Optimization, testing and validation of DirecTES thermal infrared land surface temperature and emissivity separation algorithm for the upcoming TRISHNA mission L2 processing

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1. OVERVIEW

- Land surface temperature (LST) and emissivity (LSE) separation algorithm **DirecTES** [Marcq et al., 2023] of the upcoming TRISHNA mission (CNES-ISRO, 2028) is optimized and tested with simulated top-of-atmosphere (TOA) radiances.
- A new generalist spectral library is developed from CAMEL database.
- Optimized DirecTES improves biais and RMS error on retrieved LST and LSE, especially in desertic regions: **LST RMSE is below 0.9K on any surface and around 0.5 K on urban/vegetated surfaces.**
- LST retrieved from ECOSTRESS TOA measurements is validated with surface radiometric measurements at La Crau site (France).

2. INTRODUCTION

TOA radiance L_{TOA} in thermal infrared (TIR) domain:

$$L_{TOA} = (\varepsilon L_{BB}(T_S) + (1-\varepsilon)L_{atm}^{\downarrow})\tau + L_{atm}^{\uparrow} \quad (1)$$

L_{BB} : Planck law
$L_{atm}^{\downarrow}, L_{atm}^{\uparrow}, \tau$: atmospheric coefficients

Less equations (number of TIR bands) than unknowns (1 emissivity ε per band + 1 temperature T_S)!
=> (1) can not simply be inverted for LST = T_S and LSE = ε...

Solution: DirecTES algorithm [Marcq et al. 2023]

- Invert **(1)** to retrieve T_S for each material of an emissivity (ε) **spectral library**
- **Select materials that match pixel surface material**: a priori, they verify **criteria std$_{band}$(T_S) < 3 K**
- LST = mean$_{band,\ mat}$(T_S)
- LSE inverted using retrieved LST

Limits of original DirecTES

- LST is not retrieved if criteria not verified by any material of the spectral library
- High error when all materials verify criteria
- Spectral library (SAIL179) is not generalist enough and performs poorly on desert pixels

Objectives

- Improve DirecTES selection criteria
- Create **new spectral library: generalist and representative of global conditions**
- Test and validate new DirecTES using simulated TOA radiances and measured by ECOSTRESS
- **RMSE on LST must be < 1 K**

3. METHODS

How to evaluate DirecTES performance?

