VH-RODA 2023 Workshop
27 – 30 November 2023 | ESA – ESRIN | Frascati (RM), Italy

TIR Top-of-Atmosphere Calibration Network

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TIRCALNet Context:

- CEOS has identified the lack of a thermal calibration network and to address this as a high priority. The activity is followed in the CEOS-IVOS WG inside the CEOS WG for Cal/VAL
- Several TIR missions operational: ECOSTRESS, ASTER, LANDSAT-8&9, MODIS, VIIRS, SLSTR, SEVIRI…
- TIR future missions with higher resolution: TRISHNA, LSTM, SBG
- More and more demanding LST accuracy requirements better than 0.1 K for climate studies
- Importance of vicarious calibration for the validation of on-board calibration systems (black bodies) or direct calibration
- L2 products (temperature & emissivity) validation need

In addition, numerous new space TIR companies are launching their missions !

TIRCALNet Objectives:

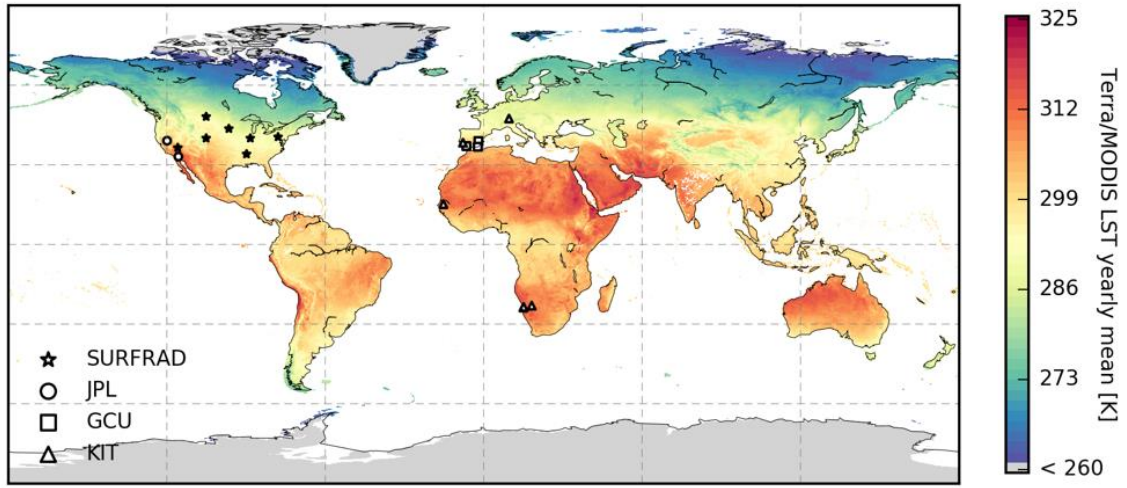
- To collect surface temperature and emissivity, and atmospheric data necessary for the simulation of observations by TIR optical sensors and thus verify their radiometric calibration
- To increase the number of matchups between in-situ measurements and space sensor observations and reduce the overall uncertainties, and reduce the efforts of individual agencies
- To ensure traceability of the space sensor radiometry to the “Système International” (SI)
- To support the establishment of the Global Earth Observation System of Systems by providing measurements to verify the radiometric consistency between EO space sensors
- To build on success and experience return from RadCalNet network dedicated to VNIR-SWIR optical sensors cal/val

Current Limitations of LST Cal/Val sites:

- Spatial representativeness of the in-situ reference measurements
- Directional effects
- Lack of emissivity measurements
- Data access
- Data harmonization
- Typically do not provide TOA radiances
- Data quality assurance (error budget traceable to SI)
- In-situ instruments calibration quality and traceability
- Needs for the development of denser ground-based reference Network

THE EXISTING "NETWORKS"

