OPTIMIZATION OF DIRECTES THERMAL INFRARED LAND SURFACE TEMPERATURE AND EMISSIVITY SEPARATION ALGORITHM FOR THE UPCOMING TRISHNA MISSION

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CONTEXT

TRISHNA
*Thermal infra**R**ed **I**maging **S**atellite*
*for **H**igh-resolution **N**atural resource **A**ssessment*

Joint CNES-ISRO (Franco-Indian) mission (2028)
dedicated to monitor **hydric stress**, **water and energy cycles**, **thermal anomalies** (e.g. urban heat islands)

- *L2 products:*
    - **Land and Sea Surface Temperatures (LST, SST)**
    - **Land Surface Emissivity (LSE)**
- *4 Thermal InfraRed (TIR) bands:* 8.65, 9, 10.6 and 11.6 µm
- *Revisit:*
    - 3 passes every 8 days (different view angles)
    - 8 days (same angle)
- *Pixel size:*
    - 57 m (nadir) to 90 m

TRISHNA (CNES, ISRO)

PROBLEM

TRISHNA objective : retrieve Land Surface Temperature and Emissivity from top-of-atmosphere (TOA) radiances

Radiative transfer equation:

unknowns

TOA radiance (measurement): $L_{TOA} = (\boldsymbol{\varepsilon} L_{BB}(\boldsymbol{T_s}) + (1 - \boldsymbol{\varepsilon}) L_{atm}^{\downarrow})\tau + L_{atm}^{\uparrow}$ for each TIR bands

Ground leaving radiance (Planck's Law)

Atmospheric coefficients (e.g. computed from ERA5 profiles with RTTOV, MODTRAN,…)

Problem: more unknowns (ε: number of TIR bands + T_s) than equations (number of TIR bands)

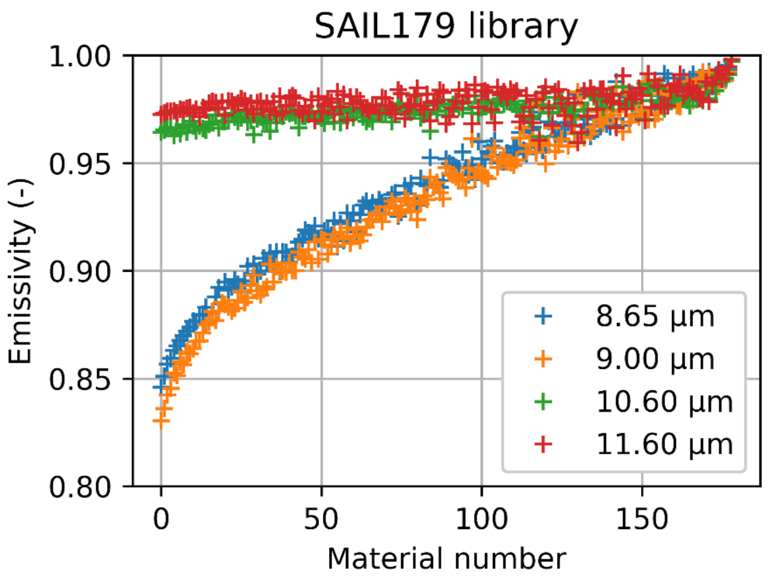
Solution : Temperature and Emissivity separation algorithm DirecTES (Marcq et al., 2023)

- Invert the equation to retrieve $\boldsymbol{T_s}$ for each TIR bands and for each emissivity spectra ($\boldsymbol{\varepsilon}$) of a spectral library (SAIL179): **T_s = f(band, mat)**
- Temperature should not depend on wavelength => **Select materials that verify criteria: $std_{band}(T_s) < 3K$**
- **Land Surface Temperature: *LST* = $median_{band, mat}(T_s)$**
- **Land Surface Emissivity: *LSE* inverted using retrieved *LST***

OBJECTIVES

Limits of original DirecTES (V1)

