Recent advances in Land Surface Temperature (LST) retrieval and validation with in-situ measurements

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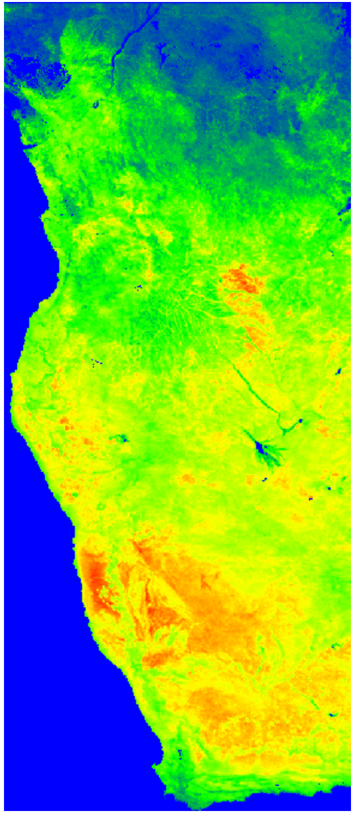
Overview

- Land Surface Temperature (LST)
  - What is LST?
  - Why is it difficult to retrieve?
- In-situ validation and results
- Recent advances in LST&E retrieval



What is LST?

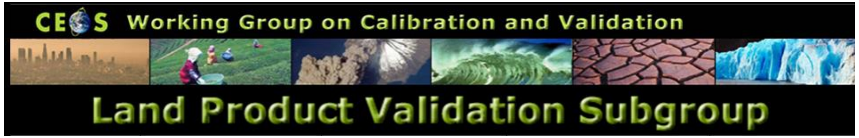
Karlsruhe Institute of Technology

Land Surface Temperature (LST) is a kinetic quantity, independent of wavelength, that represents the thermodynamic temperature of the skin layer of a given surface, i.e. it is a measure of how hot or cold the surface of the Earth would feel to the touch. It is also referred to as (directional) radiometric or skin temperature.

For ground-based, airborne, and spaceborne remote sensing instruments it is the **aggregated radiometric surface temperature of the ensemble of components within the sensor's field of view.**

Norman & Becker (1995)

This definition has been adopted by various international groups and projects, e.g. CEOS WGCV, GCOS, ESA GlobTemperature and ESA FRM4STS.



What is LST?

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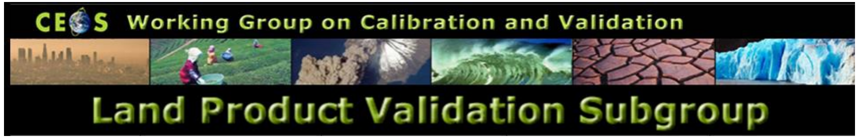
Since 2017 LST is an Essential Climate Variable (ECV)

This definition has been adopted by various international groups and projects, e.g. CEOS WGCV, GCOS, ESA GlobTemperature and ESA FRM4STS.



Why is LST difficult to retrieve?

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- **Sea** Surface Temperature (SST)
  - Homogeneous within pixel
  - Constant emissivity ≈ 1
  - Close to air temperature
  - Flat surface

Uncertainty ≈ 0.2 K

- **Land** Surface Temperature (LST):
  - Inhomogeneous within pixel
  - Unknown & variable emissivity < 1
  - May differ strongly from air temperature
  - Topography and land cover variability

Uncertainty ≈ 1.0 - 1.5 K

Thermal Infrared (TIR) Radiative Transfer

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Emissivity

Land Surface Temperature (LST)

Sky irradiance

Transmissivity

Path radiance

Surface Radiance

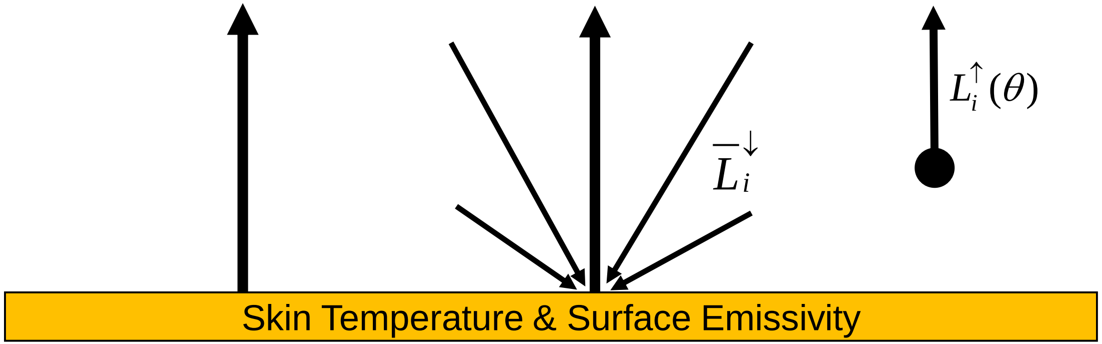
Sensor Radiance

$$L_i(\theta) = \tau_i(\theta) \cdot e_i \cdot B_i(T_S) + \tau_i(\theta) \cdot (1-e_i) \cdot \overline{L}_i^{\downarrow} + \int B_i(T(P))\, d\tau_i$$

Surface Emission

Surface Reflection

Atmospheric Emission



Adapted from G. Hulley (2018)

LST retrieval: an under-determined problem

<u>N spectral measurements, N + 1 unknowns (N emissivities & Temperature)</u>

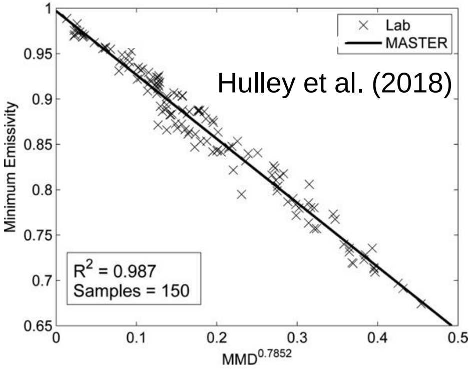
1. Generalized Split-Windows (Wan and Dozier, 1996) ← **LSA-001**
   - Requires 2 bands

$$LST = \left(A_1 + A_2\frac{1-\epsilon}{\epsilon} + A_3\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_{IR1}+T_{IR2}}{2} + \left(B_1 + B_2\frac{1-\epsilon}{\epsilon} + B_3\frac{\Delta\epsilon}{\epsilon^2}\right) + C$$

   - Regression coefficients should represent all configurations (atmospheric water content, view angle, surface T_{air}, …)
   - **Estimate** spectral emissivity, e.g. via Fraction of Vegetation Cover (FVC)

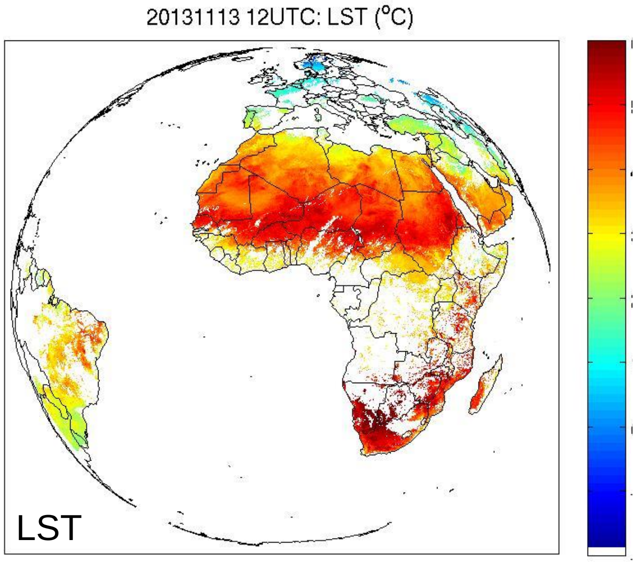
EUMETSAT LSA SAF

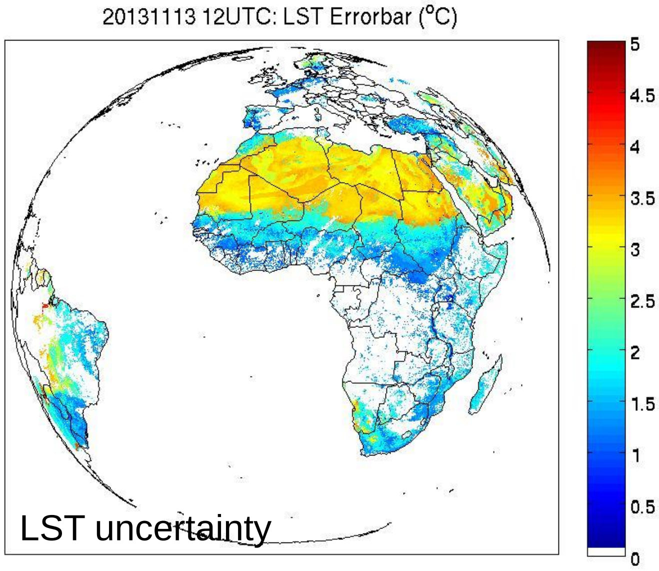
2. Temperature-Emissivity Separation (TES) ← **MOD21**
   - Multispectral (**minimum** 3 bands)
   - Requires atmospheric profiles
   - Full atmospheric correction with MODTRAN
   - Based on **emissivity model** (Calibration Curve)



