TIRAMISU
(Thermal InfraRed Anisotropy Measurements over India and Southern eUrope) project in preparation of the TRISHNA mission

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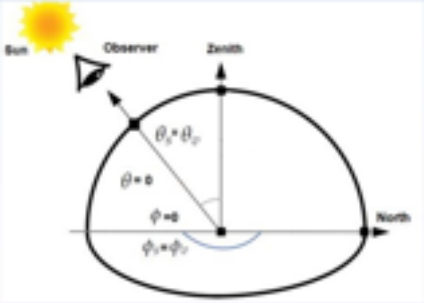
Context and objectives

HR TIR mission (TRISHNA, LSTM, SBG) will have an orbit pass ~12:30.

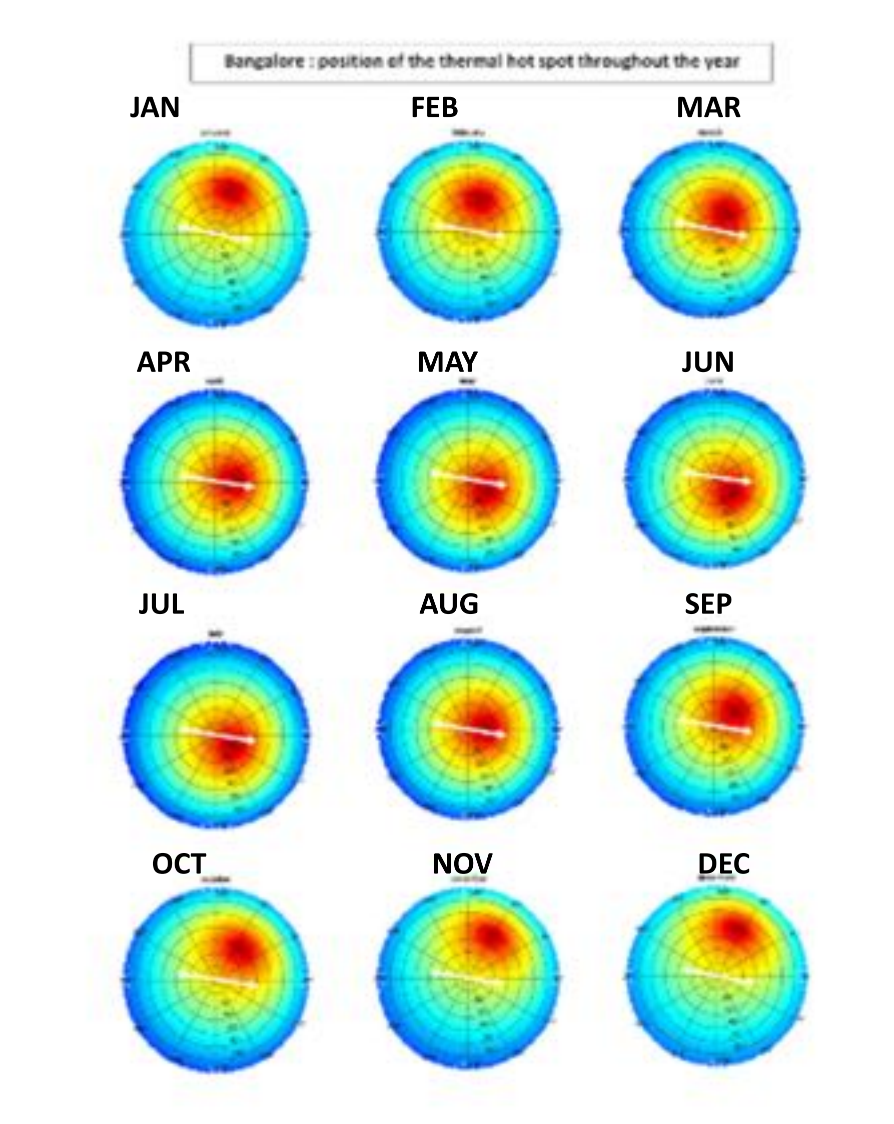
In the tropics, from March to October, many observations will be close (or even in) to the hot spot (HS) geometry (the satellite and Sun directions coincide).

This justifies effort for the HS phenomenon to be characterized, modeled, and possibly data sets decontaminated from the HS (or discarded).

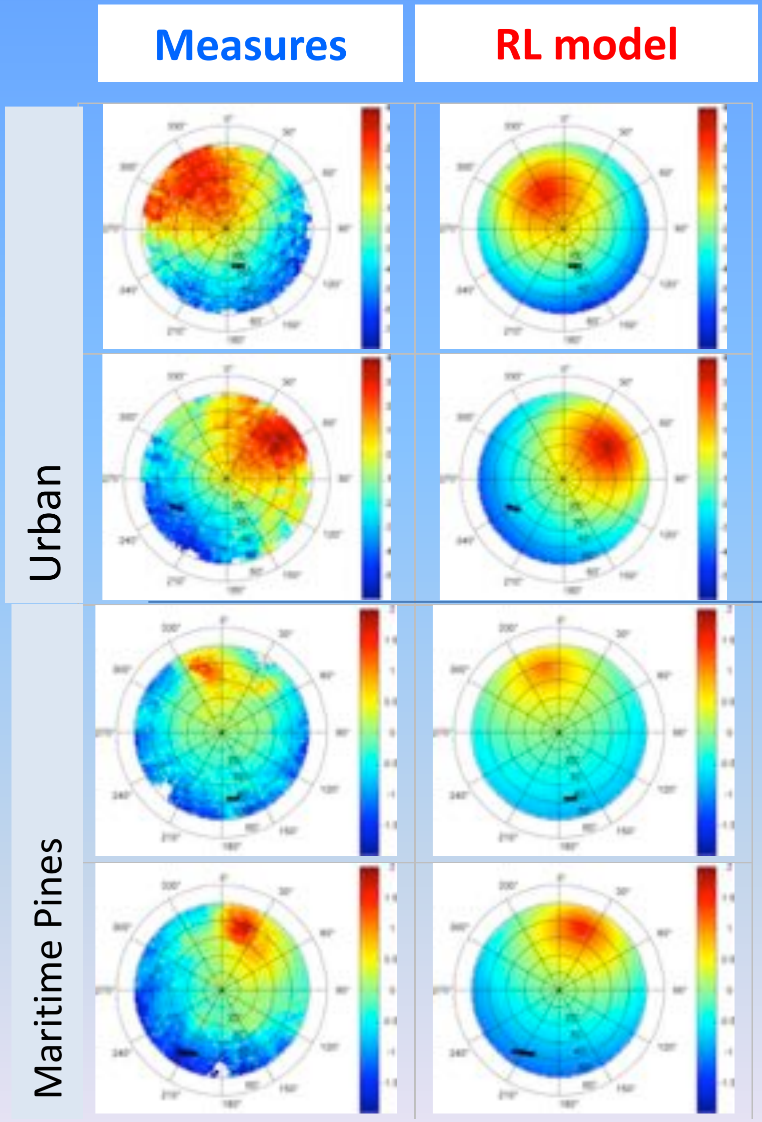
HS features are poorly known in TIR domain compared to optical domain (which is also true for directional effects in general).



BANGALORE : position of the hot spot throughout the year



Historical background

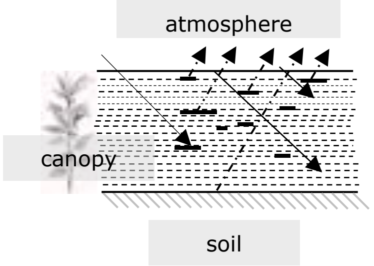


(crédit J.P. Lagouarde & M. Irvine)

3 categories of hot spot model:

- ❑ 3D (urban, vegetation, ex: DART)
  [Lagouarde et al., RSE 2010 and 2012]

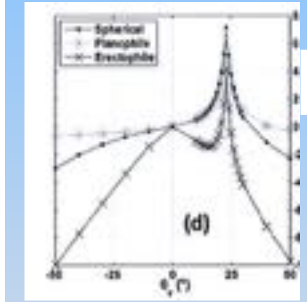
- ❑ SCOPE 1D (multilayers)
  [Duffour et al., 2015 and 2016a]



- ❑ Parametric (Roujean-Lagouarde)
  [Duffour et al., 2016b]

$$T(\theta_s,\theta_v,\varphi)-T_N=(T_{HS}-T_N)\frac{[\exp(-kf)-\exp(-kf_N)]}{[\exp(-kf_{HS})-\exp(-kf_N)]}$$

$$f=\sqrt{\tan^2\theta_s+\tan^2\theta_v-2\tan\theta_s\tan\theta_v\cos\varphi}$$



7 K

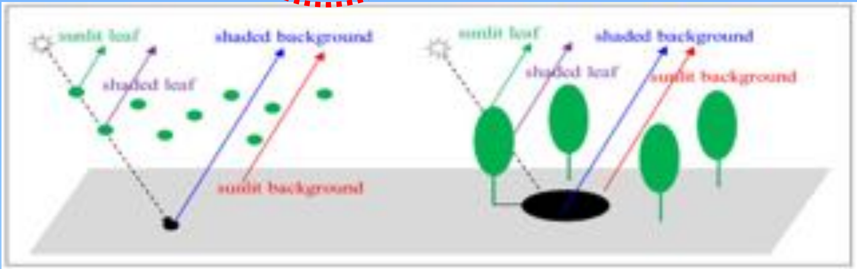
Duffour et al. / RSE, 158 (2015) 362–375
Duffour et al. / RSE, 177 (2016a) 248–264
Duffour et al. / RSE, 186 (2016b) 250–261