- ***LST* not retrieved if criteria not verified** by any material of the spectral library
- High errors when all materials verify criteria
- **Spectral library (SAIL179) is not generalist enough** →



Our objectives

- Build a **new spectral library**: generalist and representative of global conditions
- Improve DirecTES material **selection criteria**
- **Validate** new DirecTES results using simulated TOA radiances and measurements by ECOSTRESS
- Specification: **RMSE (LST) < 1 K !**

GENERATION OF A NEW, GENERALIZED SPECTRAL LIBRARY

- **CAMEL** (Combined ASTER MODIS Emissivity over Land) spectral database (*Borbas et al. 2018*)
  1 year of data (2007): 68M spectra!

↓ **k-means algorithm**

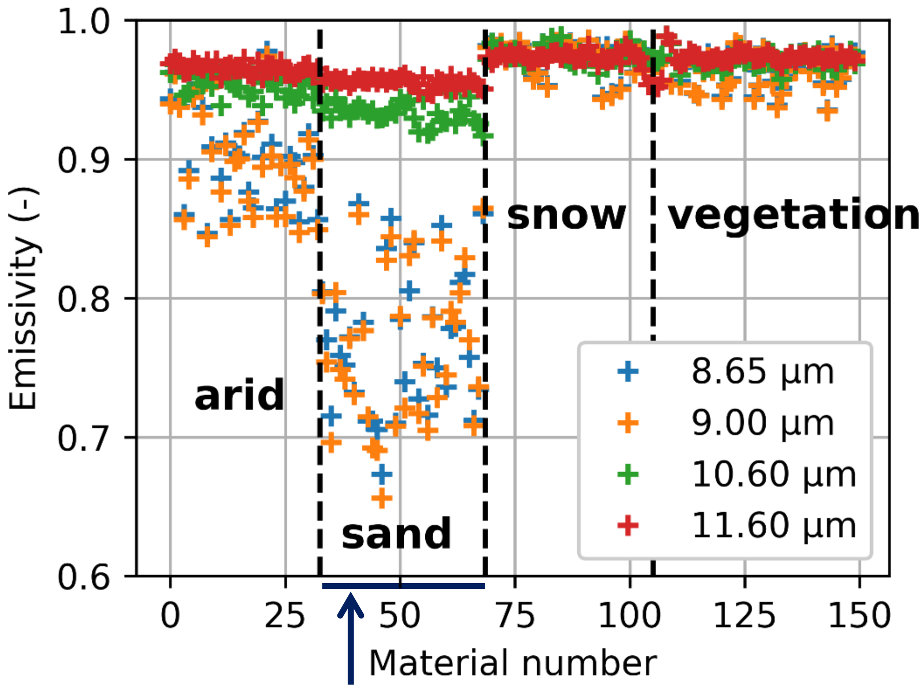
- Spectra classified into 4 categories using emissivity values in each 4 TRISHNA bands, NDVI and snow fraction

