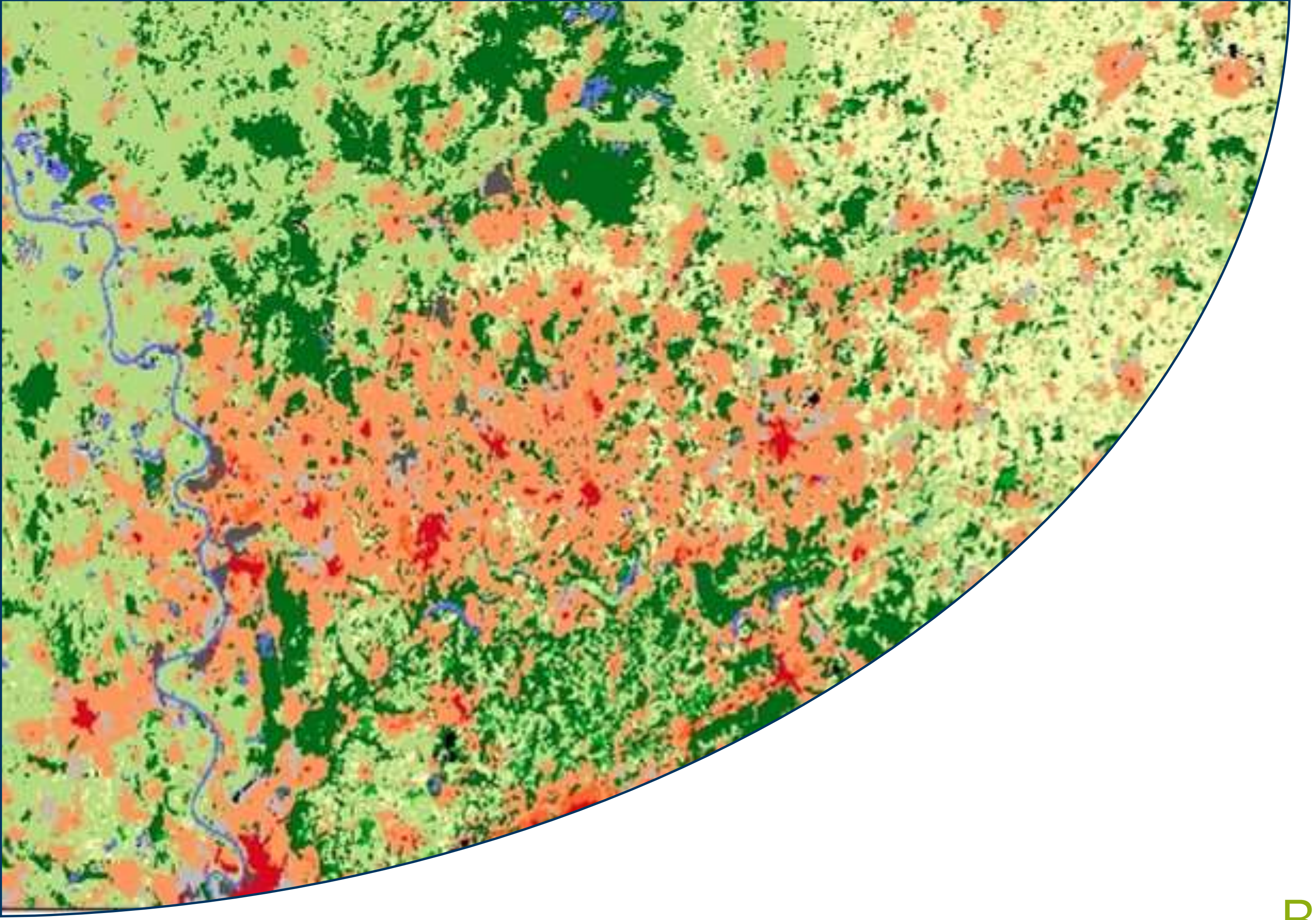


RUB URB cli

Introduction to Satellite Remote Sensing (of Urban Climates)

Bochum Urban Climate Summer School, 26.9.2022

Benjamin Bechtel, Panagiotis Sismanidis, Matthias Demuzere, Daniel Fenner et al.

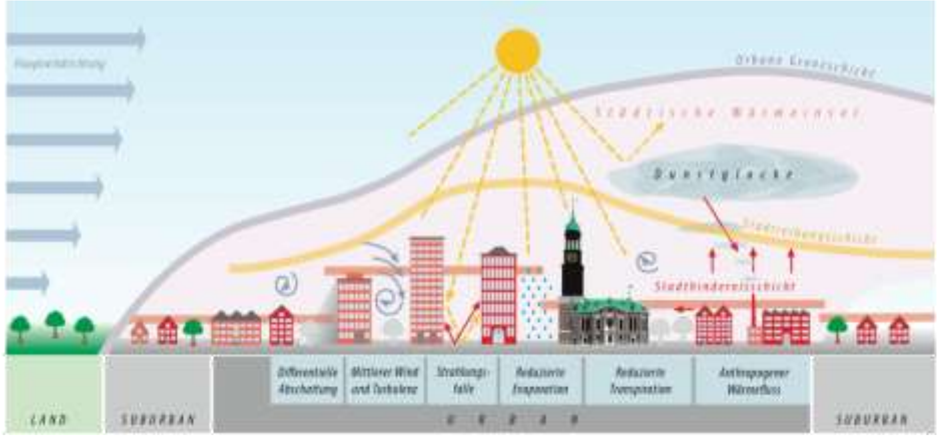
RUBclim

Geographisches Institut

About me

Geographisches Institut

Benjamin.Bechtel@rub.de



Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

Team Climatology

Benjamin Bechtel

Matthias Demuzere

Panagiotis Sismanidis

Nooshin Nowzamani

Annika Gomell

Caroline Güers

Andreas Pflitsch

Charlotte Hüser

Jonas Kittner

Teresa Mansheim

Lara van der Linden

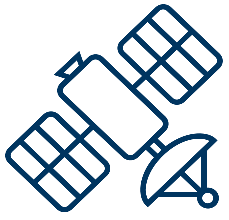
Selina Mähner

Christian Moede

Sebastian Trenk

Jens Steer

About us – RUB urban climatology



Remote sensing of urban climates

green ?

Characterization of urban structures and modelling

Crowd sourcing and smart city

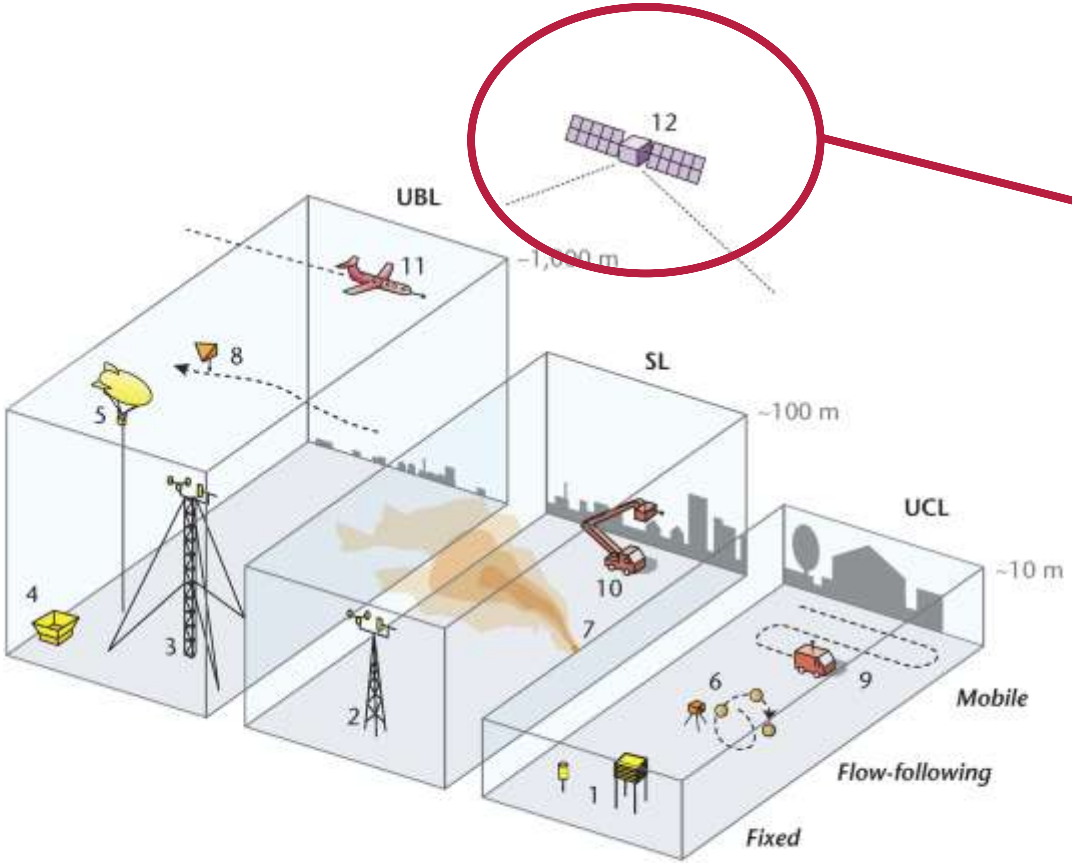
smart

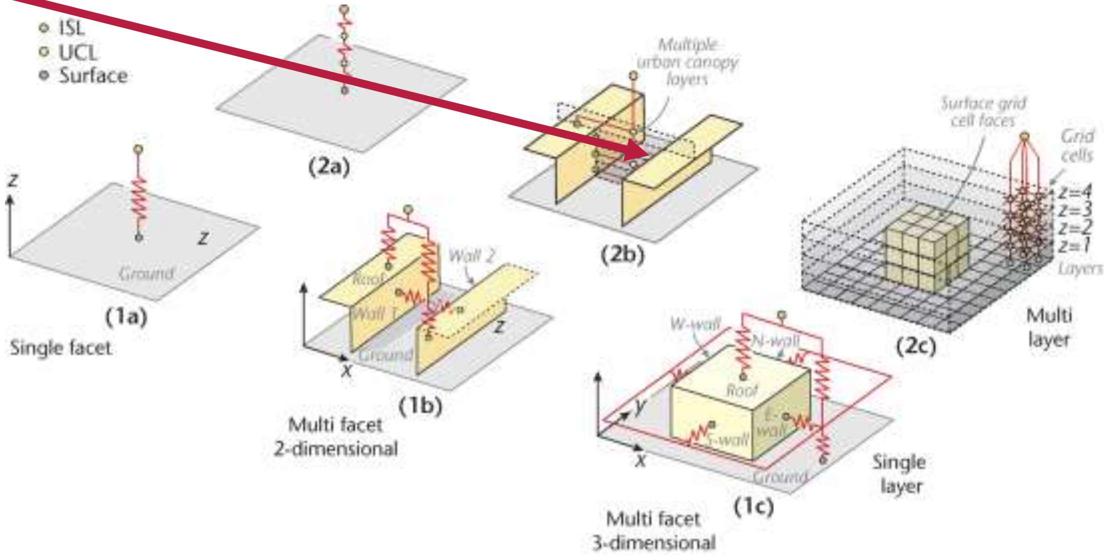
Applied urban climatology and climate adaption

resilient

Quelle

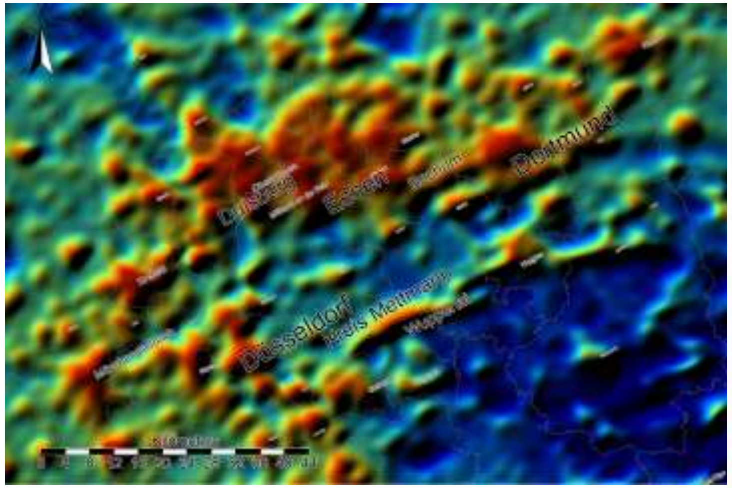
Methods in Urban Climatology

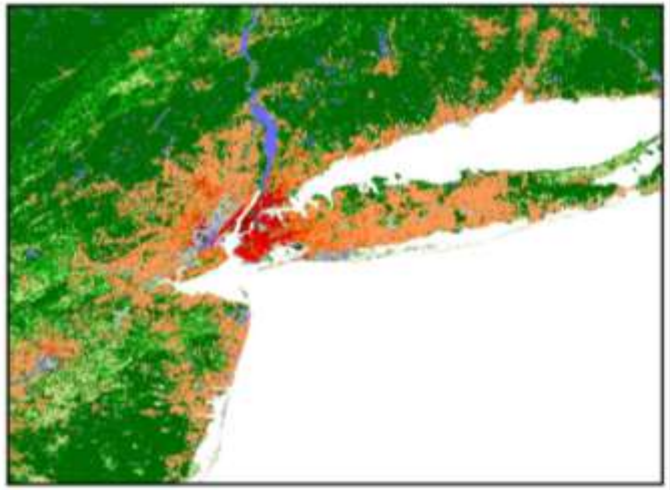




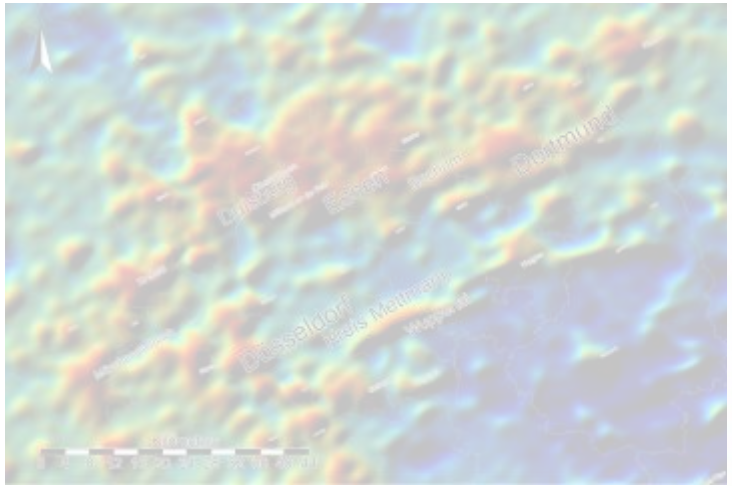
Oke et al. (2017)

outline





Remote Sensing Fundamentals

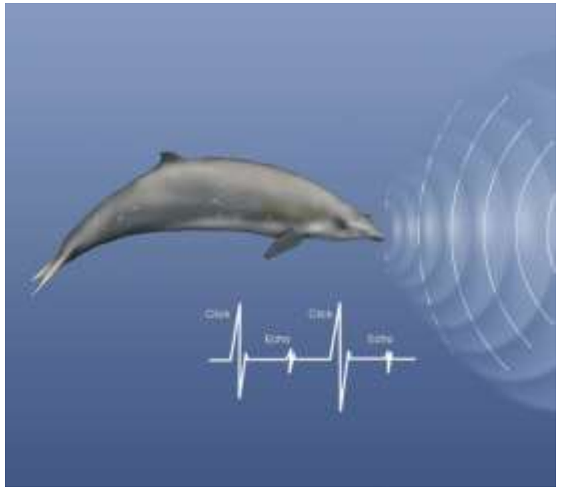
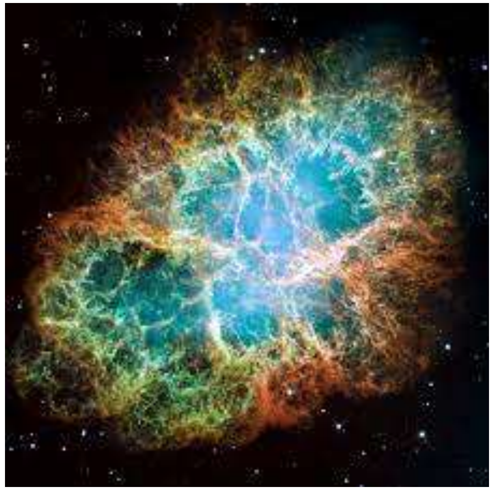


Quelle

What is Remote Sensing?

- Remote sensing is defined as the acquisition of information about an object **without** being in physical contact with it.



Something more concise?

- Remote sensing is the practice of deriving information about the Earth’s land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth’s surface

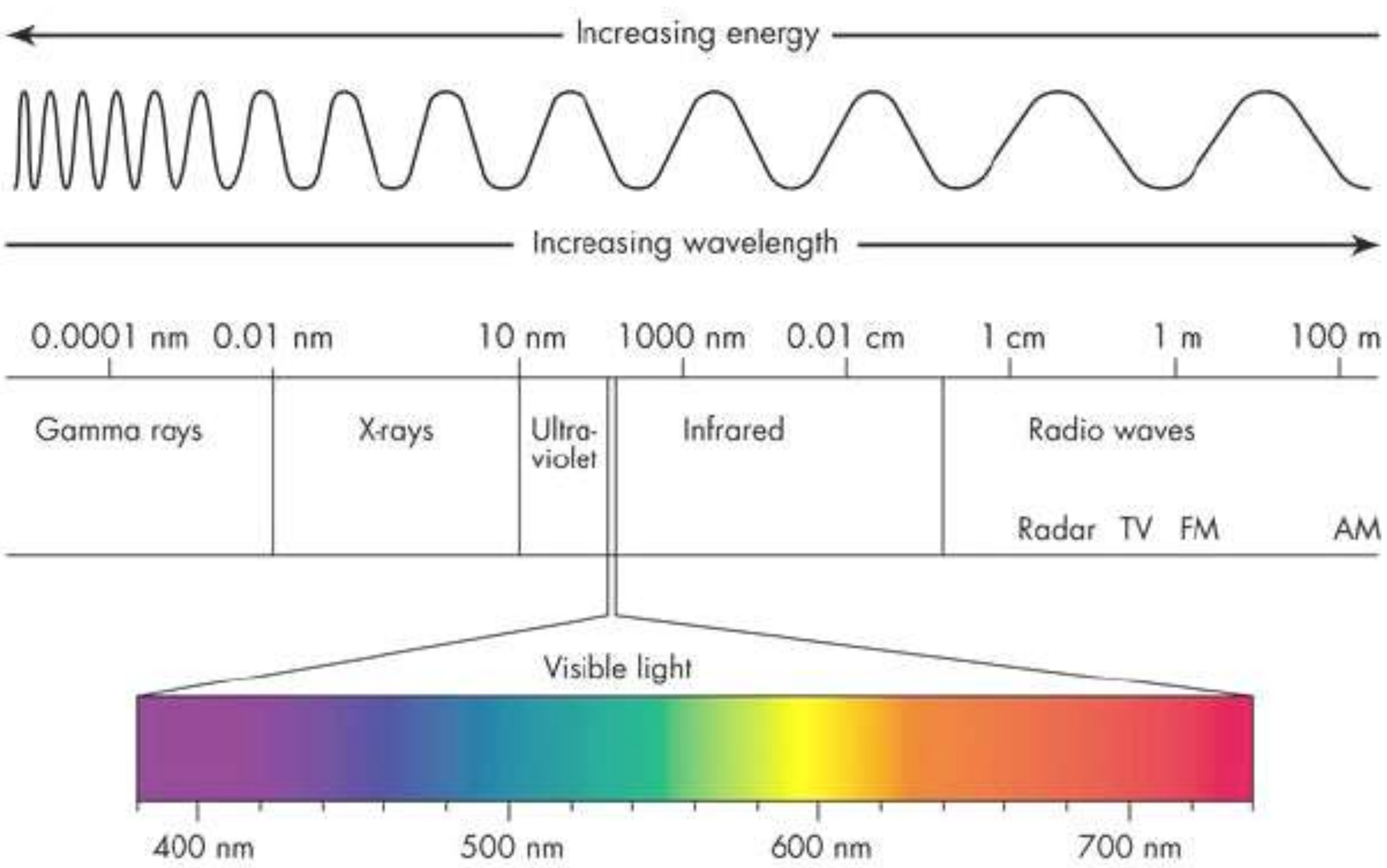
Campbell & Wynne, 2008

Something more concise?