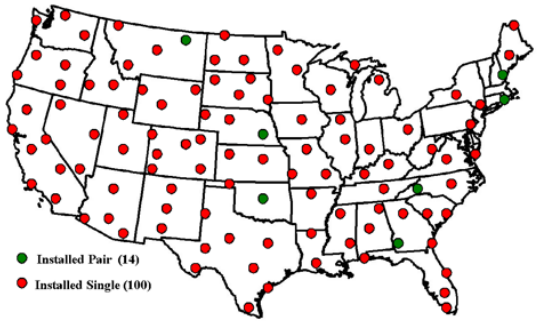
- Excellent work performed by WGCV/LPV subgroup dedicated to Land Surface Temperature Product Validation Best Practice Protocol (jan. 2018) which identifies the existing networks and their limitations



Location of ground observational networks currently used to validate standard LST products derived from US and European spaceborne instruments.

SURFRAD: Surface Radiation, NOAA
GCU: Global Change Unit, University of Valencia
KIT (Karlsruhe Institute of Technology) stations
JPL network

USCRN: US Climate Reference network



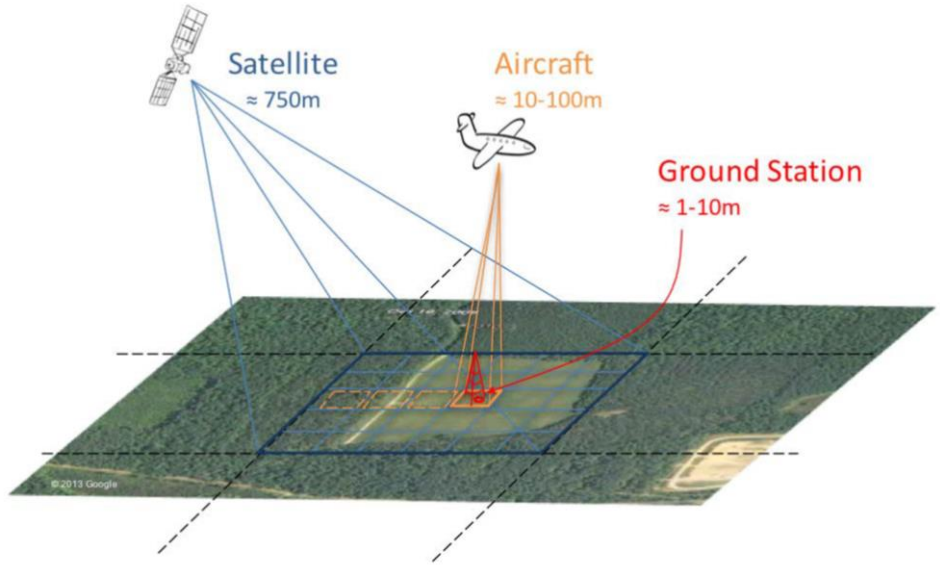
First activities for TIRCALNet

ESA and CNES defined after discussions with domain and agency (CNES, ESA & NASA) experts that TIRCALNet should be able to provide TOA Brightness Temperature signals propagated from BOA measurements of ~ 0.5K uncertainty and a set of tasks were identified :

- Task 1 → Identification of uncertainty contributors to TOA-derived BT
- Task 2 → Sensitivity analysis of uncertainties on TOA BT estimation
- Task 3 → Definition of best site characteristics, optimal instrumentation and forward propagation scheme
- Task 4 → Selection of potential candidate sites based on Task 3
- Task 5 → Interaction with Working Groups and network roadmap

Site uncertainty assessment:

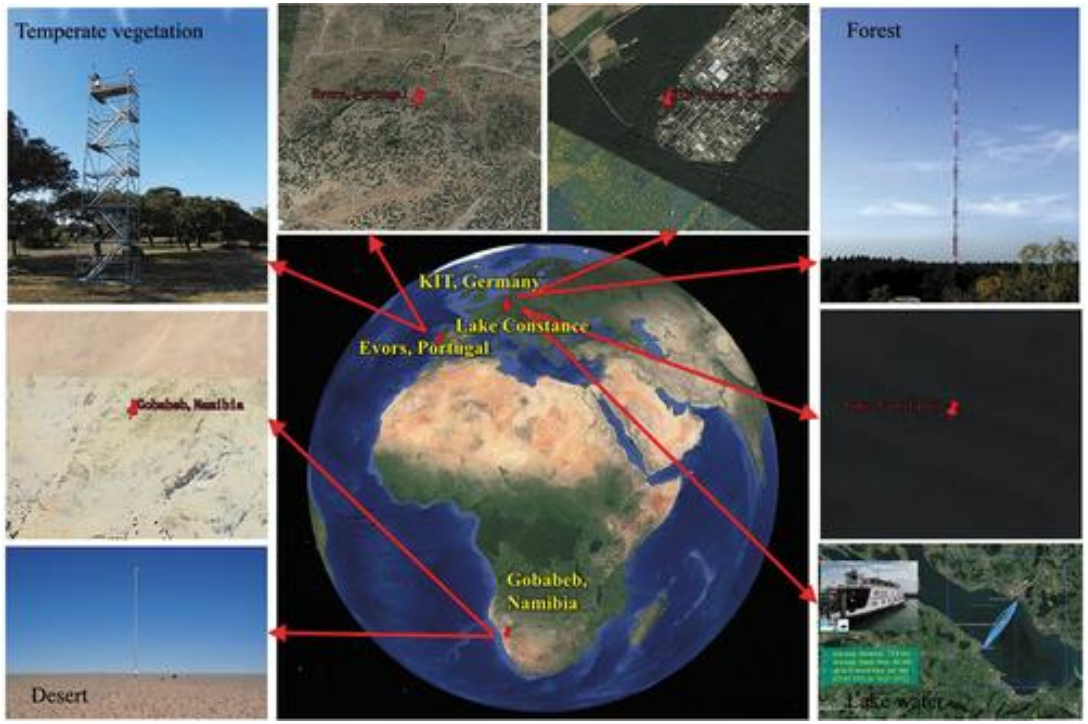
- FRM approach traceable to metrological standards will be applied
- Spatial and temporal uncertainty components of LSE estimation will be accounted for
- Spatial and temporal uncertainty components of LST estimation to be quantified
- Spatial matchup uncertainty in terms of upscaling
- Directional effects on sites to be investigated



CEOS LST best practices validation protocol to be used as a driving document for the in situ and upscaling uncertainties of the network.

Site characteristics and selection

- Different criteria to be applied
- Homogeneity of sites to result in lowest uncertainty induced by upscaling to a satellite footprint
- Should we focus largely on water sites with a very well characterised and stable emissivity ?
- Can we get sites over other surfaces (sand, gravel, etc.) that could get close to ToA uncertainty provided by water sites but give a different calibration point in the radiometry range ?
- Should sites with directional effects be discarded or can they be quantified with low enough uncertainty and for what surface types ?
- What instrumentation may already be available



Instrumentation review for Sites

- Key aspect for the instrument definition is the minimisation of in-situ LST measurement uncertainty
- Instrumentation and their deployment design needs to account for surface and site environmental measurement conditions to ensure safe operations without minimal intervention or replacement
- Instrumentation will need to autonomously deliver routine measurements as far as possible.
- Broad-band design vs narrow-band radiometers ?
- What auxiliary instrumentation is needed for atmospheric and emissivity characterisation ?
- FRM4STS LST FICE (Field Intercomparison Exercise) of high relevance

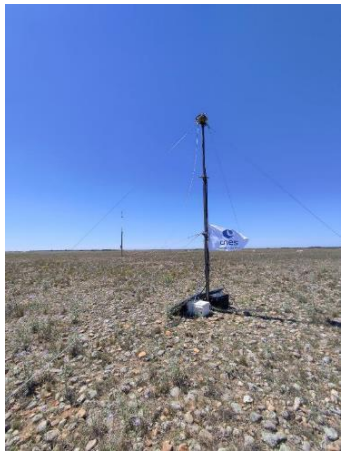
Various Cal/Val sites exist that may be suitable:

Lake Tahoe JPL-NASA

Salton Sea JPL-NASA

Russell Ranch JPL-NASA

Autonomous validation sites for absolute radiometric calibration of thermal sensors.