Hulley et al. (2018)

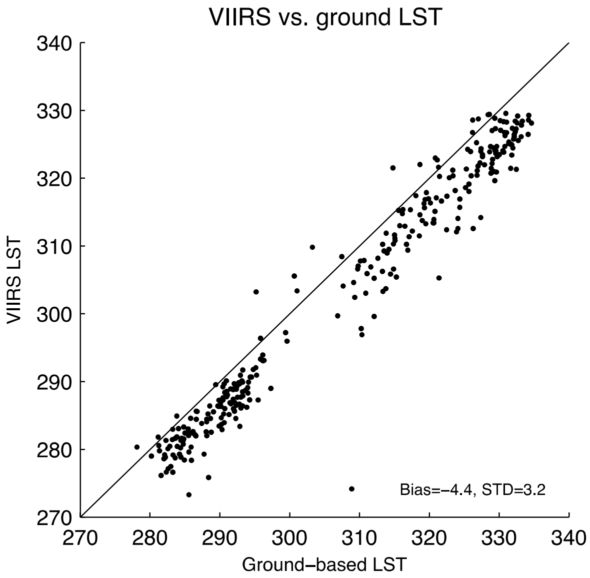
SEVIRI/MSG - LST

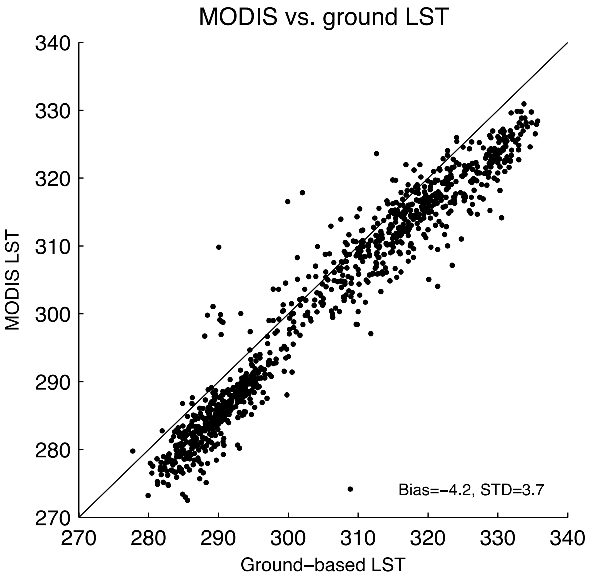




- Temporal sampling: 15 min; poorer under the ITCZ
- Spatial resolution over Africa: 3km up to ~5km
- LST uncertainty highly influenced by emissivity over (semi-)arid regions

Critical need for ground truth





VIIRS vs. MOD11 algorithms: similar poor performance over **arid** areas

Land Surface Emissivity at Gobabeb

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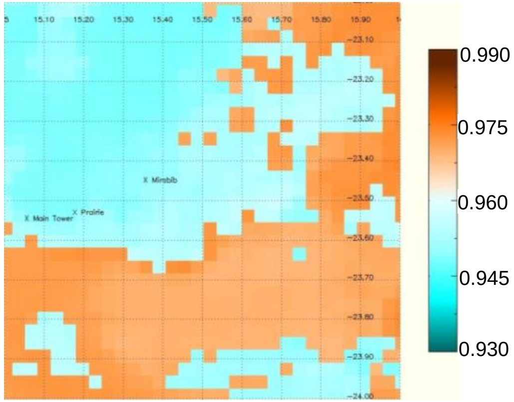
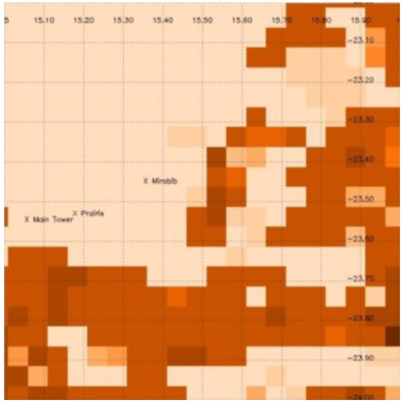
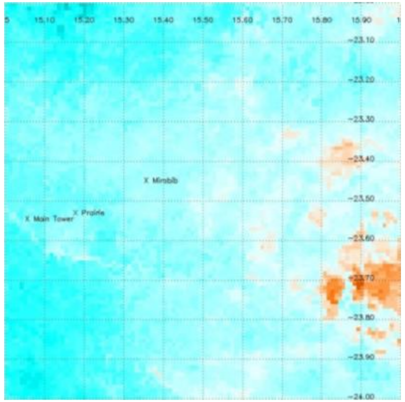


SEVIRI ch10.8



MOD11B1.v05, MODIS ch31



MODTES, MODIS Ch31

SEVIRI ch10.8 **in-situ** emissivity for Gobabeb*:

Sand dunes: 0.941 ±0.004
Gravel plains: **0.944** ±0.015

Göttsche and Hulley (2012)