PARAMETRIC MODELING

A General Framework of Kernel-driven Modeling in the Thermal Infrared Domain

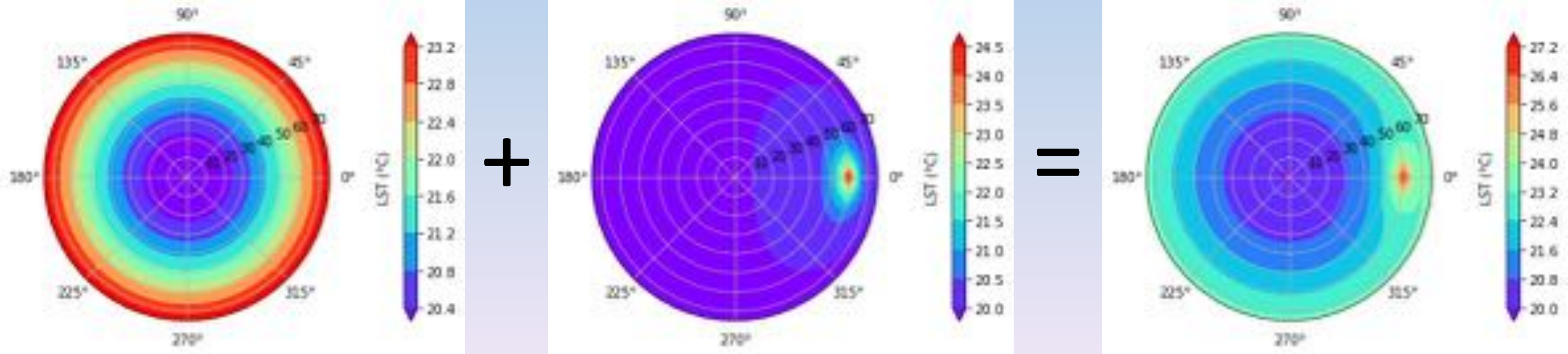
[Biao Cao, Jean-Louis Roujean, Jean-Philippe Gastellu-Etchegorry et al.]

Remote Sensing of Environment, 2021, 252 112157. https://doi.org/10.1016/j.rse.2020.112157

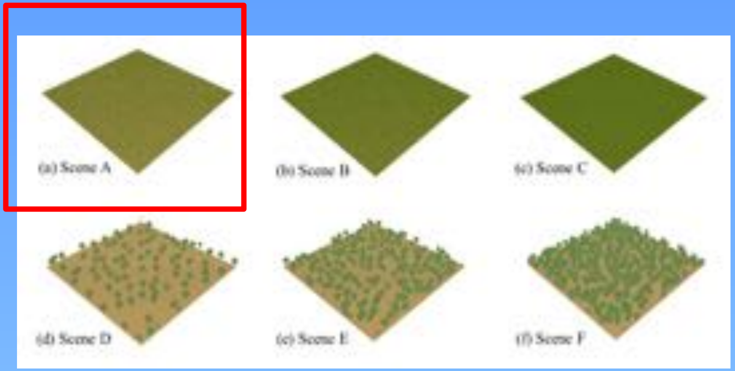


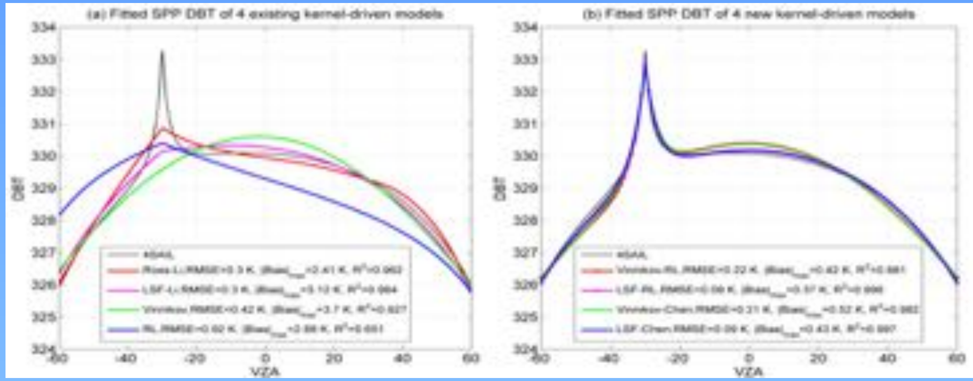
$$R(\theta_s,\theta_v,\Delta\varphi) = a_{slsoil}(\theta_s,\theta_v,\Delta\varphi)L(BT_{slsoil}) + a_{shsoil}(\theta_s,\theta_v,\Delta\varphi)L(BT_{shsoil}) + a_{slleaf}(\theta_s,\theta_v,\Delta\varphi)L(BT_{slleaf}) + a_{shleaf}(\theta_s,\theta_v,\Delta\varphi)L(BT_{shleaf})$$

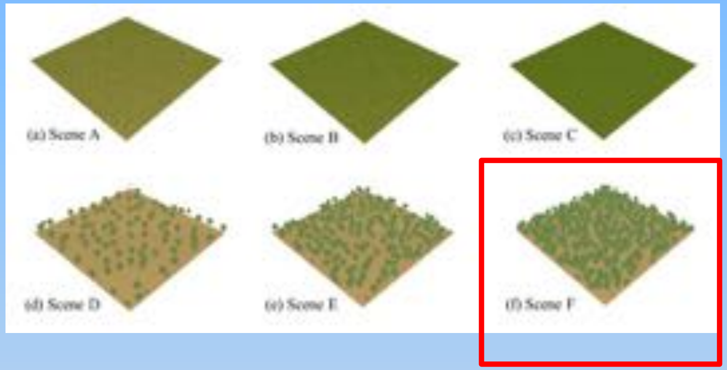
$$T(\theta_s,\theta_v,\Delta\varphi) = f_{iso} + f_{BaseShape}K_{BaseShape}(\theta_v) + f_{Hotspot}K_{Hotspot}(\theta_s,\theta_v,\Delta\varphi,width)$$