CNES operated Cal/Val station La Crau including a JPL radiometer since early 2023.
A sensitivity study has been performed identifying the major contributors to the uncertainty of the ToA brightness temperature.

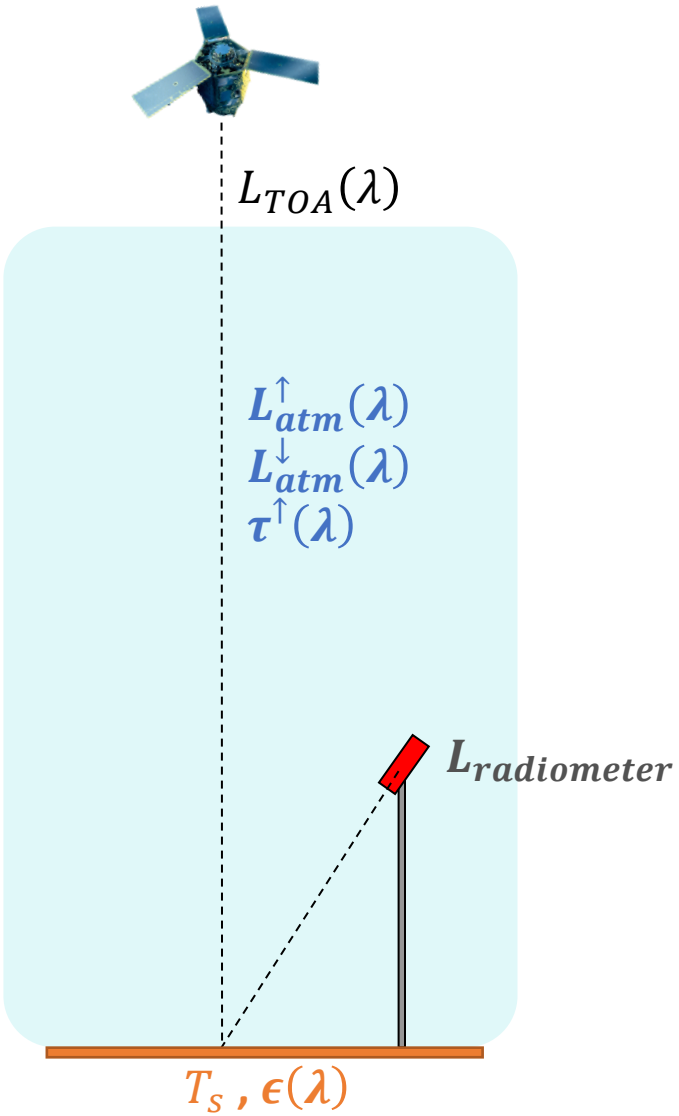
-> See Arthur Dick's presentation in the afternoon.

TIRCALNet Preparation Study has been kicked of 22nd of November:

- Transfer of CNES La Crau uncertainty budget template to other sites and perform similar simulations to gain an understanding how site environment may influence the uncertainty.
- Development of a site measurement and forward propagation protocol to minimise uncertainties at TOA
- Analysis of site characteristics (surface, cloud cover, etc.) to find possible candidate sites (e.g. Lake Tahoe, Acqua Alta platform, Russel Ranch, Lake Constance, Gobabeb)
- Develop a roadmap to equip and operate sites
- Discussions with partnering agencies on how to collaborate and set up and operate networks (funding for instrumentation, site operation, data analysis, supporting studies, etc.)
- Should the choice of an initial space reference sensor also be made ?