LST validation with in-situ measurements

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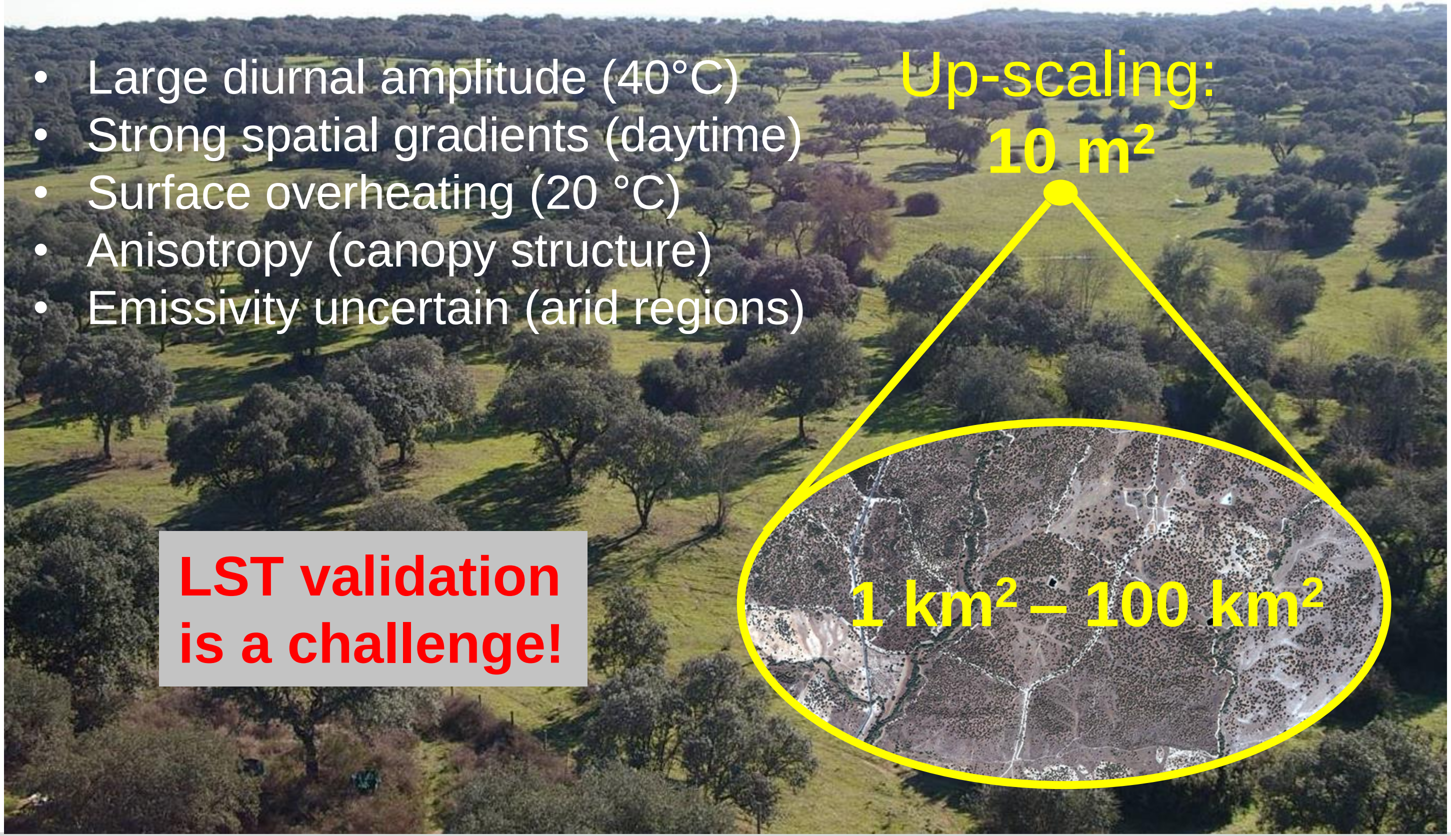
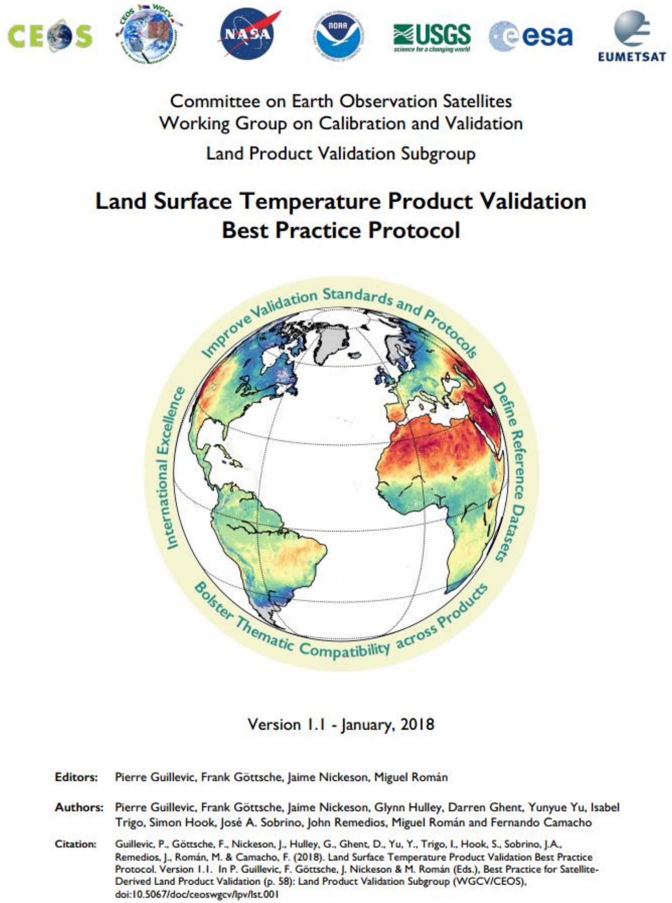
- Large diurnal amplitude (40°C)
- Strong spatial gradients (daytime)
- Surface overheating (20 °C)
- Anisotropy (canopy structure)
- Emissivity uncertain (arid regions)



LST validation is a challenge!

CEOS LST Product Validation Protocol

Karlsruhe Institute of Technology



Committee on Earth Observation Satellites
Working Group on Calibration and Validation
Land Product Validation Subgroup

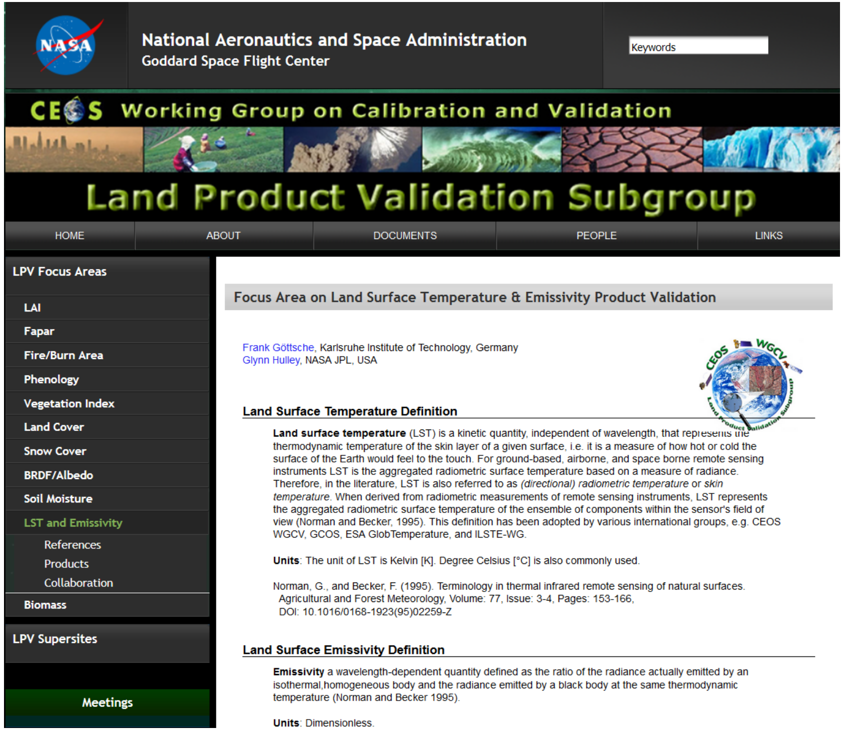
Land Surface Temperature Product Validation
Best Practice Protocol

Version 1.1 - January, 2018

Editors: Pierre Guillevic, Frank Göttsche, Jaime Nickeson, Miguel Román

Authors: Pierre Guillevic, Frank Göttsche, Jaime Nickeson, Glynn Hulley, Darren Ghent, Yunyue Yu, Isabel Trigo, Simon Hook, José A. Sobrino, John Remedios, Miguel Román and Fernando Camacho

Citation: Guillevic, P., Göttsche, F., Nickeson, J., Hulley, G., Ghent, D., Yu, Y., Trigo, I., Hook, S., Sobrino, J.A., Remedios, J., Román, M. & Camacho, F. (2018). Land Surface Temperature Product Validation Best Practice Protocol. Version 1.1. In P. Guillevic, F. Göttsche, J. Nickeson & M. Román (Eds.), Best Practice for Satellite-Derived Land Product Validation (p. 58): Land Product Validation Subgroup (WGCV/CEOS), doi:10.5067/doc/ceoswgcv/lpv/lst.001



National Aeronautics and Space Administration
Goddard Space Flight Center

Keywords

CEOS Working Group on Calibration and Validation

Land Product Validation Subgroup

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LPV Focus Areas

- LAI
- Fapar
- Fire/Burn Area
- Phenology
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- Snow Cover
- BRDF/Albedo
- Soil Moisture
- LST and Emissivity
  - References
  - Products
  - Collaboration
- Biomass

LPV Supersites

Meetings

Focus Area on Land Surface Temperature & Emissivity Product Validation

Frank Göttsche, Karlsruhe Institute of Technology, Germany
Glynn Hulley, NASA JPL, USA

Land Surface Temperature Definition

Land surface temperature (LST) is a kinetic quantity, independent of wavelength, that represents the thermodynamic temperature of the skin layer of a given surface, i.e. it is a measure of how hot or cold the surface of the Earth would feel to the touch. For ground-based, airborne, and space borne remote sensing instruments LST is the aggregated radiometric surface temperature based on a measure of radiance. Therefore, in the literature, LST is also referred to as *(directional) radiometric temperature* or *skin temperature*. When derived from radiometric measurements of remote sensing instruments, LST represents the aggregated radiometric surface temperature of the ensemble of components within the sensor's field of view (Norman and Becker, 1995). This definition has been adopted by various international groups, e.g. CEOS WGCV, GCOS, ESA GlobTemperature, and ILSTE-WG.