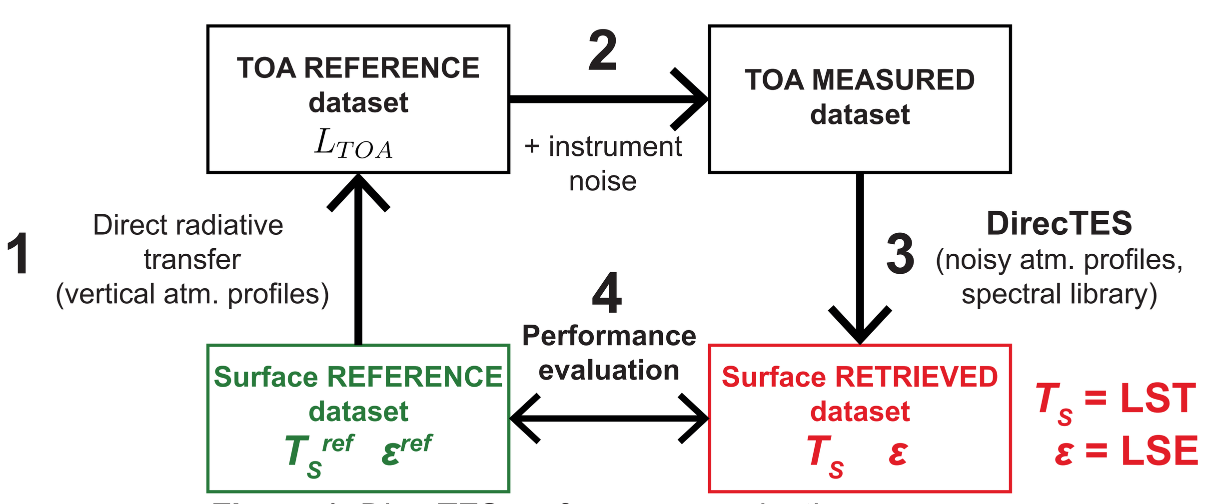

***Figure 1:** DirecTES performance evaluation process*

Generation of a new, generalized spectral library

CAMEL spectral database
[Borbas et al., 2018]
↓ *k-means algorithm*
Classified into 4 categories using emissivity values in each 4 TRISHNA bands, NDVI and snow fraction (***Figure 2***)
↓ *average by close neighbours*
Generalized library of 866 emissivities (~215 each category)
↓ *random sampling of 150 values*
Operational spectral library
(***Figure 3***)

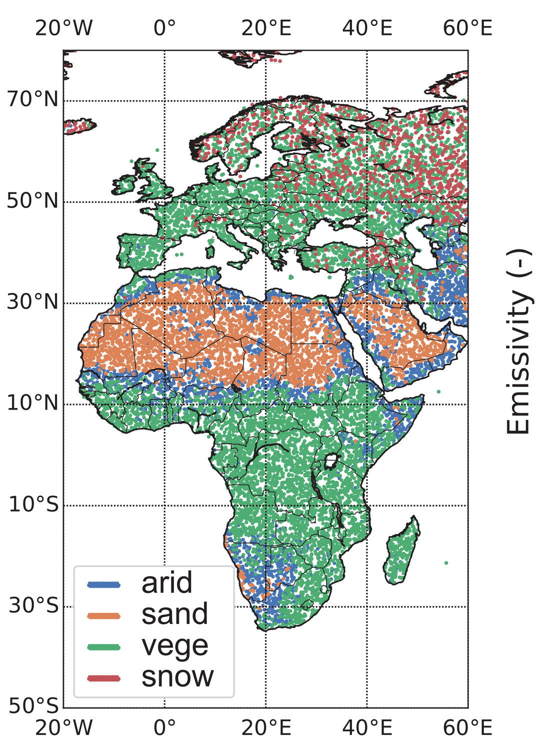

***Figure 2:** Spatial distribution of the categorized CAMEL emissivities*

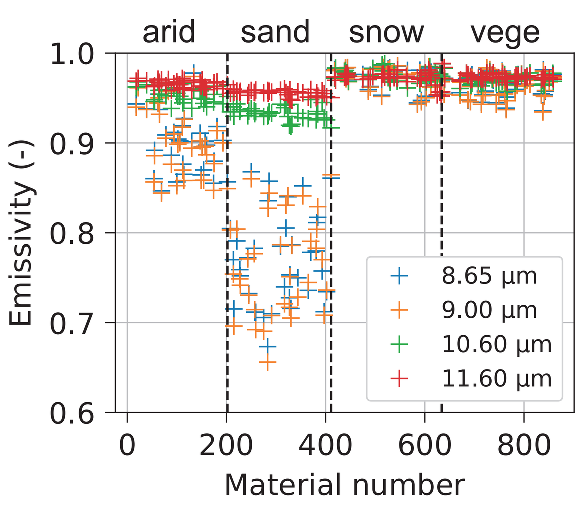

***Figure 3:** New spectral library*

Optimization of DirecTES algorithm

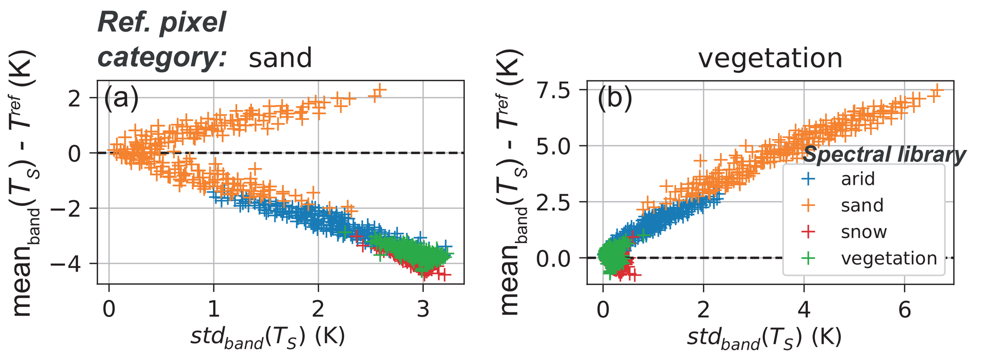

***Figure 4:** Difference between T_S^{ref} and mean$_{band}$(T_S), for each material of the spectral library (+) as a function of std$_{band}$(T_S), when the category of ε^{ref} is (a) «sand» or (b) «vegetation»*