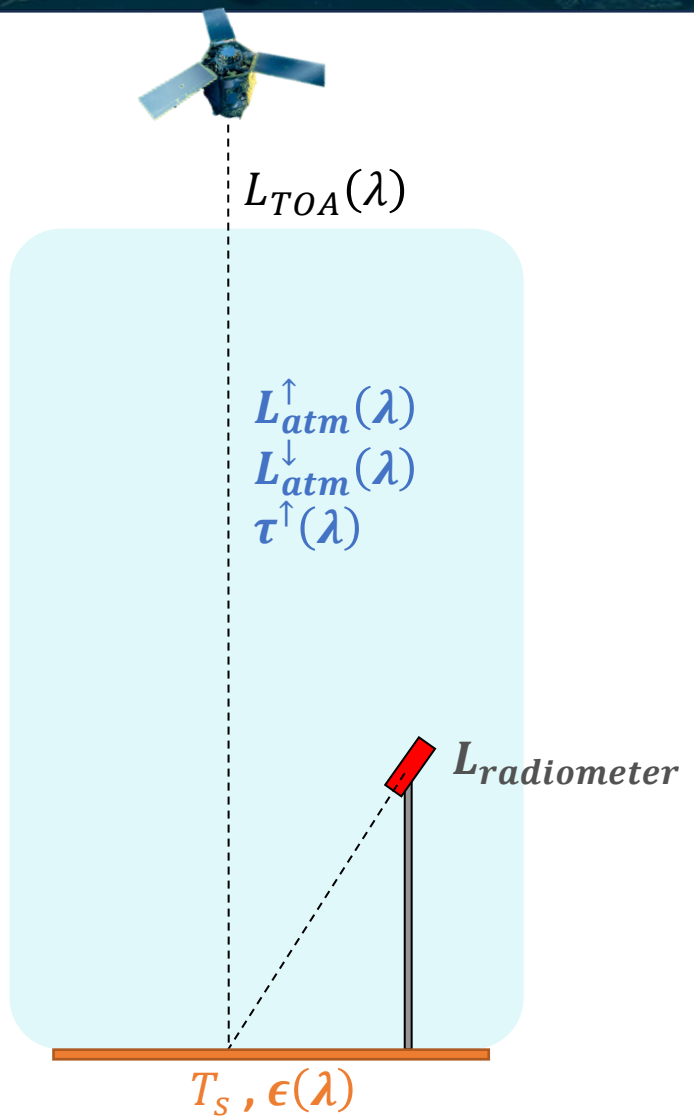
CNES La Crau end-to-end simulation sensitivity study

- Radiative transfer equation
  $$\boldsymbol{L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow}\left(\epsilon\, L_{BB}(T_S) + (1-\epsilon)\, L_{atm}^{\downarrow}\right)}$$
- General assumptions
  - Lambertian surface
  - Nadir satellite
- « Known » quantities
  - Atmospheric profiles (ECMWF)
    - + RTTOV with IASI spectral bands: $L_{atm}^{\uparrow}(\lambda)$, $L_{atm}^{\downarrow}(\lambda)$, $\tau^{\uparrow}(\lambda)$
  - Surface emissivity $\epsilon(\lambda)$ (Labed 91 for LaCrau soil)
  - Radiometer measurement $L_{radiometer}$
- Derived quantities
  - Estimated surface temperature $\tilde{T}_S$
- True quantities : known quantites + uncertainty, $\boldsymbol{T_s}$



Uncertainty choices for this study

- Atmospheric profiles
  - LaCrau 2022 monthly average, 1 pm (ERA5 reanalysis)
    - January (driest month), July (hottest), October (wettest)
  - Uncertainty: white gaussian noise with following std
    - 10% for WV content (per pressure level)
    - 20% for ozone content (per p.l.)
    - 0.8K for temperature profile (per p.l.)
- Emissivity
  - LaCrau soil (Labed & Stoll 1991)
  - Uncertainty: white gaussian noise with following std
    - 0.02 (for each discretized λ)
    - 0.01 (for mean emissivity)
- Temperature
  - T_{skin} (ECMWF)
- Radiometer
  - Uncertainty: white gaussian noise with following std
    - 0.02 W/m²/sr/µm (0.1-0.2K)

