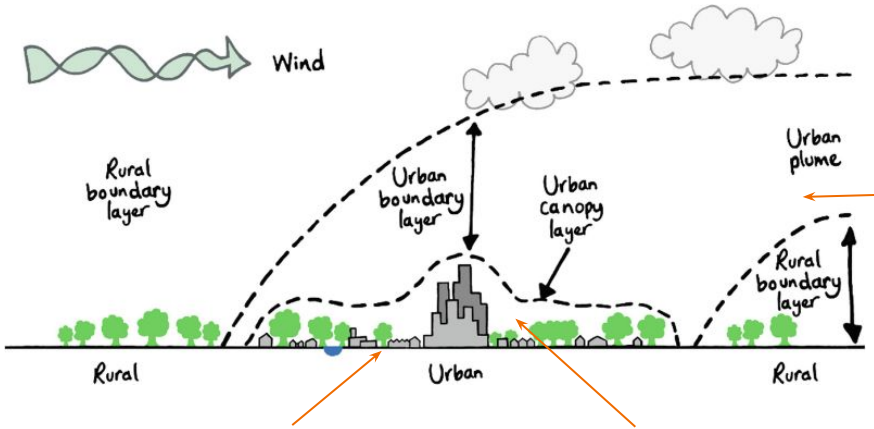
Refinement of Urban Heat Island mapping using Landsat satellite imagery

Hana Bobáľová

Department of Physical Geography and Geoinformatics
Comenius University in Bratislava

Urban Heat Island (UHI)



BLHI (Boundary Layer Heat Island)

SUHI (Surface Urban Heat Island)

CLHI (Canopy Layer Heat Island)

Source: https://www.linkedin.com/pulse/urban-heat-island-uhi-global-phenomena-mira-shivani-sankar

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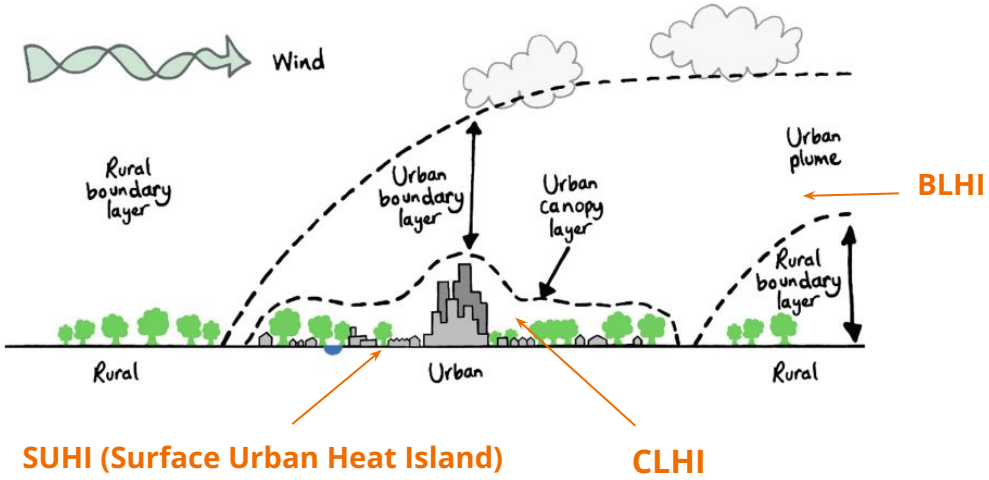

Satellite images in Thermal Infrared (TIR) band of the spectrum

Landsat (TM, ETM, TIRS), MODIS, ASTER, VIIRS, Sentinel-3, Ecostress …

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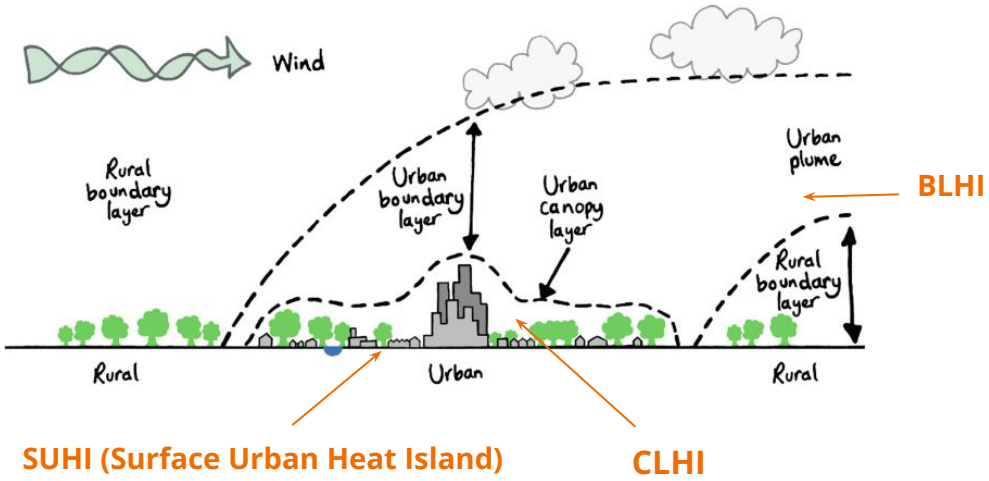

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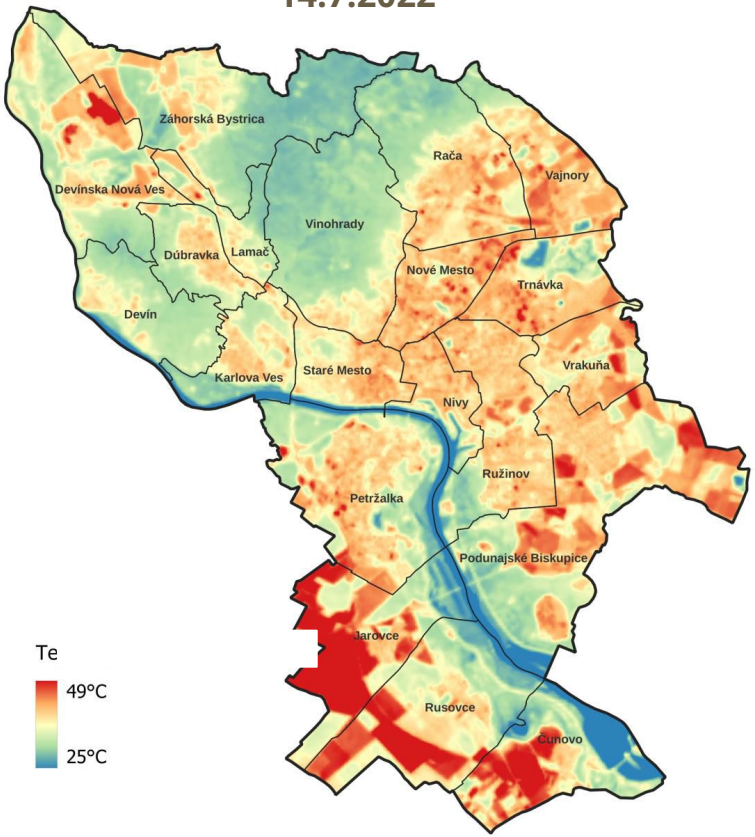
Surface Temperature in Bratislava 14.7.2022