Units: The unit of LST is Kelvin [K]. Degree Celsius [°C] is also commonly used.

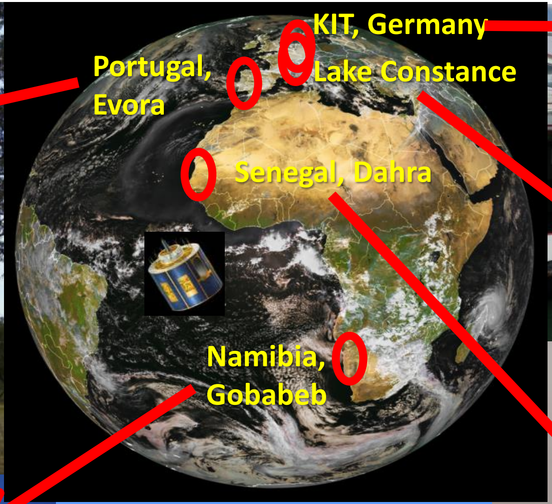
Norman, G., and Becker, F. (1995). Terminology in thermal infrared remote sensing of natural surfaces. Agricultural and Forest Meteorology, Volume: 77, Issue: 3-4, Pages: 153-166, DOI: 10.1016/0168-1923(95)02259-Z

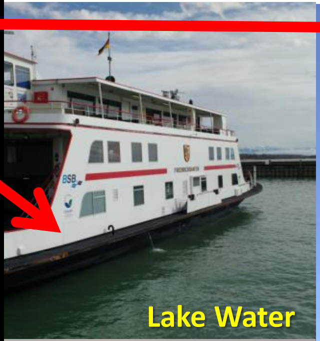
Land Surface Emissivity Definition

Emissivity a wavelength-dependent quantity defined as the ratio of the radiance actually emitted by an isothermal,homogeneous body and the radiance emitted by a black body at the same thermodynamic temperature (Norman and Becker 1995).

Units: Dimensionless.

Dedicated LST Validation Stations





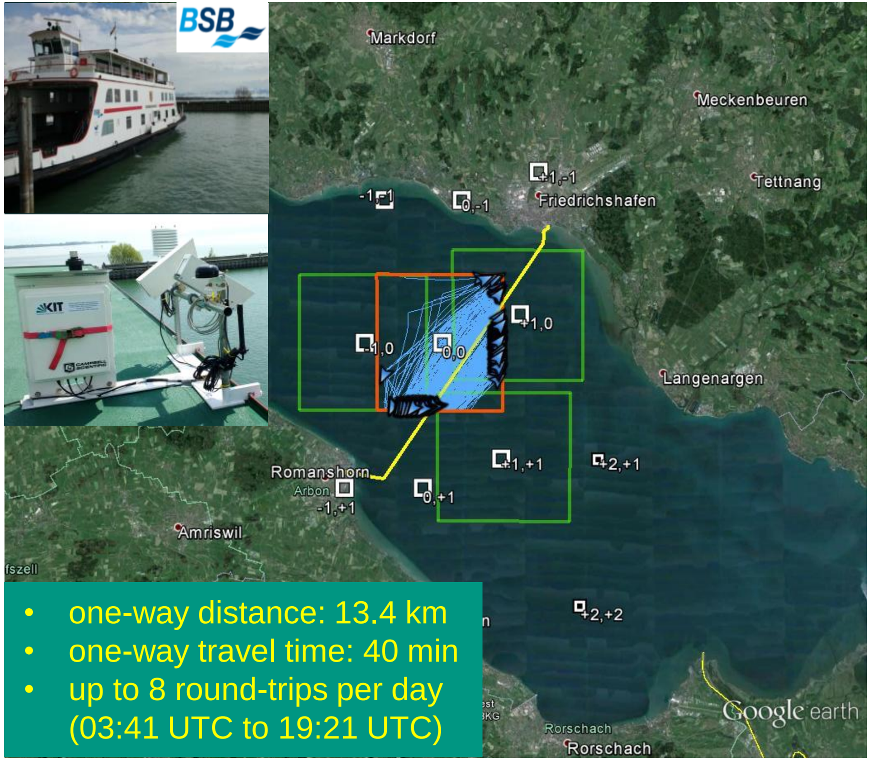
- Large, **homogeneous** sites
- Well **characterised**
- Different climates & biomes
- **Dedicated** to LST validation

Copernicus LAW project
for Sentinel-3 validation

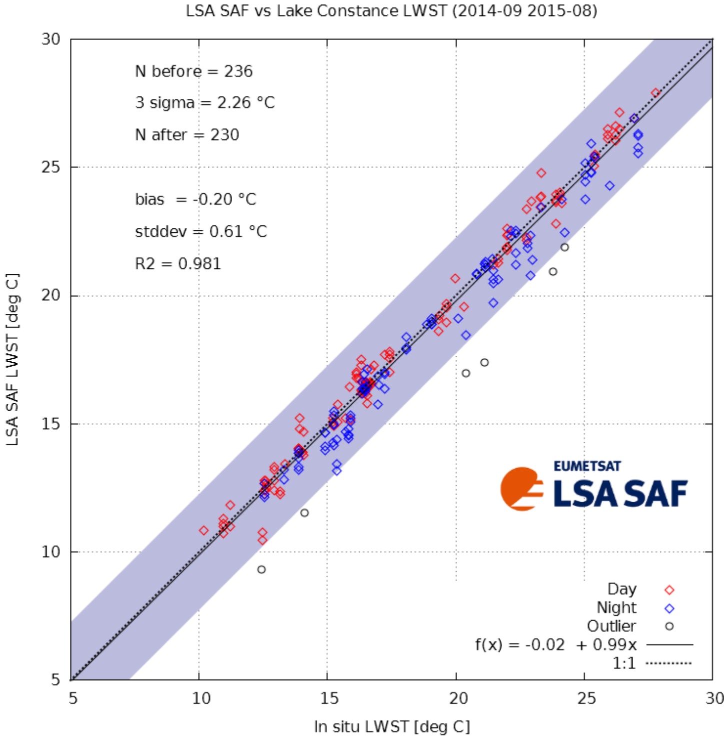
Main instrument: Heitronics KT15.85 IIP

- chopped, precision radiometer:
  stability better than 0.12% per year
- narrow band 9.6µm -11.5µm
  (completely in atmospheric window)
- Full view angle: 8.5°
- better than ±0.3K absolute accuracy
- One KT15 for **each end-member** plus a KT15 for **sky radiance** (reflected component!)
- Sampling rate of **1 min**

Lake Water Surface Temperature – Lake Constance



- one-way distance: 13.4 km
- one-way travel time: 40 min
- up to 8 round-trips per day (03:41 UTC to 19:21 UTC)



Sentinel-3 SLSTR Split Window Algorithms

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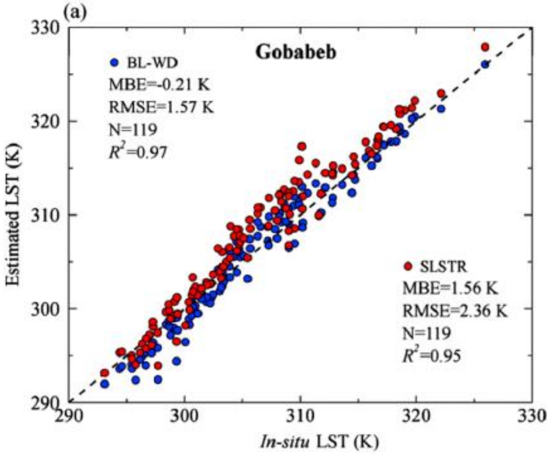