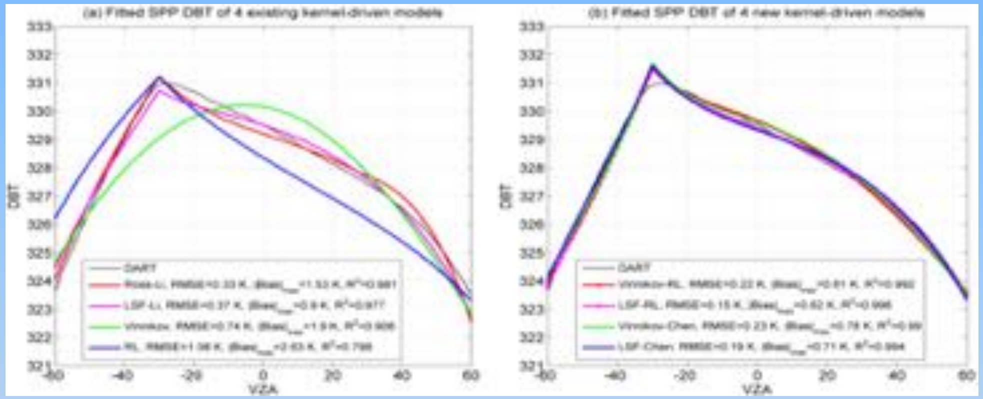


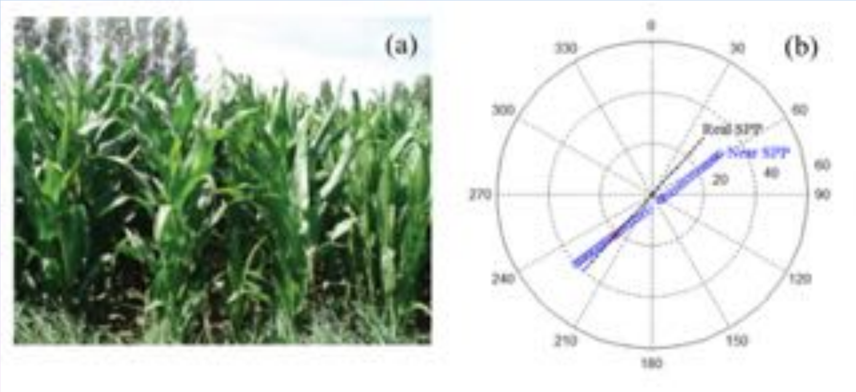
Old kernels => New kernels

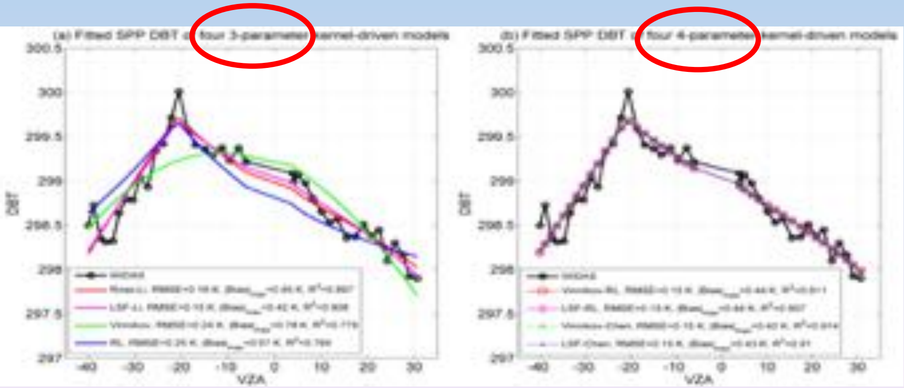








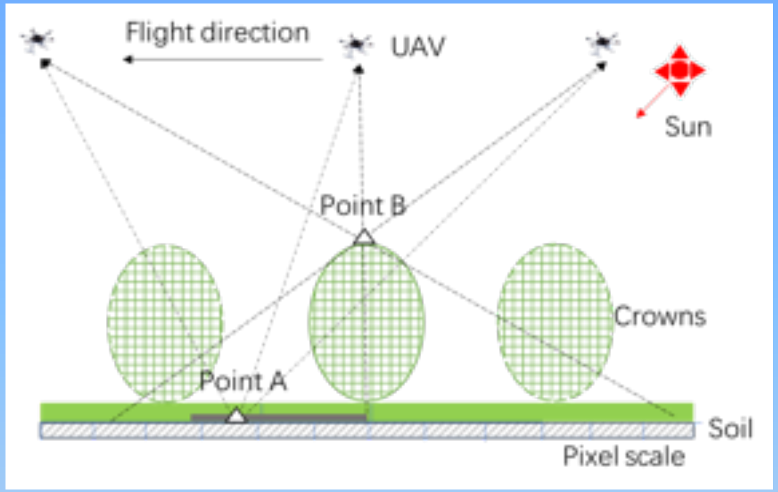


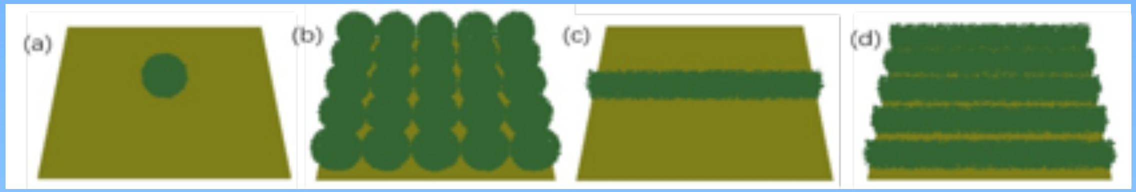


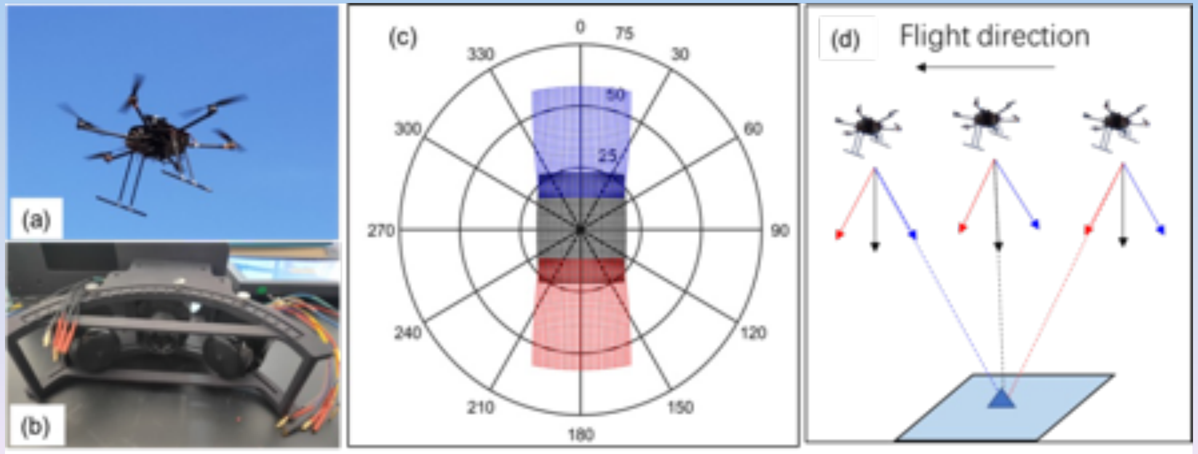
Simulation of the directional anisotropy of fine-scale emissions over tree and crop canopies based on UAV measurements

Zunjian Bian[1]. Jean-Louis Roujean[2], Biao Cao[1], Yongming Du[1], Hua Li[1], Philippe Gamet[3], Junyong Fang[1,4], Qing Xiao[1,4], Qinhuo Liu[1,4]

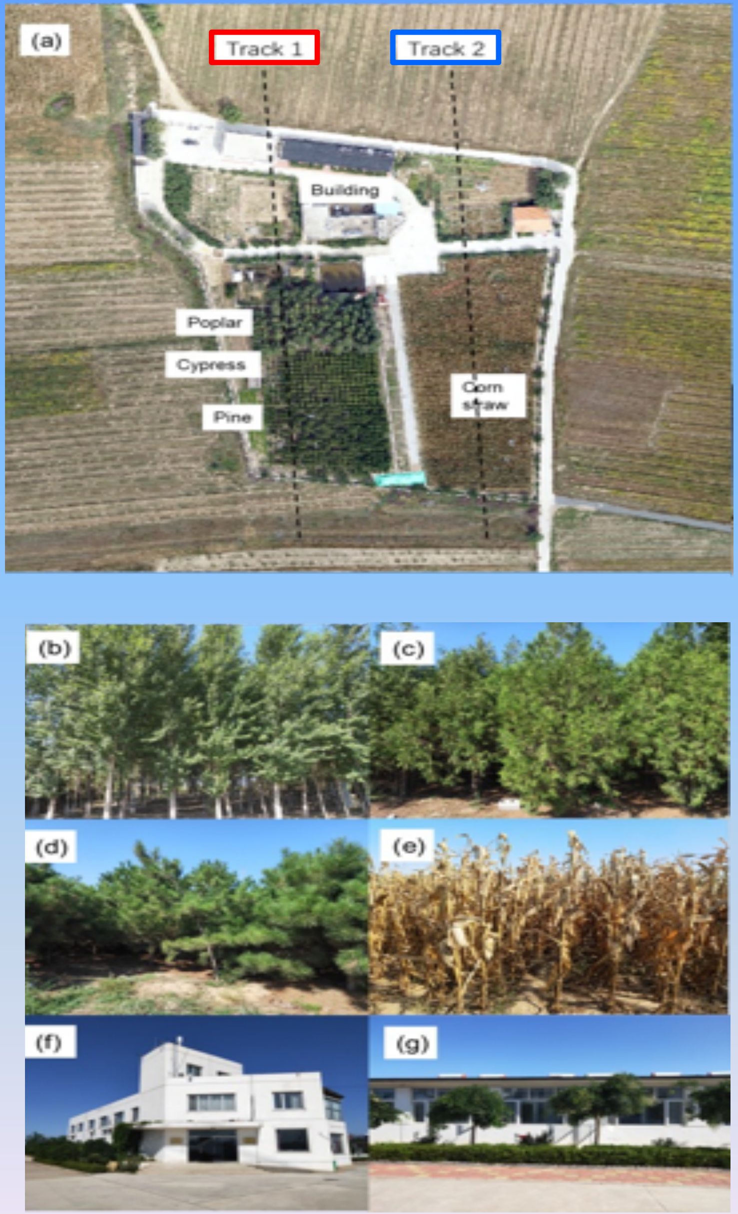
Remote Sensing of Environment, Volume 252, 2021, 112150, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2020.112150.