- Remote sensing is the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface.

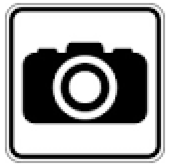
  Campbell & Wynne, 2008

Elektromagnetic spectrum – world of λ



Basics – Remote Sensing

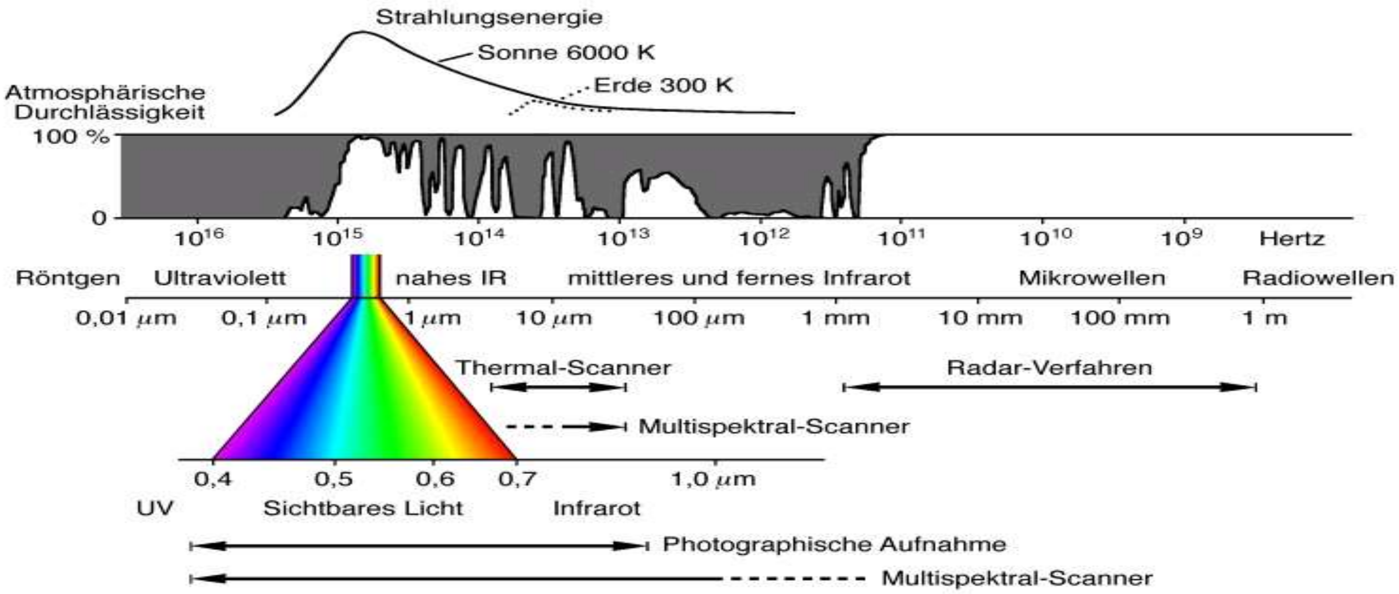
EM spectrum and atmospheric windows



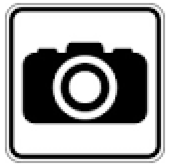
reflected

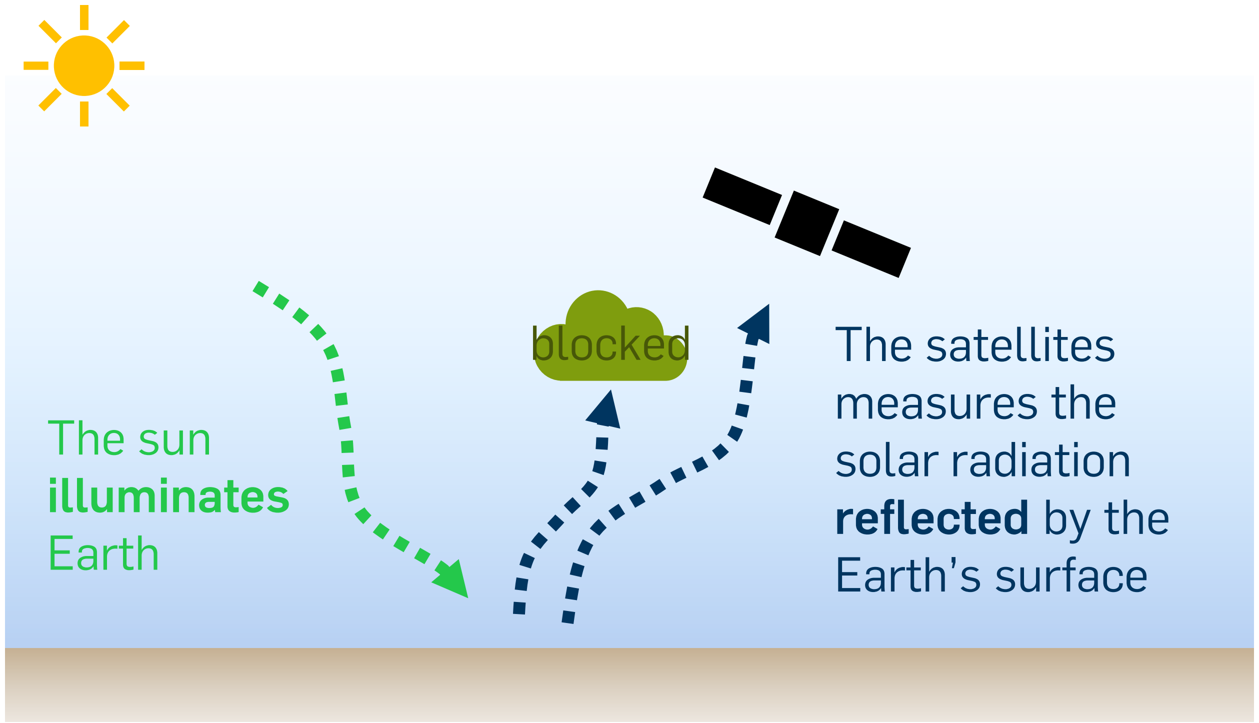
emitted

active



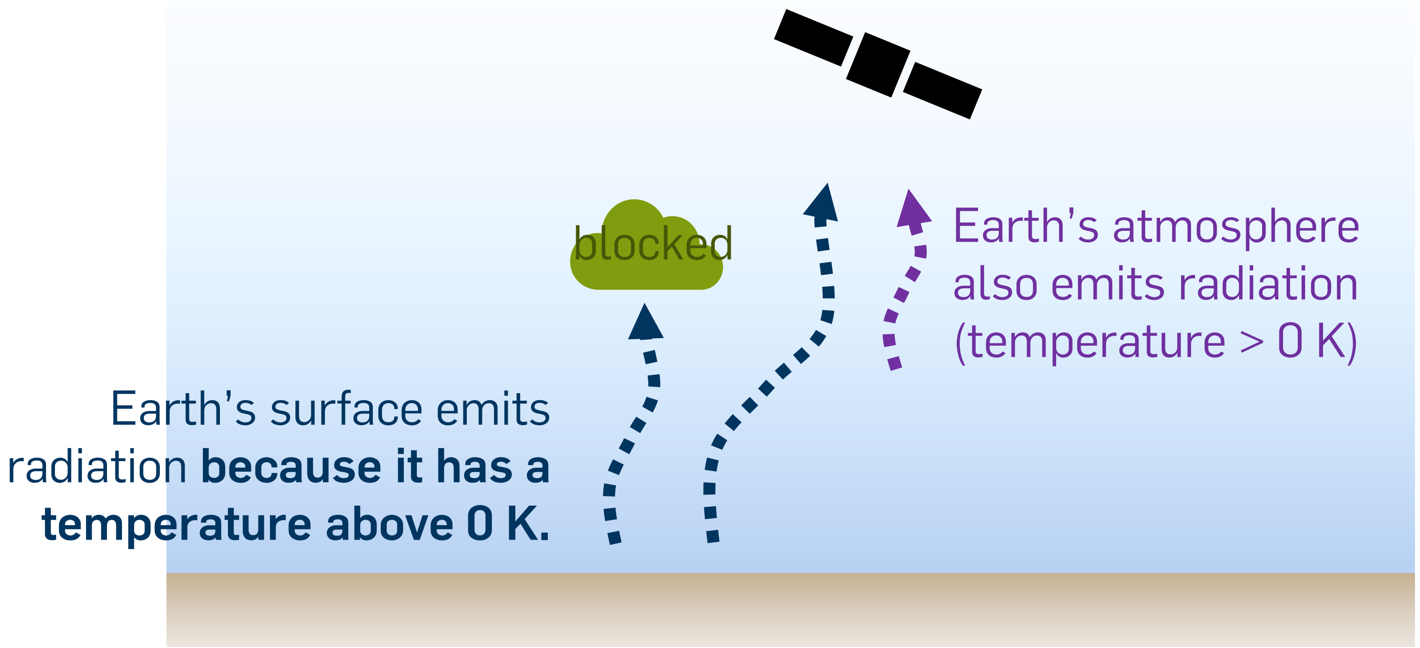
1. reflected (Passive Remote Sensing)





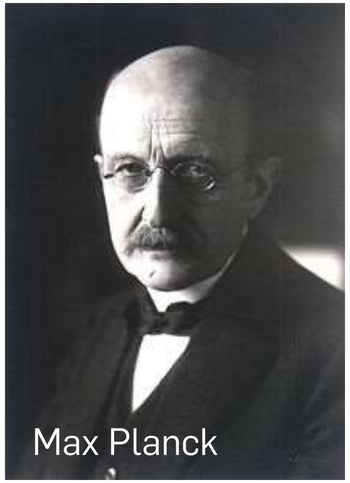
- These are called “passive” sensors because they measure the radiation that is naturally available.
- Solar radiation is available only during the day
- Clouds block the solar radiation.
- Strongly influenced by the atmosphere

2. Emitted (Passive Remote Sensing)



- Earth-emitted radiation is available throughout the day.
- Clouds block the emitted radiation (In TIR).
- Strongly influenced by the atmosphere.
- The Earth's surface has a skin temperature that typically ranges from 258 K to 318 K (the climatological mean is 288 K).

Blackbody Radiation



A blackbody is a hypothetical body that absorbs all the radiation it receives and under thermal equilibrium conditions emits EM radiation with perfect efficiency and with a spectral distribution that obeys Planck's law.

$$\boxed{B_\lambda(T)} = \frac{2hc^2}{\lambda^5}\frac{1}{e^{ch/\lambda kT} - 1}$$

where: $B_\lambda(T)$ = blackbody spectral radiance ($\mathrm{W\,m^{-3}\,sr^{-1}}$)

T = thermodynamic temperature (K)

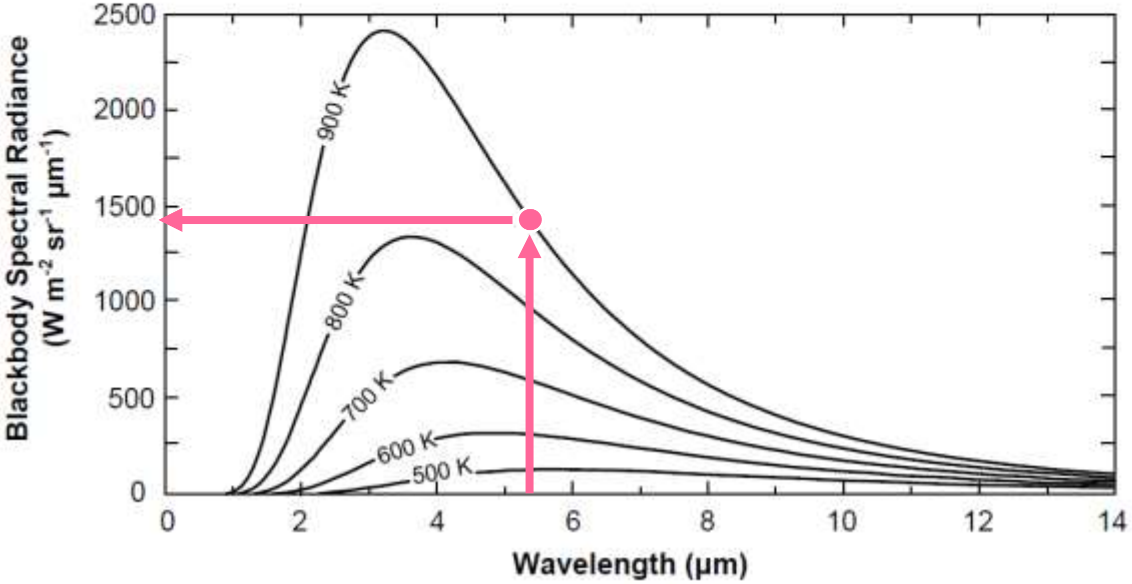
λ = wavelength (m)

h = Planck's constant (equal to $6.626 \times 10^{-34}\ \mathrm{W\,s^2}$)

c = velocity of light (equal to $2.9979 \times 10^{8}\ \mathrm{m\,s^{-1}}$)

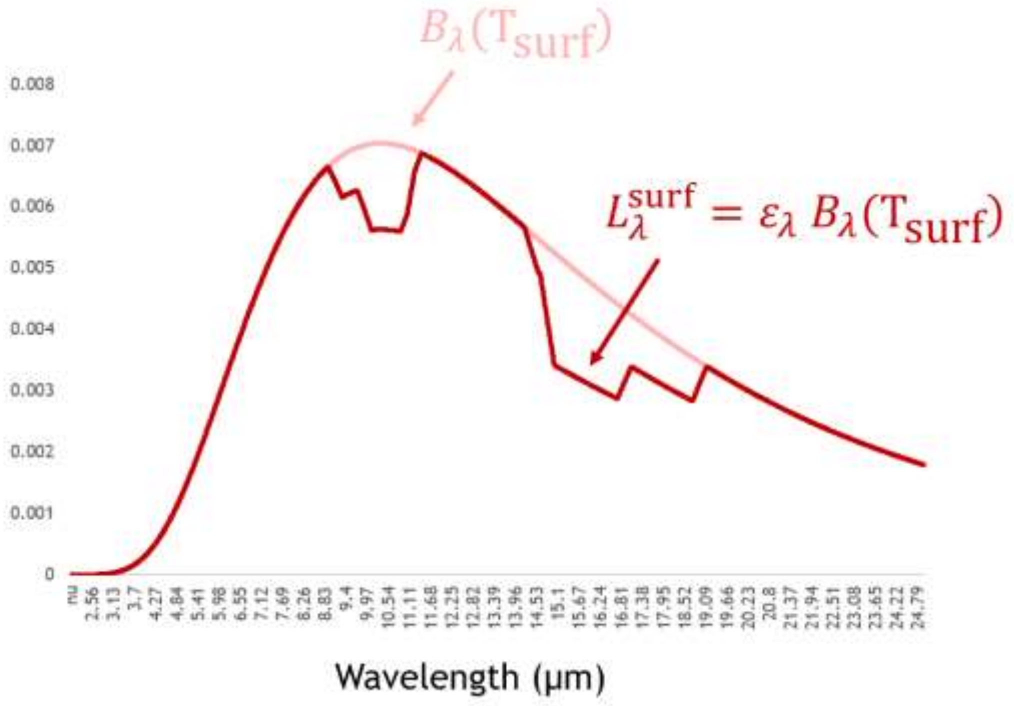
k = Boltzmann's constant (equal to $1.38 \times 10^{-23}\ \mathrm{W\,s\,K^{-1}}$)

Blackbody Radiation



GLOW


Spectral Emissivity



- Real physical bodies are not perfect emitters.
- To account for the wavelength-depended emission efficiency we use a factor called spectral emissivity with a range [0, 1].

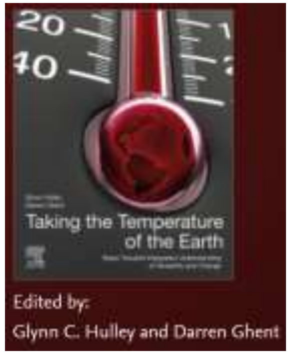
$$\varepsilon_\lambda = \frac{\text{emitted radiation at } T}{\text{blackbody radiation at } T}$$

- Hence the spectral radiance emitted by a real body with a temperature *T* will be:

$$\boxed{\mathrm{L}_\lambda(T) = \varepsilon_\lambda\, \mathrm{B}_\lambda(T)}$$

What is Land Surface Temperature (LST)?