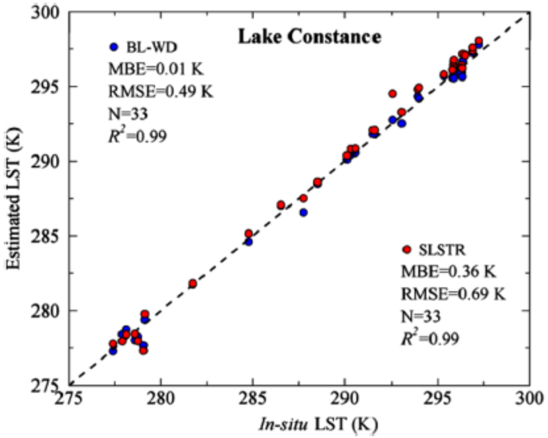

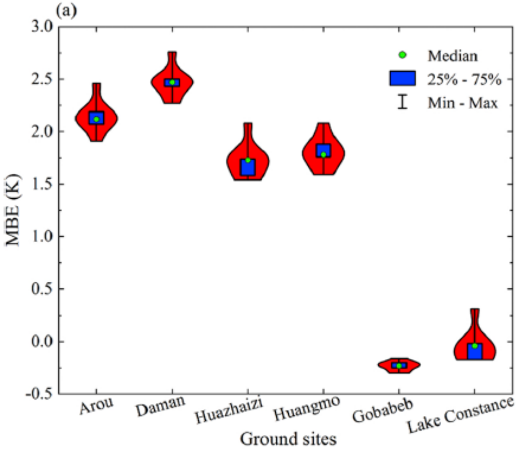

Yang et al. (2020), doi: 10.1016/j.jag.2020.102136:

- Trained & investigated seventeen different Split Window Algorithms (SWA)
- The nine best SWAs performed similarly to ‘Becker & Li (1990) and Wan & Dozier (1996)’
- Better performance than operational Sentinel-3 SLSTR LST product (improved version under way)

fiducial reference temperature measurements

ESA FRM4STS Project

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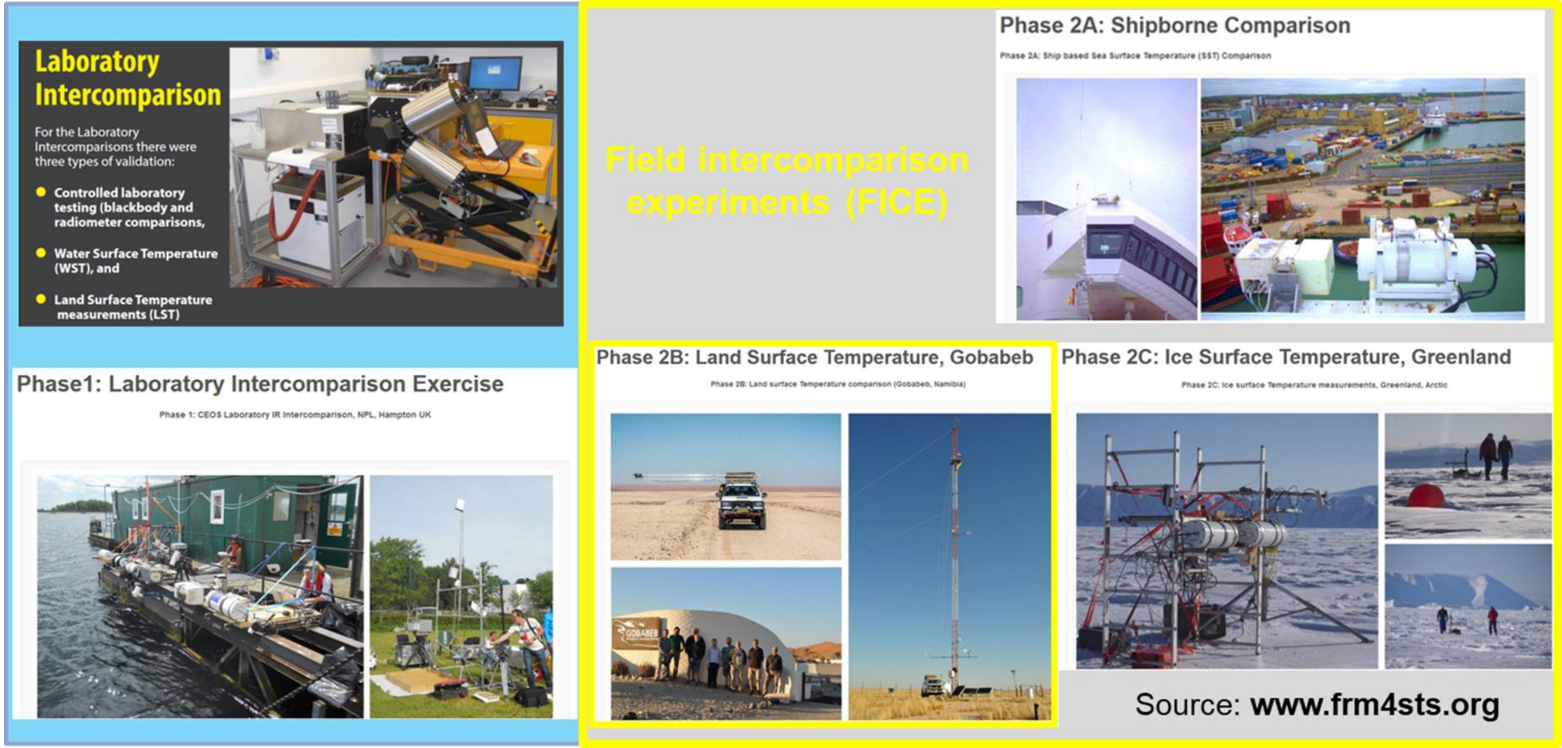
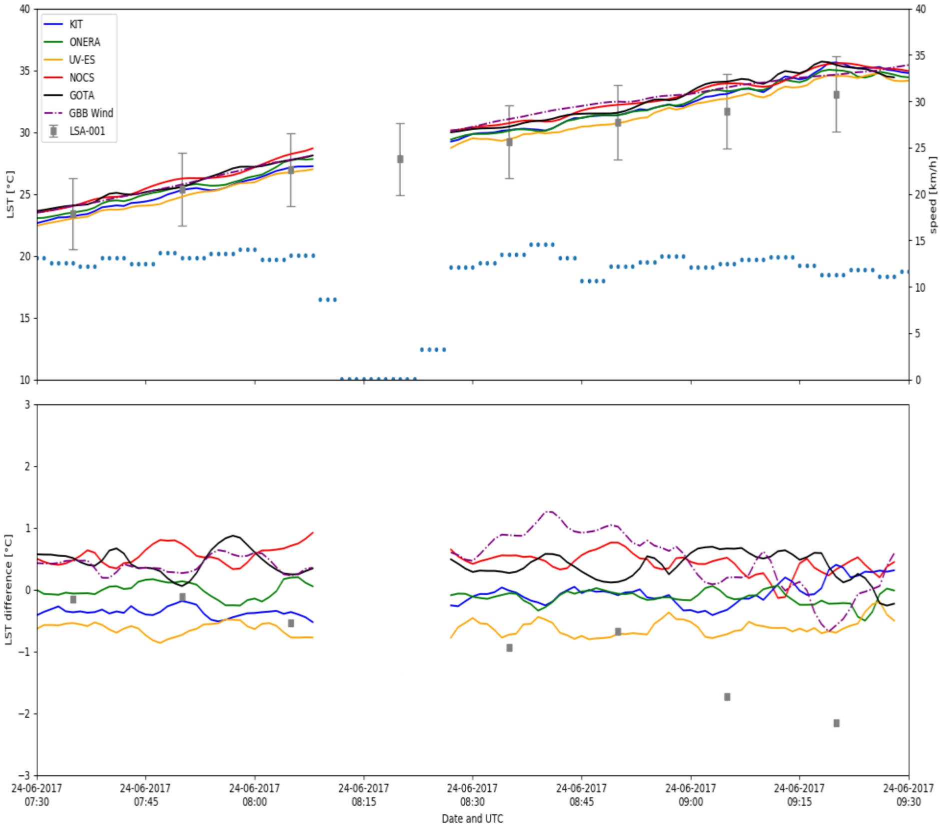


‘International harmonisation and interoperability through a set of intercomparisons’

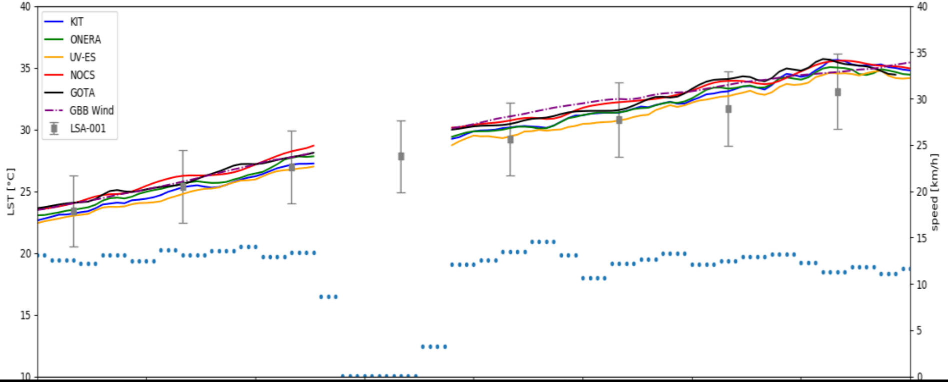
Field inter-comparison experiment, Gobabeb

Five radiometers (teams):ISAR (NOCS), Heitronics KT19.85 II (ONERA), CIMEL 312-2 (GOTA), Heitronics KT15.85 IIP (KIT), and CIMEL 312-1 (UV-ES).