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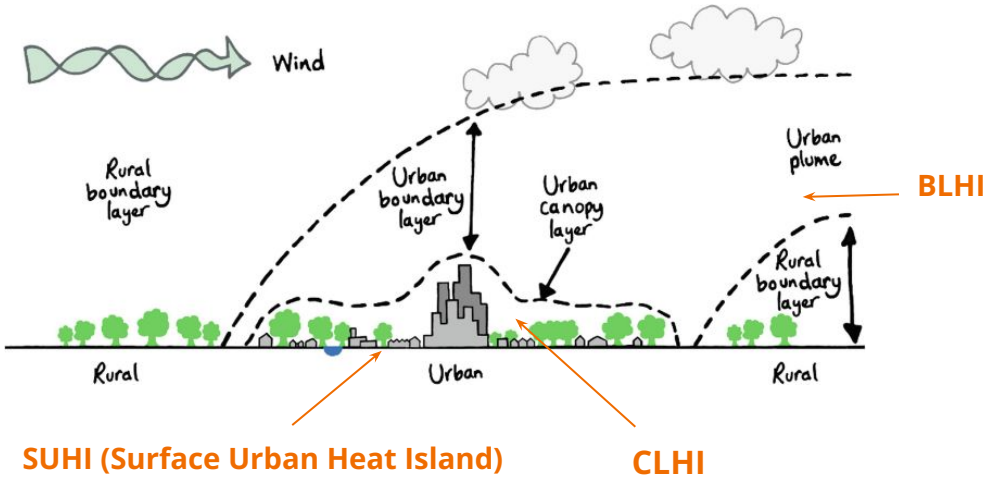

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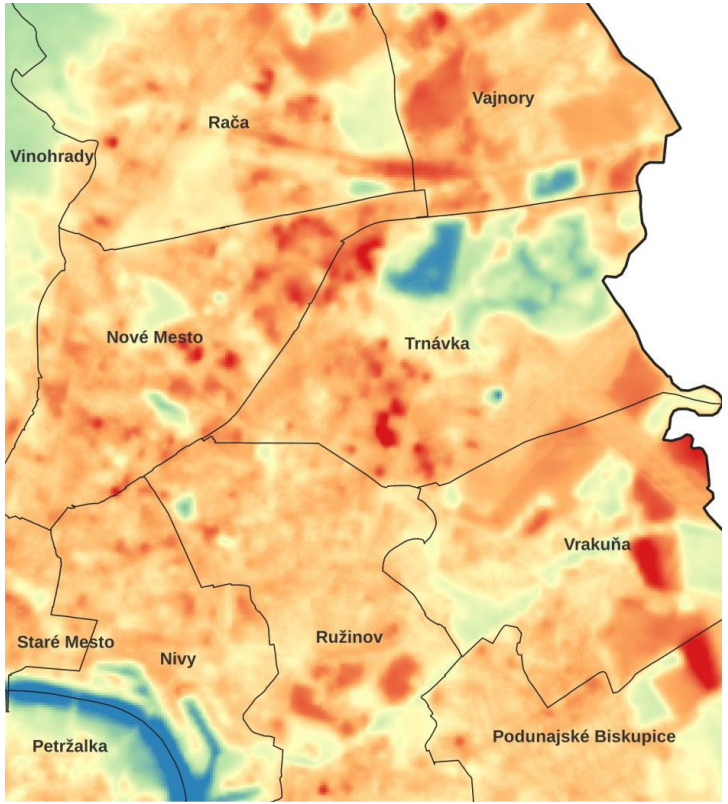

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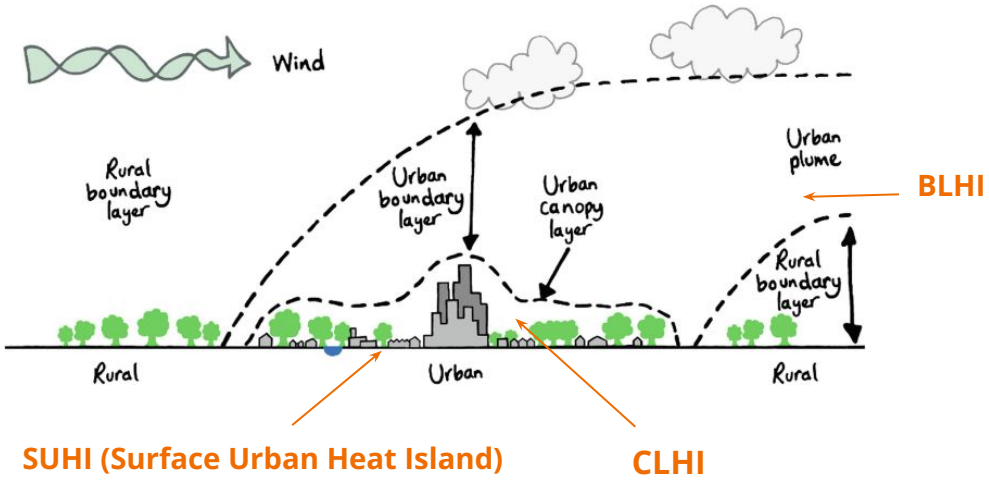