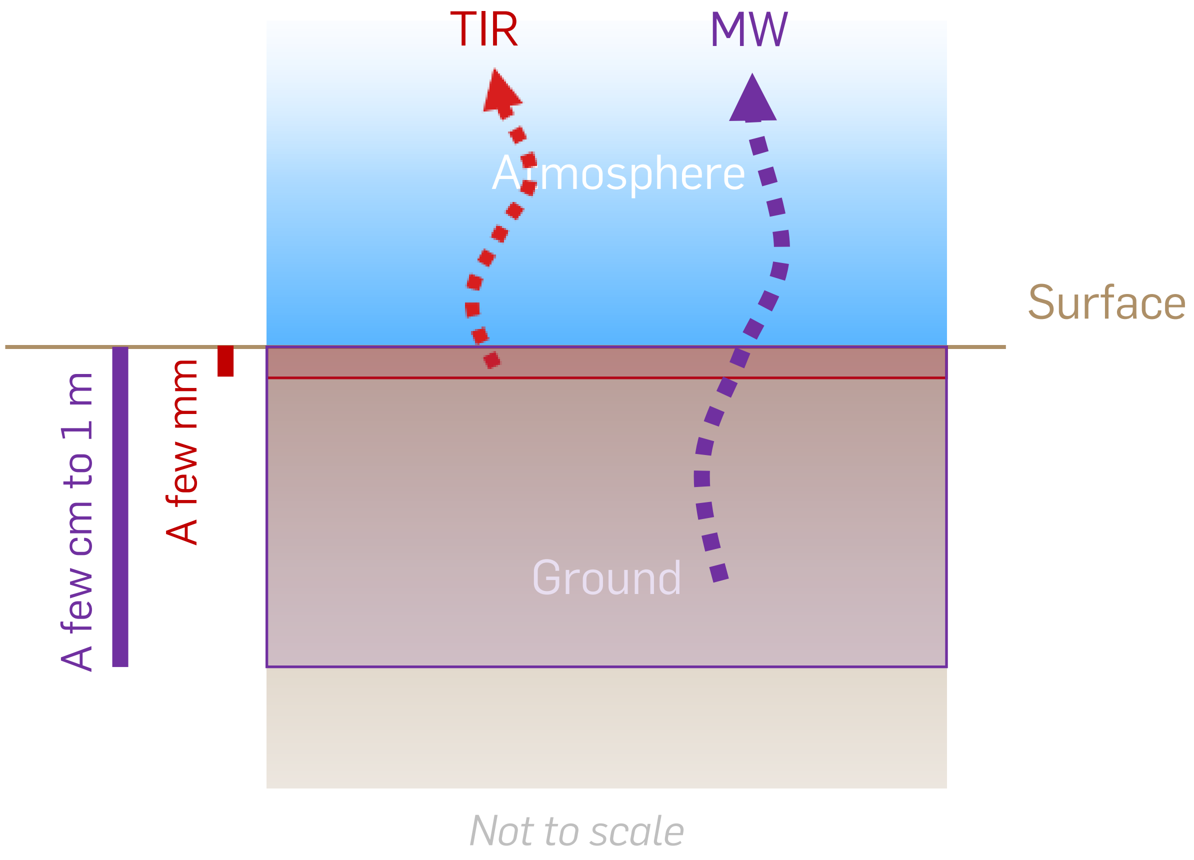
“LST is often referred to as the “skin” temperature, or radiometric temperature, and should not be confused with near surface air temperature, which is the temperature of the air near the surface as routinely measured at meteorological stations and included in daily weather reports. Instead, the **LST is a direct measure of how hot or cold the surface of the Earth would feel to the touch**. **For bare soil surfaces, the LST is the temperature of the top few micrometers of the soil surface, while for dense vegetation it is the temperature of the leaves of the canopy**. For sparse vegetation, it is the ensemble temperature of the canopy, the understory (limbs, branches, etc.), and the soil surface.”



G. C. Hulley et al., in Taking the Temperature of the Earth, G. C. Hulley, D. Ghent, Eds. (Elsevier, 2019; http://www.sciencedirect.com/science/article/pii/B9780128144589000034), pp. 57–127.

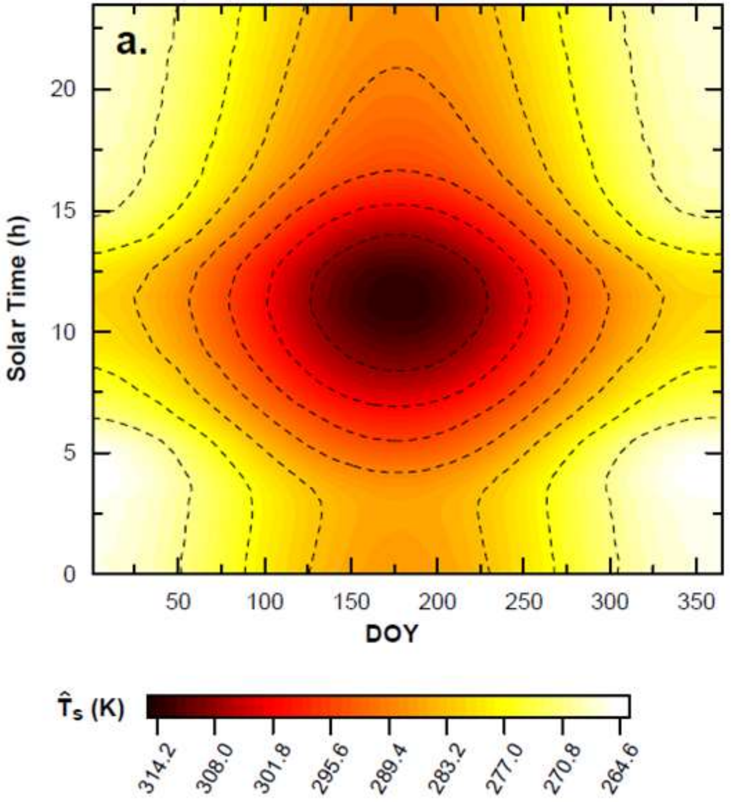
What does “skin” mean?

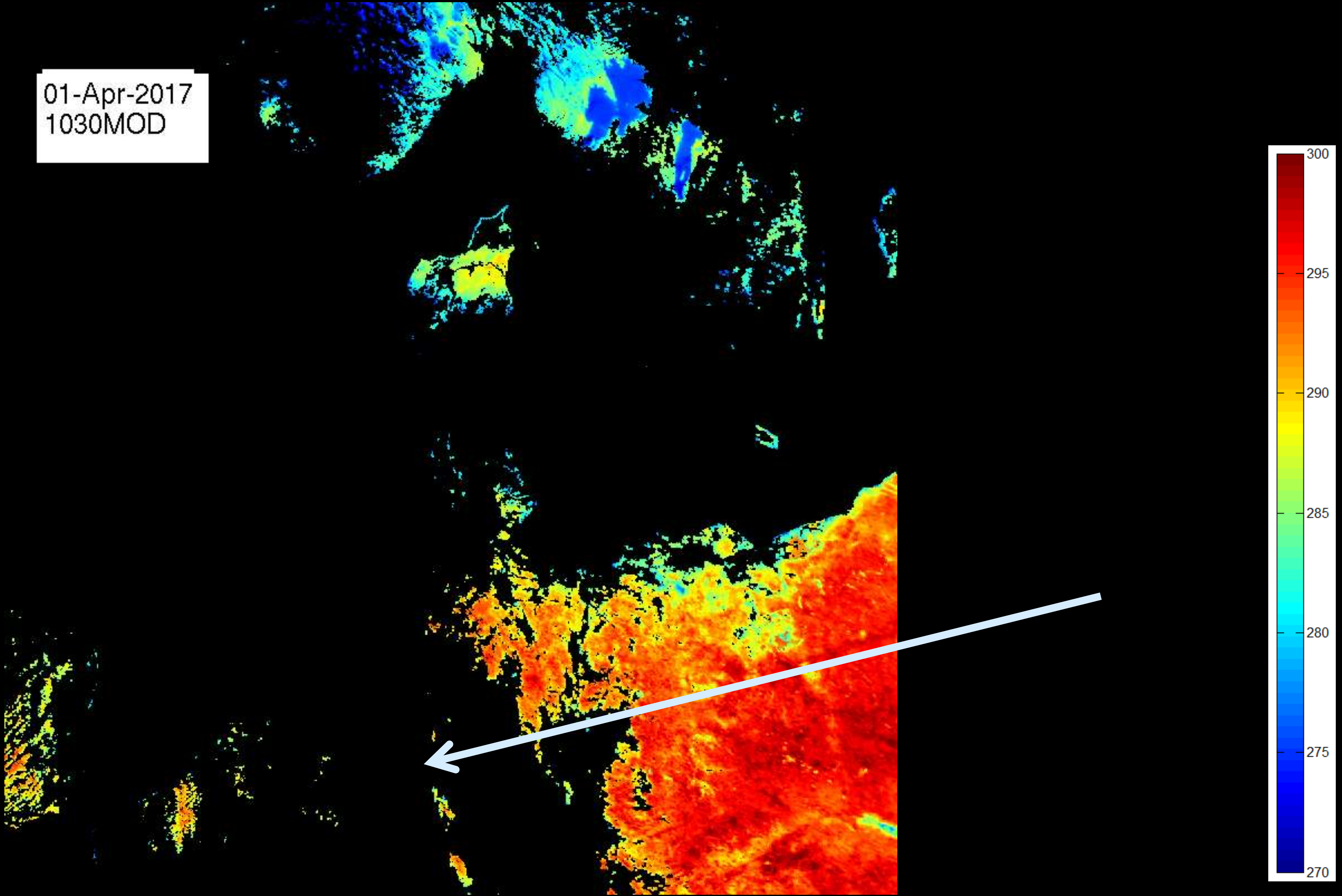
- For TIR wavelengths (8–15 µm), the radiation we measure is emitted by the first few millimeters.
- MW (0.15-30 cm) LSTs may refer to a skin depth of a few centimeters to a meter depending on the substrate.
- 1 cm = 10,000 µm



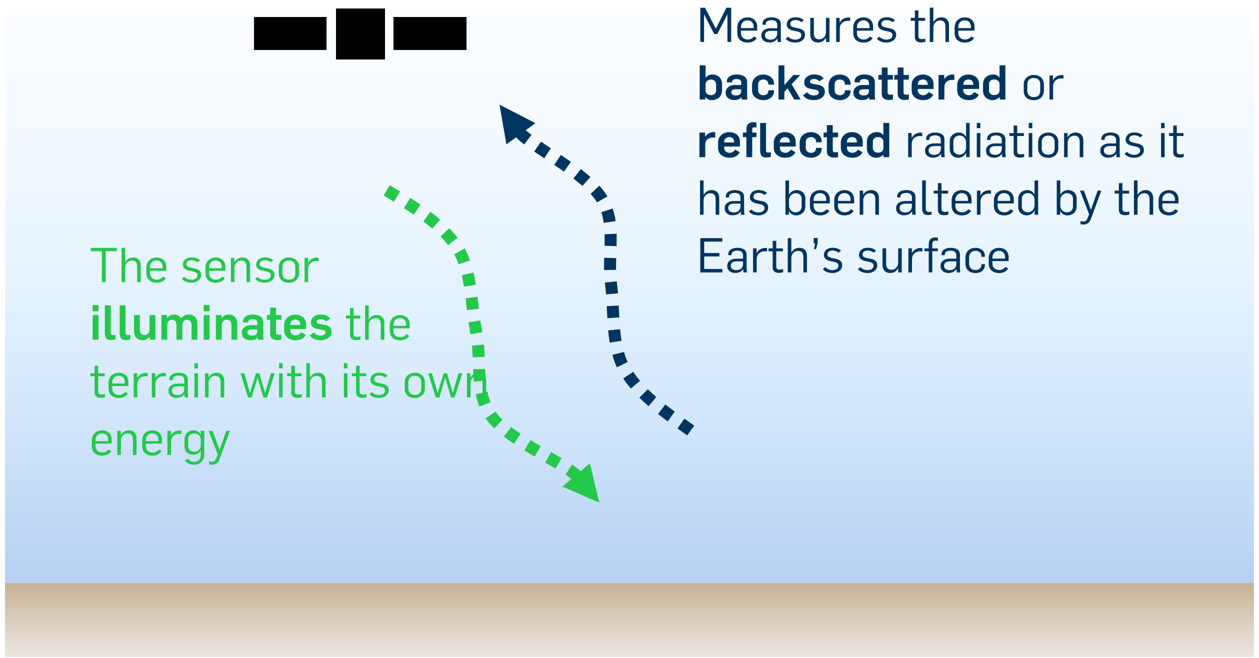
LST is highly variable

LST Temporal Evolution



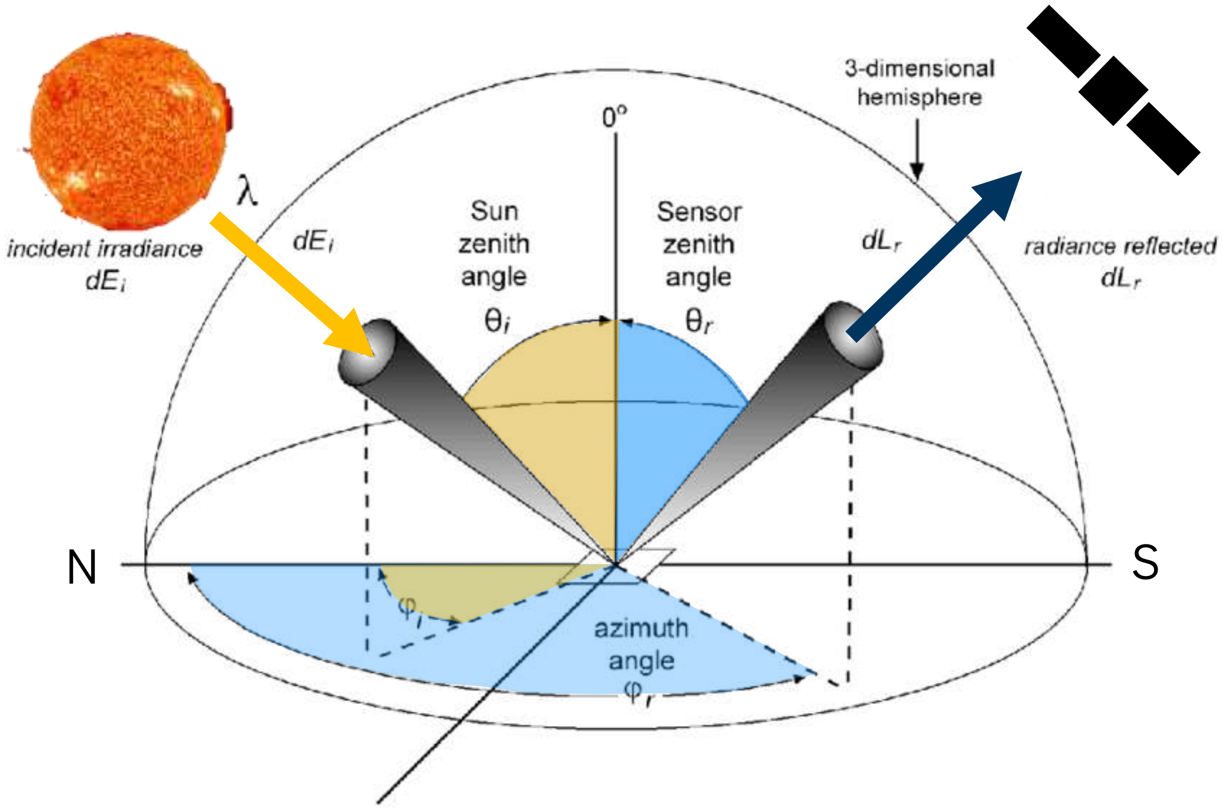

01-Apr-2017
1030MOD
300
295
290
285
280
275
270

3. Active Remote Sensing



- These are called "active" sensors because they use their own energy.
- We select the wavelength that serves our needs the best.
- Independent of day or night or clouds.
- Best represented by imaging radars and lidars.

Radiance is a Directional Quantity



Reflected VNIR-SWIR radiation

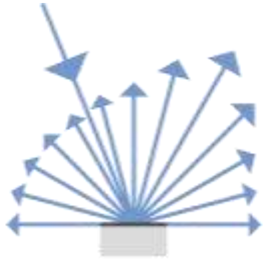
$$L(\varphi_{sun}, \theta_{sun}, \varphi_{sat}, \theta_{sat})$$

Emitted TIR radiation

$$L(\varphi_{sat}, \theta_{sat})$$

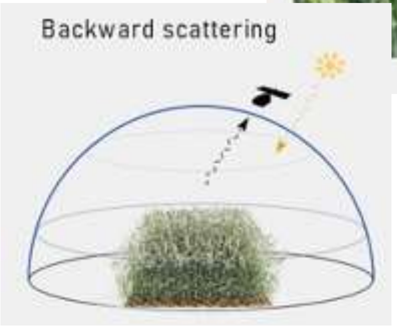
Why is this important?

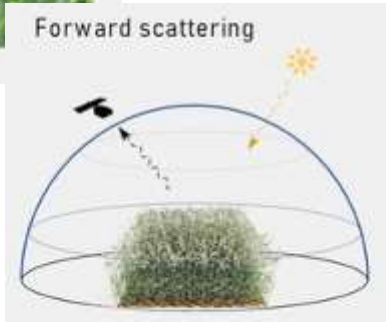
*Because the reflectance and **emission** of real surfaces is **anisotropic***



Example

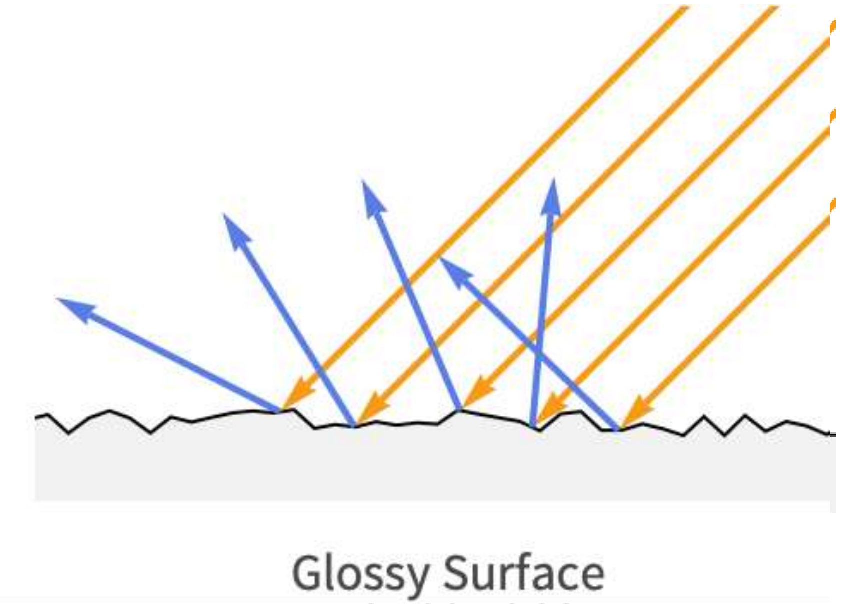
Same target but here it looks much greener.

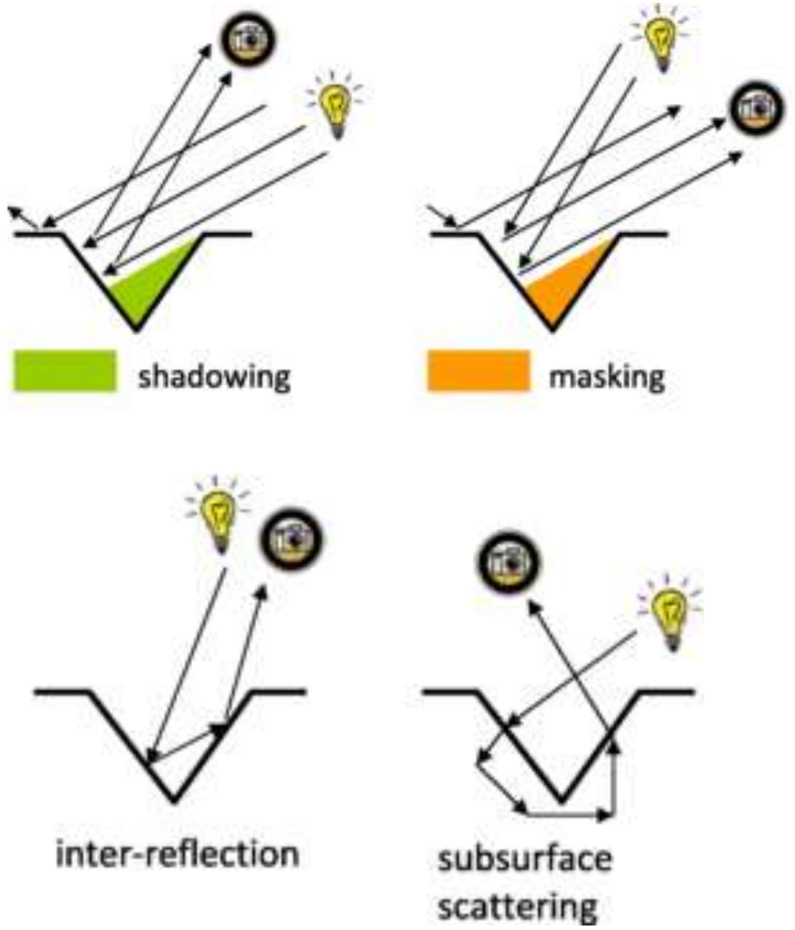




Source:
https://www.gfz-potsdam.de/en/section/remote-sensing-and-geoinformatics/projects/enmap/spectral-modelling/

Why this happens?