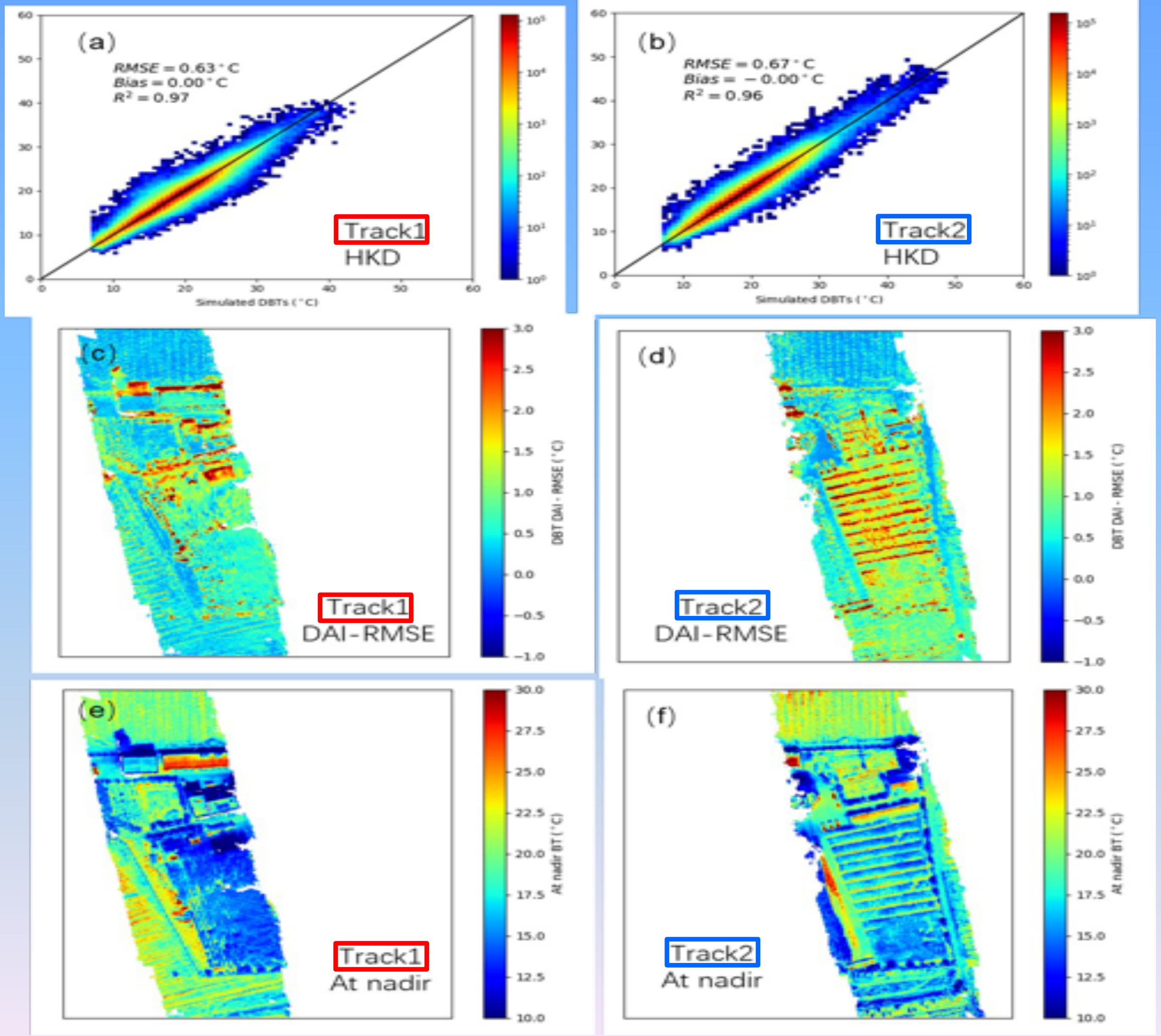






3D simulations vs measurements of brightness temperature (DAI = Directional Anisotropy Index)

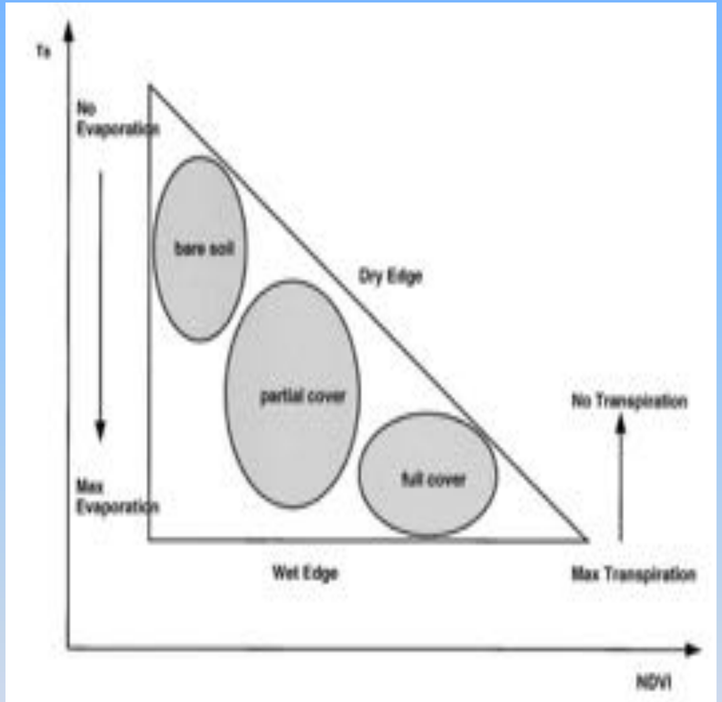




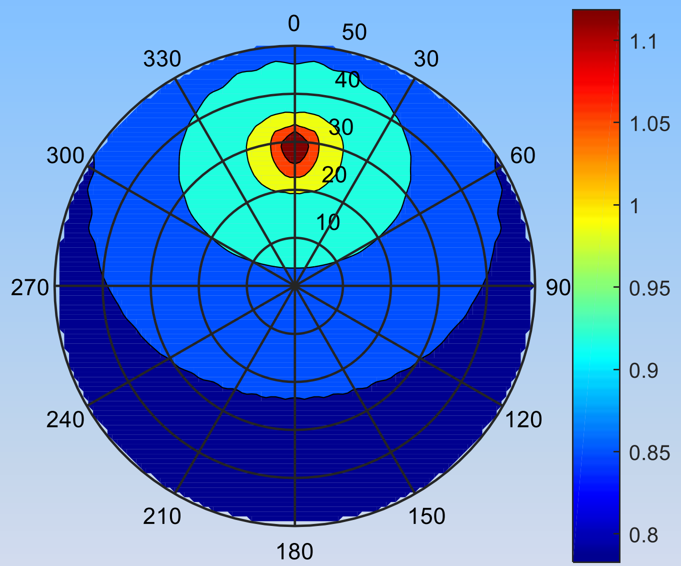
TVDI : Thermal Vegetation Dry Index

$$\mathrm{TVDI} = \frac{T_s - T_{s_{min}}}{a + b\mathrm{NDVI} - T_{s_{min}}}$$

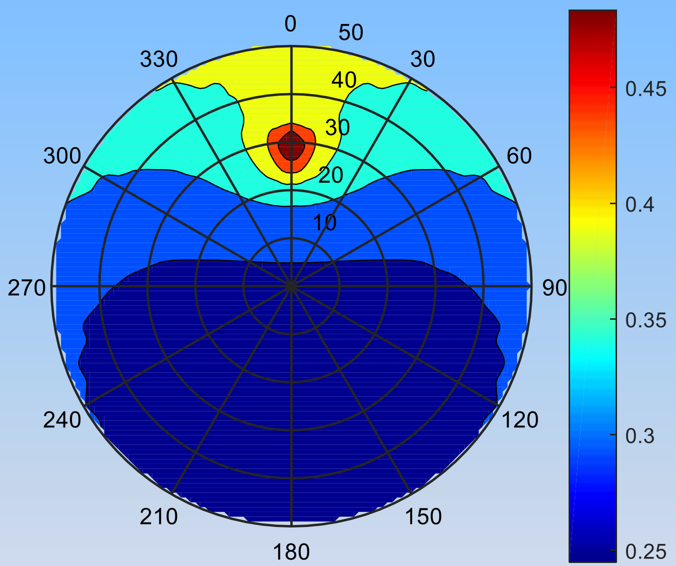
TVDI determined by LST and NDVI, including their directional anisotropy.



Drought
LAI = 2.1
SMC = 0.17



Wet
LAI = 2.1
SMC = 0.45



A semi-empirical approach for modeling the vegetation thermal infrared directional anisotropy of canopies based on using vegetation indices

Zunjian Bian[a,b], J.-L. Roujean[c], J.-P. Lagouarde[d], Biao Cao[a], Hua Li[a], Yongming Du[a,*], Qiang Liu[e], Qing Xiao[a,b], Qinhuo Liu[a,b]

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ISPRS Journal of Photogrammetry and Remote Sensing

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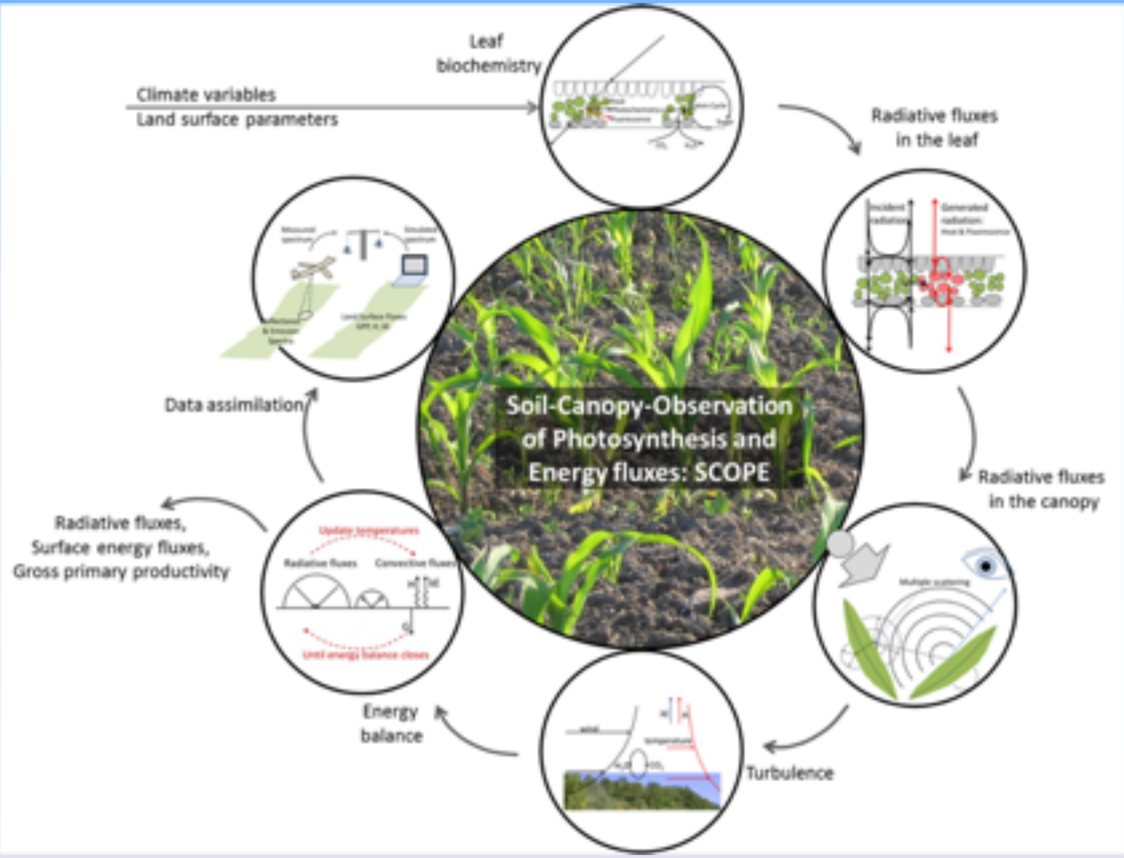
SCOPE (python version v.1.73):

