# Summary of the Opening Session (S1)

- Welcome the >300 participants to the workshop
- Key note speech from FAO highlighted the worldwide needs regarding agriculture and water management:
  - 828 Million people suffer from hunger
  - 3.2 Billion people live in agricultural zones with high to very high water shortage
  - 85% of the crop increase are irrigated areas


- Three institutional flagship missions were presented:
  - TRISHNA (CNES/ISRO mission) , SBG-TIR (NASA JPL/ASI mission), LSTM (ESA/EU mission)
- Strong collaboration between the three missions:
  - Universal Mask
  - Aligned MLST 12:30
  - Daily coverage combining data from missions


- Questions, discussion and recommendation:
  - Audience noted the importance of the collaboration between the missions and asked for reinforcing synergies and complementarities
  - Audience asked about data format and algorithms harmonization across missions. The speakers confirm the intention to harmonize input data and benchmark the algorithms from the three missions.
  - Making use of the future field campaigns is essential, maybe a way to liaise with New Space
  - Missions should keep a close link to application field
  - Recommendation for a continue the dialogue of the three missions together with the thermal community

# S.1.2: Summary of the Harmonization of international missions

- consider data format harmonization between the missions
- provide also input data
- explore new products in synergy with other missions (ie VIS-SWIR)
- showed benefits of lower satellite revisit time on the uncertainty in monitoring  EV
- new security applications (climate security) expand the portfolio of potential products

# Session 1.3 : New Space for Thermal EO

The key elements from each presentation were:

- HiVE (High-resolution VEgetation monitoring mission) from ConstelIR with global daily revisit, spatial resolution VNIR 10-60m (Sentinel-2 bands) and TIR 30m, swath 20km, first launch in 2024.
- FOREST-2 from OroraTech, a precursor for a large constellation of TIR imagers (100 satellites), 30min revisit, launch in 10.06.2023, 200m GSD, swath 400km.
- HYDROSAT mission, first launches in 2024, VNIR bands at 30m TIR bands at 70m, 70km swath, 16 satellites for daily revisit.
- Satellite Vu, first launch June 2023, 8-satellite constellation, 3.5m GSD, point and stare forward motion compensation, targeted observations.
- SuperSharp, self-aligning thermal infrared space telescopes for targeted observations. First launch 2025 of demo unfolding mirrors design. 16U TIR telescope with 6m GSD and smallsat with 3m GSD.
- EarthDaily, daily coverage of all landmasses, nadir-view, 240km swath, smallsat, 22 bands VNIR at 5m GSD, SWIR at 95m GSD and TIR 110m GSD.
- Planet LST, 100m resolution LST product for soil water content, yield forecast, ET, crop health, heat/cold monitoring, urban heat islands. Combining passive microwave, optical solar reflective domain and optical thermal data.
- IrriWatch, advocating for the need of higher spatial resolution (<=10m) for agricultural applications. Daily cycle being essential. VNIR information not sufficient for determining crop health. Also the importance of diurnal LST monitoring was indicated.

# Session 1.3 : New Space for Thermal EO

- ✓ The session illustrated the large amount of private sector missions/products being developed.
- ✓ There is a consensus of the need of having high spatial resolution LST products for several applications (e.g. agriculture, urban heat islands, industrial facilities monitoring, security).
- ✓ The New Space private initiatives nicely complement with the public sector missions (e.g. Landsat, LSTM, SBG, Trishna) offering:
    - Higher spatial resolution with global coverage (e.g. HiVE)
    - Higher spatial resolution for targeted observations at  (e.g. Satellite VU, SuperSharp)
    - Global coverage with VNIR higher-resolution data (e.g. EarthDaily, HYDROSAT)
    - Higher temporal revisit (e.g. FOREST)
- ✓ Fused products have been highlighted as a way of increasing the temporal revisit and spatial resolution. The LST product form Planet (combining data from optical solar reflective domain (e.g. Sentinel-2), optical thermal domain (e.g. Sentinel-3) and passive microwaves (e.g. AMSR-E)) and the case was also brought forward by IrriWatch with a focus on agricultural applications.
- ✓ A new golden age of high-resolution thermal imaging is ahead of us combining a large number of initiatives from both the public and private sectors.