Field inter-comparison experiment, Gobabeb

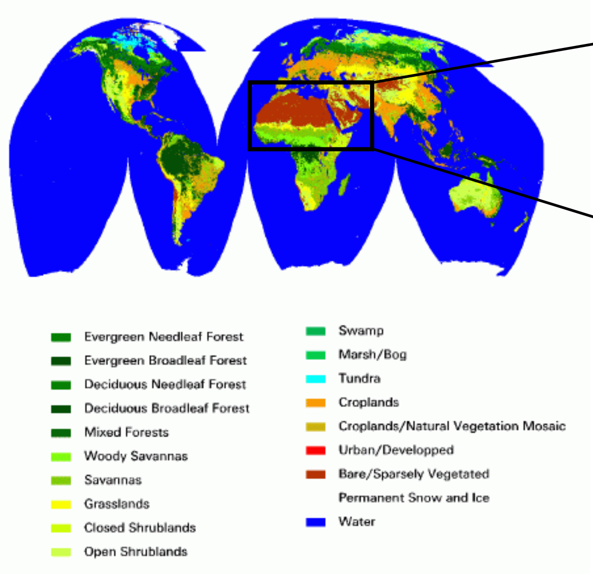


Field inter-comparison experiment, Gobabeb

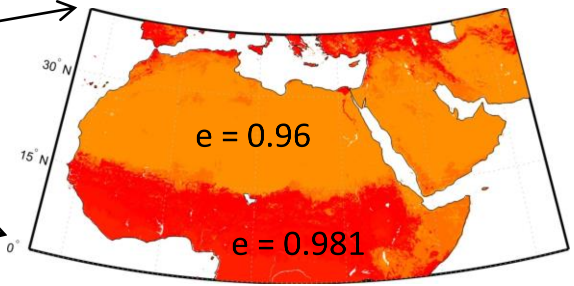


Team	Mean difference [°C]	Stdev of difference [°C]
Team 1	-0.20	0.22
Team 2	-0.07	0.14
Team 3	-0.64	0.12
Team 4	0.48	0.19
Team 5	0.43	0.22
GBB Wind	0.45	0.39

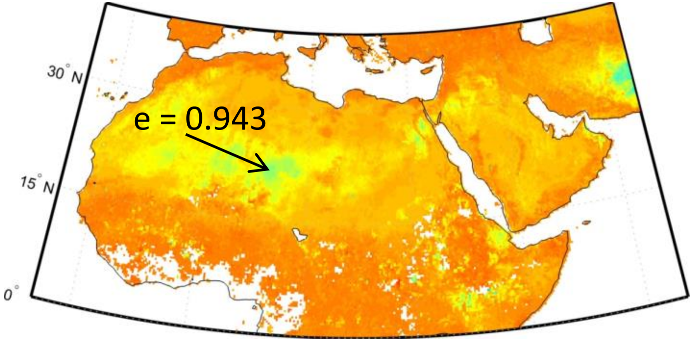
Emissivity: Split-Window vs TES



Split-window:
MOD11 band 31 (11 µm)



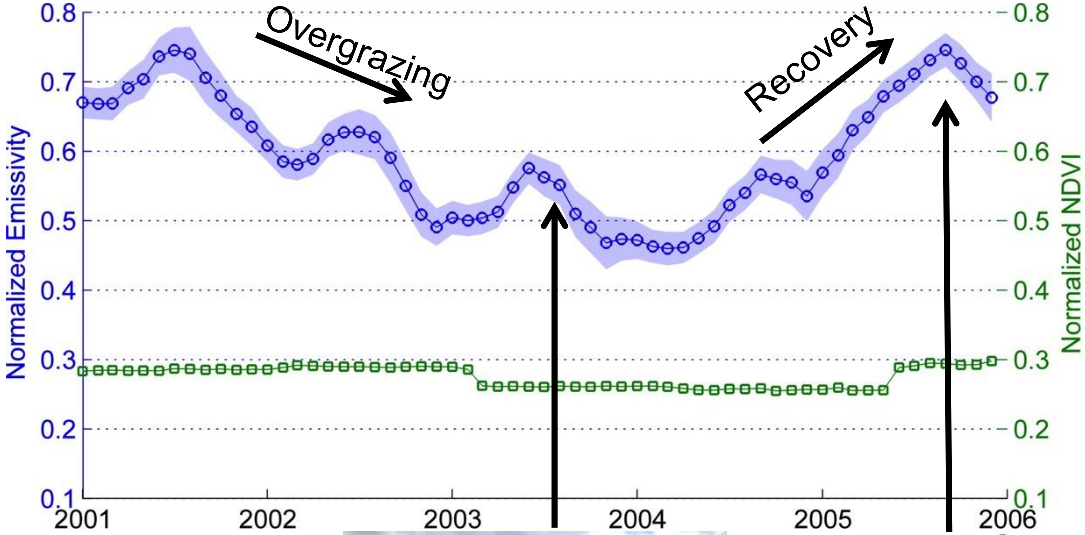
TES Retrieval:
MOD21 band 31 (11 µm)



MOD11 classified as bare and assigned single emissivity but a wide range in emissivity as seen with MOD21 (TES)

Adapted from Hulley et al.

New thermal-based techniques for land cover change detection in climate sensitive zones



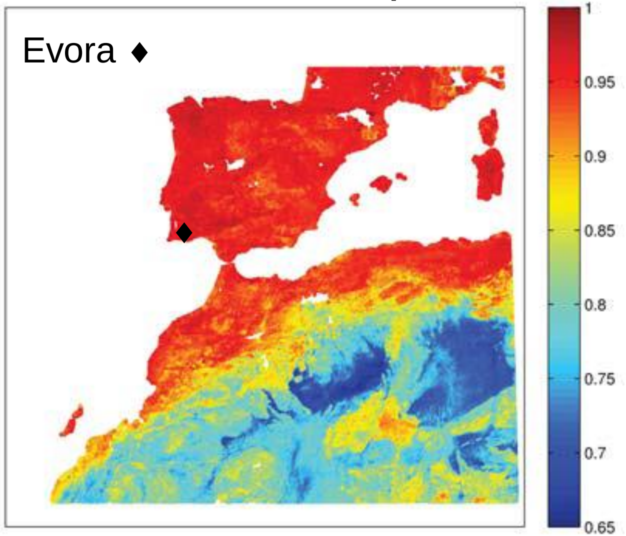
MOD21 Band 29 (8.55 µm) Emissivity,
Jornada Experimental Range

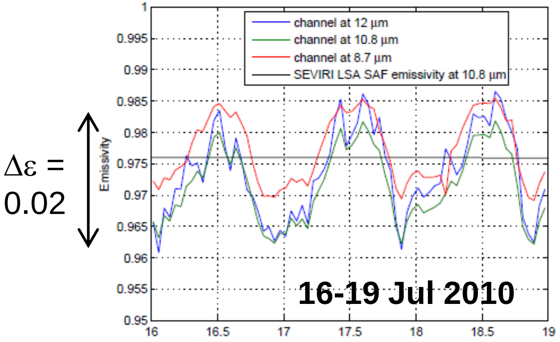
Hulley et al. 2014

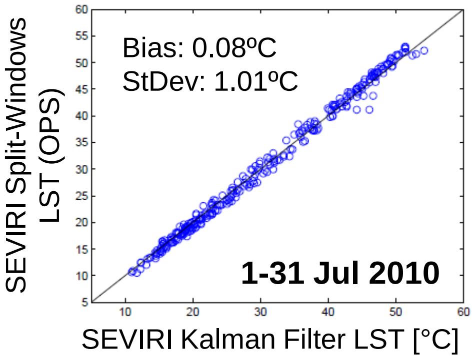
Emissivity Retrieval

Under Testing: Kalman Filter approach to exploit the high temporal sampling
Channels **8.7, 10.8 and 12.0µm** ⇒ **Emissivity** & LST