- SCOPE (Soil Canopy Observation, Photochemistry and Energy fluxes) model is a radiative transfer and energy balance model
- Used to generate VNIR and TIR data sets
- DAI (Directional Anisotropic Index) is calculated
- **DAI = Reflectance at Hotspot – Reflectance at Nadir** (in optical)
- **DAI = Temperature at Hotspot – Temperature at Nadir** (in thermal)
- **q = Leaf Width/ Vegetation height**
- q indicates canopy structure

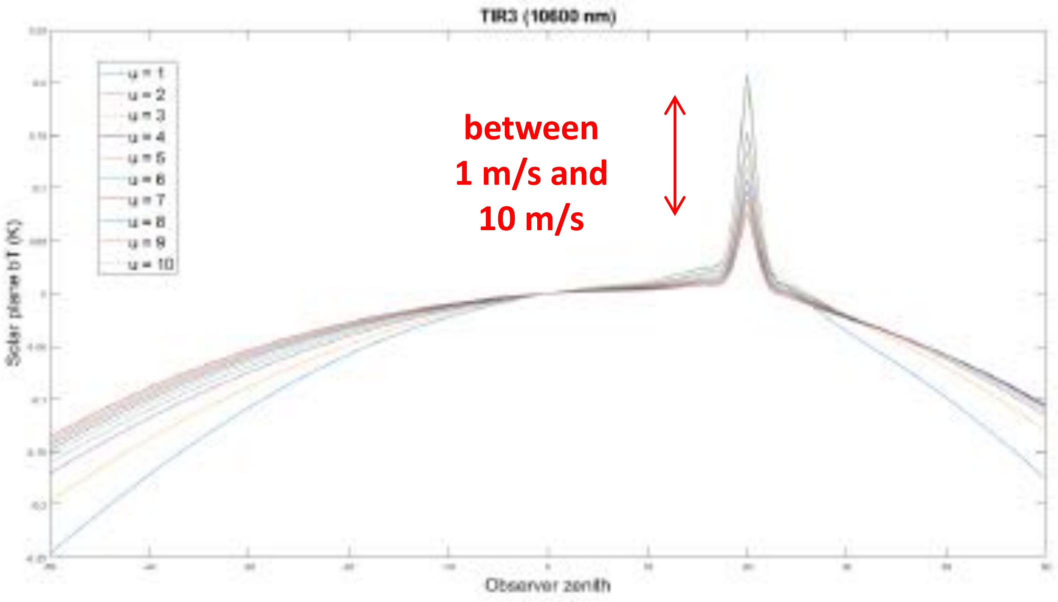
- LAI, Soil Moisture, solar angles, leaf angle



Van der Tol et al., Biogeosciences, 6(12):3109–3129, 2009.

Which parameters have an impact on the hot spot ?

- **LAI:** Modulates (partially) the intensity and mostly influences the width
- **SMC:** Rather weak influence on the hot spot.
- **q:** Strong influence on the shape of the peak (thin leaf => narrow peak)
- **Wind:** An impact on the hot spot.



Normalized brightness temperature in TIR3 for various wind speeds ($m.s^{-1}$)

Solar zenith angle = 60 °

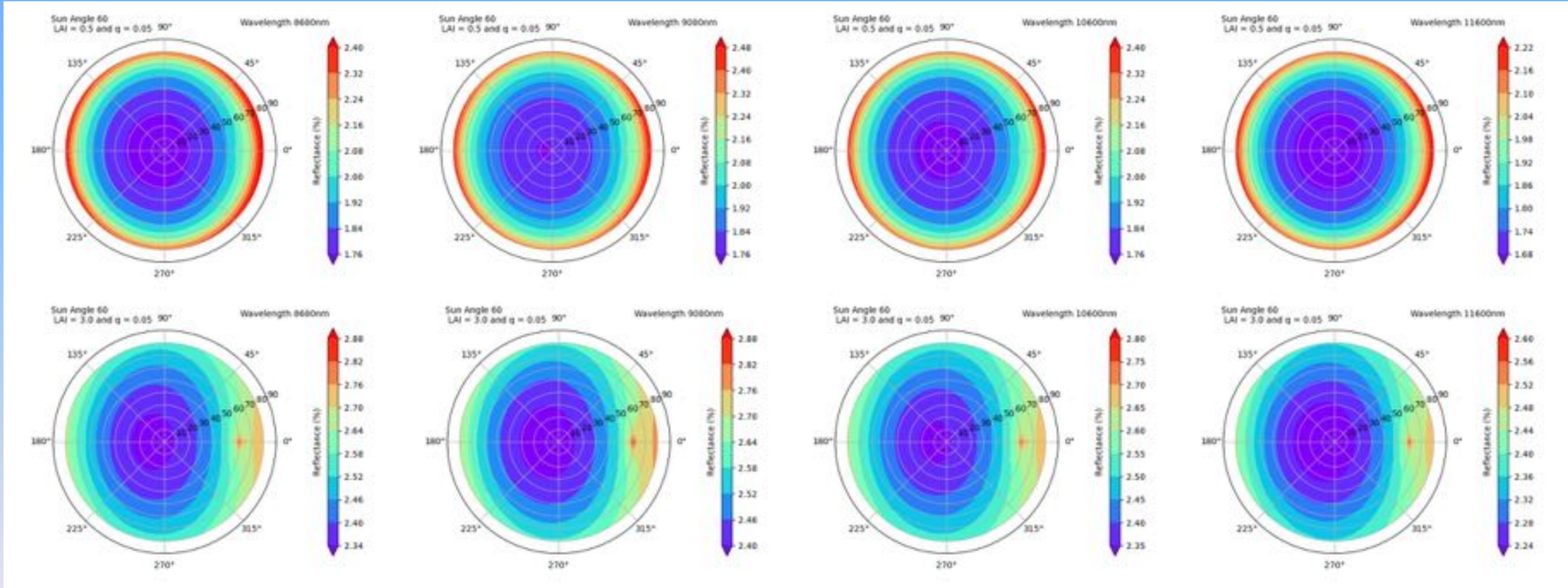
q = 0.05

SCOPE simulations for TRISHNA bands

	TIR1 : 8.6 µm	TIR2 : 9.0 µm	TIR3 : 10.6 µm	TIR4 : 11.6 µm

LAI = 0.5

LAI = 3.0



Low LAI => emissivity ~ 0.975 - 0.987

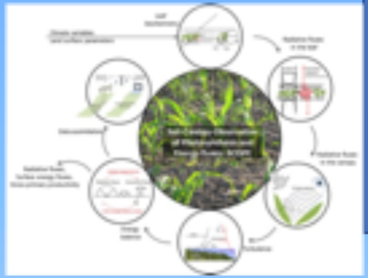
High LAI => emissivity ~ 0.972 - 0.978

=> Error probably enhanced with 3D modeling

TIRAMISU
(Thermal InfraRed Anisotropy Measurements over India and Southern eUrope)

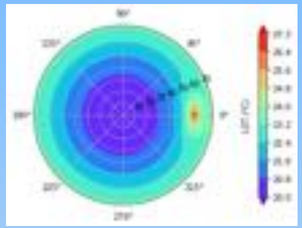
France (2022) , India (2023)

Correlations of parameters



SCOPE 1D model

Parametric model



Auzeville site mock up

Auzeville site real data

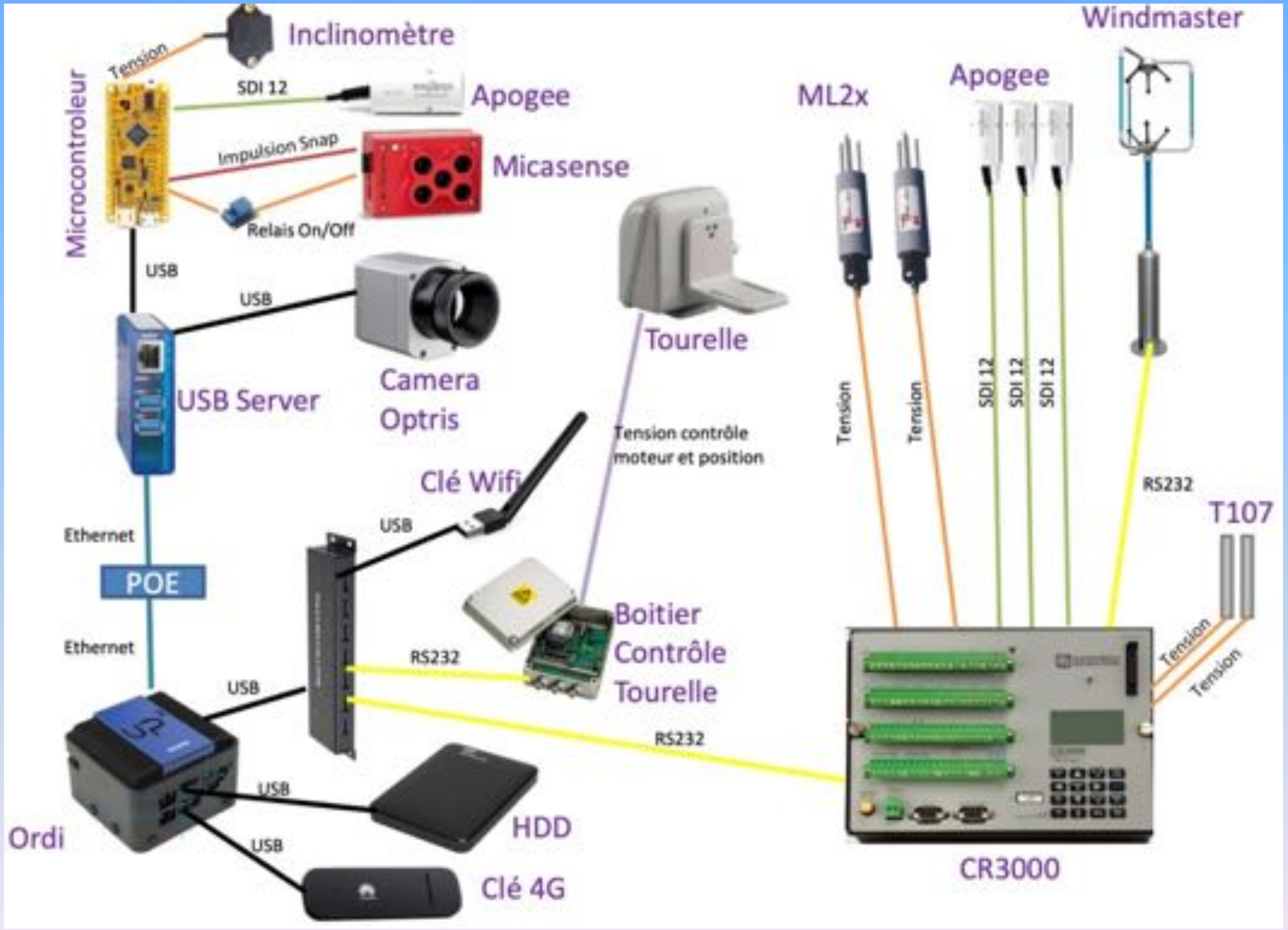
The picture can't be displayed.