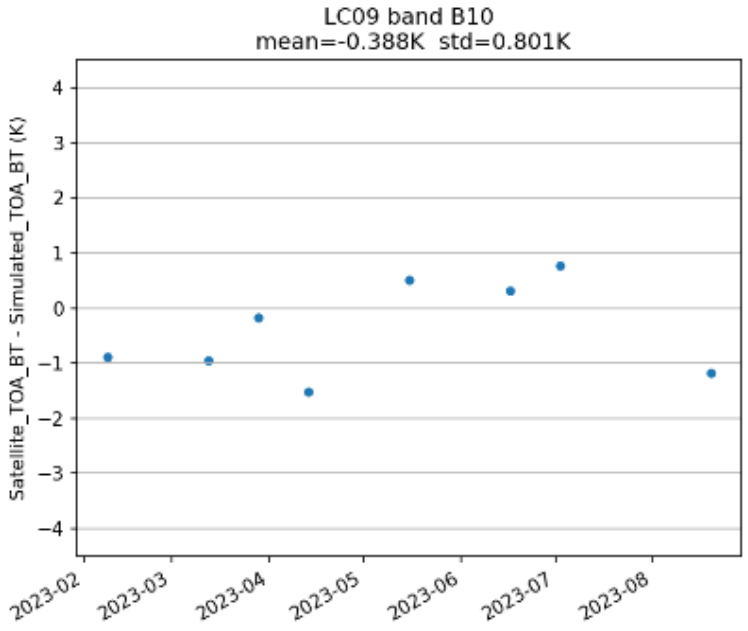


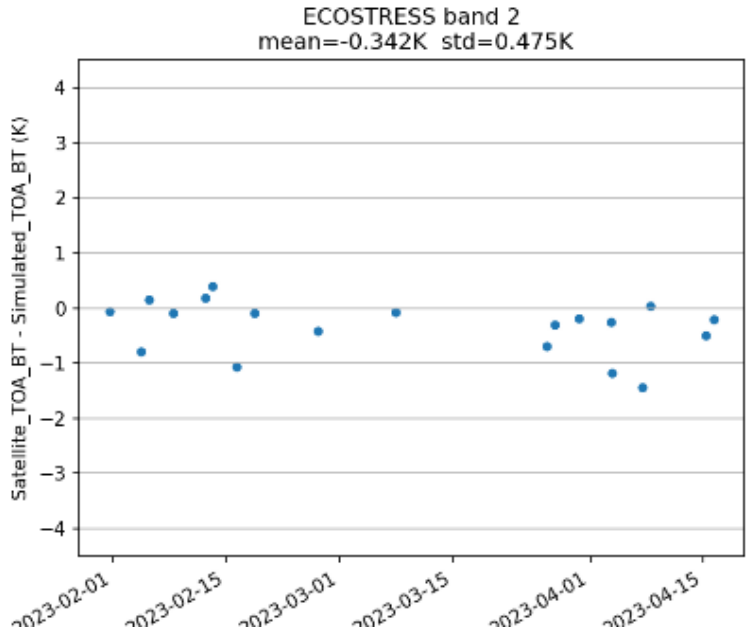
Main conclusions from CNES sensitivity study are:

- Atmospheric uncertainties are negligible compared to emissivity uncertainties and there seems no need for a fully accurate in-situ atmosphere characterization.
- Correcting the integrated water vapour content does not seem necessary
- The overall uncertainty of the BT at ToA is driven by the emissivity of the surface
- The uncertainty of the ToA BT seems lower for months with more rainfall

This work is being continued to study temporal site evolutions for emissivity variation as well as turbulence and directional effects. Furthermore a recharacterisation of the overall site emissivity is planned.

Promising Results for ToA Intercomparison with ECOSTRESS & LANDSAT9





For a short time series already an overall quite close consistency for both sensors. Full results to be presented by Arthur Dick later in the afternoon session.