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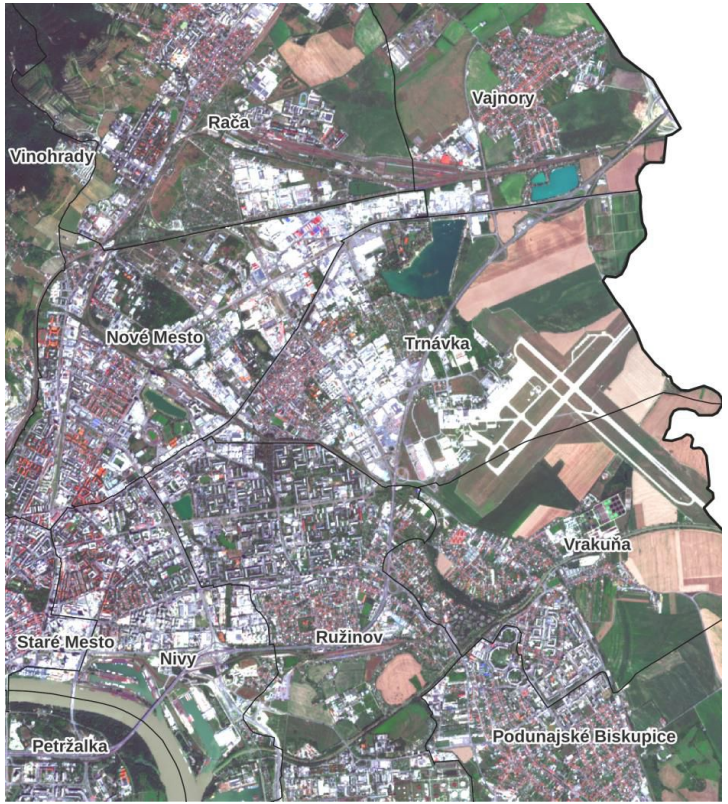

Land Surface Temperature (LST)

Single-channel methods:

1. **Radiative Transfer Equation (RTE) - Dash et al. (2001)**

$$L_\lambda = \tau\varepsilon B_\lambda(T_S) + L_\lambda^{\uparrow} + \tau(1-\varepsilon)L_\lambda^{\downarrow}$$

Landsat Surface Temperature (ST) product

Landsat Collection 2 Level 2

2. **Single-Channel Agorithm (SCA) - revised by Jiménez-Muñoz et al. (2009)**
3. **Mono-Window Algorithm (MWA) - Qin et al. (2001)**
4. **Statistical Mono-Window (SMW) - Sun et al. (2004)**

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

Google Earth Engine (GEE) code

Ermida et al. (2020)

5. **....**

Split-window methods:

Temperature and Emissivity Separation (TES), Temperature Independent Spectral Index (TISI), ...

Land Surface Temper

Single-channel methods:

1. Radiative Transfer Equation (RTE

$$L_\lambda = \tau\varepsilon B_\lambda(T_S) + L_\lambda^{\uparrow} + \tau(1-\varepsilon) L_\lambda^{\downarrow}$$

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3. Mono-Window Algorithm (MWA)
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$$LST = A_i \frac{Tb}{\varepsilon} + B_i \frac{1}{\varepsilon} + C_i$$

5. ....

Split-window methods:

Temperature and Emissivity Separatio

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]

1 Instituto Português do Mar e da Atmosfera (IPMA), 1749-077 Lisbon, Portugal; isabel.trigo@ipma.pt
2 Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisbon, Portugal
3 Department of Earth Sciences, Universidade de Coimbra, 3030-790 Coimbra, Portugal; patriciaalsoares12@hotmail.com (P.S.); vasco.mantas@dct.uc.pt (V.M.)
4 Institute of Meteorology and Climate Research (IMK-ASF), Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany; frank.goettsche@kit.edu
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check for updates

Abstract: Land Surface Temperature (LST) is increasingly important for various studies assessing land surface conditions, e.g., studies of urban climate, evapotranspiration, and vegetation stress. The Landsat series of satellites have the potential to provide LST estimates at a high spatial resolution, which is particularly appropriate for local or small-scale studies. Numerous studies have proposed LST retrieval algorithms for the Landsat series, and some datasets are available online. However, those datasets generally require the users to be able to handle large volumes of data. Google Earth Engine (GEE) is an online platform created to allow remote sensing users to easily perform big data analyses without increasing the demand for local computing resources. However, high spatial resolution LST datasets are currently not available in GEE. Here we provide a code repository that allows computing LSTs from Landsat 4, 5, 7, and 8 within GEE. The code may be used freely by users for computing Landsat LST as part of any analysis within GEE.

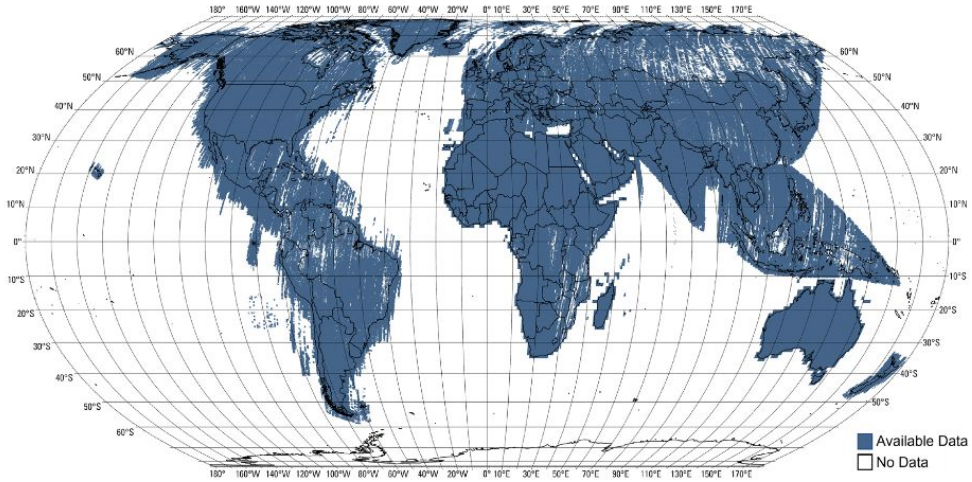
Land Surface Emissivity (LSE)

$$\varepsilon_\lambda(T) = \frac{L_\lambda(T)}{B_\lambda(T)}$$

ε - ratio of radiance emitted by a body at temperature T to the radiance of a black body at the same temperature