Materials of the spectral library with lowest std$_{band}$(T_S) over TIR bands have smallest mean$_{band}$(T_S) bias with reference temperature T^{ref} (***Figure 4***).

- *sand* pixels: only materials from *sand* category can retrieve the LST with small bias (***Figure 4a***).
- *vegetation* pixels: some materials from a different category (*arid* or *snow*) can also retrieve LST with low bias (***Figure 4b***).

DirecTES V2
LST = mean$_{band,\ mat}$(T_S) and LSE = mean$_{mat}$(ε)
for the 10 selected materials with smallest std$_{band}$(T_S)
=> Indirect benefit: LST and LSE retrieved for all pixels!

4. RESULTS

Comparison of DirecTES V1 and V2 performances

Optimized DirecTES (V2) globally improves bias and RMSE on retrieved LST and LSE with respect to original DirecTES (V1) (***Figure 5***), with both versions using the same spectral library of ***Figure 3***.

RMSE on LST is below target threshold of 1 K (---) for all surface types (*Figure 5b*).

Important improvement on desertic surfaces (*sand* category). Performances not degraded on vegetated and snowy surfaces.

Error on LSE more important for low wavelengths because emissivities are more sensitive to material (***Figure 3***).

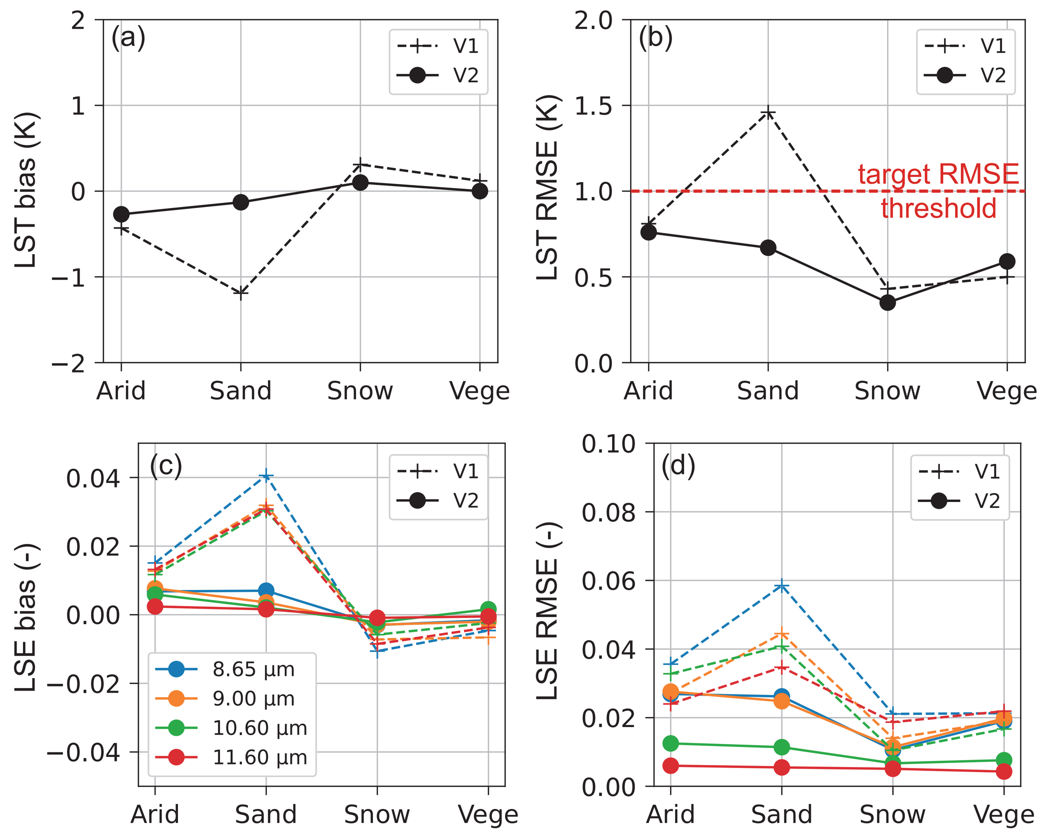

***Figure 5:** Bias and RMSE on LST and LSE retrieved by original (V1) and optimized (V2) versions of DirecTES, from TOA radiances simulated with emissivities from different categories (arid, sand, snow and vege).*

Spatialized error

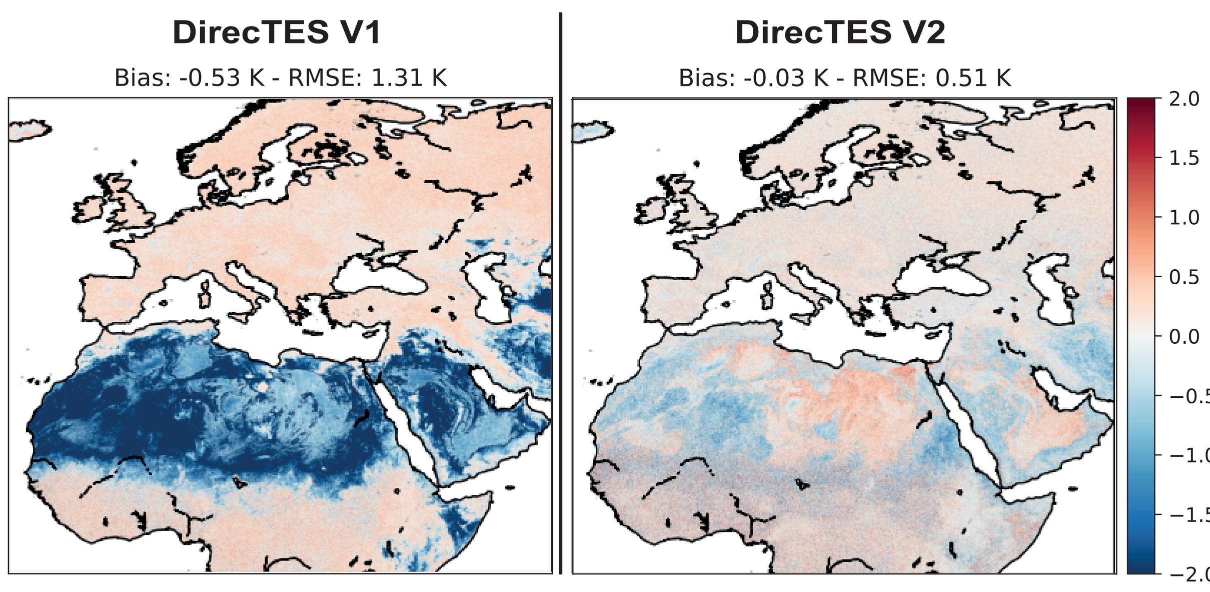

***Figure 6:** Bias on LST retrieved with DirecTES V1 and V2, on images of TOA radiances simulated with CAMEL and ERA5 monthly averaged databases at 0.05° spatial resolution for August 2017.*

Bias and RMSE on LST and LSE are globally much lower with DirecTES V2 than with DirecTES V1 especially on **desertic regions** (***Figure 6***).

LST/LSE not so well retrieved on sand dune deserts (***Figure 7a***).

By adding a few emissivities of desertic areas to the spectral library, DirecTES V2 performances are further improved on deserts and are not deteriorated in other regions (***Figure 7b***).

DirecTES V2 can appropriately select the materials corresponding to the observed surface in the spectral library, for each pixel.