↓ **Average by close neighbours in each category**

- Generalized library of ~900 spectra

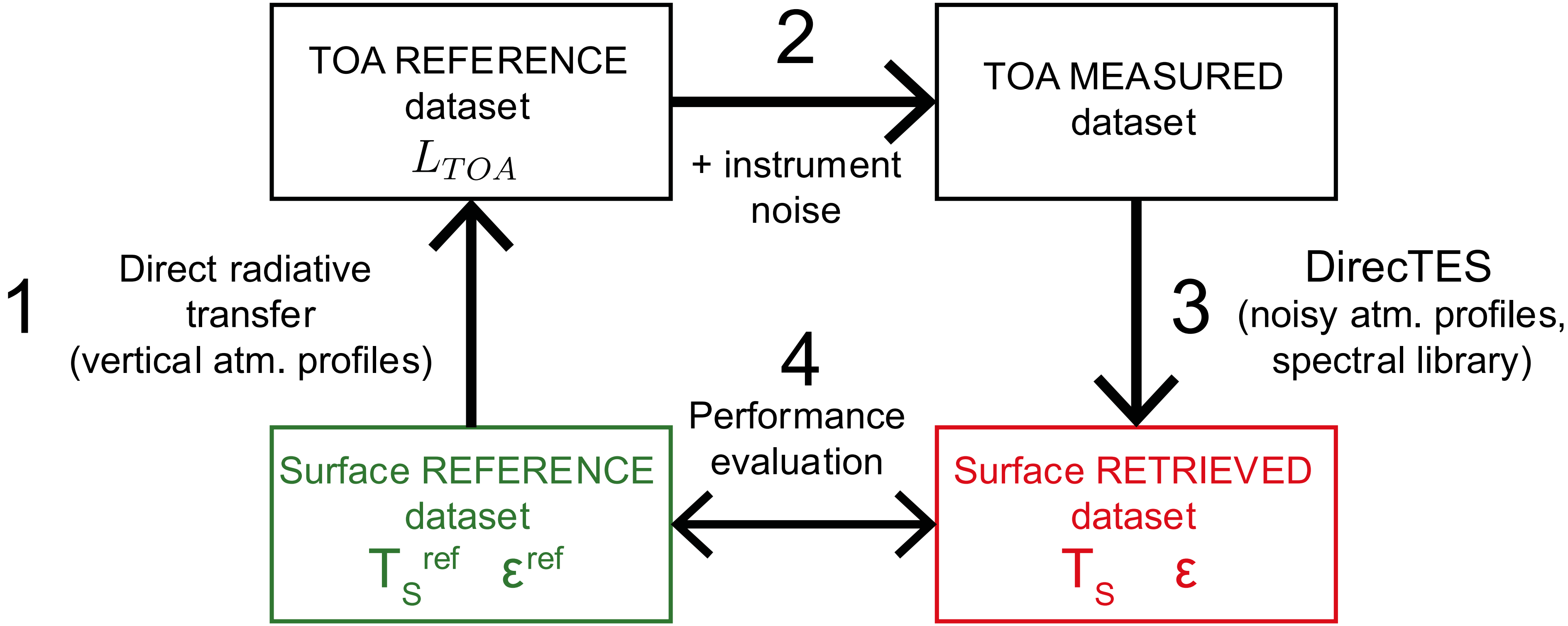
↓ **Random sampling of 150 spectra**

- **New operational spectral library** →



Addition of spectra from desertic regions (not present in SAIL179 spectral library)

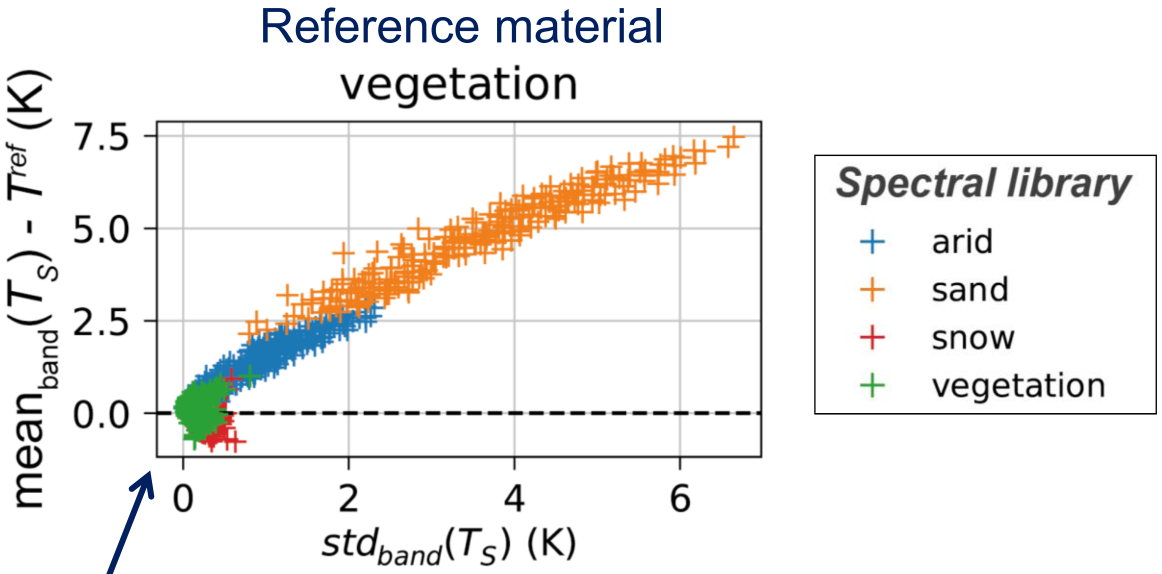
HOW TO EVALUATE THE ALGORITHM PERFORMANCES?