1. ASTER Global Emissivity Dataset (GED) v3

LST and LSE from ASTER 2000-2008 satellite scenes (all cloud-free pixels)



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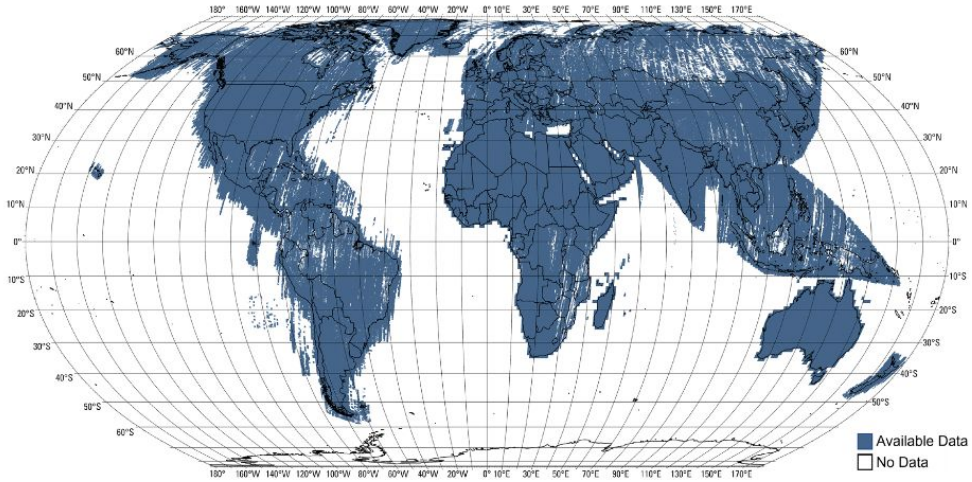
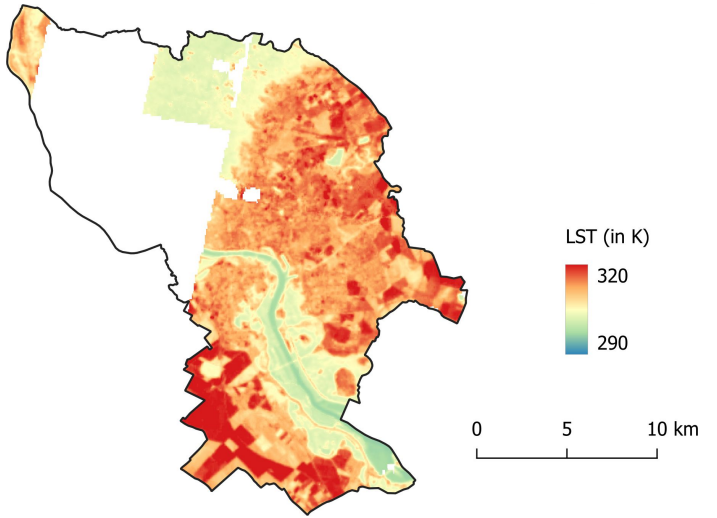


UA = Ukraine



Land Surface Emissivity (LSE)

1. **ASTER Global Emissivity Dataset (GED) v3**

   LST and LSE from ASTER 2000-2008 satellite scenes (all cloud-free pixels)

2. **Classification-Based Emissivity Methods (CBEM)** - Snyder et al. (1998)

3. **NDVI-Based Emissivity Methods (NBEM)** - Sobrino and Raissouni (2000), Sobrino et al. (2004)

NDVI-threshold method ($NDVI^{THM}$)

$$\varepsilon = a_i \rho_{RED} + b_i$$

$$\varepsilon = \varepsilon_V FVC + \varepsilon_S (1 - FVC) + C_i$$

$$\varepsilon = \varepsilon_V + C_i$$

Simplified NDVI-threshold method ($SNDVI^{THM}$)

$\varepsilon = \varepsilon_S$	$NDVI < NDVI_S$	**Bare soil**
$\varepsilon = \varepsilon_S FVC + (\varepsilon_V - \varepsilon_S) FVC$	$NDVI_S \leq NDVI \geq NDVI_V$	**Mixed**
$\varepsilon = \varepsilon_V$	$NDVI > NDVI_V$	**Vegetation**

ε_s, ε_v - emissivity of soil and vegetation $NDVI_S$, $NDVI_V$ - threshold values for soil and vegetation

Land Surface Emissivity (LSE)

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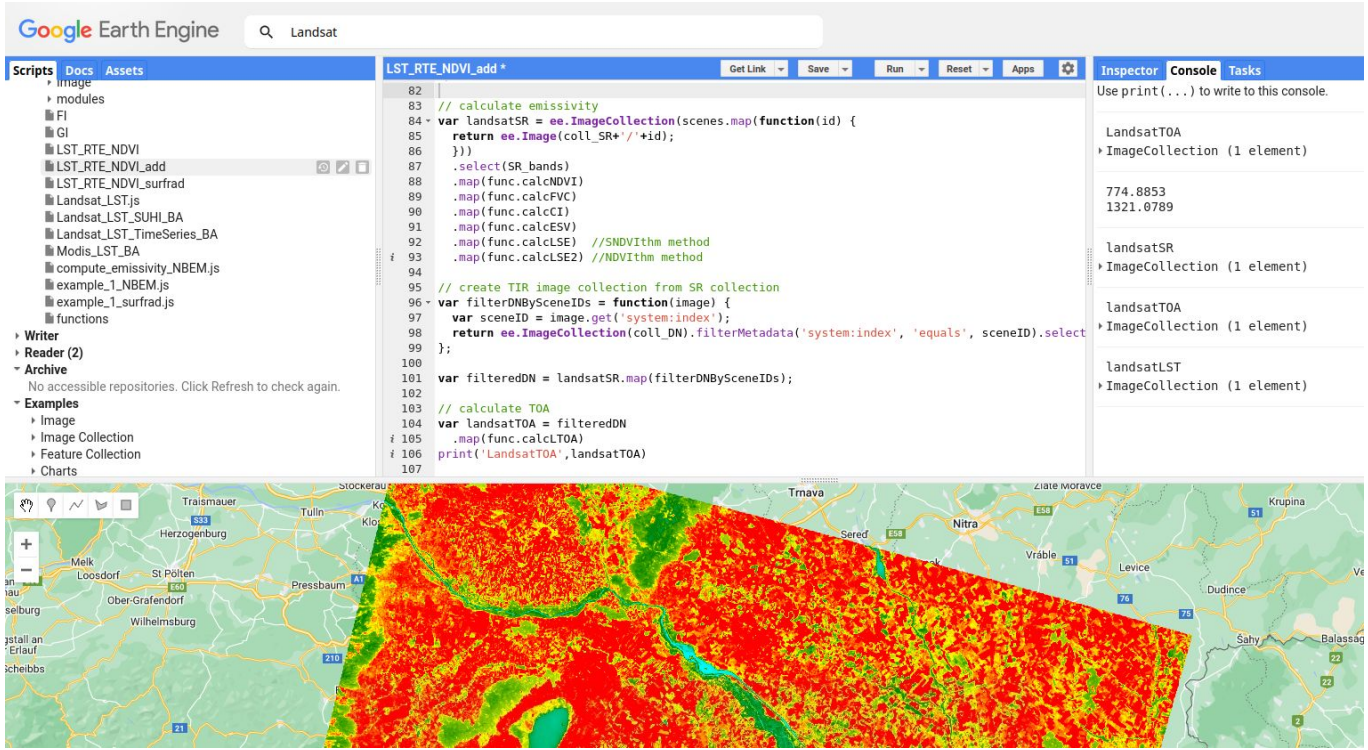
3. **NDVI-Based Emissivity Methods (NBEM)**

