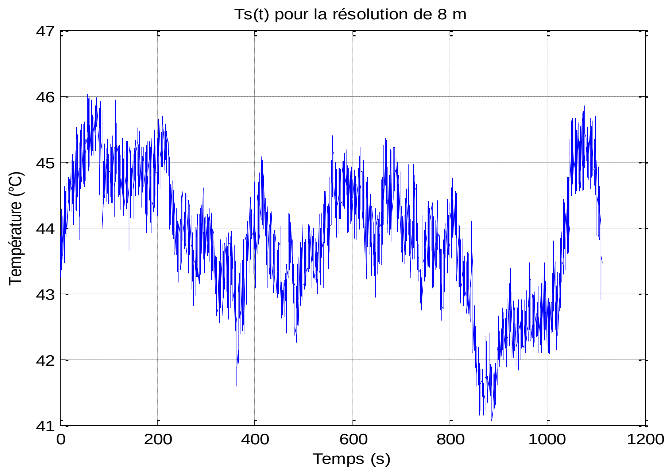
4 **Hot spot impact**



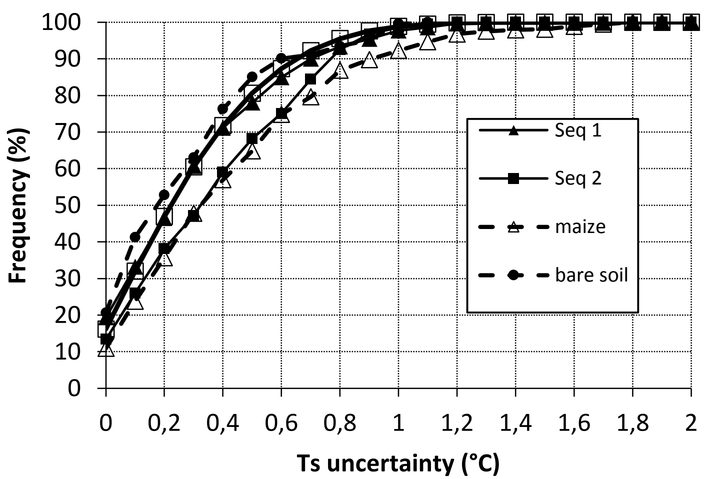
For mid-latitudes, scan perpendicular to principal plane →limitations of hot spot effects

Not true for inter-tropical zone!

Mission specifications - Instrument sensitivity



Atmospheric turbulence- induced uncertainty on LST

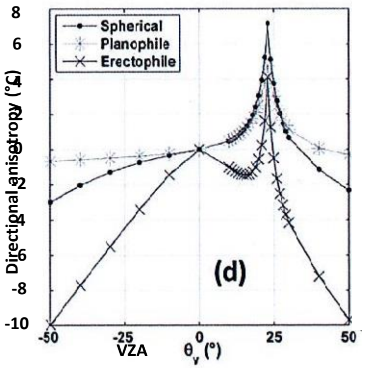


NeDT specification better than 0.3 K not necessary for continental surfaces at 50 m resolution

TBC for water surfaces

Mission specifications - Orbit definition

The TIR Hot Spot within the inter-tropical area

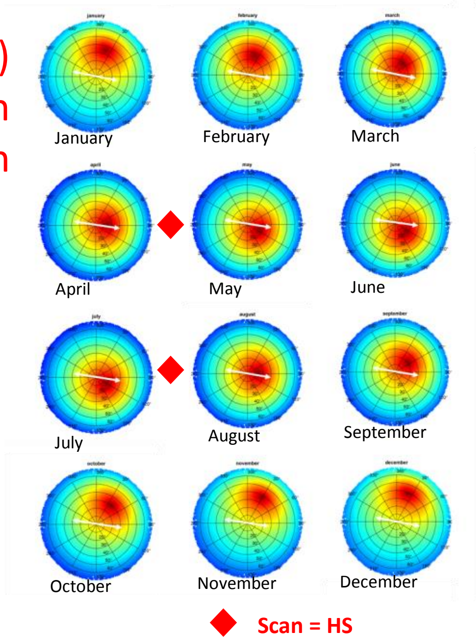


HS from SCOPE simulations
(Duffour et al., RSE 177, 248-264, 2016)