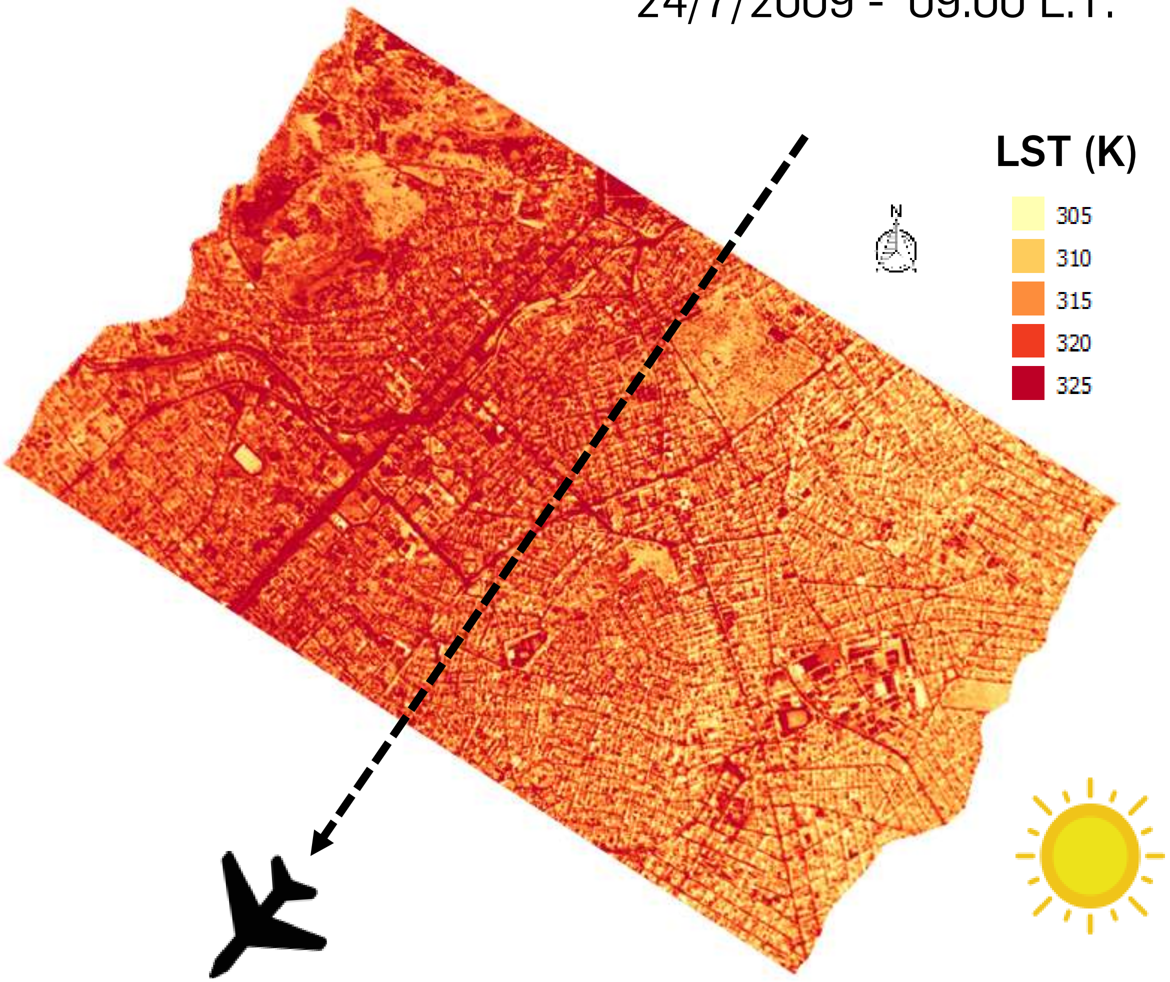
Keep in mind that this explanation is NOT complete.


Urban Surfaces are (likely) the most convoluted on the planet!
D. Zhou et al., Remote Sensing. 11 (2019)

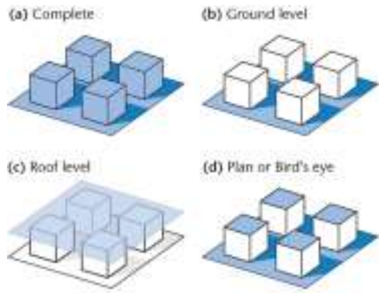
What is LST over cities ?

Athens, Greece

24/7/2009 - 09:00 L.T.



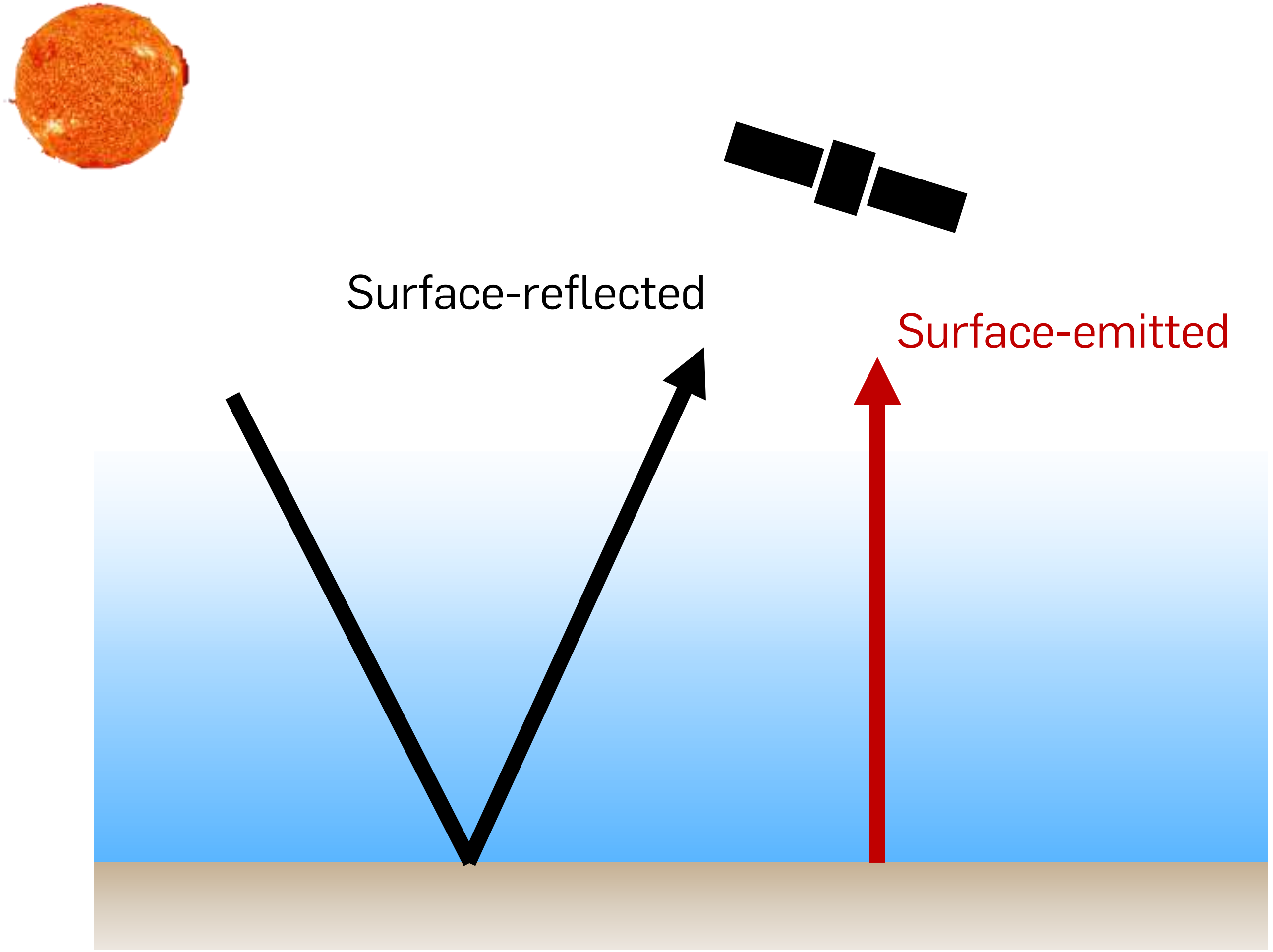
Red is warm!



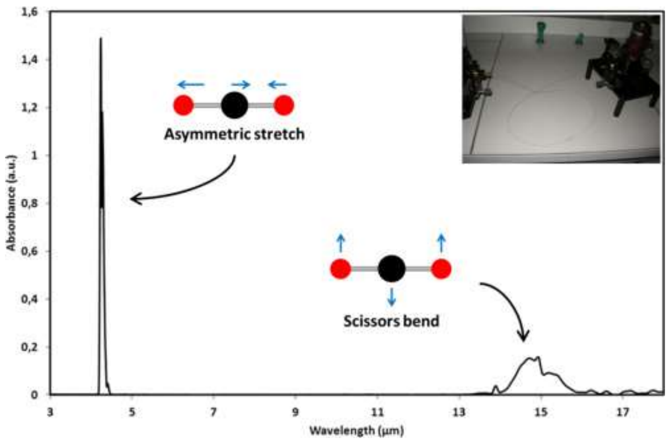
Oke et al. (2017)

- Data: Thermopolis 2009 (ESA)

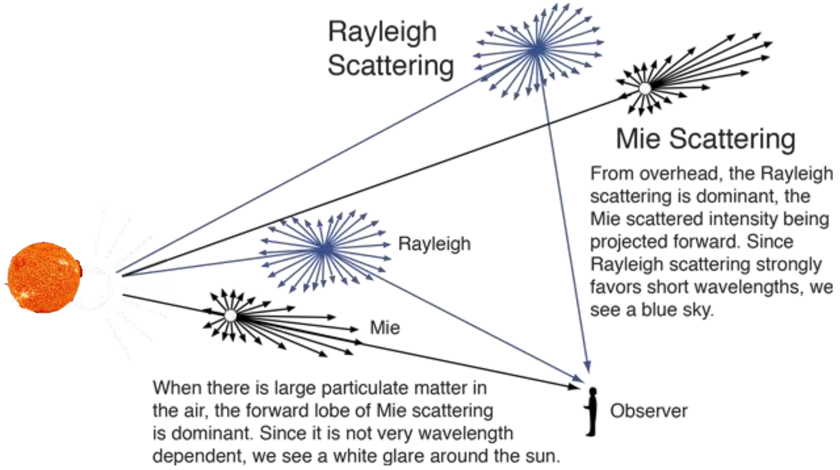
Atmospheric Influence

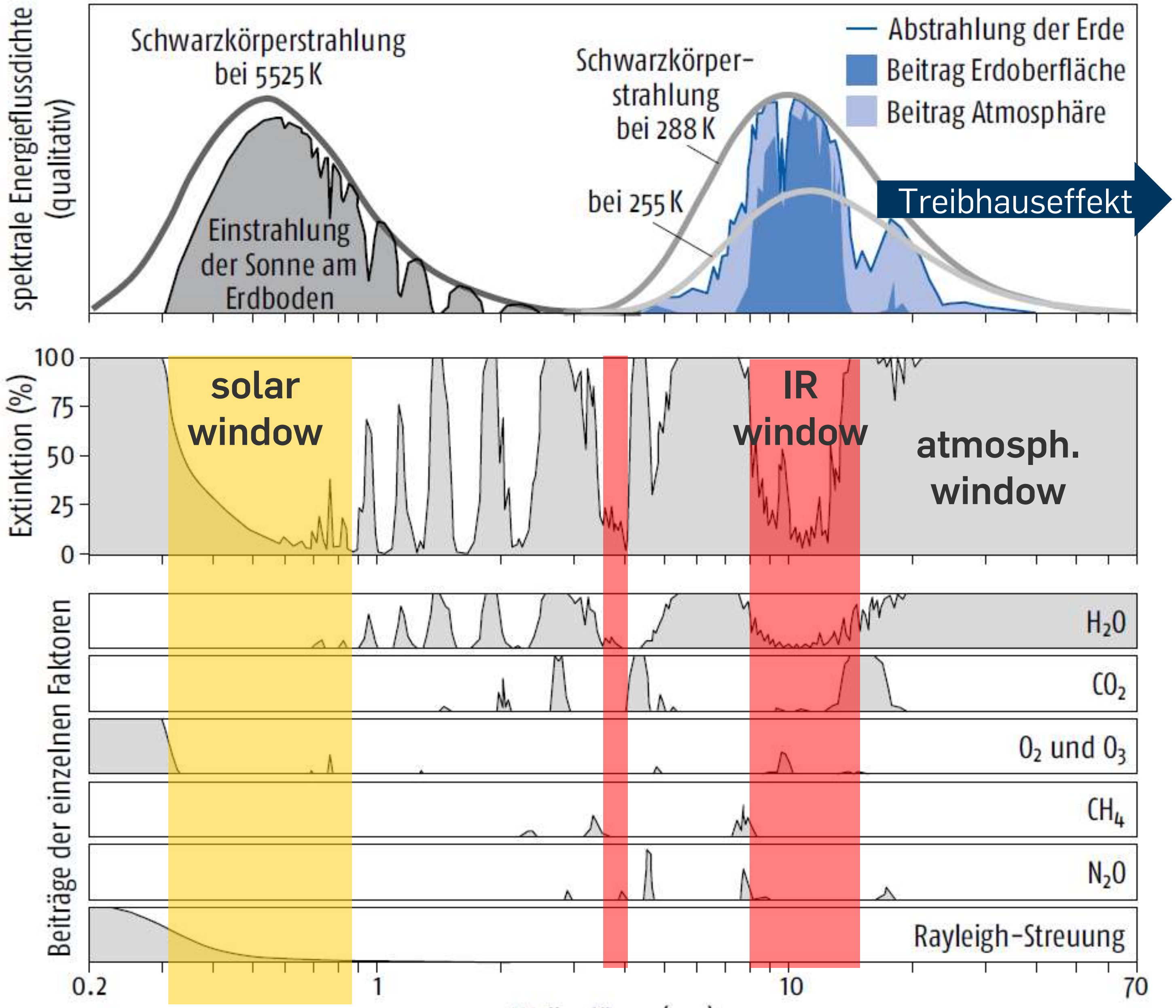


Absorption



Scattering



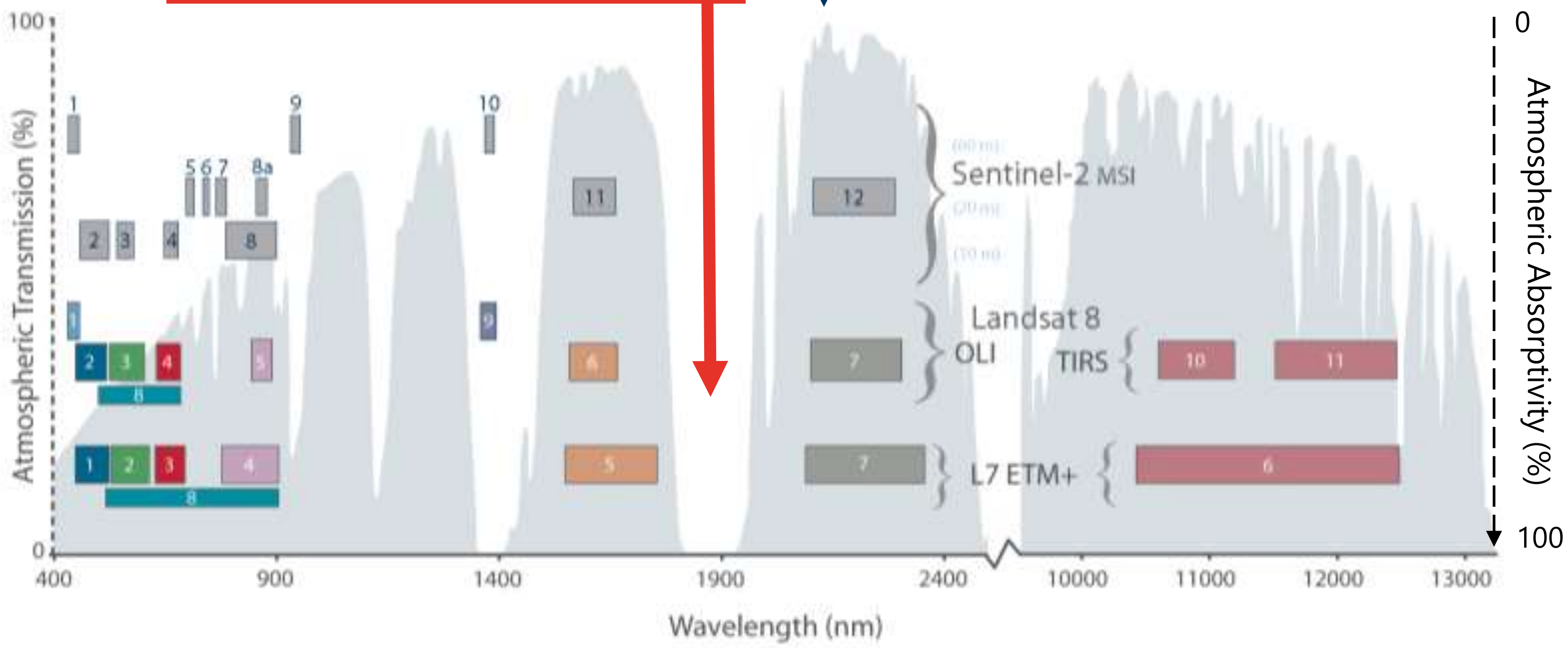


Schwarzkörperstrahlung
bei 5525 K
Einstrahlung
der Sonne am
Erdboden
Schwarzkörper-
strahlung
bei 288 K
bei 255 K
Abstrahlung der Erde
Beitrag Erdoberfläche
Beitrag Atmosphäre
Treibhauseffekt
spektrale Energieflussdichte
(qualitativ)
solar
window
IR
window
atmosph.
window
Extinktion (%)
100
75
50
25
0
Beiträge der einzelnen Faktoren
H_2O
CO_2
O_2 und O_3
CH_4
N_2O
Rayleigh-Streuung
0.2
1
10
70
Wellenlänge (µm)