RTE method, SMW method

Method	Reference	Spectral library
$NDVI^{THM}$ SO	Sobrino et al. (2008)	ASTER
$NDVI^{THM}$ SK	Skoković et al. (2014)	ASTER
$NDVI^{THM}$ YU	Yu et al. (2014)	MODIS
$SNDVI^{THM}$ SK	ε_s, ε_v from Skoković et al. (2014)	ASTER
$SNDVI^{THM}$ YU	ε_s, ε_v from Yu et al. (2014)	MODIS
$SNDVI^{THM}$ WA	ε_s, ε_v from Wang et al. (2015)	ASTER

GEE code

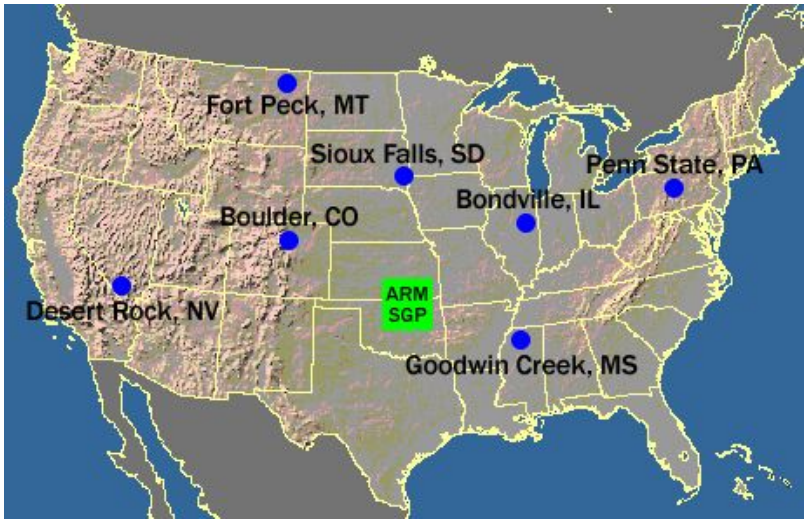
GEE Code Editor



LST validation

SURFRAD (Surface Radiation Budget) Network

- broadband downwelling and upwelling IR radiance



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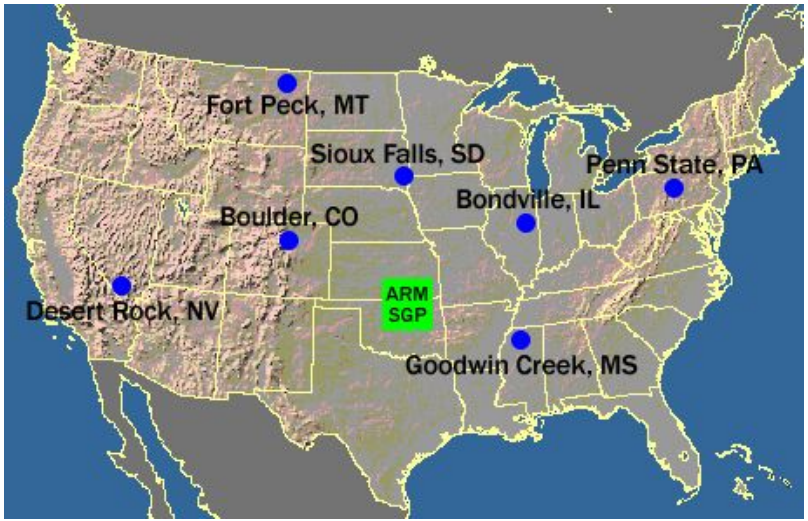
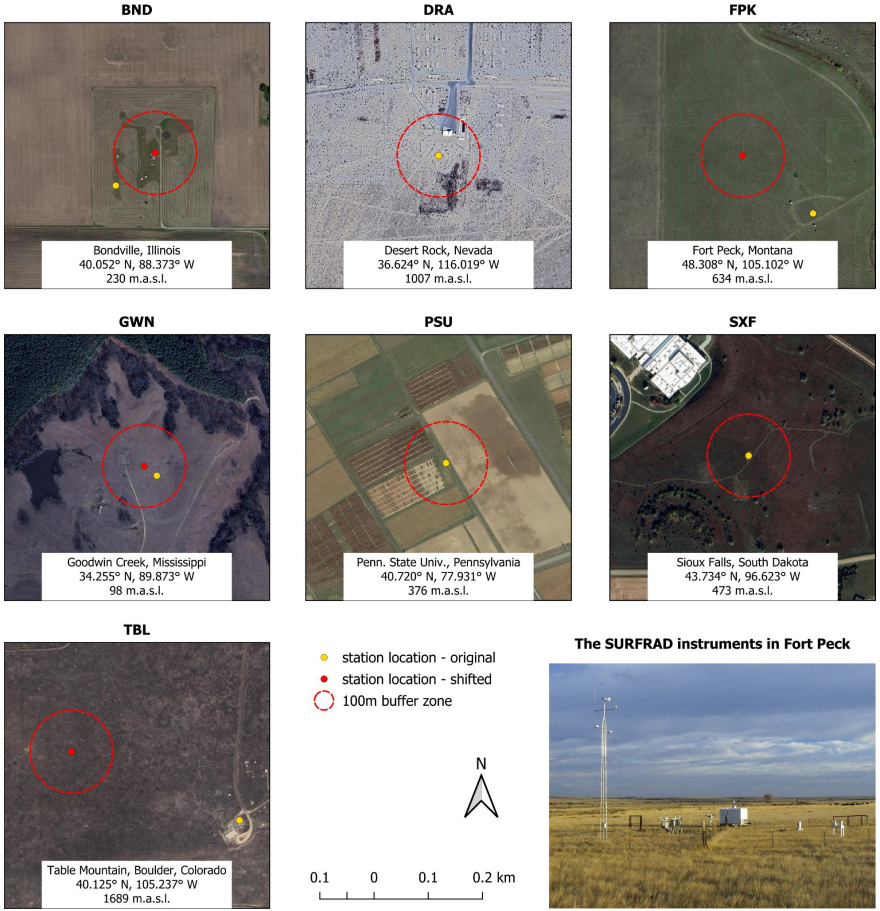