Sources of errors : instrument noise, atmospheric noise, algorithm, choice of the spectral library

Comparison of bias of $mean_{band}(Ts)$ with reference temperature T^{ref} as a function of $std_{band}(Ts)$ for all materials of the spectral library

Bias with reference temperature

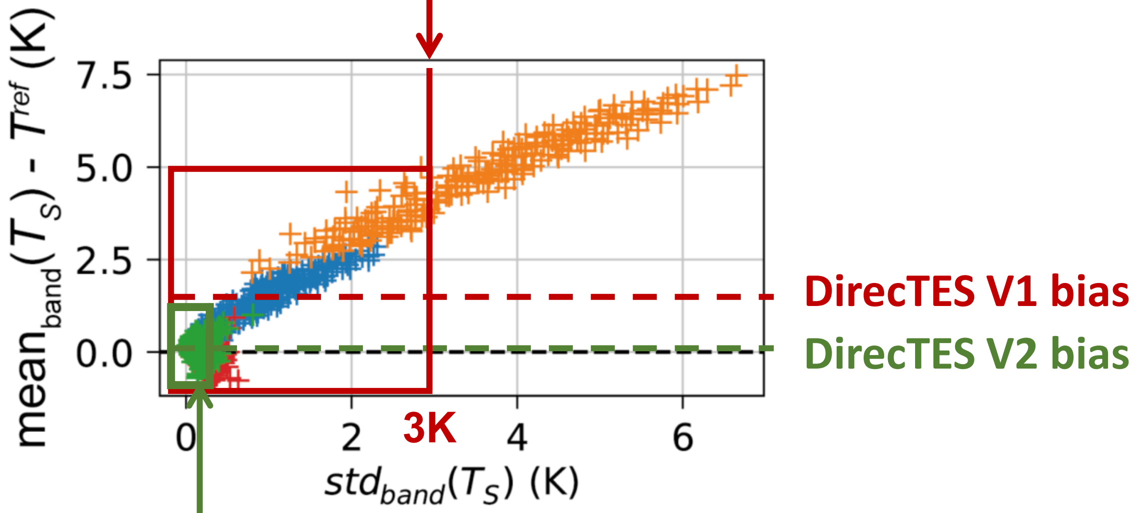


Standard deviation of T_s between bands

Low $std_{band}(T_s)$ => low bias!

OPTIMIZATION OF DIRECTES ALGORITHM

DirecTES V1: material selection with constant threshold
$std_{band}(T_s)$ < 3K => high errors



New selection criteria

DirecTES V2
$LST = median_{band,\ mat}(T_s)$ and $LSE = median_{mat}(\varepsilon)$
for the 10 materials with smallest $std_{band}(T_s)$