No robust model of Hot Spot available today ⇒ large uncertainty of LST close to HS

In inter-tropical (IT) area, HS very often close to the scan line

Bangalore : position of the TIR hot spot throughout the year
RL model simulations (qualitative)

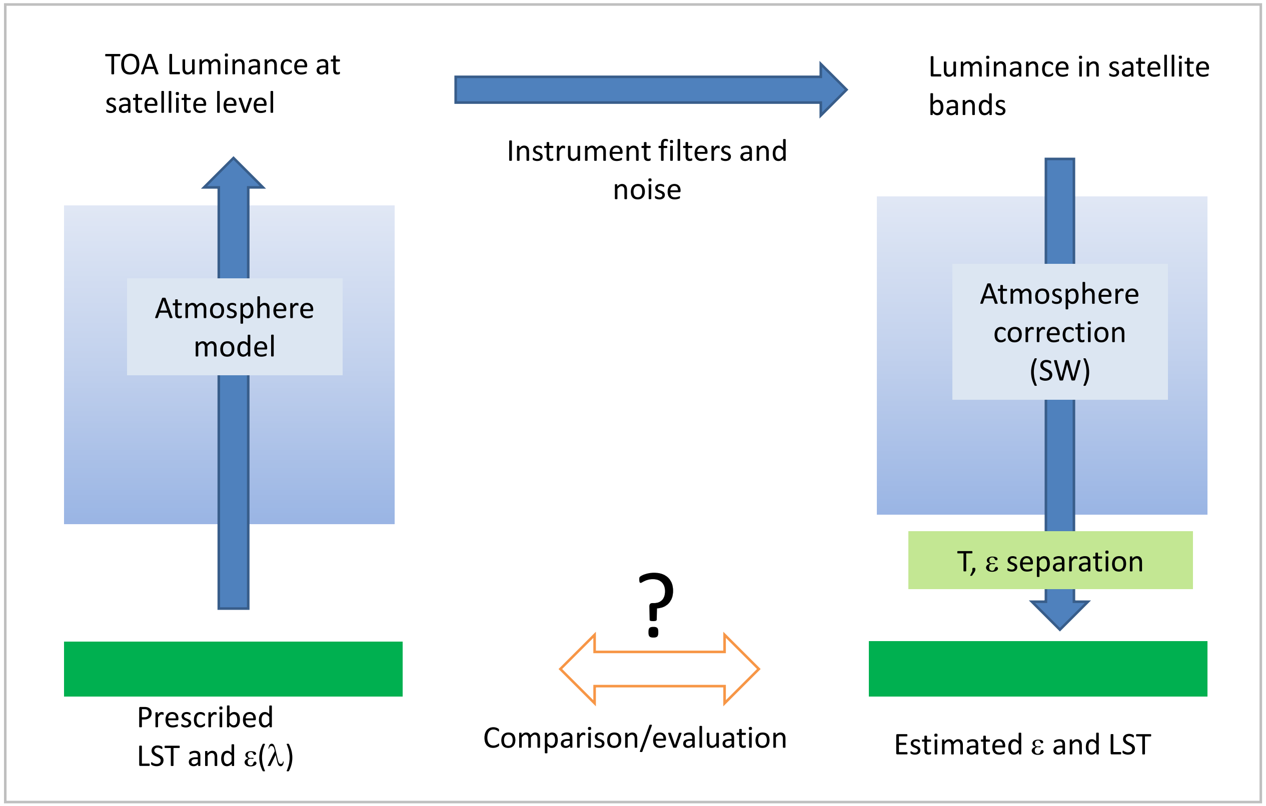


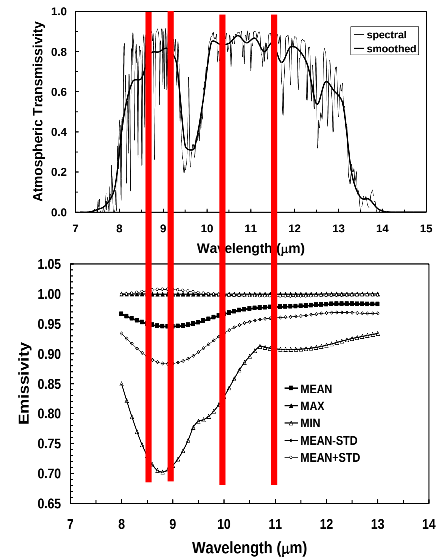
Debate between *(i) a* 3 day (666 km) and *(ii) a* 8 day (679 km) orbit providing 3/2/3 day sub-cycles with different viewing configurations