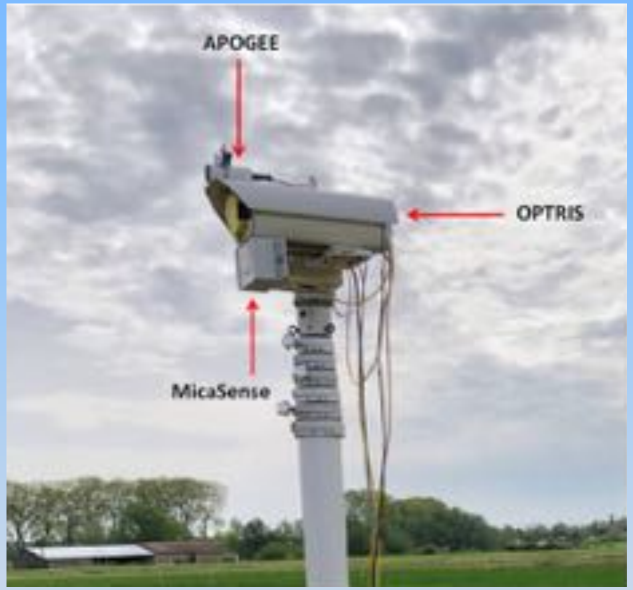
DART 3D model

In – situ Measures

DART

Architecture of the installed equipment at site





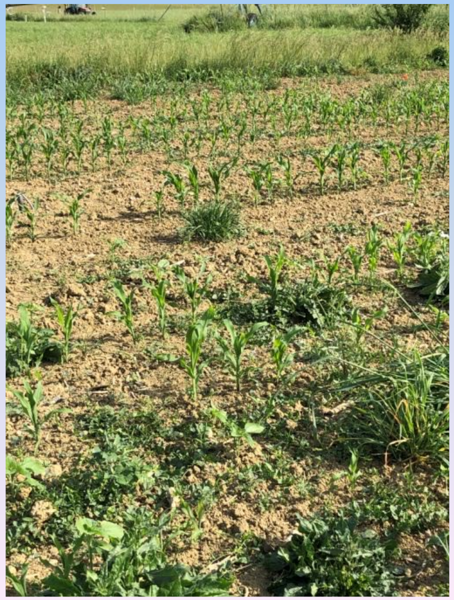
MicaSense : 475, 560, 628, 842, 717nm

OPTRIS: 7.7 – 13 µm

Methods and Materials to study : In-Situ measurements

- **Dry maize crop – High heterogeneity**
- **Located at INRAE Auzeville, near Toulouse. (43°31'42.33'' N / 1°30'13.33'' E)**
- **Studied plot has 10 rows of Maize plants (around 560 plants) (15.3m x 8.42m).**
- **Monitoring of entire phenological cycle (from April to September).**

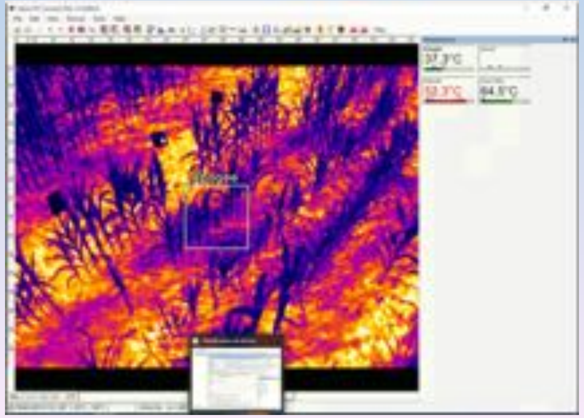
May



July

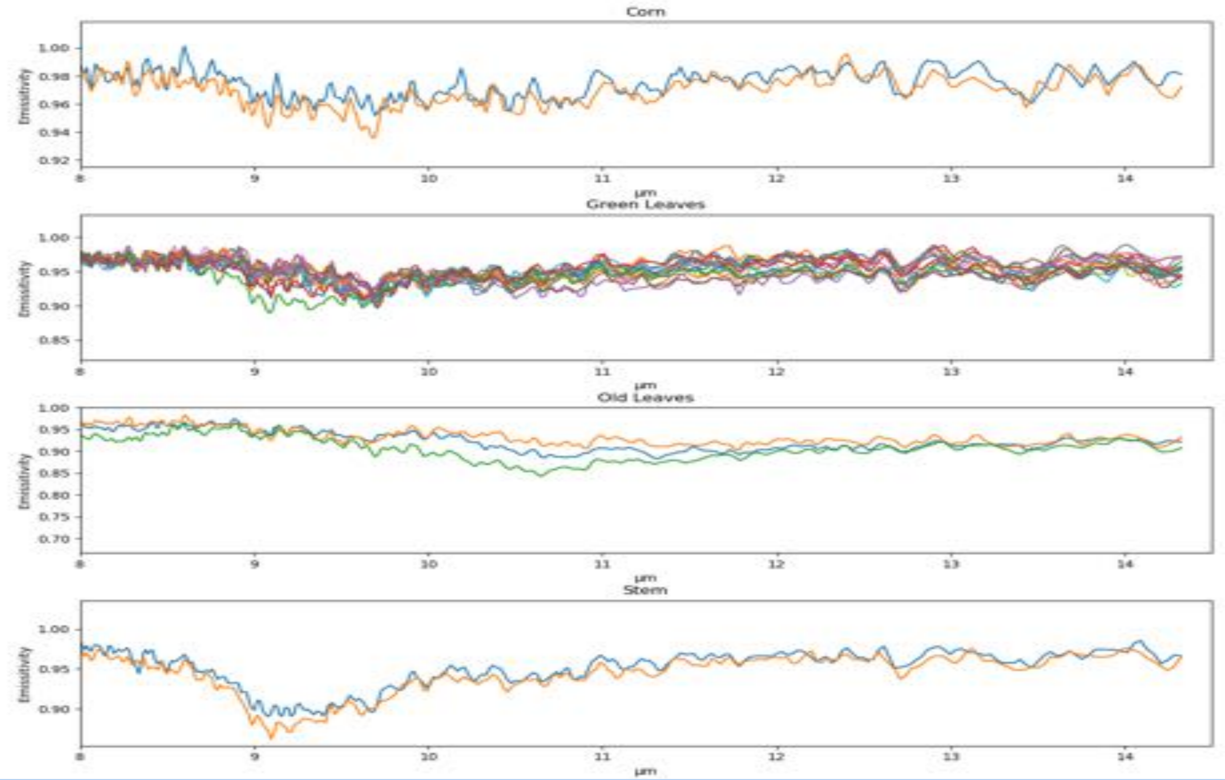
August

- OPTRIS camera (1 thermal image) and MicaSense (optical images at 5 wavelengths).
- Hotspots between 12 to 13 hours local time.
- 5 Azimuth angles (330, 340, 0, 15 and 30) and 8 Zenith angles (30, 33, 36, 39, 42, 45, 48 and 51)
- 4 images at every 2 mins with 20 positions, then 10 Hz video (ravi format) with 40 positions
- 3 APOGEE (TIR radiometer of reference) for cross calibration with OPTRIS