COMPARISON OF DIRECTES V1 AND V2 PERFORMANCES

Bias on LST

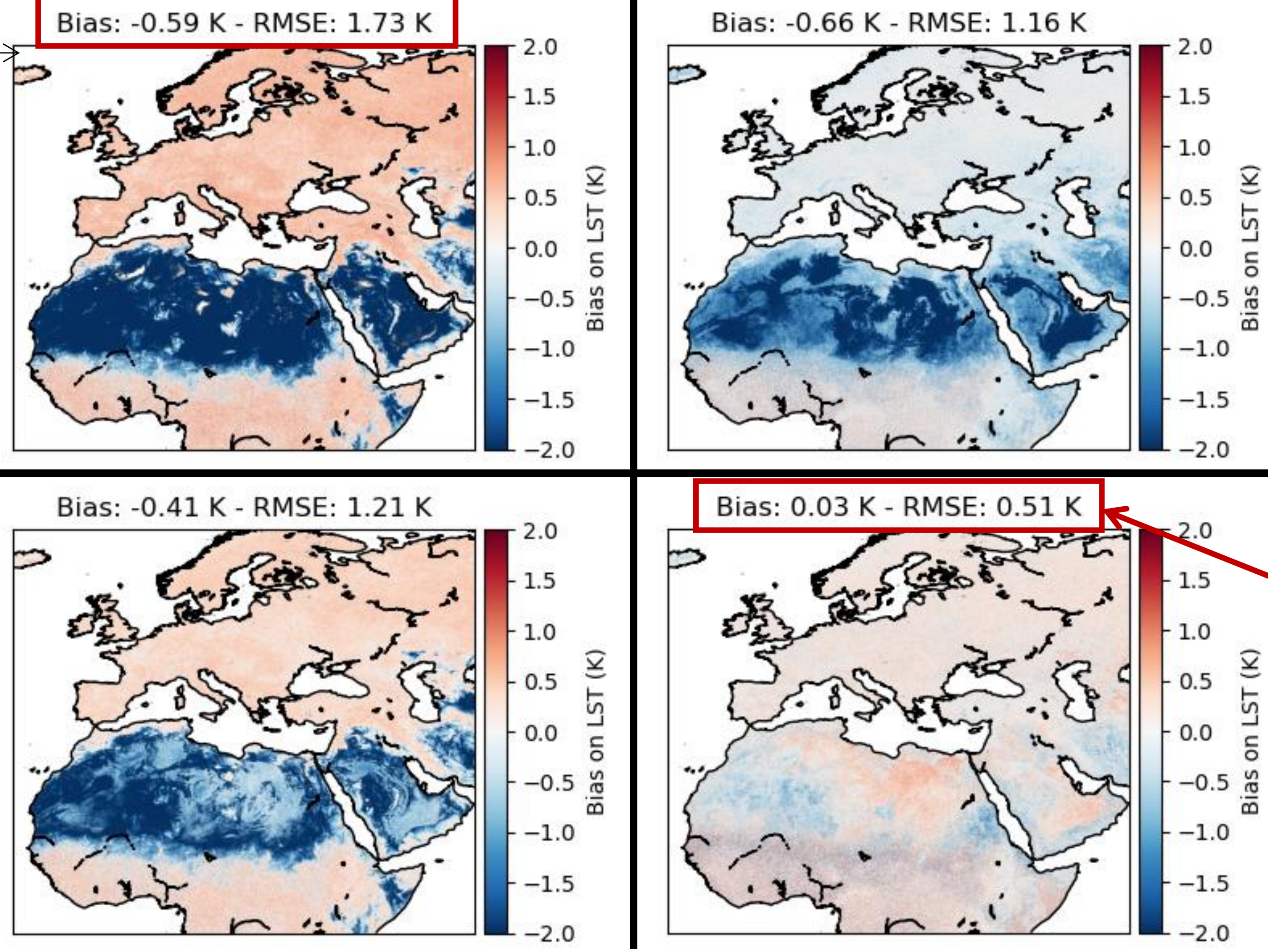
LST retrieved from TOA radiances simulated with ECMWF ERA5 profiles ($T_s^{ref} = t_{skin}$) and CAMEL emissivity database