# S1.4 Algorithm development

Chairs: Itziar Barat - ESA, Jean-Louis Roujean - CESBIO

**Roujean, Jean-Louis (CESIO)**

TIRAMISU: measuring (cameras), modeling (SCOPE, DART, paremetric) directional effects (hot spot) combining VSWIR and TIR data. Hotspot will be present on TRISHNA, SBG and LSTM images and impact on LST can be up 4 K. A strategy needs to be developed (correct or discard obs). Maize crop (France) and paddy rice (India) for test bed.

**Snyders, Louis (VITO)**

Tb directionallty . Application to SwathSense: LIAISE (TASI, SASI, CASI): FOV 40°, 4m, 32 bands. Alfalfa is the reference field. Method uses both training data and parametric models. Directional correction (Vinnikov-RL model) has a limited effect due to the weakness of directional effects.

New SwathSense in 2023 will provide a better framework with enhanced directional effects.

**Sobrino, Jose (University of Valencia)**

Assessment of LST algo for LSTM and TRISHNA using 3 different SW and TES. Use of MODTRAN simulations, emiss. from ECOSTRESS. LSTM and TRISHNA: best channels are identified for SW. Application to LIAISE campaign (TASI 600): LST validation again corn and grass. Synthetic images generated (TOA radiance: 5 LSTM maps) for algo validation of LST and LSE. Similar performance for TRISHNA and LSTM. Daily ET: conversion is of good agreement: 0.4 mm/day .

# S1.4 Algorithm development

Chairs: Itziar Barat - ESA, Jean-Louis Roujean - CESBIO

**Delogu, Emilie (CNES)**

Different algorithms to retrieve LST and LSE. Direct TES (developed at CNES) depends on the spectral library used. 2 processing chains: Land / Water (TRISHTES). Comparison between TES and DirecTES: ECOSTRESS, TRISHNA-like. ECOSTRESS L2 = RTTOV + TES: only 3 ECOSTRESS bands is not ideal for DirecTES. In situ data: lake Tahoe: best results obtained using a water emissivity. TES and direcTES perform similarly for LST retrievals (for ECOSTRESS ).

**Crawford, Christopher**

Landsat 40 years of data (since 1982). Orbit calibration, vicarious calibration. Collection 2 TIR products offerings. Landsat C2 LST: algo with MODTRAN

C3 collection: improve emissivity inputs (ASTER GED). Landsat next TIR observation with LNext science products: L2 LST LSE.

**Hook, Simon (NASA/JPL)**

Simulating SBG with ECOSTRESS and EMIT. SBG and ECOSTRESS missions presented. EMIT (telescope): Dyson spectrometer, swath of 75 km, 60 m. ECOSTRESS data analysis (uncertainty included for all products). SBG L2 LST: processing chain for ET. LST and ET error budget. EMIT data analysis. ECOSTRESS vs SBG for geological studies. SBG mineral mapping (combining VSWIR and TIR). MASTER TIR for mapping % of silica (idem with HyTES, ECOSTRESS). EMIT for geological studies : calcite, ...iron oxyde, soil fraction (adjusted abundance). ECOSTRESS + EMIT provide an excellent data set to simulate SBG, also AVIRIS + HyTES.

**Jennifer Adams , Agnieszka**

EARSEL Thermal Remote Sensing Special Interest Group (SIG)

# Session 2.1 Agriculture – irrigation, evapotranspiration

Chairs: Kerry Cawse-Nicholson, Philippe Maisongrande

## Mallick – missing biophysical link

Presented driving variables for single-pixel models. Uses relationships between conductance parameters, but still needs VPD and other radiative information (less dependent on wind speed).

## Ait Hssaine – high-res ET using disaggregated LST

Current models overestimate ET in semi-arid regions. Benefit of SWIR.

## Nieto Solana – fusing ECOSTRESS, PRISMA, Sentinels

Bridge the gap between energy balance and crop physiology. Late-spring transpiration deficit greatest predictor of crop yield.

## Bartkowiak – Sentinel-3 LST downscaling

Landcover type drove ET accuracy - disaggregation difficult over highly heterogeneous regions (e.g. mountainous forests).