Results - Landsat 8

All Landsat 8 scenes with cloud cover < 11%

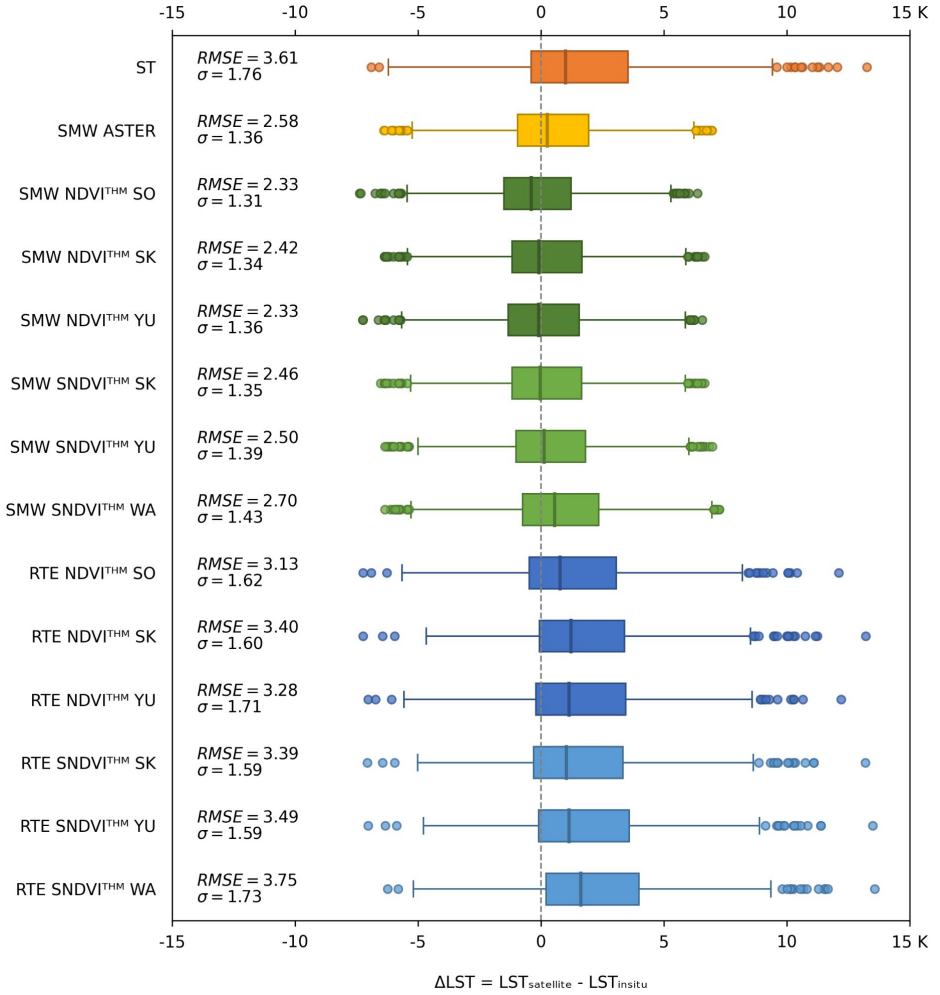
Validation statistics:

RMSE, accuracy/bias *μ*, precision *σ*

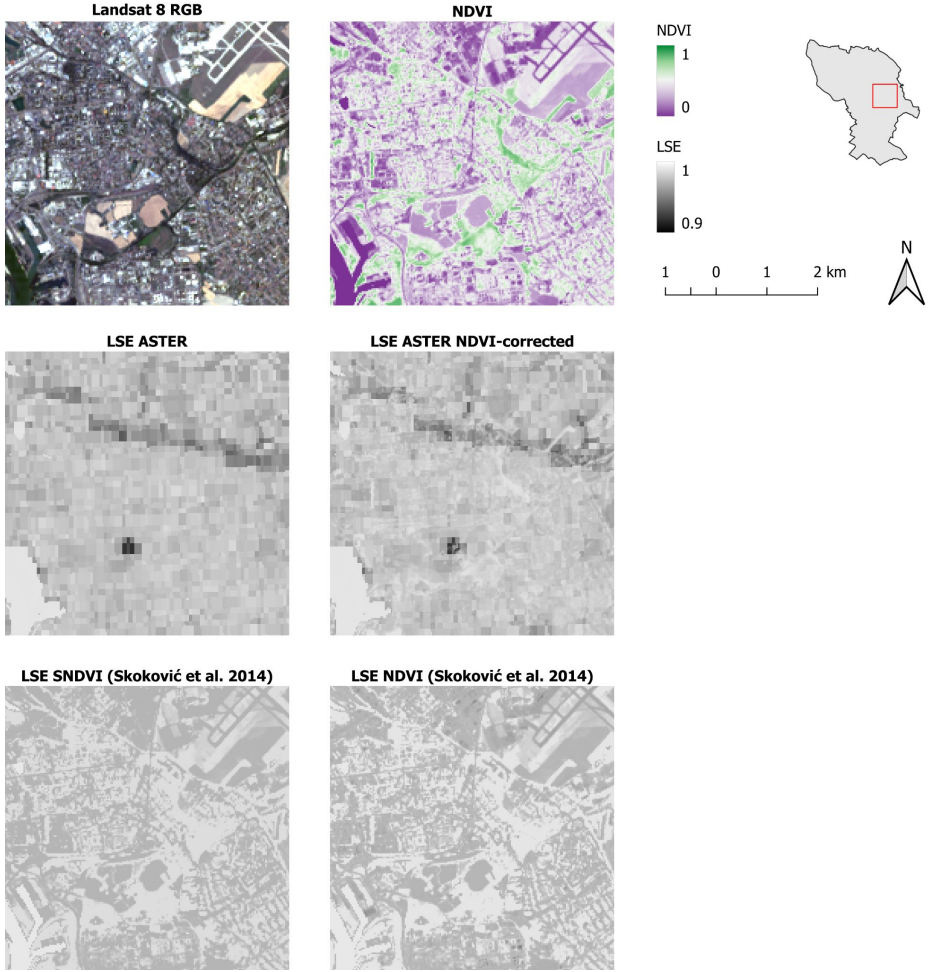
3σ-Hampel identifier to exclude outliers