Marcq et al. 2023 →

DirecTES V1 | **DirecTES V2**

SAIL179

New spectral library



Bias and RMSE much lower with DirecTES V2 and the new spectral library **especially on desertic regions**

COMPARISON OF DIRECTES V1 AND V2 PERFORMANCES

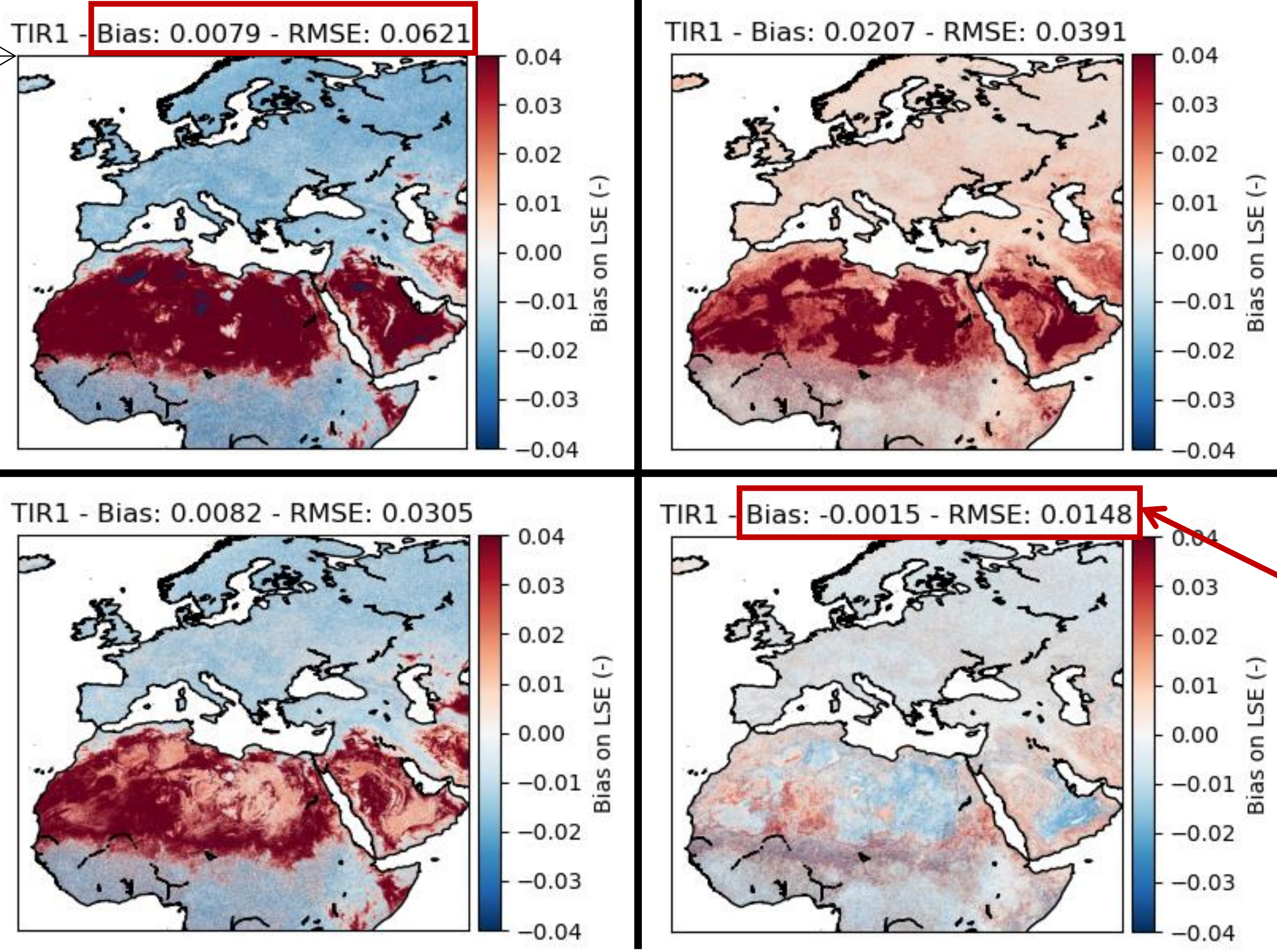
Bias on LSE (TIR1)