Duffour et al. / RSE 186 (2016) 250–261
Duffour et al. / RSE 177 (2016) 248–264

Mission specifications - TIR spectral bands specification

Simulations being performed with a end-to-end simulator to consolidate TIR bands (jointly at CNES, ONERA, IRD and Univ. Valencia)





4 **bands :**

8.6 µm $\Delta\lambda$ **= 0.35 µm**
9.1 µm $\Delta\lambda$ **= 0.35 µm**
10.3 µm $\Delta\lambda$ **= 1 µm**
11.5 µm $\Delta\lambda$ **= 1 µm**

Mission specifications - VNIR spectral bands specification

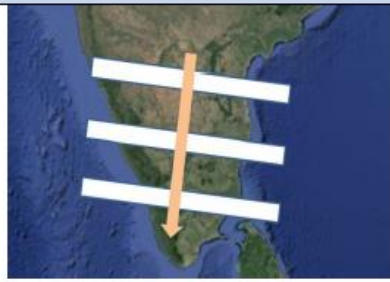
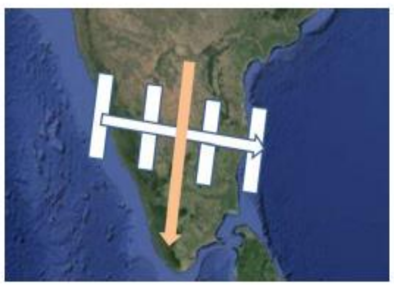
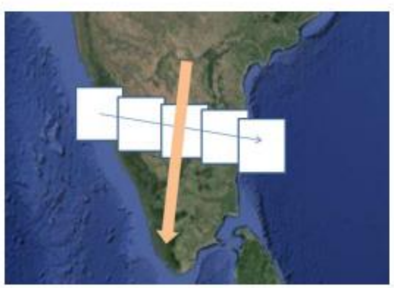
- VNIR bands together with TIR for :

  → Registrating TIR imagery
  → Cloud detection and filtering
  → Disaggregation of TIR
  → Contextual approaches
  → Surface parameters estimation
  → ...

Band	Central wavelength (µm)	Need	Status
Blue	0.485	Clouds discrimination	Mandatory *(degraded resol)*
Green	0.555	Coastal, sediments, snow	Mandatory
Red	0.650	Vegetation	Mandatory
Near Infrared	0.860	Vegetation	Mandatory
SWIR 2	2.13	Atmosphere	ISRO requirement
SWIR 1 *	1.38	Atmosphere, cirrus detection	Optional, TBD *(degraded resol)*

Simultaneity between TIR and VNIR measurements needed
$\Rightarrow$ both instruments on the same platform

Current studies - Concept & technologies trade-offs

Observation principle	Illustration	Main characteristics
Pushbroom		• All ACT field imaged at once, • Reduced requirement for mechanisms, • Very large number of pixels in focal plane, • Ground gaps for IR calibration.
Scanner		• Reduced optical field and pixel number in the focal plane, • Easy access to IR calibration views, • Natural implementation of Multispectral and TDI capacities, • Very short integration time • Agile scan mechanism
Starer		• Image stability and reduced optical field, • Easy access to IR calibration views, • Short integration time, • Complex 2D pointing mechanism, • Increased complexity for multispectral capacity implementation

Concept

- Push-broom concept killed off
- One study on a scanner
- One study with step and stare

Technologies

- µbolometer too “slow” for such required performances
- MCT cooled detector as baseline

Mislestones

- **November 2017 : French-Indian Mission Design Review, to verify :**
  - the scientific needs and how they are interpreted in a mission specification
  - the data distribution policy
  - The work share between France and India

- **2018-2019 : phase A, including an industrial instrumental phase A study**

- **Launch 2024-2025 ?**