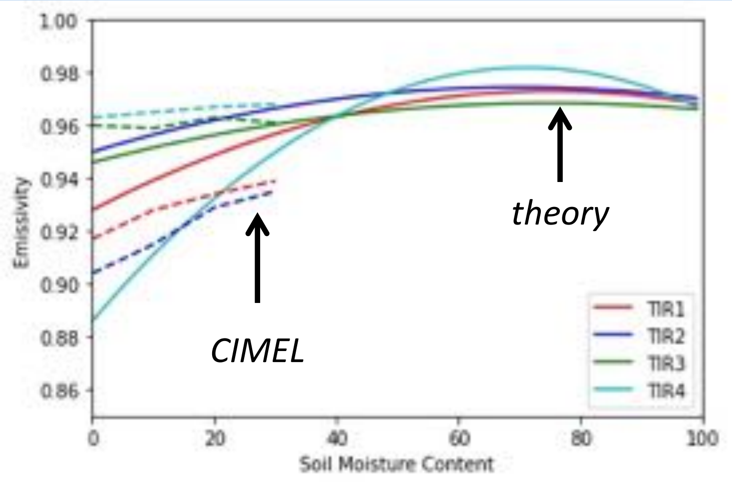


Emissivity measurements

- Performed by ONERA in a white room
- Emissivity = 1 – Reflectance



vegetation



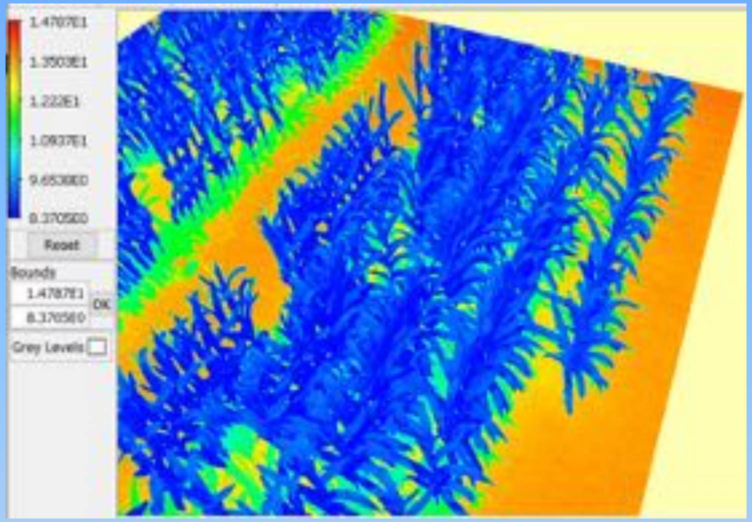
soil

DART 3D mock-up

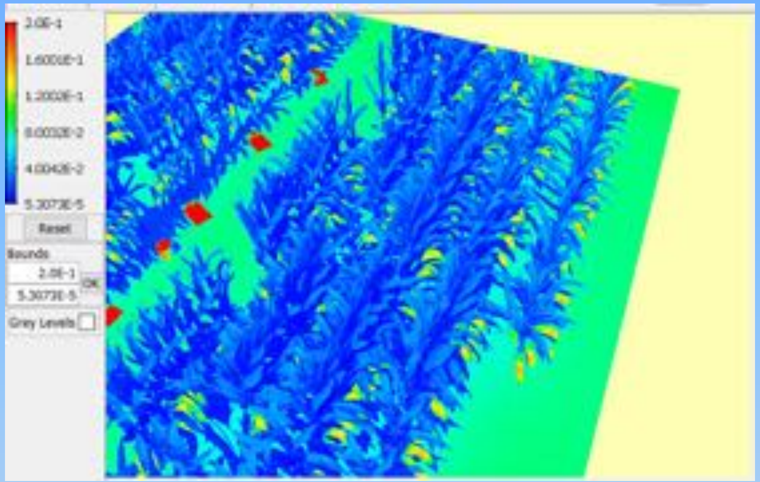
- DART simulates TIR images of the mock-up
- Structure : Architectural measurements (distance between rows, distance between plants, plant orientations, positions of other objects placed in field, etc) have been collected
- Spectral : Hyperspectral (ASD) and Emissivity measurements regularly collected