DirecTES V1 | **DirecTES V2**

Marcq et al. 2023 →

SAIL179

New spectral library

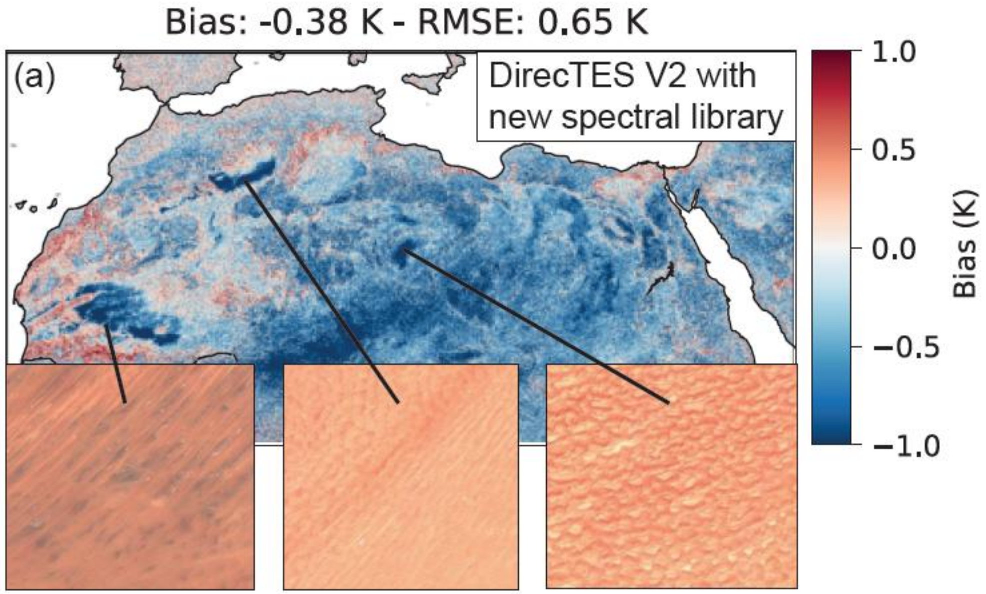


LSE retrieved from TOA radiances simulated with ECMWF ERA5 profiles ($T_s^{ref} = t_{skin}$) and CAMEL emissivity database

Bias and RMSE much lower with DirecTES V2 and the new spectral library **especially on desertic regions**

FURTHER IMPROVEMENT ON SAND DUNES REGIONS

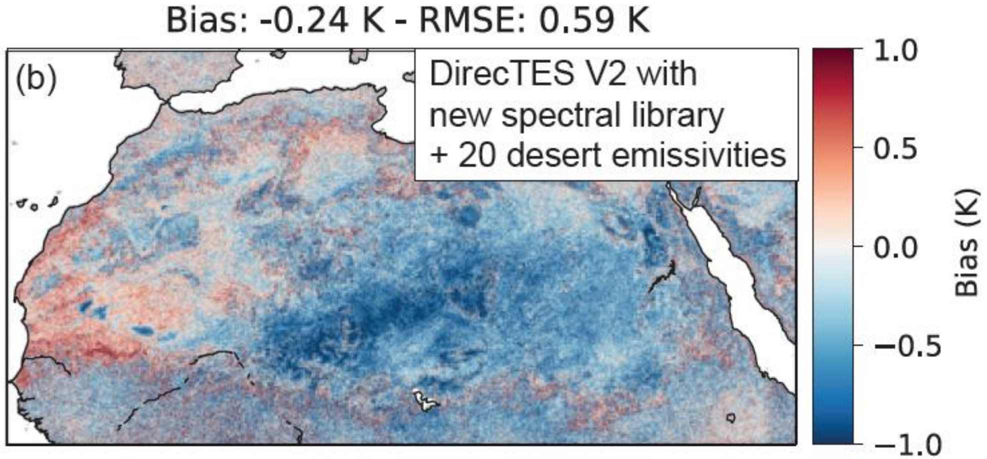
LST/LSE are not so well retrieved on sand dune deserts