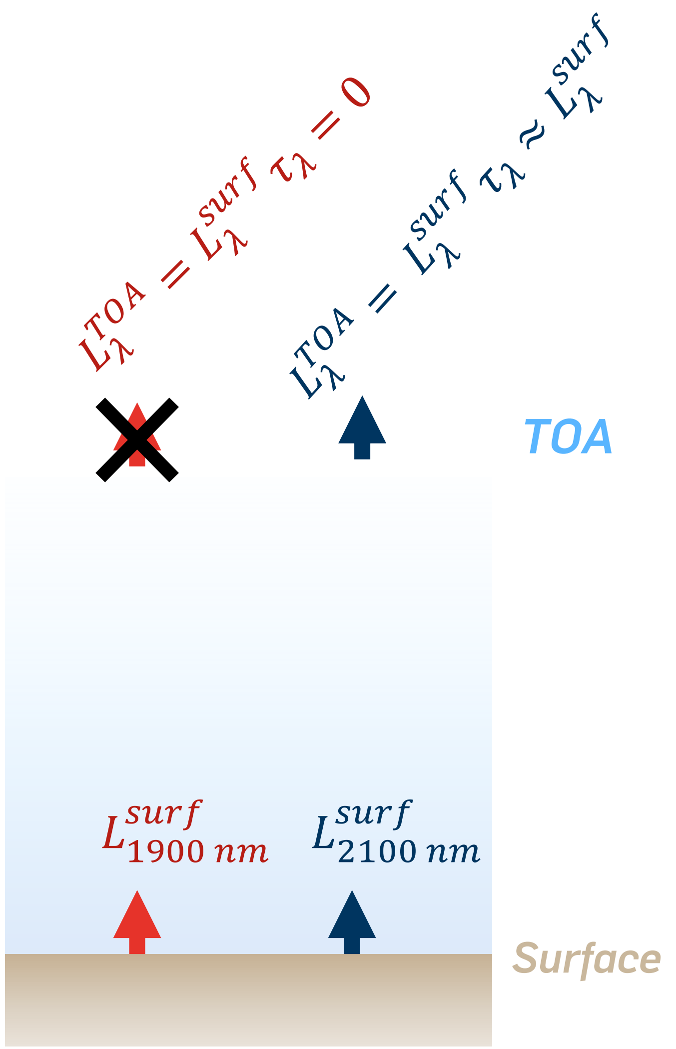
Atmospheric Windows

For $\lambda = 1900\ nm, \tau = 0$

For $\lambda = 2100\ nm, \tau \approx 1$

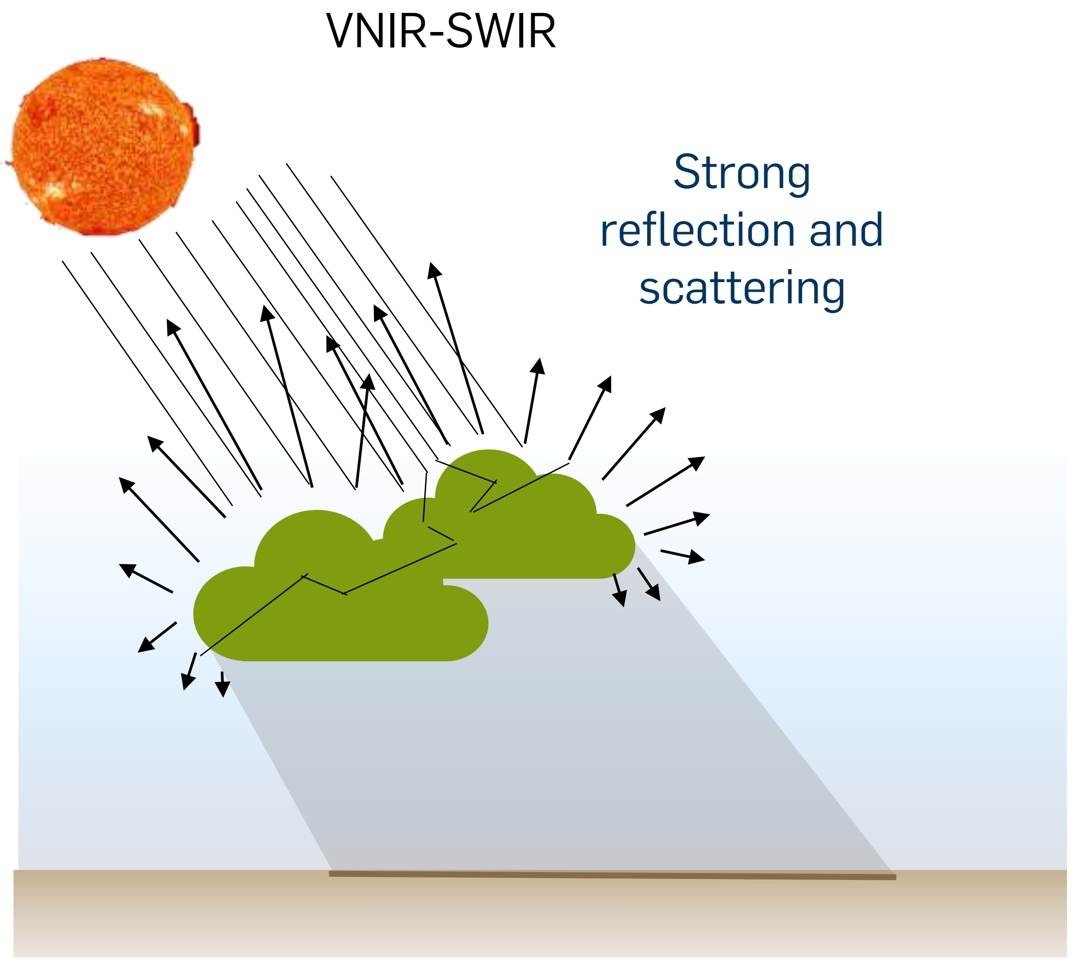


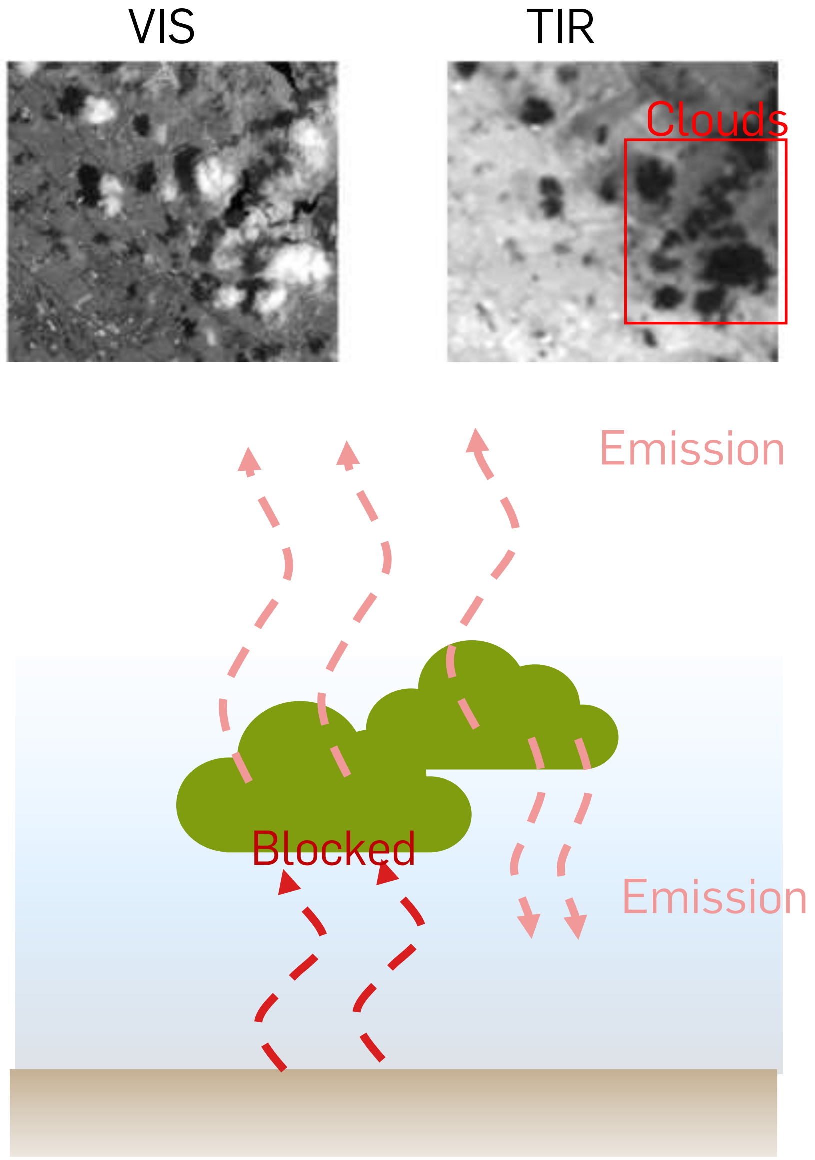
Transmissivity ∝ Absorptivity



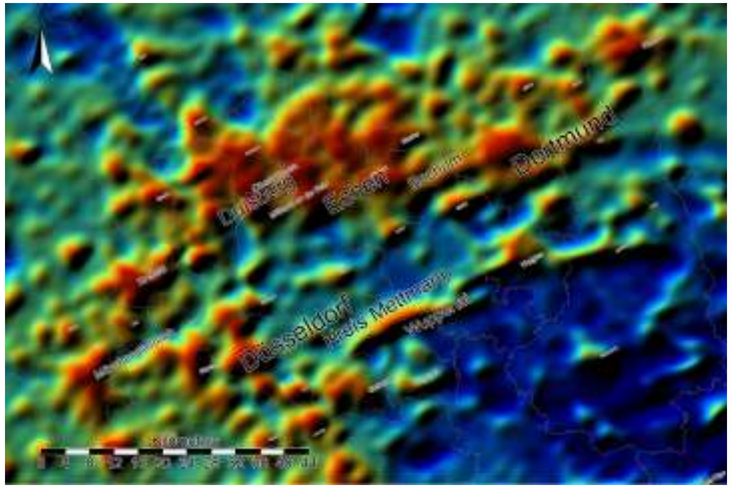
TOA: Top-of-the-Atmosphere

Clouds


VNIR-SWIR
Strong reflection and scattering

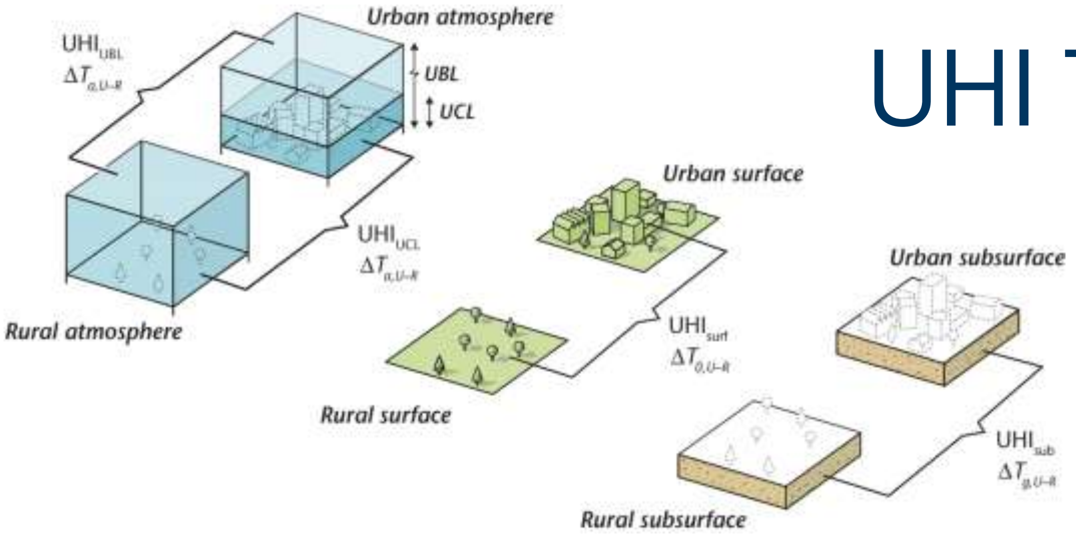

VIS
TIR
Clouds
Emission
Blocked
Emission

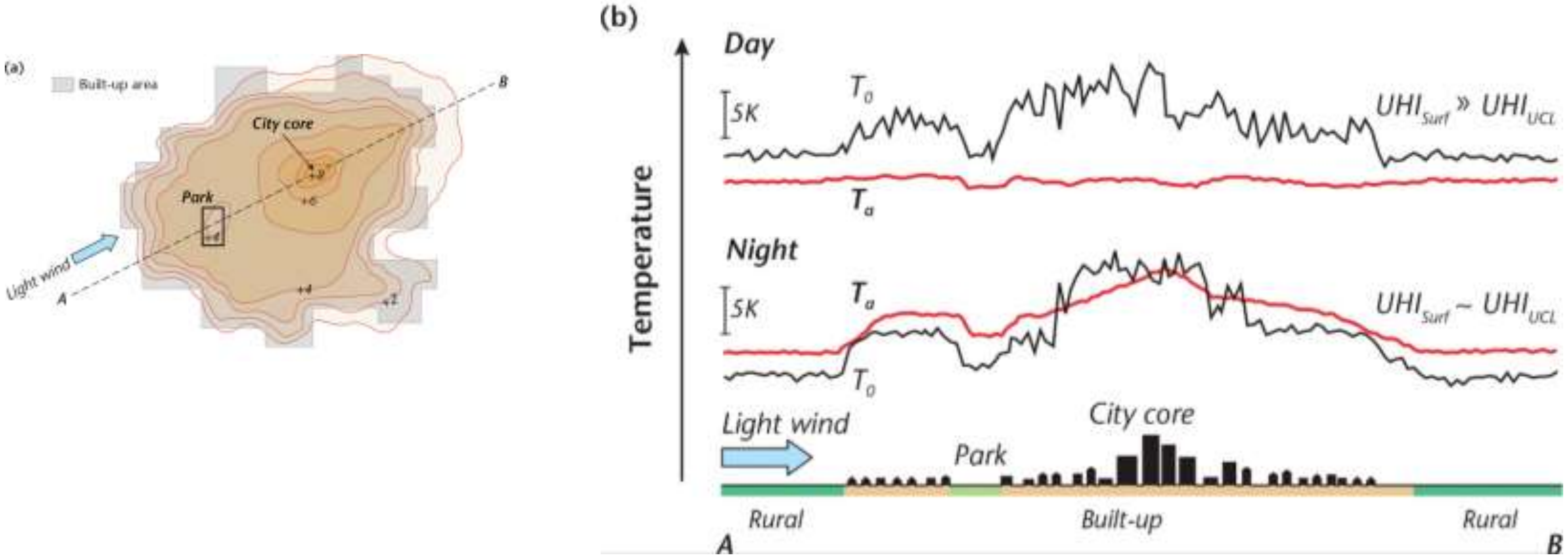
2. Surface Urban Heat Islands



Quelle

UHI Types





- Oke et al. 2017

There is a problem

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Remote Sensing of Environment 86 (2003) 370–384

Remote Sensing of Environment

www.elsevier.com/locate/rse

2003

Thermal remote sensing of urban climates

J.A. Voogt[a,*], T.R. Oke[b]

[a] Department of Geography, University of Western Ontario, London, ON, Canada N6A 5C2

[b] Atmospheric Science Program, Department of Geography, University of British Columbia, Vancouver, BC, Canada V6T 1Z2

Received 8 April 2002; received in revised form 20 September 2002; accepted 28 December 2002

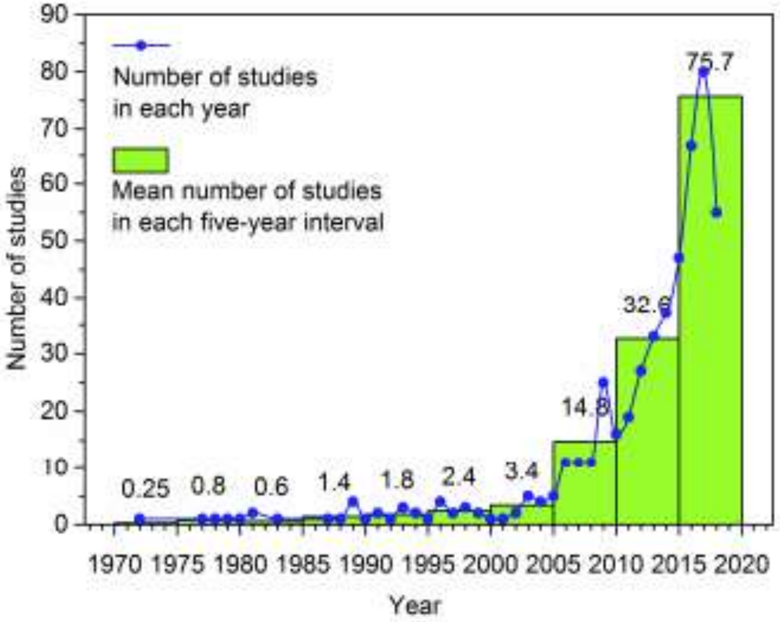
Abstract

Thermal remote sensing has been used over urban areas to assess the urban heat island, to perform land cover classifications and as input for models of urban surface atmosphere exchange. Here, we review the use of thermal remote sensing in the study of urban climates, focusing

[International Journal of Remote Sensing 10 (1989) 1699]. The review demonstrates that while some progress has been made, the thermal remote sensing of urban areas has been slow to advance beyond qualitative description of thermal patterns and simple correlations. Part of the

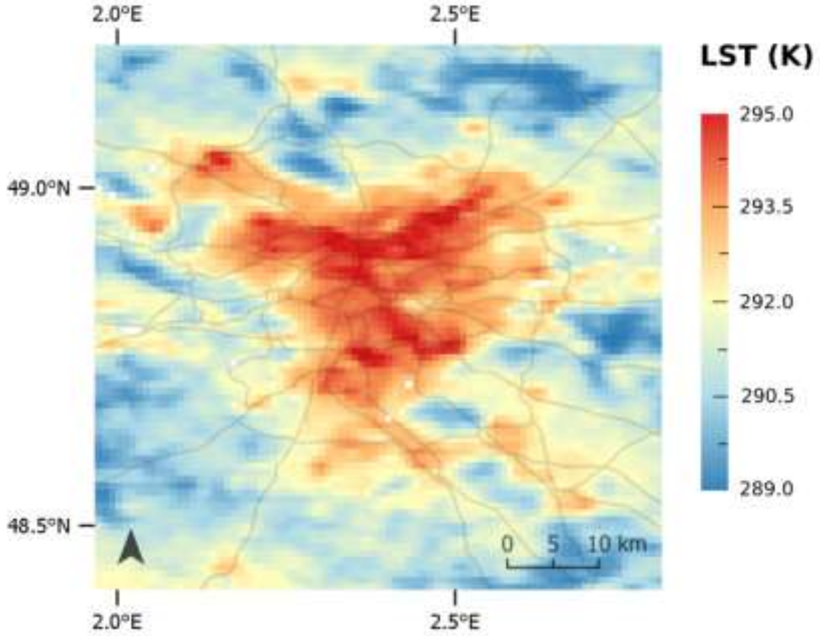
surface descriptors. Advances in the application of thermal remote sensing to natural and agricultural surfaces suggest insight into possible methods to advance techniques and capabilities over urban areas. Improvements in the spatial and spectral resolution of current and next-generation satellite-based sensors, in more detailed surface representations of urban surfaces and in the availability of low cost, high resolution portable thermal scanners are expected to allow progress in the application of urban thermal remote sensing to the study of the climate of urban areas.