RMSE (in K)

N	ST ASTER	SMW ASTER	LSE	NDVI^{THM}			SNDVI^{THM}		
				SO	SK	YU	SK	YU	WA
882	3.61	2.58	SMW	**2.33**	2.42	2.33	2.46	2.50	2.70
951	7.15	6.18		6.08	6.10	**6.05**	6.16	6.16	6.22
			RTE	3.13	3.40	3.28	3.39	3.49	3.75
				6.90	7.00	6.92	7.04	7.07	7.18



Results - LSE

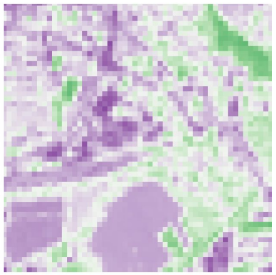

Landsat 8 RGB
NDVI
NDVI
1
0
LSE
1
0.9
1 0 1 2 km
N
LSE ASTER
LSE ASTER NDVI-corrected
LSE SNDVI (Skoković et al. 2014)
LSE NDVI (Skoković et al. 2014)

Results - LSE

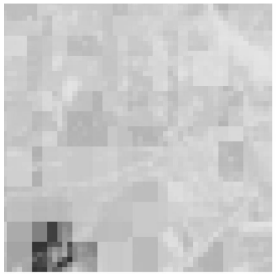
Google Satellite Orthophotomap

Landsat 8 RGB

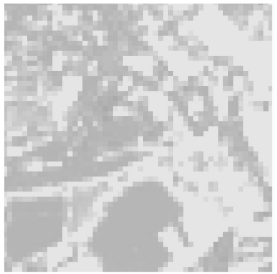
NDVI



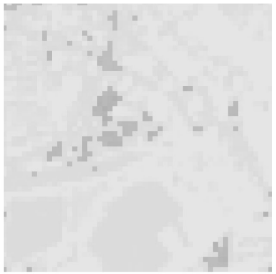
LSE ASTER NDVI-corrected



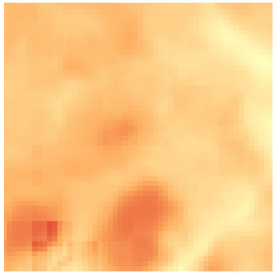
LSE NDVI^{THM} SK



LSE NDVI^{THM} SO



SMW
ASTER (NDVI-corrected)



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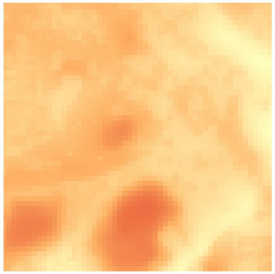

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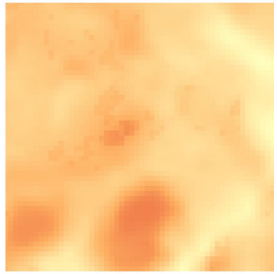
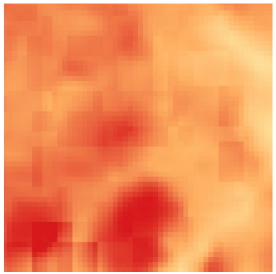
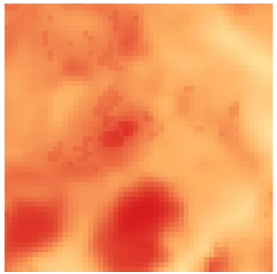
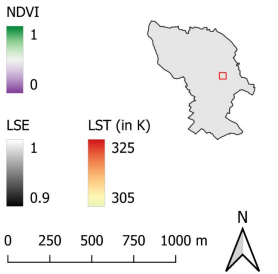