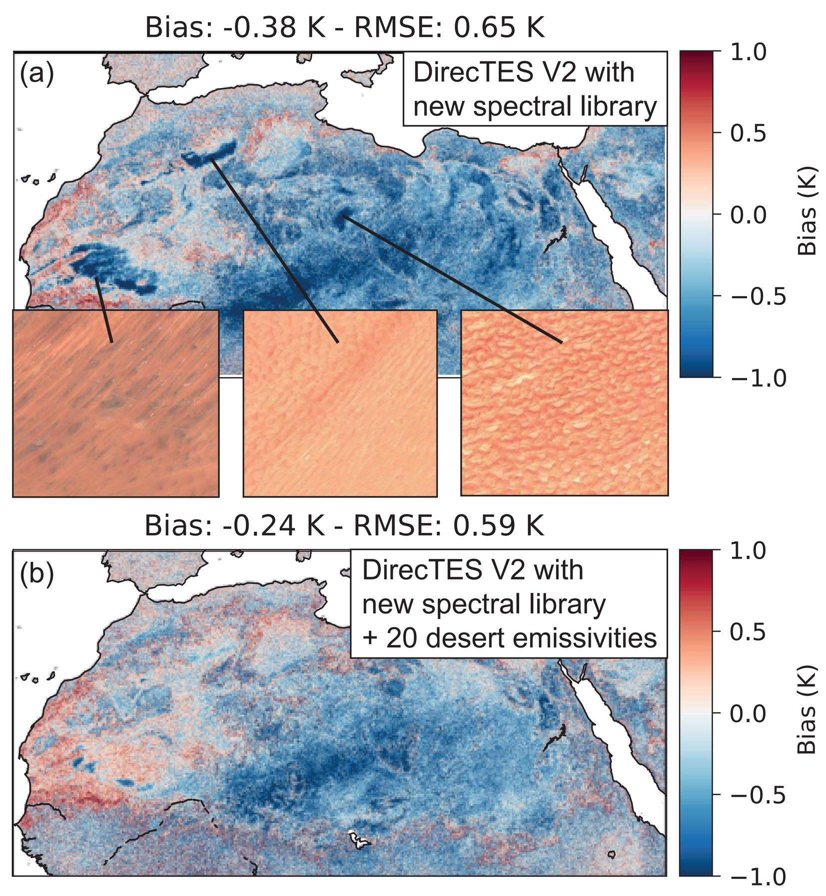

***Figure 7:** Bias on LST retrieved with DIrecTES V2 for April 2007 (a) with generalist spectral library (**Figure 3**) and (b) by adding 20 sand emissivities to the library.*

Validation of retrieved LST with in situ radiometric measurements

LST is retrieved from ECOSTRESS TOA measurements for 52 dates spanning from February 2023 to May 2024 with DirecTES V2 above La Crau validation site (France).

Retrieved LST is compared with in situ LST measurements performed with a CIMEL CE312 infrared radiometer (***Figure 8***).

Overall, LST is well retrieved, with bias close to 0 K and **RMSE < 1 K**.

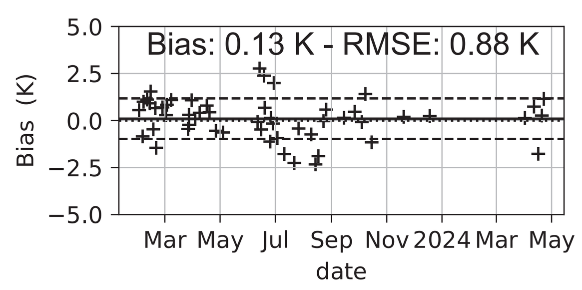

***Figure 8:** Bias between LST retrieved from ECOSTRESS TOA images and that measured in situ with a IR radiometer at La Crau validation site (France).*

5. CONCLUSIONS

- DirecTES algorithm 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 are improved, **especially on desertic regions**, where they can be further enhanced by adding a few emissivities from these regions in the spectral library.
- LST retrieved with DirecTES from ECOSTRESS images has been validated with in situ LST measurements at La Crau validation site.

REFERENCES

DirecTES algorithm: Marcq et al., 2023, Remote Sens.,15, 517.
CAMEL emissivity database: Borbas et al., 2018, Remote Sens., 10, 643.
TIGR atmospheric profile database: Chevalier et al., 2000, Meteorol. Soc., 126, 777-785.
ERA5 monthly averaged data: Hersbach et al., 2023, Copernicus Climate Change Service (C3S).