Surface Urban Heat Islands Literature



Zhou et al., 2019

Paris, France

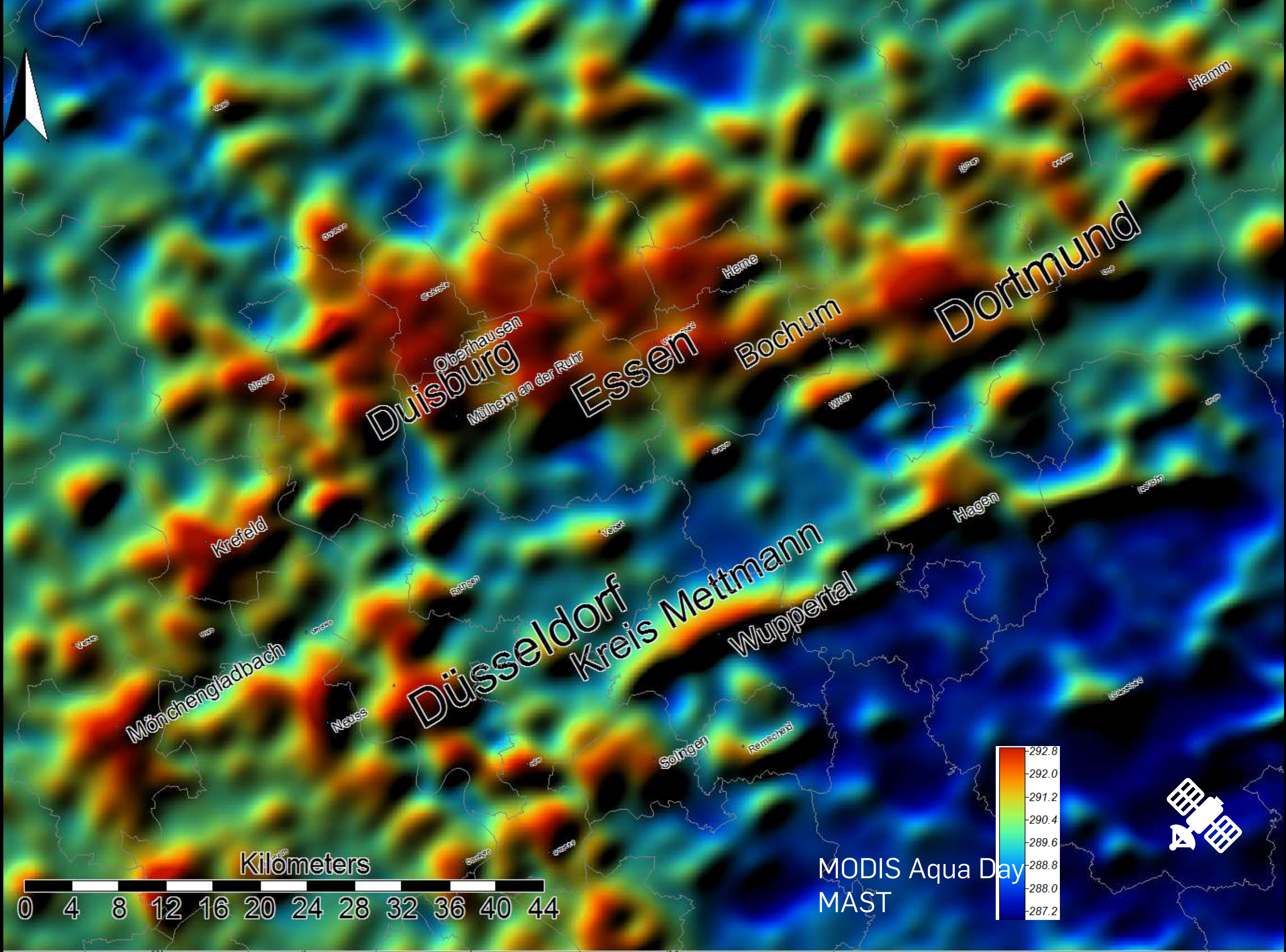


“Over the last few decades, advancements of remote sensing along with spatial science have considerably increased the number and quality of SUHI studies that form the major body of the urban heat island (UHI) literature.” (Zhou et al. 2019)

there are relevant misunderstandings between UC und URS communities and cooperation remains behind its potential.

D. Zhou et al., Remote Sensing. 11 (2019), doi:10.3390/rs11010048.

"With the advent of thermal remote sensing satellites, we are able to observe UHIs at large spatial scales and understand their primary causal factors." (Zhu et al. 2019)



There is a problem

remote sensing

MDPI

Article

Regarding Some Pitfalls in Urban Heat Island Studies Using Remote Sensing Technology

Eberhard Parlow

Department for Environmental Sciences, Meteorology, Climatology and Remote Sensing, University Basel, CH-4056 Basel, Switzerland; eberhard.parlow@unibas.ch

Abstract: This paper attempts to illustrate the complexity of thermal infrared (TIR) data analysis for

(using the term "surface urban heat island") could be observed, the literature is full of incorrect conclusions and results using erroneous terminology. This seems to be the result of the ease of such

drawing conclusions for urban planning authorities. It seems that the UHI is easy to measure, easy to explain, easy to find, and easy to illustrate—simply take a TIR-image. Due to this apparent simplicity, many authors seem to jump into UHI studies without fully understanding the nature of the phenomenon as far as time and spatial scales, physical processes, and the numerous methodological pitfalls inherent to UHI studies are concerned. This paper attempts to point out some of the

2021

~~Urban Heat Island~~

Surface Urban Heat Island !

Got it. Let‘s mitigate ...

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com

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Is the Urban Heat Island intensity relevant for heat mitigation studies?

Alberto Martilli[a,*], E. Scott Krayenhoff[b,1], Negin Nazarian[c,1]

[a] Department of Environment, CIEMAT, Madrid, Spain
[b] School of Environmental Sciences, University of Guelph, Guelph, Canada
[c] Faculty of Built Environment, University of New South Wales, Sydney, Australia

ABSTRACT

The Urban Heat Island concept is often used to describe 'excess' heat associated with urban areas, and is therefore frequently considered to be a negative phenomenon that requires mitigation. In this short communication we use clear examples to show that this is not necessarily true. Furthermore, we demonstrate that the Urban Heat Island intensity has little relevance for urban heat mitigation, and suggest the term "urban heat mitigation" to more accurately describe strategies aimed at cooling cities. We conclude with the research questions that, in our view, should guide future studies in the fields of urban thermal climate and heat mitigation. These questions are primarily rooted in the assessment of differences of climate responses between built Local Climate Zones in different climatic and geographical contexts.

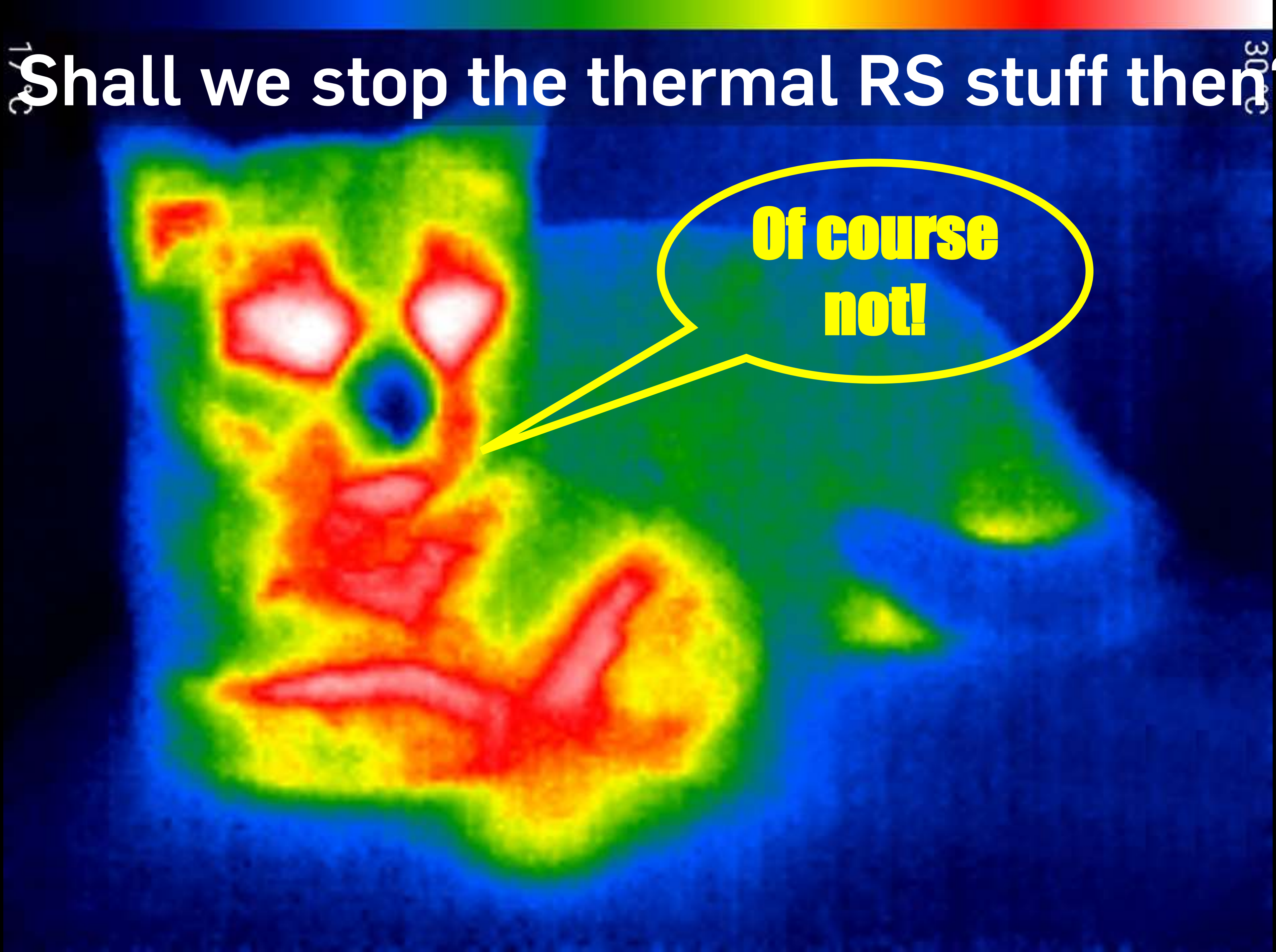
Kilometers

0 4 8 12 16 20 24 28 32 36 40 44

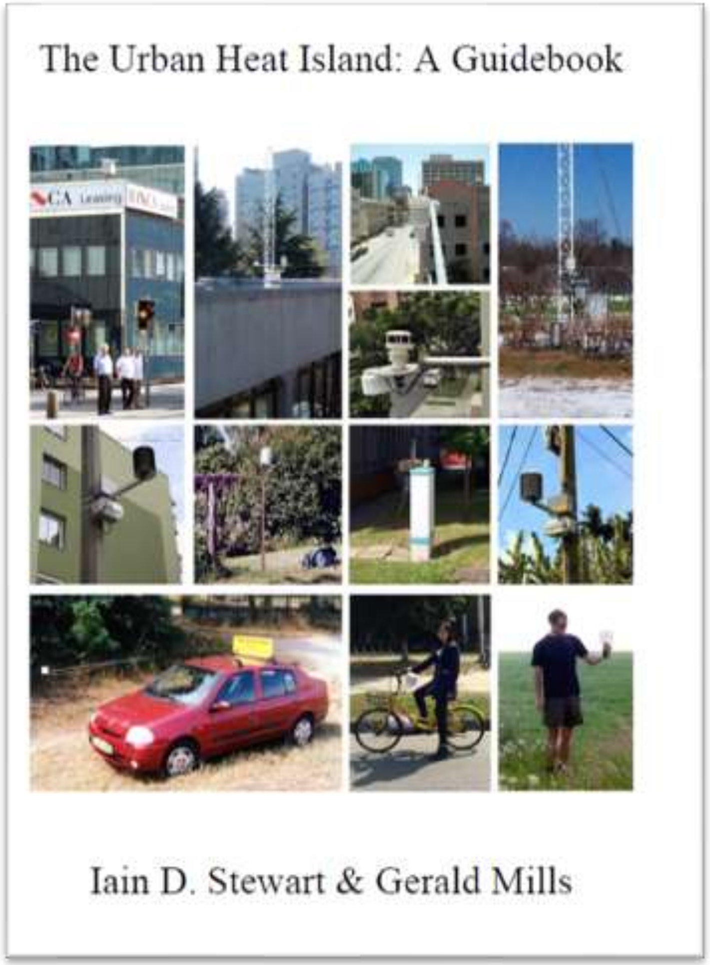
Dortmund Duisburg Essen Bochum Herne Mülheim an der Ruhr Hamm

MODIS Aqua Day MAST

Shall we stop the thermal RS stuff then?



Why continue?

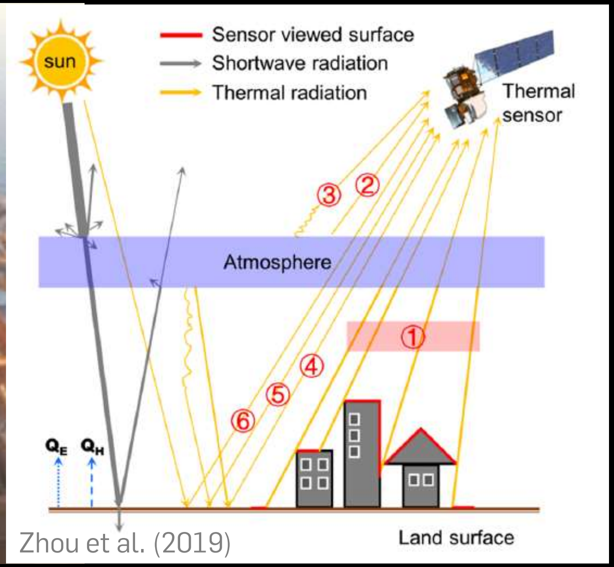


"The near-surface air and **surface temperatures can be regarded as a simple diagnostic tool to identify where and when the urban warming impact is greatest, and to guide planning and design interventions.** Temperature can be described as a 'response' variable that represents the net impact of a series of interacting exchange processes, most of which are difficult to measure."

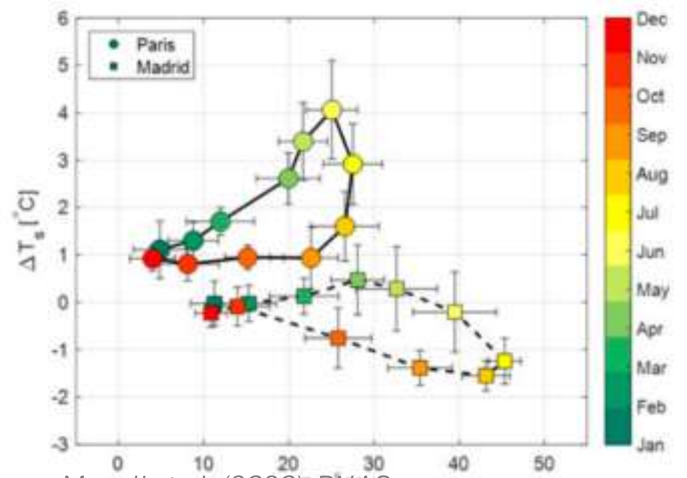
"The SUHI is a starting point for understanding all other heat island types"

"The measurement of UHI patterns in individual cities can provide valuable datasets for other studies, while guiding urban planning and design policies and **filling in gaps in the existing descriptive literature**. These gaps are linked to coverage rather than content (with a few exceptions), as **most studies have been completed for cities of the mid-latitudes with distinct seasonal patterns** that affect heating/cooling needs and vegetative growth."

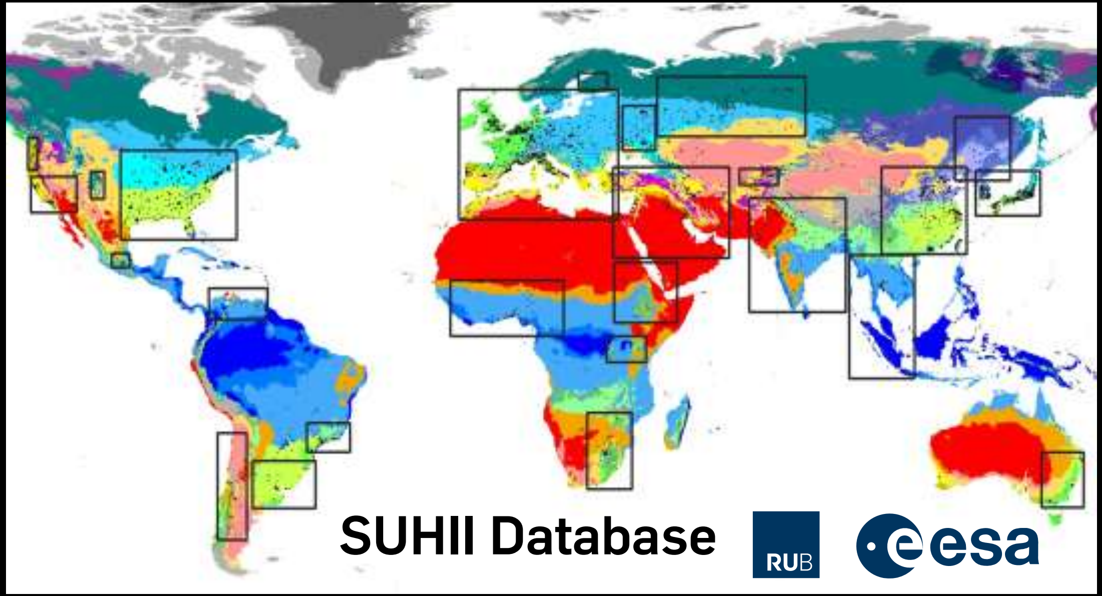
- I.D. Stewart, G. Mills, The Urban Heat Island (Elsevier, San Diego, UNITED STATES, 2021)



Zhou et al. (2019)



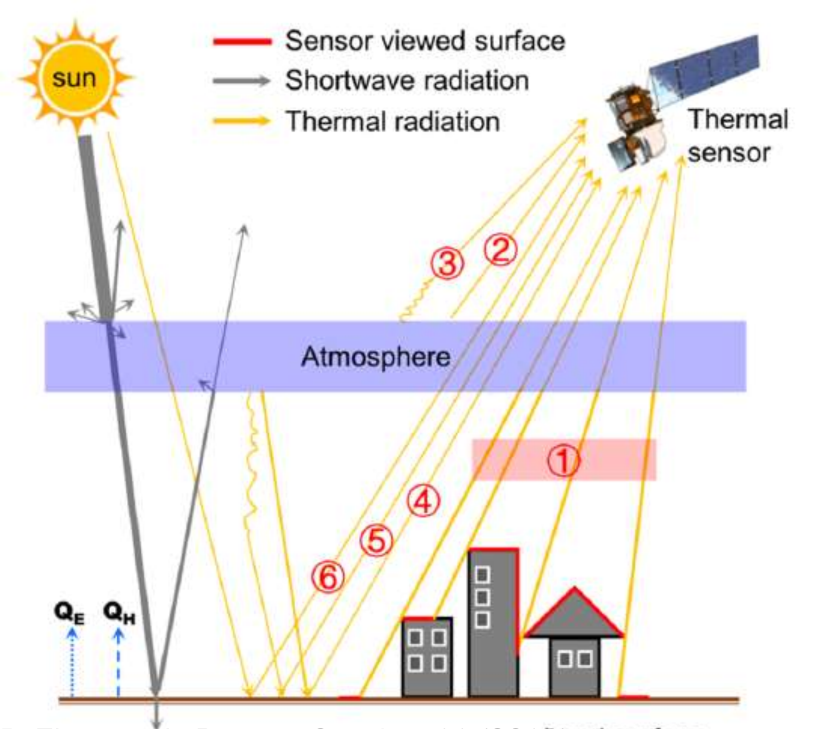
Manoli et al. (2020) PNAS



Directions: Understanding

Classical questions by Roth et al. 1989

- (1) What are the characteristics of the urban surface as viewed by thermal remote sensors? M. Roth, T. R. Oke, W. J. Emery, International Journal of Remote Sensing. 10, 1699–1720 (1989).