+20 desert spectra

→

in spectral library

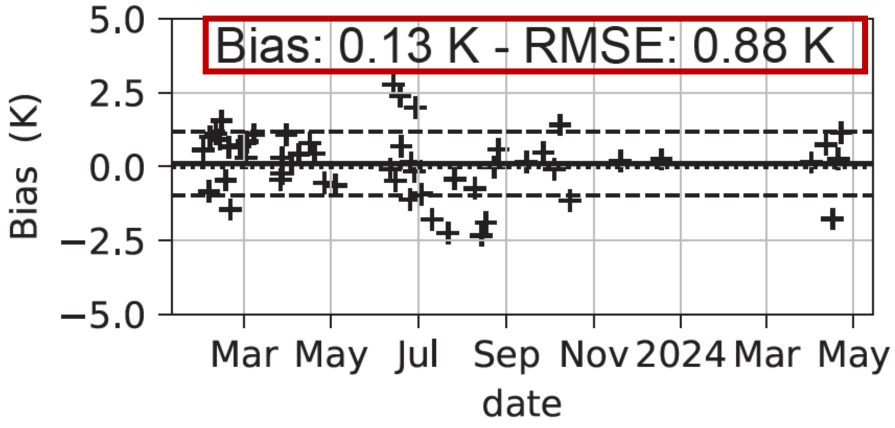


Performances are improved on deserts and **not deteriorated in other regions**

VALIDATION OF RETRIEVED LST WITH IN SITU RADIOMETRIC MEASUREMENTS

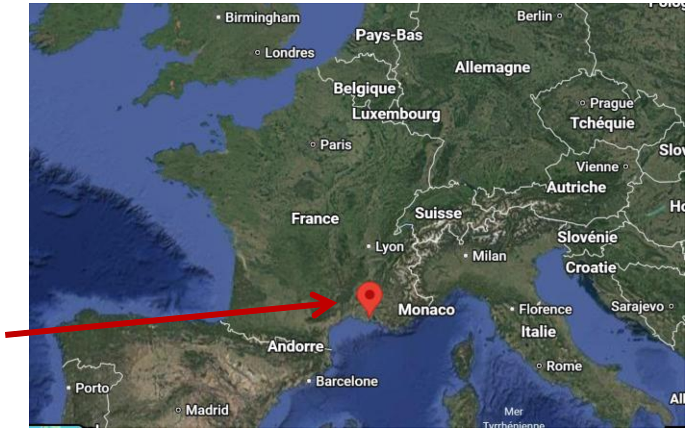
LST is retrieved from ECOSTRESS TOA radiances for 52 cloud-free dates from 02/2023 to 05/2024 with DirecTES V2 above La Crau with ERA5 atmospheric profiles

Comparison with in-situ LST measurements with a CIMEL CE312 infrared radiometer:



LST is retrieved with bias close to 0K and RMSE < 1K

La Crau validation site France



CONCLUSIONS

- DirecTES is the operational temperature-emissivity separation algorithm for the upcoming TRISHNA mission.

- DirecTES has been optimized with a **new, generalist spectral library** built from CAMEL database and a **modified selection criteria** of materials in the spectral library.

- DirecTES performances can be **further enhanced** in specific regions **by adding a few emissivities** from these regions **in the spectral library**.

- LST retrieved with DirecTES from ECOSTRESS TOA radiances has been **validated with in situ LST measurements** at La Crau validation site.