1-31 Jul 2010
EMISSIVITY 8.7µm







Masiello et al. (2013); doi: 10.5194/amt-6-3613-2013

Google Earth Engine Landsat LST product

remote sensing

MDPI

Article

Google Earth Engine Open-Source Code for Land Surface Temperature Estimation from the Landsat Series

Sofia L. Ermida [1,2,*], Patrícia Soares [3], Vasco Mantas [3], Frank-M. Göttsche [4] and Isabel F. Trigo [1,2]

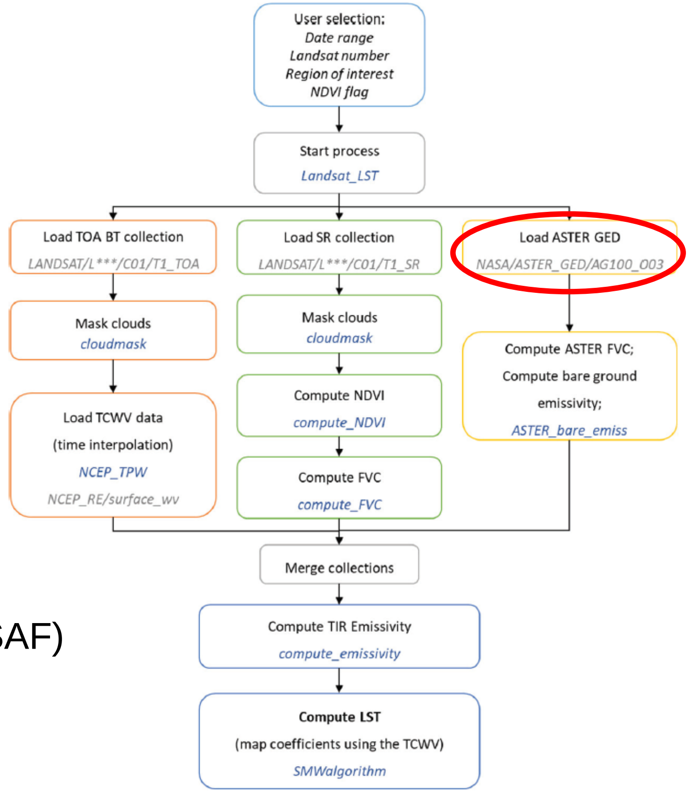
Remote Sens. **2020**, *12*, 1471; doi:10.3390/rs12091471

Emissivity of Landsat band:

$$\varepsilon_b = FVC\varepsilon_{b,\mathrm{veg}} + (1 - FVC)\varepsilon_{b,\mathrm{bare}}$$

Statistical Mono-Window (SMW) algorithm of the Climate Monitoring Satellite Application Facility (CM-SAF)

$$LST = A_i \frac{Tb}{\varepsilon} + B_i \frac{1}{\varepsilon} + C_i$$

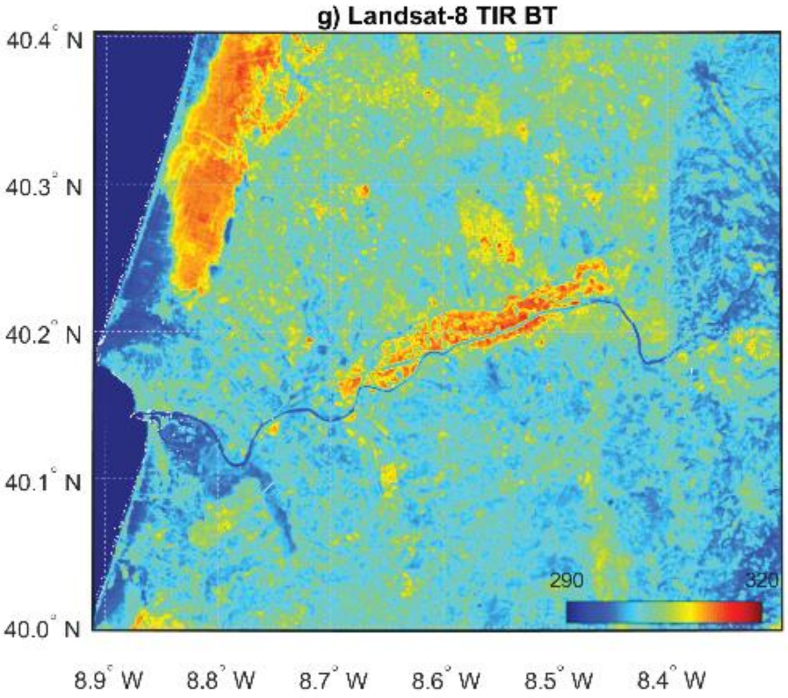


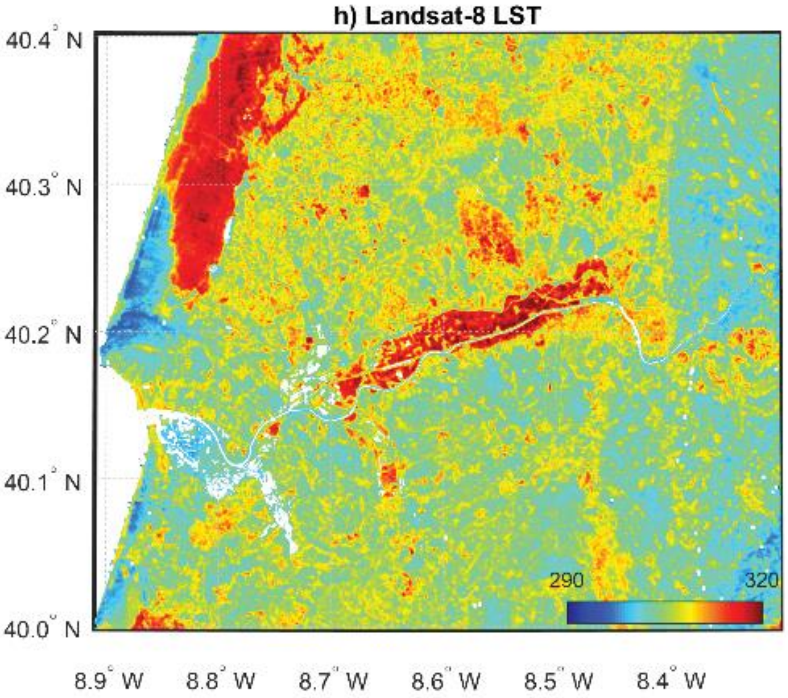
Google Earth Engine Landsat LST product

remote sensing

MDPI

User selection:
Date range



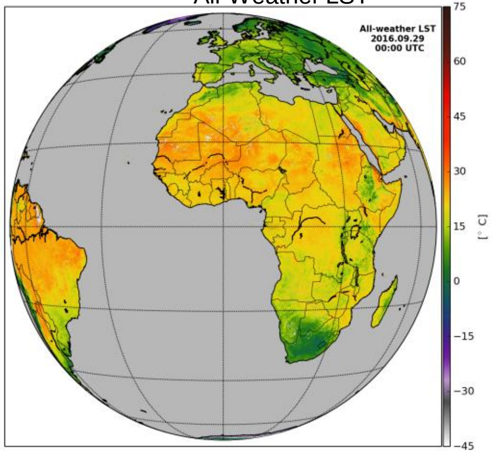


Energy Balance & All-Weather LST

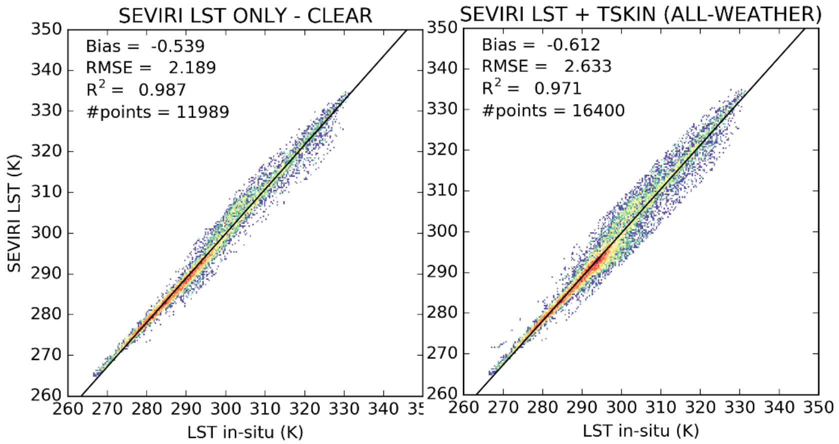
Solving the **Energy Balance** by cover type within each pixel using SEVIRI down-welling radiation, Albedo, Vegetation, LST, …. ⇒ Turbulent Fluxes (ET) and **Skin Temperature**

