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?

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. This definition has been adopted by various international groups and projects, e.g. CEOS WGCV, GCOS, ESA GlobTemperature and ESA FRM4STS.
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Since 2017 LST is an Essential Climate Variable (ECV)

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Why is LST difficult to retrieve?

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

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

Uncertainty \( \approx 0.2 \) K

Uncertainty \( \approx 1.0 \) - 1.5 K
Thermal Infrared (TIR) Radiative Transfer

\[ L_i(\theta) = \tau_i(\theta) \cdot e_i \cdot B_i(T_S) + \tau_i(\theta) \cdot (1-e_i) \cdot \bar{L}_i + \int B_i(T(P))d\tau_i \]

- **Sensor Radiance**
- **Land Surface Temperature (LST)**
- **Surface Radiance**
- **Surface Emission**
- **Surface Reflection**
- **Sky irradiance**
- **Transmissivity**
- **Path radiance**
- **Atmospheric Emission**

Adapted from G. Hulley (2018)
LST retrieval: an under-determined problem

N spectral measurements, N + 1 unknowns (N emissivities & Temperature)

1. Generalized Split-Windows (Wan and Dozier, 1996) \( \leftrightarrow \) LSA-001
   
   - Requires 2 bands
   
   \[
   LST = \left( A_1 + A_2 \frac{1 - \varepsilon}{\varepsilon} + A_3 \frac{\Delta \varepsilon}{\varepsilon^2} \right) \frac{T_{IR1} + T_{IR2}}{2} + \left( B_1 + B_2 \frac{1 - \varepsilon}{\varepsilon} + B_3 \frac{\Delta \varepsilon}{\varepsilon^2} \right) + C
   \]
   
   - 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)

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

Hulley et al. (2018)
- 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

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

- 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!

Up-scaling:

10 m²

1 km² – 100 km²
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

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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. as a measure of how hot or cold the surface of the Earth would feel to the touch. For ground-based, airborne, and spaceborne remote sensing instruments LST is the aggregated radiometric surface temperature based on a measure of radiation. Therefore, in the literature, LST is also referred to as physiologically adiabatic 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 (Orban and Bolton, 1993). This definition has been adopted by various international groups, e.g. CEOS WCRP, GOCO, ESA (LST-Temperature), and ILSTE-WG.

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


Land Surface Emittance Definition

Emittance is 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 (Wieland and Bock, 1985).

Units: Dimensionless
Dedicated LST Validation Stations

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

Desert
Temperate vegetation

Portugal, Evora
Lake Constance

Senegal, Dakhra

Namibia, Gobabeb
Lake Water

KIT, Germany

Broadleaved deciduous forest

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

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)
ESAFRM4STS Project

Field intercomparison experiments (FICE)

‘International harmonisation and interoperability through a set of intercomparisons’
Field inter-comparison experiment, Gobabeb

- Speed: 10-15 km/h
- Mounting height: 1.8 m
- View angle: 35°
- Footprint Ø ≈ 30 cm

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

<table>
<thead>
<tr>
<th>Team</th>
<th>Mean difference [°C]</th>
<th>Stdev of difference [°C]</th>
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<tr>
<td>Team 1</td>
<td>-0.20</td>
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<tr>
<td>GBB Wind</td>
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Emissivity: Split-Window vs TES

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 12.0\(\mu\)m \(\Rightarrow\) **Emissivity & LST**

1-31 Jul 2010
EMISSIVITY 8.7\(\mu\)m

\[\Delta \varepsilon = 0.02\]

Masiello et al. (2013); doi: 10.5194/amt-6-3613-2013
Google Earth Engine Landsat LST product

Emissivity of Landsat band:

\[ \varepsilon_b = FVC \varepsilon_{b,\text{veg}} + (1 - FVC) \varepsilon_{b,\text{bare}} \]

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

\[ \text{LST} = A_i \frac{T_b}{\varepsilon} + B_i \frac{1}{\varepsilon} + C_i \]
Google Earth Engine Landsat LST product

g) Landsat-8 TIR BT

Emissivity of Landsat band:

h) Landsat-8 LST
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

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

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

19 June 2020
Frank Göttzsche – NOAA / STAR seminar
Institute of Meteorology and Climate Research
Angular correction of LST

- 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

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