D. Zhou et al., Remote Sensing. 11 (2019)

What can be done?

remote sensing MDPI

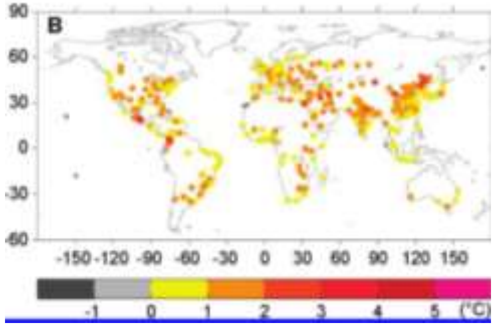
Article

Regarding Some Pitfalls in Urban Heat Island Studies Using Remote Sensing Technology

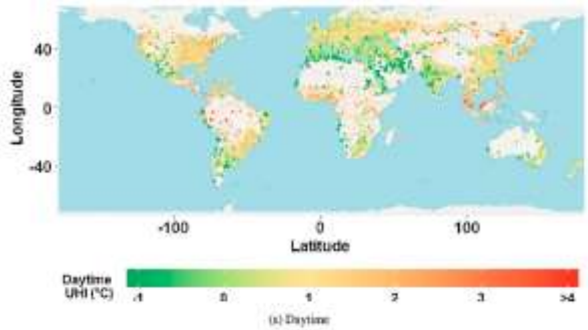
to explain, easy to find, and easy to illustrate—simply take a TIR-image. Due to this apparent simplicity, many authors seem to jump into UHI studies without fully understanding the nature of the phenomenon as far as time and spatial scales, physical processes, and the numerous methodological pitfalls inherent to UHI studies are concerned. This paper attempts to point out some of the

conclusions and results using erroneous terminology. This seems to be the result of the ease of such literature implicitly suggesting that "warm surfaces" result in "high air temperatures", ultimately drawing conclusions for urban planning authorities. It seems that the UHI is easy to measure, easy to explain, easy to find, and easy to illustrate—simply take a TIR-image. Due to this apparent simplicity, many authors seem to jump into UHI studies without fully understanding the nature of the phenomenon as far as time and spatial scales, physical processes, and the numerous methodological pitfalls inherent to UHI studies are concerned. This paper attempts to point out some of the

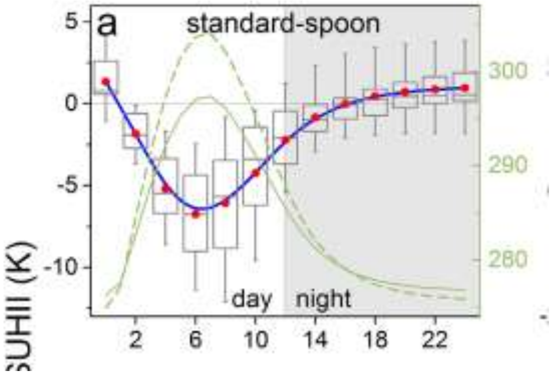
Large scale variation and temporal dynamics



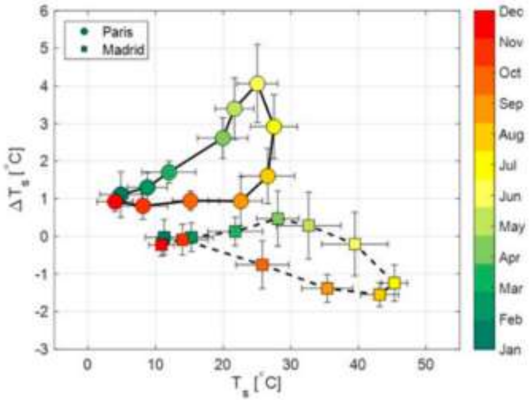
S. Peng et al., Environ. Sci. Technol. 46, 696–703 (2012).



T. Chakraborty, X. Lee, International Journal of Applied Earth Observation and Geoinformation. 74, 269–280 (2019).



J. Lai et al., Remote Sensing of Environment. 217, 203–220 (2018).



Manoli et al. (2020), PNAS

What else can be done?

Better data will lead to **better research**.

- For multi-city SUHI studies there are a lot of variables that you need to control, e.g.:
  - Climate,
  - Elevation,
  - Form & Function,
  - Materials,
  - Distance from the sea,
  - Urban Green
  - etc.
- Facilitating this will help people to focus on analyzing the data instead of collecting data.

Athens, GR

Amsterdam, NL

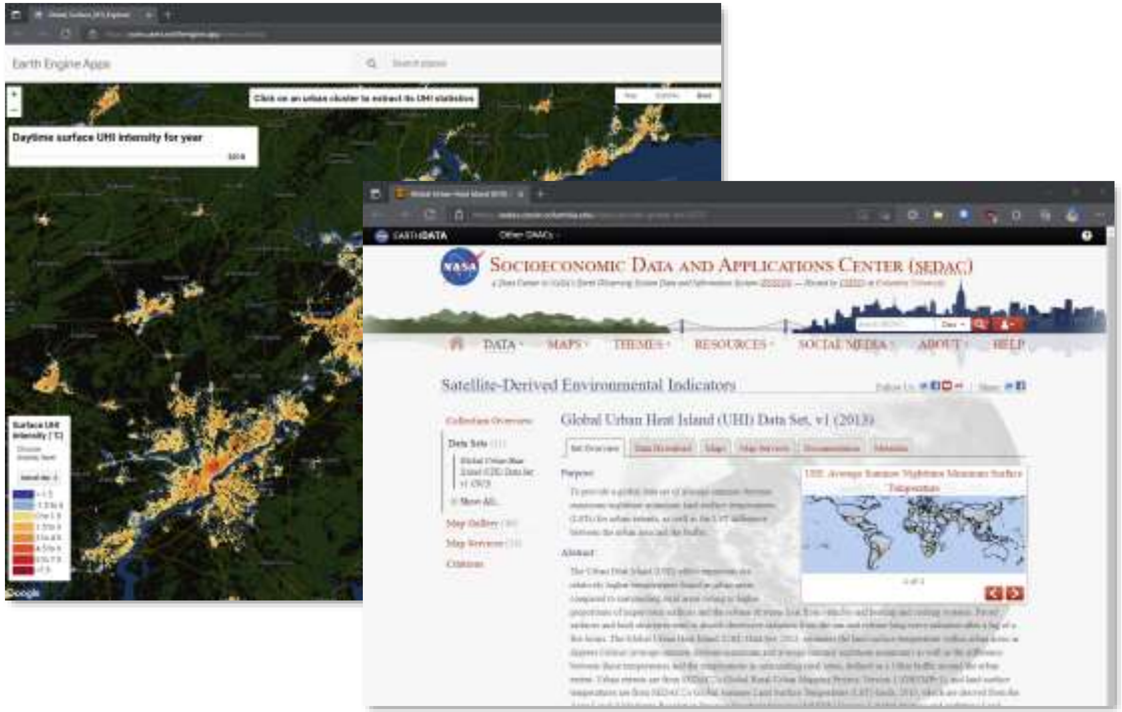
Phoenix, US

Riyadh, SA

Our Aim

- Global SUHI Dataset
- Analysis-ready tabular data
- Consistent urban/rural definition
- Long time-series of data (>20 years)
- Daytime / Nighttime data
- Documented Uncertainties
- Ancillary data to facilitate data analysis

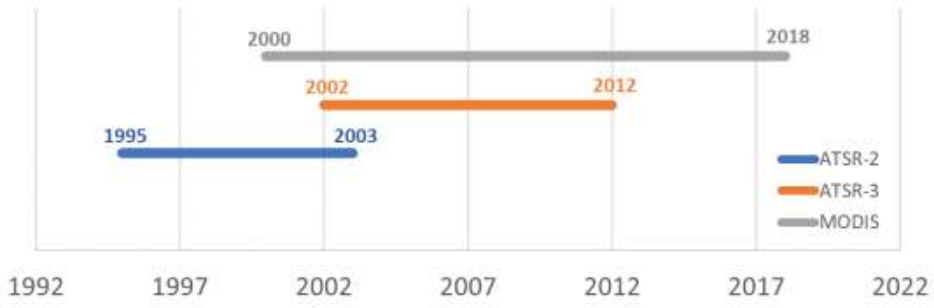
Available Datasets



Build upon previous works
- Keep what works
- Address some of the weaknesses.

LST_cci

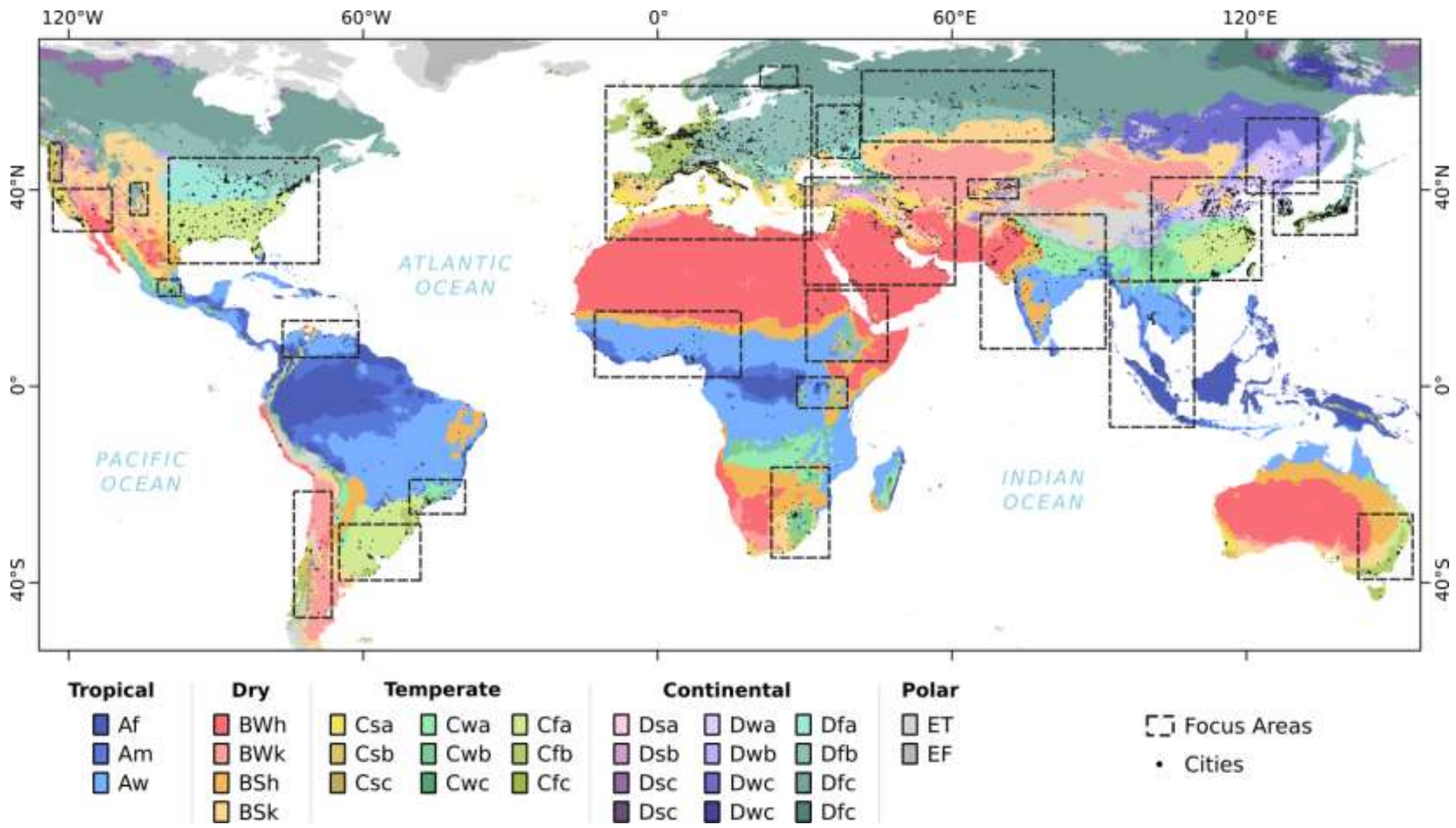
- The focus of CCI is on climate applications
- Target accuracy and precision is < 1 K
- Consistent LST retrieval algorithm
- Quantification of uncertainties
- 1 km LST data available since 1995



esa

land surface temperature cci

Global Coverage

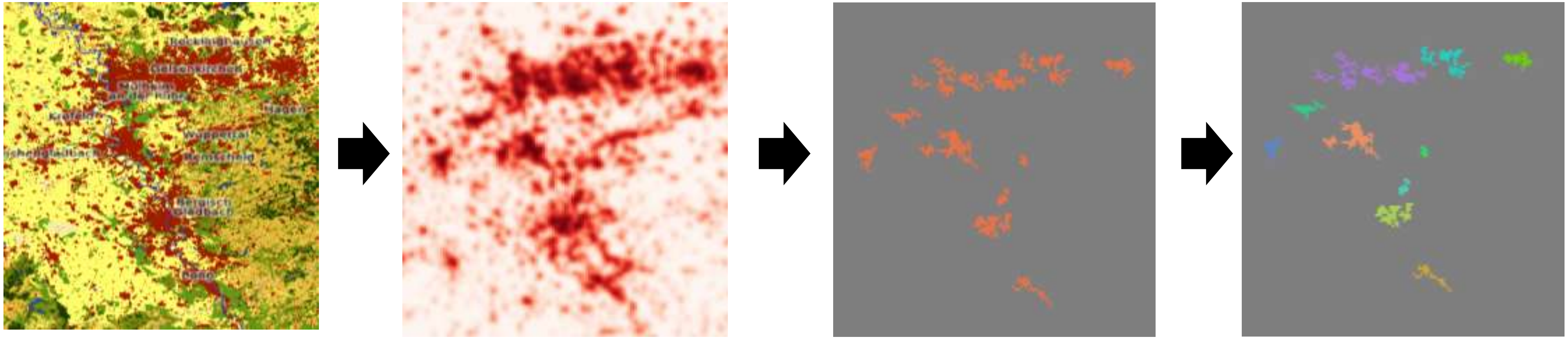


Köppen-Geiger Climate Zones

City Delineation (1/5)

- We use a custom implementation of the **City Clustering Algorithm**.

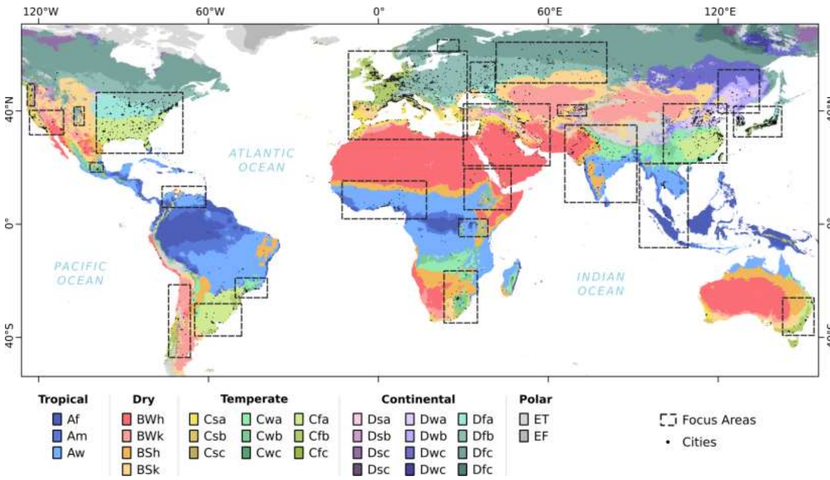
300 m Land Cover | 1 km Urban Fraction | Filtered Urban Mask | Labelled Urban Clusters

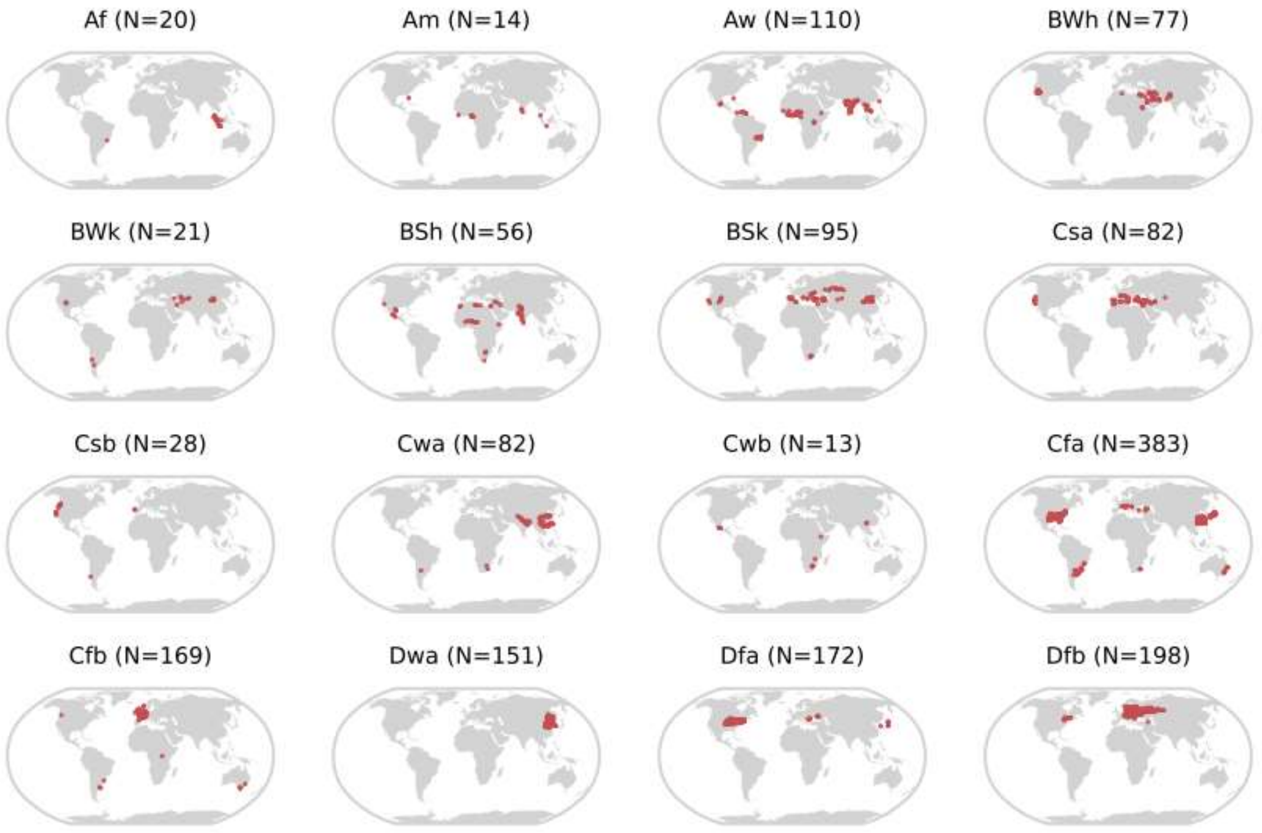


1995 to Today

- Urban Fraction >95%
- Water fraction 0%
- Distance from coastline > ~2 km
- 9 or more connected pixels