Split-Window LST + Skin Temperature

All-Weather LST



Kalahari

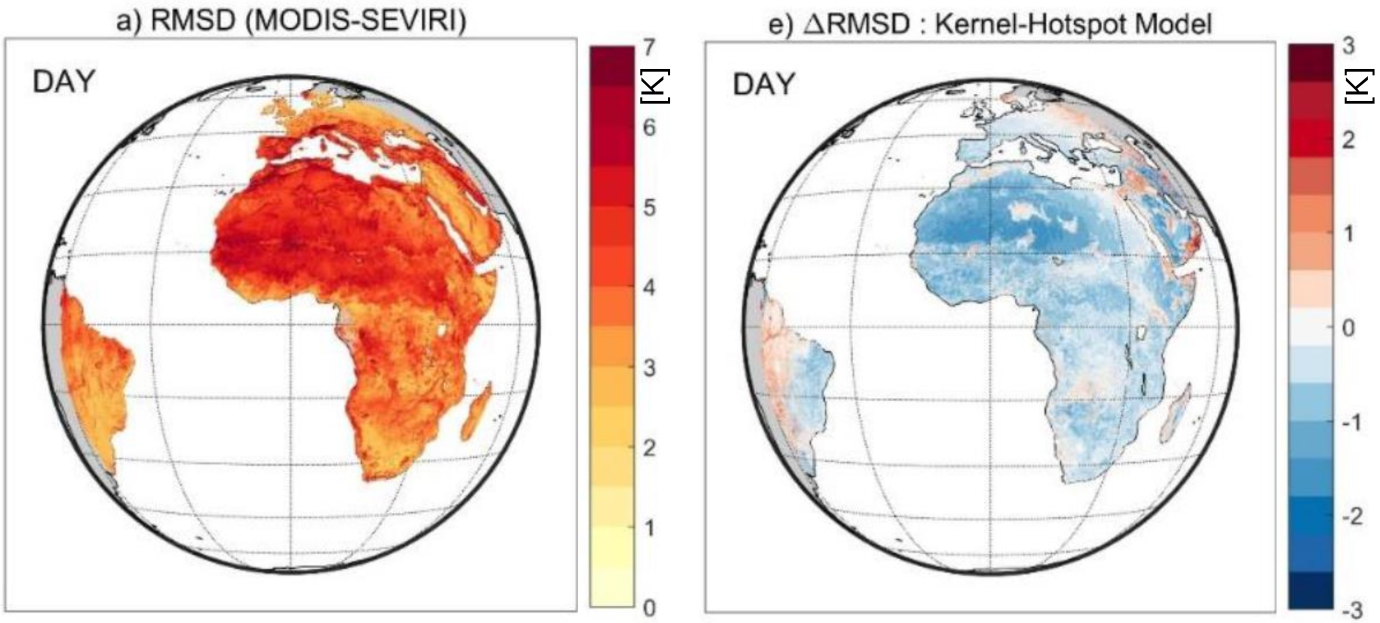


SEVIRI/MSG:
- **30 min / 3 km sub-satellite point**
- **Daily composites**

EUMETSAT LSA SAF

Martins et al. (2019), doi: 10.3390/rs11243044

Angular correction of LST



Ermida et al. (2018),
A Methodology to Simulate LST Directional Effects Based on Parametric Models and Landscape Properties.
doi: 10.3390/rs10071114

- Average reduction in daytime RMSD of 1.1 K (i.e. for right plot) for the calibration data basis
- ‘Correction to nadir’ data layer for LSA SAF’s operational MSG/SEVIRI LST

Thank you!

Related Journal Publications

[1] F. Becker and Z.-L. Li. Towards a local split window method over land surfaces. International Journal of Remote Sensing, 11(3):369–393, 1990.

[2] S. L. Ermida, P. Soares, V. Mantas, F.-M. Göttsche, and I. F. Trigo. Google Earth Engine open-source code for land surface temperature estimation from the Landsat series. Remote Sensing, 12(9):1471, may 2020.

[3] S. L. Ermida, I. F. Trigo, C. C. DaCamara, and J.-L. Roujean. Assessing the potential of parametric models to correct directional effects on local to global remotely sensed LST. Remote Sensing of Environment, 209:410–422, 2018.

[4] F.-M. Göttsche and G. C. Hulley. Validation of six satellite-retrieved land surface emissivity products over two land cover types in a hyper-arid region. Remote Sensing of Environment, 124:149–158, sep 2012.

[5] P. Guillevic, F. Göttsche, J. Nickeson, G. Hulley, D. Ghent, Y. Yu, I. Trigo, S. Hook, J. A. Sobrino, J. Remedios, M. Román, and F. Camacho. Land Surface Temperature Product Validation Best Practice Protocol. Version 1.1.0. In P. Guillevic, F. Göttsche, J. Nickeson & M. Román (Eds.), Best Practice for Satellite-Derived Land Product Validation (p. 58): Land Product Validation Subgroup (WGCV/CEOS). Technical report, 2018.

[6] G. Hulley, S. Veraverbeke, and S. Hook. Thermal-based techniques for land cover change detection using a new dynamic MODIS multispectral emissivity product (MOD21). Remote Sensing of Environment, 140:755–765, Jan 2014.

[7] G. C. Hulley, N. K. Malakar, T. Islam, and R. J. Freepartner. NASA's MODIS and VIIRS land surface temperature and emissivity products: A long-term and consistent earth system data record. IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, 11(2):522–535, 2018.

[8] J. P. A. Martins, I. F. Trigo, N. Ghilain, C. Jimenez, F.-M. Göttsche, S. L. Ermida, F.-S. Olesen, F. Gellens-Meulenberghs, and A. Arboleda. An all-weather land surface temperature product based on MSG/SEVIRI observations. Remote Sensing, 11(24):3044, dec 2019.

[9] G. Masiello, C. Serio, I. De Feis, M. Amoroso, S. Venafra, I. F. Trigo, and P. Watts. Kalman filter physical retrieval of surface emissivity and temperature from geostationary infrared radiances. Atmospheric Measurement Techniques, 6(12):3613–3634, 2013.

[10] G. Masiello, C. Serio, S. Venafra, G. Liuzzi, F. Göttsche, I. Trigo, and P. Watts. Kalman filter physical retrieval of surface emissivity and temperature from SEVIRI infrared channels: a validation and intercomparison study. Atmospheric Measurement Techniques, 8(7):2981–2997, 2015.

[11] Norman, J. M., Becker, and Francois. Terminology in thermal infrared remote sensing of natural surfaces. Remote Sensing Reviews, 12(3-4):159–173, Jan 1995.

[12] O. Rozenstein, N. Agam, C. Serio, G. Masiello, S. Venafra, S. Achal, E. Puckrin, and A. Karnieli. Diurnal emissivity dynamics in bare versus biocrusted sand dunes. Science of The Total Environment, 506-507:422–429, Feb 2015.

[13] Z. Wan and J. Dozier. A generalized split-window algorithm for retrieving land-surface temperature from space. IEEE Transactions on Geoscience and Remote Sensing, 34(4):892–905, July 1996.

[14] J. Yang, J. Zhou, F.-M. Göttsche, Z. Long, J. Ma, and R. Luo. Investigation and validation of algorithms for estimating land surface temperature from Sentinel-3 SLSTR data. International Journal of Applied Earth Observation and Geoinformation, 91:102136, sep 2020.