DART simulations

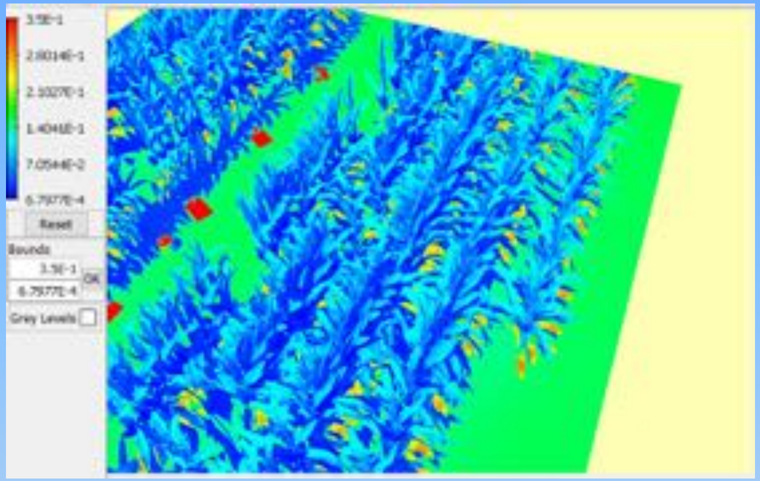
Thermal 7.5-13µm

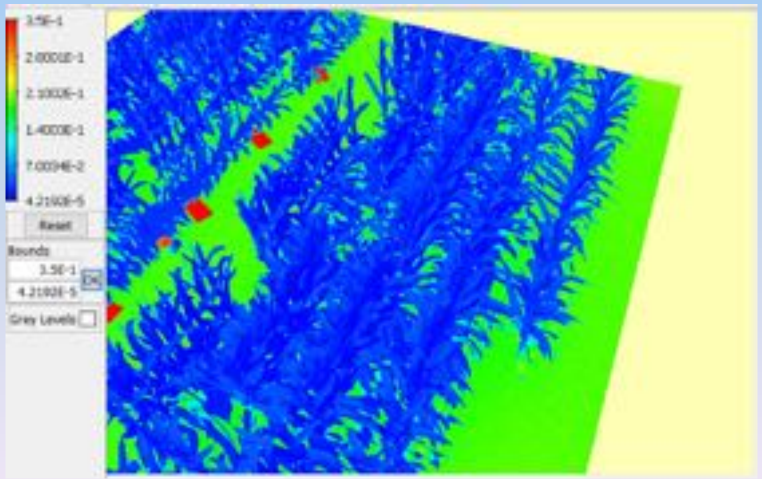


Blue-475 nm

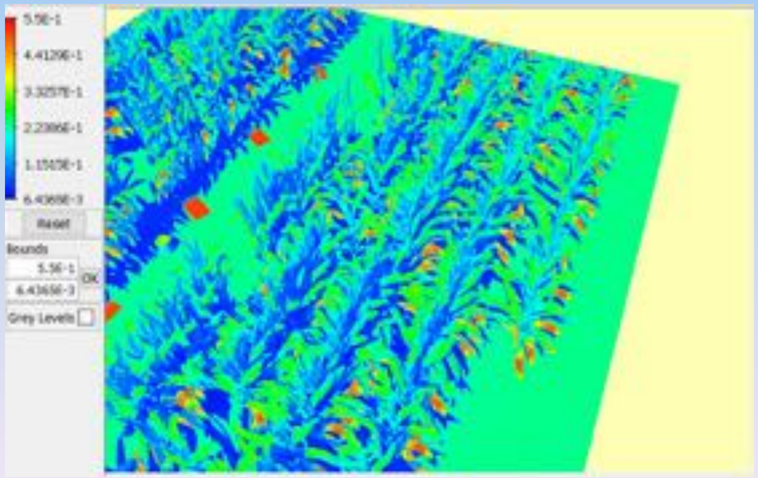


Green-560 nm

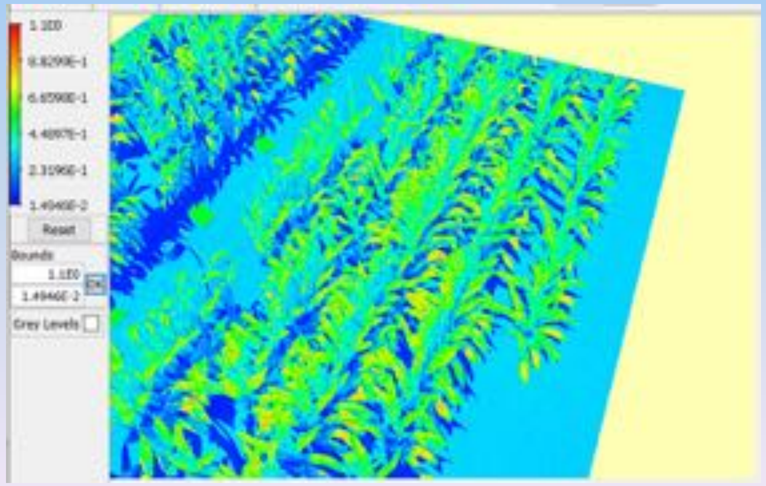




Red-628 nm



RedEdge-717 nm



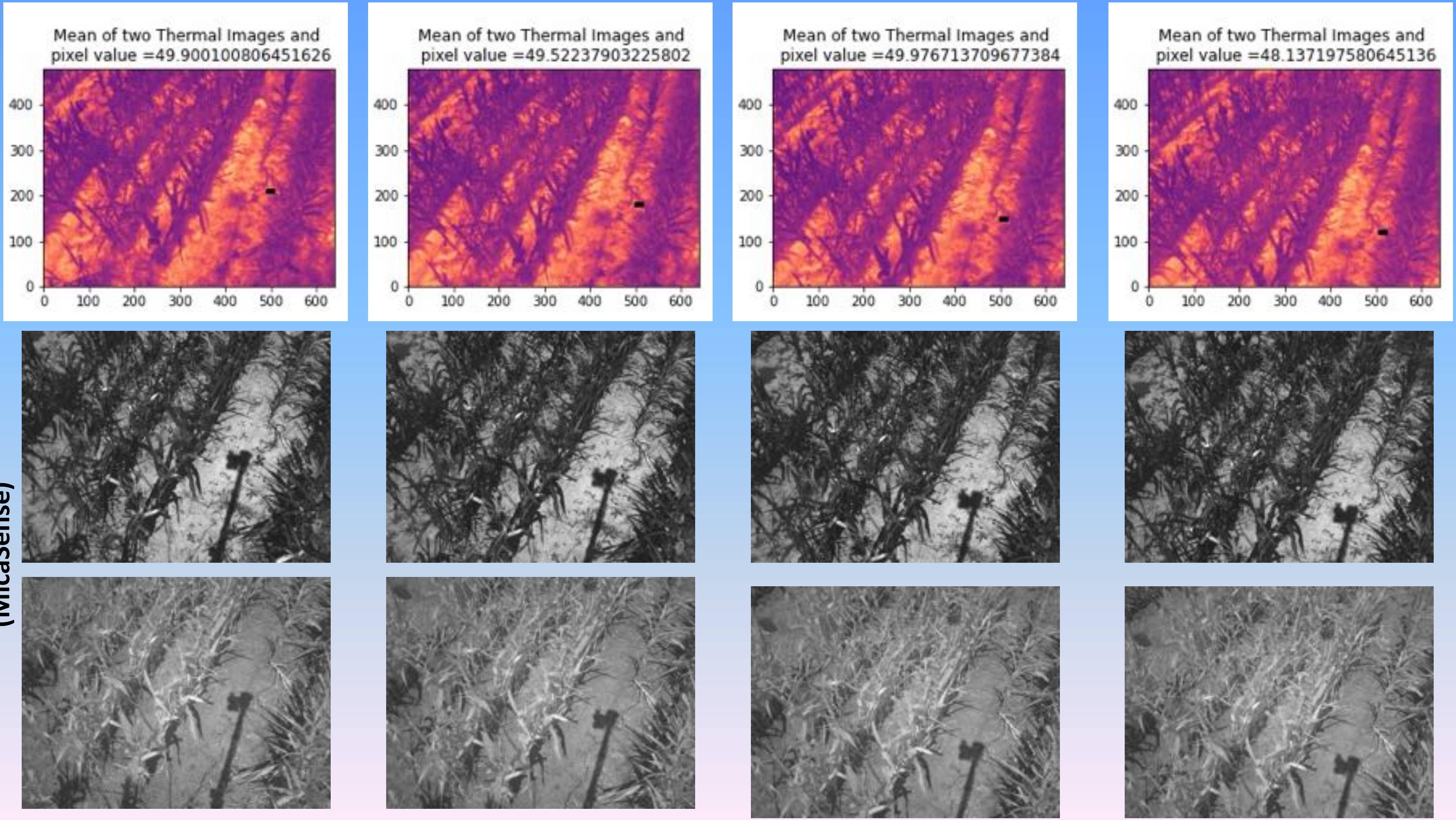
NIR-842 nm

LST (OPTRIS)

Red-628nm

(MicaSense)

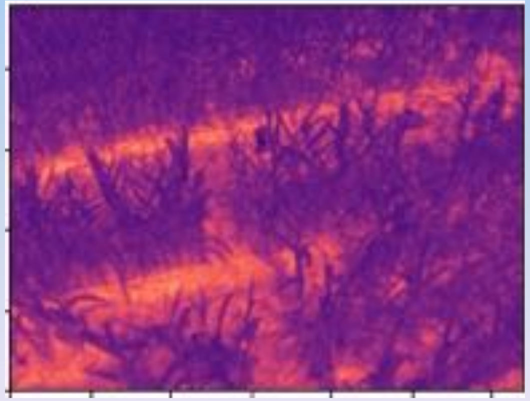
NIR- 842nm

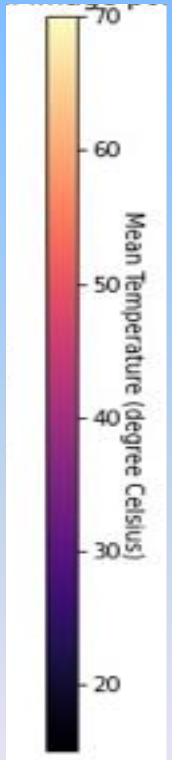


DART Thermal Image evaluation

- The ranges considered for DART are based on Optris values (may vary for different scenes)
- Emissivity measurements serve to simulate DART images

Scenario category	Optris camera (range in degrees)	DART (range in degrees)
Sunshade soil	45-48	46-47
Sunlit soil	>51	68-69
Sunshade leaf	<25	24-26
Sunlit leaf	30-32	29-30

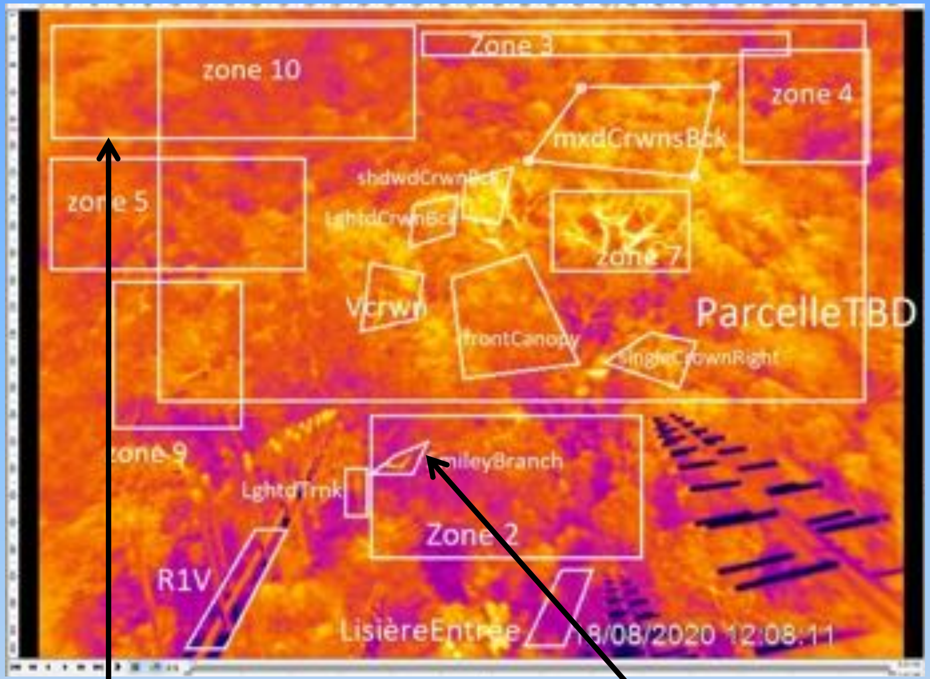


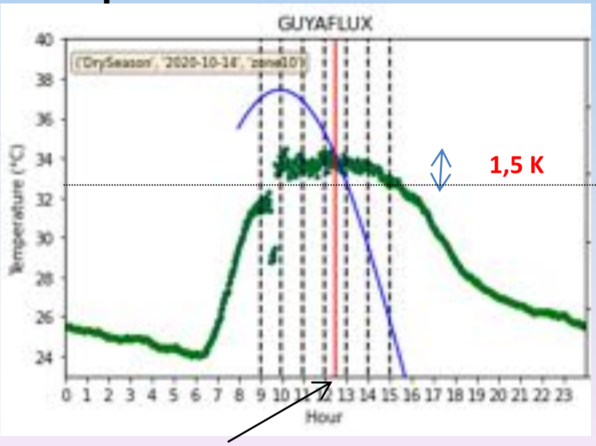


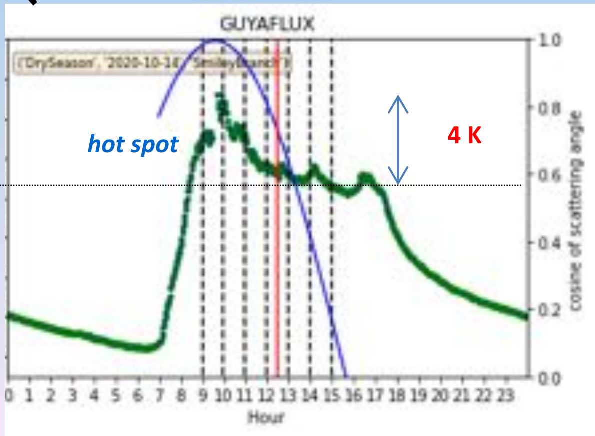
Thermal Images from DART (deg) and Optris (deg) at camera position 12

Guyaflux

(coll. with BIOMASS team: Ludovic Villard, Thierry Koleck)







TRISHNA orbit pass

< 8 days average in October 2020 >

Conclusions and Perspectives

- **TIRAMISU is designed to characterize simultaneously and continuously VNIR and TIR hot spot**
- **It confirms directional effects are real and sizeable (see also Julien Michel presentation, coll. NASA)**
- **Compared to UAV, VNIR and TIR fixed cameras can detect/monitor stress**

- **Hot spot tracking , soil DEM derived from UAV, video images (10Hz) for turbulence**
- **Camera pixels (after shadow mask) to calibrate DART hot spot => DART to simulate hot spot dynamically**
- **Relationships between VI and LST / LSE are encouraging (see Vincent Rivalland presentation)**

⇒ **TIRAMISU will continue in India from June 2023 (paddy rice crop, Ahmedabad, coll. ISRO)**

More research is needed on directional effects to guarantee the success of TRISHNA, SBG, and LSTM missions.