Landsat ST product



RTE
NDVI^{THM} SO

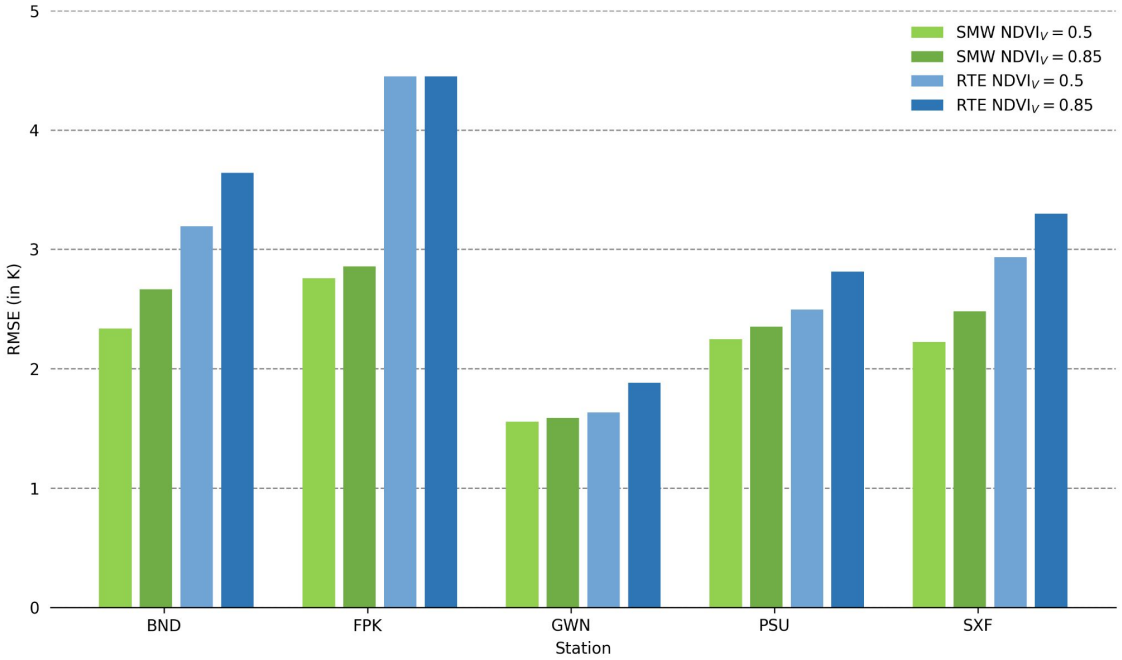




Results - NDVI

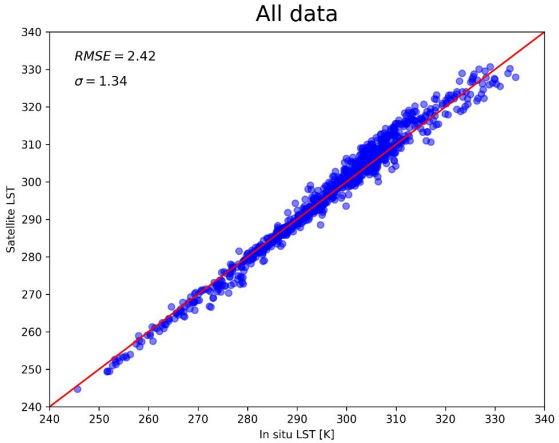
***NDVI$_V$* = 0.5** (Sobrino and Raissouni 2000; Sobrino et al. 2008; Yu et al. 2014; Ndossi and Avdan 2016; Sekertekin and Bonafoni 2020)

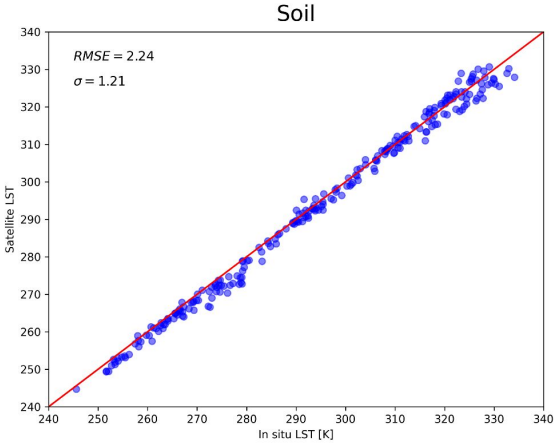
***NDVI$_V$* = 0.85** (Jiménez-Muñoz et al. 2009; Parastatidis et al. 2017; Ren et al. 2017; Ermida et al. 2020)

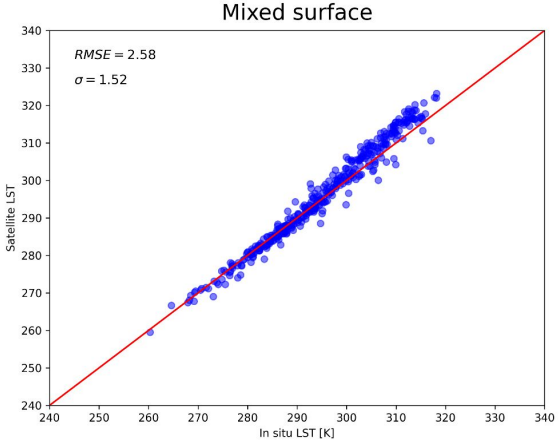


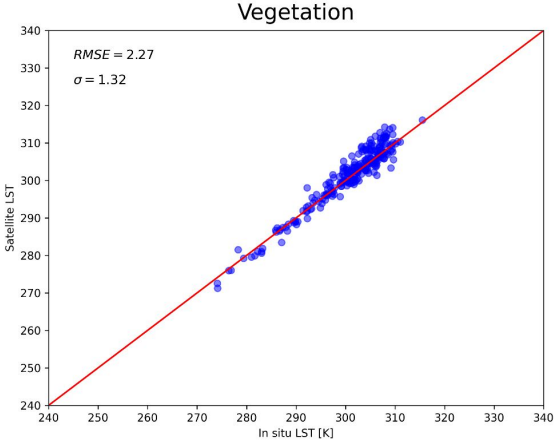
Results - NDVI

Soil	NDVI < 0.2
Mixed surface	0.2 ≤ NDVI ≤ 0.5
Vegetation	NDVI > 0.5









Results - Landsat 5, Landsat 7, Landsat 9

RMSE (in K)

Mission	*N*	ST	SMW	SMW		RTE	
				$NDVI^{THM}$	$SNDVI^{THM}$	$NDVI^{THM}$	$SNDVI^{THM}$
Landsat 5	1100	3.47	2.67	**2.36**	2.37	3.20	3.19
	1148	4.56	3.88	**3.66**	3.70	4.31	4.35
Landsat 7	1563	3.58	2.68	**2.44**	2.49	3.20	3.20
	1666	6.59	5.83	**5.69**	5.77	6.35	6.43
Landsat 8	882	3.61	2.58	**2.42**	2.46	3.40	3.39
	951	7.15	6.18	**6.10**	6.16	7.00	7.04
Landsat 9	202	3.92	2.78	**2.62**	2.65	3.85	3.83
	212	5.33	4.33	**4.23**	4.27	5.28	5.29

Conclusions

- **Operational LST calculation method from Landsat 4-5, 7, 8 and 9, implemented in GEE code repository**
- **Filling gaps and avoiding block artefacts in ASTER GED v3**
- **Considering the current state of the vegetation at the time of imaging**
- **Higher accuracy and precision than original SMW method and the USGS Landsat ST product**
- **More accurate mapping of UHI on a local and regional scale**

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Thank you for your attention !

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