## Zalite – simulating high spatial-temporal LST with sharpening

Simulation showed good results, interesting residual patterns may be correlated with terrain.

## Olioso – uncertainties and ensembles for ET depending on model types

No consensus on best model for ET. ST uncertainty not the only driver for ET uncertainty.

# Session 2.1: summary and recommendations

Chairs: Kerry Cawse-Nicholson, Philippe Maisongrande

- Scale of model complexity with two extremes – contextual (easy to implement in ground segment, based on evaporative fraction), vs. surface energy budget (single-pixel, requires more inputs, needs local forcing, hard to get rid of dependency on VPD).
- Some models can reduce degrees of freedom (valency) by taking advantage of relationships between sets of parameters (conductances). Interesting links between energy balance and photosynthesis, or water and carbon, can also be used to constrain the model.
- To improve time frequency of information and its pixel resolution, additional remote sensing information is also useful, e.g., shortwave infrared or disaggregated radiances. Existing remote sensing products provide opportunities for preparatory modeling using sharpening methods.
- Uncertainties are model dependent. Single pixel SEB models need higher density of input information with meteorology (sometimes wind speed, VPD, incoming and net radiation, etc.), which present strong uncertainties if these parameters are not well understood (difficult globally).
- Complexity increases risk of uncertainty. Contextual models present lower risk of uncertainty driven by inputs. Relative impact of thermal uncertainty on overall uncertainty budget is low relative to meteorology in some cases.
- Consistent estimation of uncertainty is very important for reliable use of ET products. No science and no market will be possible otherwise.

# Session 2.2 Agriculture – irrigation, evapotranspiration

**Chairs: Radoslaw Guzinski, Raphaël d'Andrimont**

- Five presentations about applications in agriculture with key highlights :
- WaPor V3, **ongoing production of ET product at gobal scale** (300 m) and for Africa (100 m) along with 20 irrigation sites at 20 m
- Importance of thermal for pathogens (e.g. V*erticillium dahliae, Xylella fastidiosa*), VHR RS able to **detect pathogen** (OA >80-90), importance of **synergy between thermal and hyperspectral**
- Water stress into **decision support system** in Egypt
- OPTRAM approach in California, importance of **homogenize the input data**
- **Challenges to build a 3D** demonstrator for thermal data

# Session 2.2 – main lessons

- Diversity of applications in the agricultural domain
  - Water management & Support to irrigation
  - Disease detection
- High spatial and thermal resolution thermal is essential
  - All presenters either used (very) high-resolution LST data or performed sharpening
- Thermal data needs to be complemented with shortwave optical data
  - Hyperspectral diseases detection
  - Combining optical and thermal models for complete ET timeseries
  - Perform thermal sharpening with vegetation indices
  - Biophysical parametrization for ET modeling
- New opportunities
  - New modeling approaches: 4-source models taking shadowing into account
  - Precision agriculture and irrigation

# Session 2.3 Ecosystem

**Chair: Gilles Boulet**

**ET products**:

-Tian Hu has presented the multimodel European ECOSTRESS ET product which will be an interesting reference for the future TIR HR missions;

-Recom: there is a need to assess the impact of uncertainty relevant to meteorological forcing (scale mismatch between ERA5 and the HR pixel).

**Plant health**:

-Jeffrey Luvall has presented how TIR-based ecosystem thermodynamics can be applied to assess restoration impact and nutrient access;

-Recom: beyond water stress, LST will be useful to monitoring a range of environmental stresses on ecosystems, such as temperature stress on plants (impact of heatwaves on trees).

**LST directionality issue:**

-Jennifer Adams has presented an experimental set-up to characterize directionality with goniometer-mounted TIR cameras over artificial forest mock-ups;

-Recom: how to correct for directionality is key to provide consistent surface energy budget estimates from LST, especially over heterogeneous crops such as forests or savannahs; developing simple physically-based (non parametric) models to do so is essential.

# S2.4 Urban Heat and Cryosphere

Chairs: Glynn Hulley - NASA Jet Propulsion Laboratory, Jose A. Sobrino - University of Valencia

**Glynn Hulley: High resolution imaging of urban heat islands and heatwaves.**

This talk described the use of ECOSTRESS TIR data to image urban heat focusing on three different aspects: pinpointing hotspots in urban areas; quantifying the impact of heat mitigation efforts; and in finding meaningful relationships between urban heat and societal impacts such as human health and income inequality. The results are applicable to future high resolution thermal sensors such as TRISHNA, LSTM, and SBG.