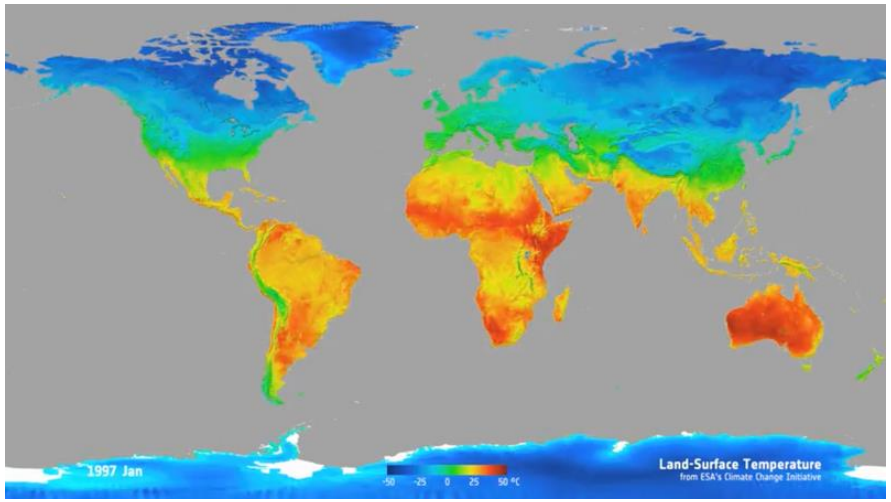
Link to other projects, networks & missions:

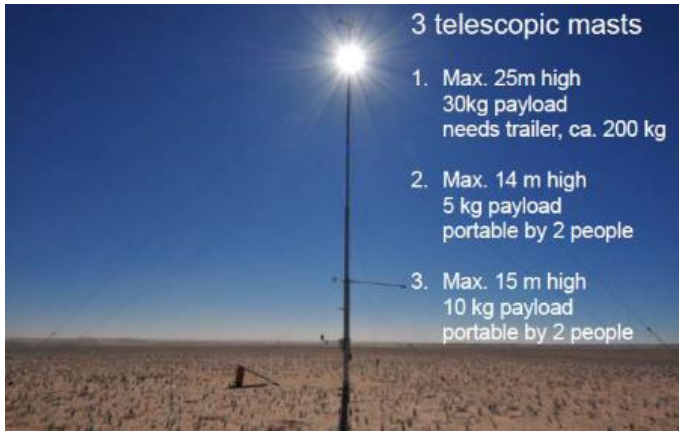
ASTeRN: Advanced Surface Temperature Radiometer and global Network
- Network consisting of 6 new sites for LST led by RAL SPACE
- Deployments starting in 2024

SLSTR and LSTM L2 processing and associated Cal/Val expertise at University of Leicester

LST-CCI involving both University of Leicester and KIT
- Provides the needs for stability criteria at L1 for climate datasets
- Strong driver for a network and longterm operation scheme

FRM4STS project led by KIT
- Field radiometer intercomparison exercises (FICE)
- In situ and lab-based emissivity characterisations





International Working Group

JPL-NASA
- Operating Lake Tahoe and Salton Sea Calibration sites
- Long data record since 1998
- Providing operational Cal/Val for several TIR missions and preparing for SBG-TIR

CNES
- Operating La Crau calibration site
- Ramping up Cal/Val facility for TRISHNA mission

ESA
- Sentinel-3 LST operator, CCI-LST, FRM4STS
- LSTM Cal/Val preparation
- Support to new space companies

CSIRO
- Interest to assess and set up a site at Pinnacles Desert

INGV
- Operating a radiometer at Acqua-Alta platform in Venice lagoon
- Preparations for SBG-TIR mission Cal/Val

Outlook for TIRCALNet

- Current preparatory study just started and going on for 18 Months
- Main project output will be a site prototype design and a roadmap towards an operational network that provides much needed TIR ToA anchoring points for radiometry cal/val
- The Working Group will then have to establish similar to Radcalnet a framework to equip sites as needed and start operating them.
- Still early to say when but at some stage beta-users from TIR mission operating entities will need to be included in the data uptake and assessment as this is **ultimately a support to ensuring well calibrated thermal data** !

Thank you very much for your attention !