**Laure Roupioz**: **Combined use of DART and SOLENE-Microclimat to investigate the effect of urban surface characteristics on LST estimation**.

This study used the SOLENE-microclimate model to simulate LST of 3D urban elements within a remote sensing scene combined with the DART model to simulate satellite TIR images with a physically based LST distribution in the scene. The presentation presented an overview of the modelling chain approach and first results obtained from synthetic and real data in link to the future IRT satellite missions such TRISHNA and SBG.

**Ana Oliveira**: **An urban energy balance-guided machine learning approach for synthetic nocturnal surface Urban Heat Island prediction:**

In this study, an energy balance-based machine learning approach is explored, considering the Local Climate Zones (LCZ), to describe the daily cycle of the heat flux components and predict the nocturnal surface urban heat island (SUHI), during a heatwave event. The results showed that the latent and storage heat flux components, together with LCZ classification, were the most important explanatory variables for the nocturnal LST prediction, supporting the adoption of the energy balance approach.

# S2.4 Urban Heat and Cryosphere

Chairs: Glynn Hulley - NASA Jet Propulsion Laboratory, Jose A. Sobrino - University of Valencia

**Kukku Sara: A study on the diurnal land surface temperature cycle during a warmer and a cooler year using high spatial resolution LST data.**

This study analyzed the spatial and temporal patterns of Land surface temperature over Jalgaon, a district in Maharashtra where frequent heatwaves were reported in the month of April for multiple years. Standardized LST anomaly maps were prepared using the observations from the MODIS 8-day average LST product for the month of April and to characterize years 2017 and 2019 as cooler and warmer years respectively. Disaggregation techniques were applied to multi-time MODIS Terra and VIIRS (day and night) LST images from 980 m to 70 m in order to investigate small-scale features of LST diurnal cycles.

**Roberto Colombo**: **Monitoring snow processes and snow density by thermal inertia**

Thermal inertia represents the responsiveness of a material to variations in temperature, but it is never exploited to evaluate snow properties. The presentation by Roberto Colombo "Monitoring snow processes and snow density by thermal inertia" introduce thermal inertia as an indicator of temporal evolution of snowmelt processes and to estimate snowpack density at catchment scale. Results shows snowmelt phases can be recognized in time and that bulk snowpack density can be estimated from thermal inertia observations, which may open new frontiers in the remote sensing of the cryosphere.

**Sara Arioli: Towards a better understanding of snow surface temperature variability in mountain regions**

Trishna LST data will significantly improve the estimation of snow water equivalent, the key variable in snow hydrology. The presentation of Sara Arioli "Towards a better understanding of snow surface temperature variability in mountain regions", shows the potential of an energy-balance model RoughSeb for the evaluation of satellite surface temperature products on snow covered areas over complex terrain.

# Recommendations Sessions 3.1 Calibration & Algorithms

- Simulated emissivity databases can help to support the separation of emissivity and temperature. Strong need for quantifiying the emissivity differences of all surface types (vegetation, urban, soil, etc.). Many different emissivity retrievals exist (in situ, lab-based, ndvi-based, etc.) but they don’t always agree well.
- Multitude of cal/val sites were presented showing the importance harmonised protocols as for Radcalnet. Early results show that TOA BT can be retrieved to an accuracy at least allowing radiometry validation and possibly calibration.
- 3D-simulations to characterise sites are useful for simulating directional, topography effects. But night-time and daytime acquisitions with different solar illumination can be used to separate some emissivity effects from temperature
- Italian new Cal/Val sites will largely be permanently equipped and bring a vailuable addition to the overall C/V facility for TIR missions
- Very good to have summer schools for Cal/Val activities and this needs to be done on a regular basis.
- Cal/Val networks also of growing interest to the new space missions thus needing precise protocols to be implemented and also followed by the new missions in the field to calibrate and validate their mission products.

# Recommendations Sessions 3.2 Calibration & Joint Campaigns

# THANKS A LOT
# for attending, contributing & exchanging