City Delineation (5/5)





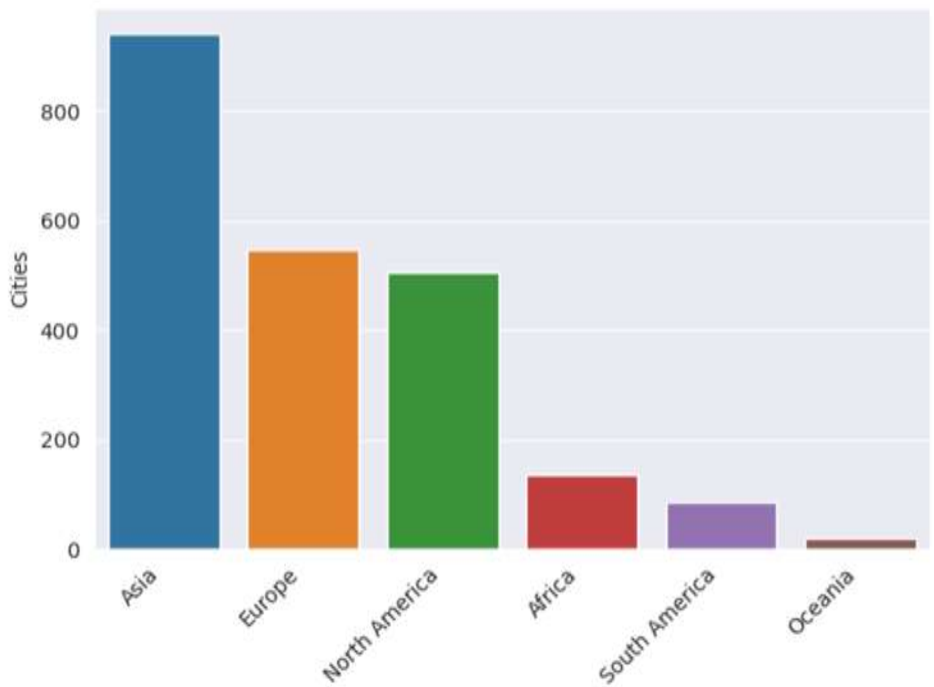
2085 Cities

in 20 Köppen-Geiger classes

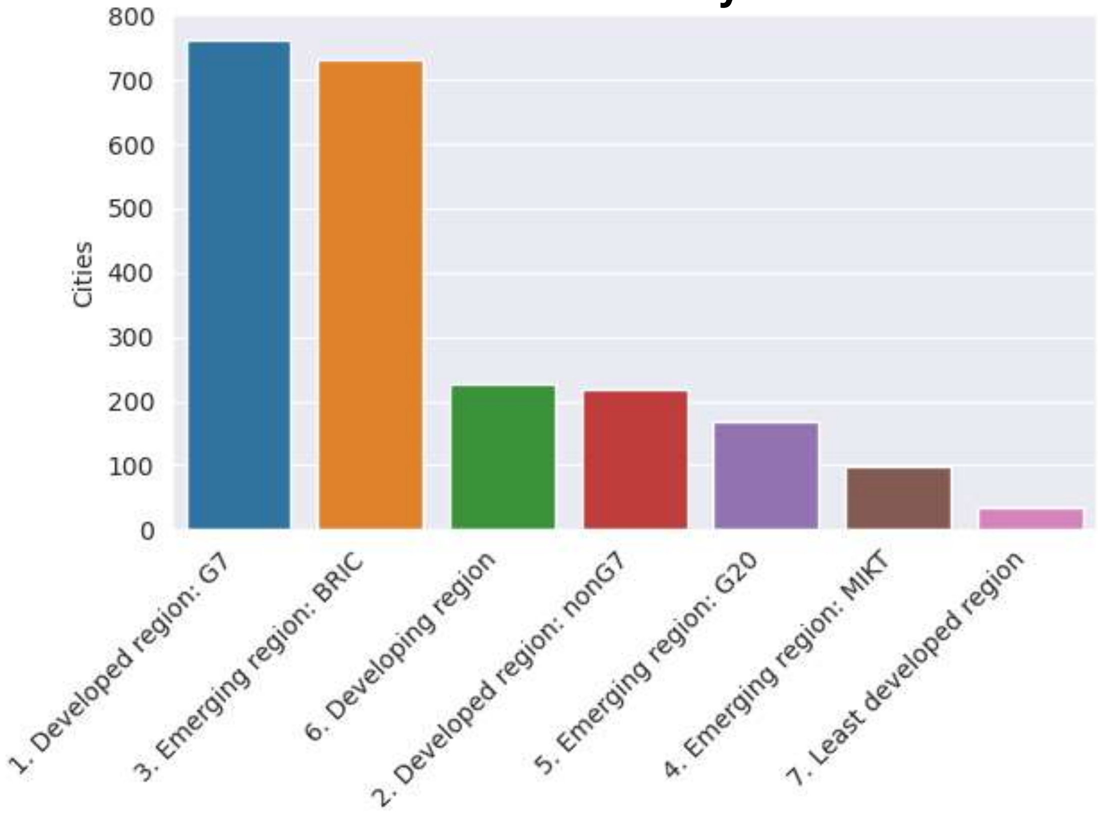
(Only the zones with 10 or more cities are shown here)

City Delineation (5/5)

Geographic Distribution



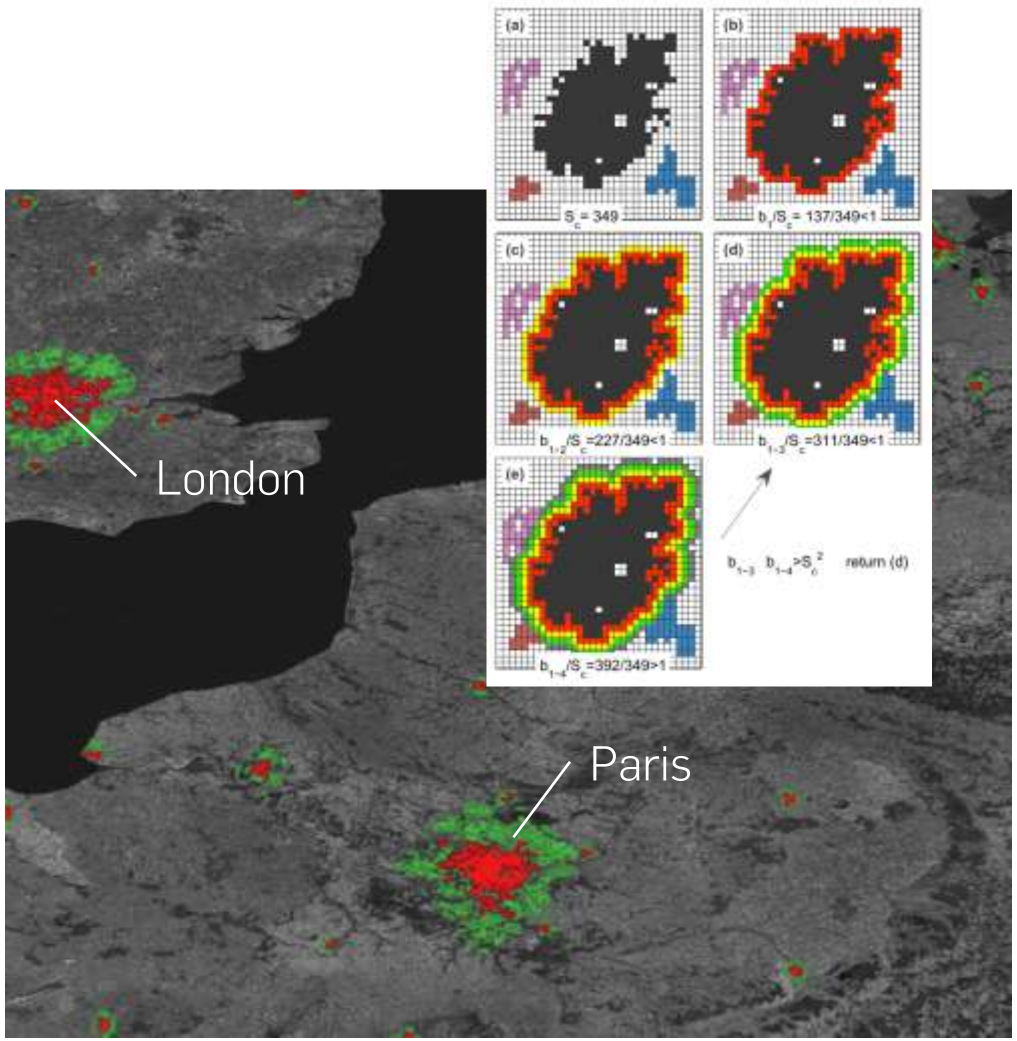
Economy



Natural Buffer (1/2)

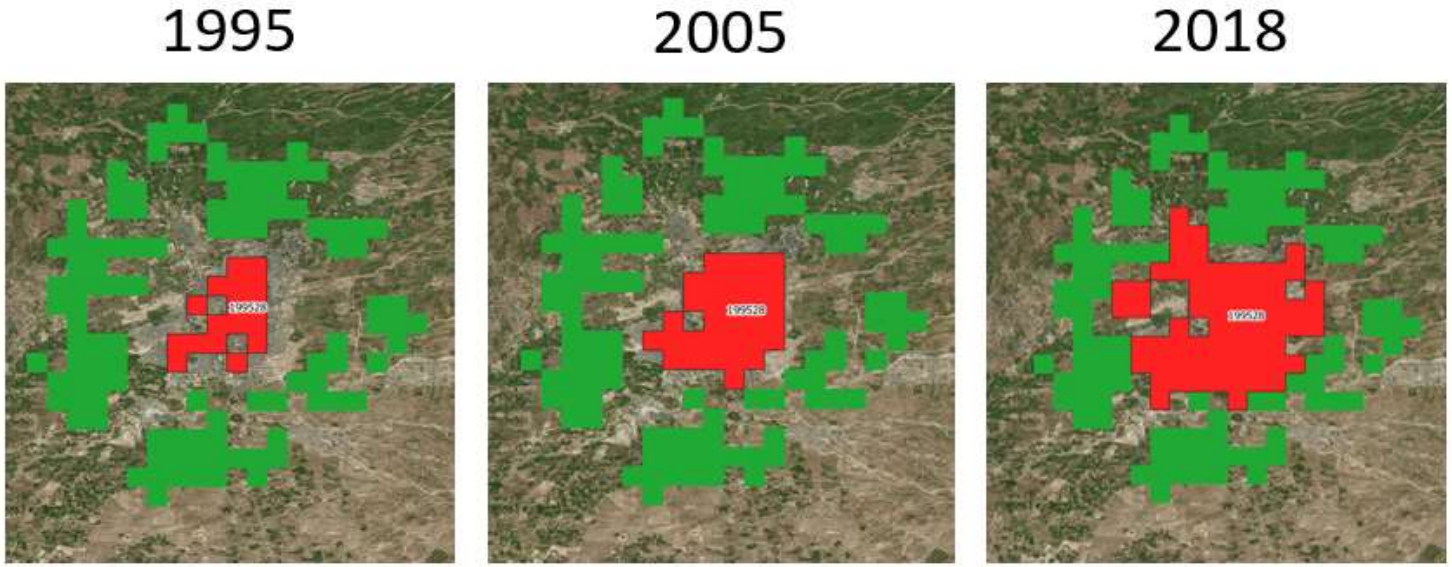
- We iteratively expand a buffer around each city until they have approx. the same city.
- One per city
- Same for all years
- Natural LC fraction is ≥95% for each year.
- Urban & water fractions are 0%.
- The elevation must not differ by more than ±200 m from the median elevation of the urban area.
- Maximum width is 30 pixels

Zhou et al. 2013

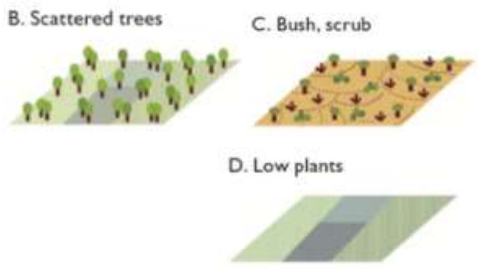


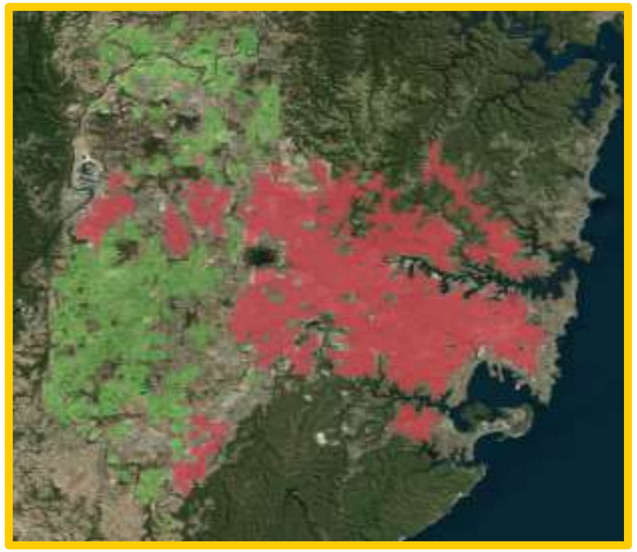
Natural Buffer (2/3)

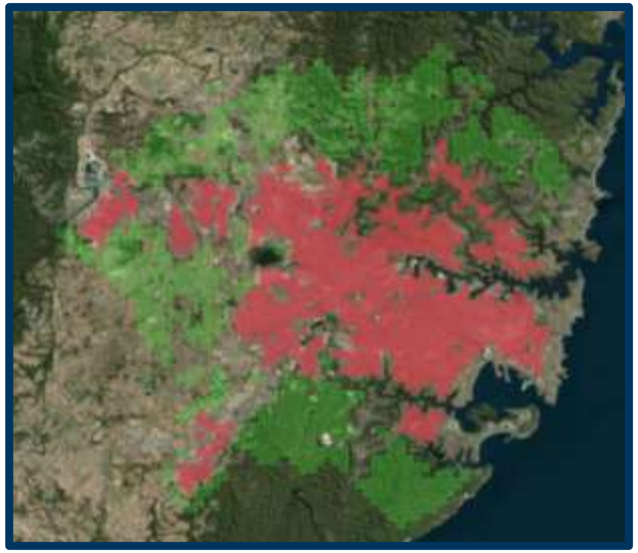
The natural buffers are representative for all the years.

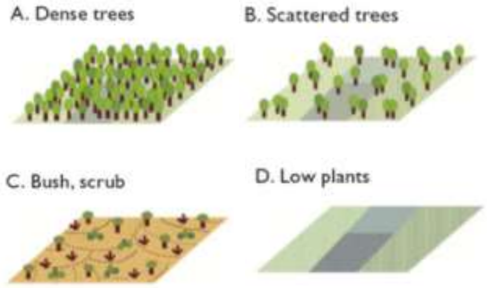


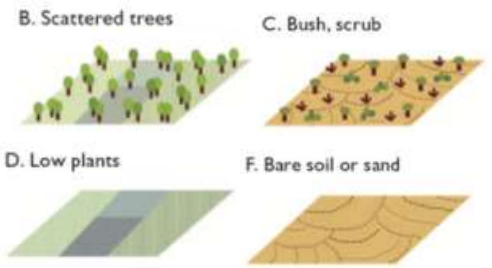
Natural Buffer (3/3)

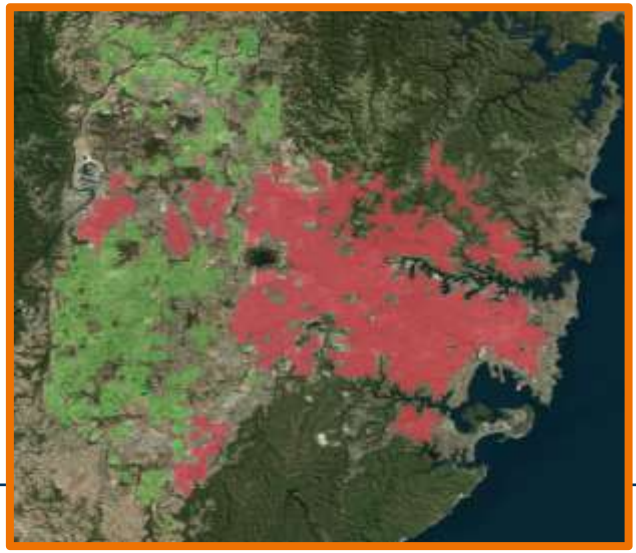


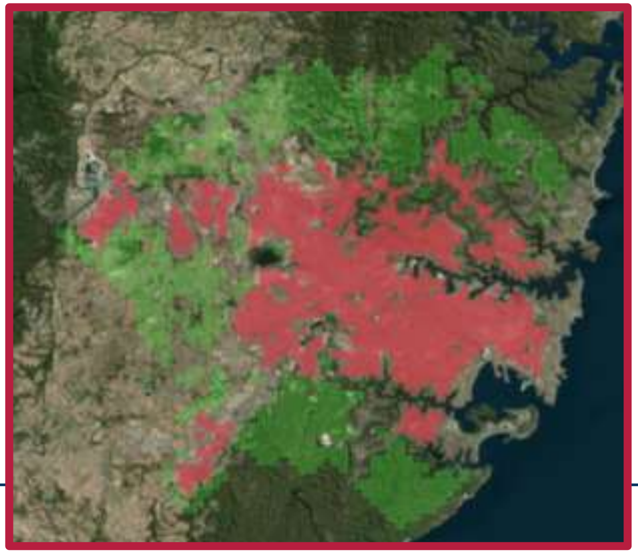


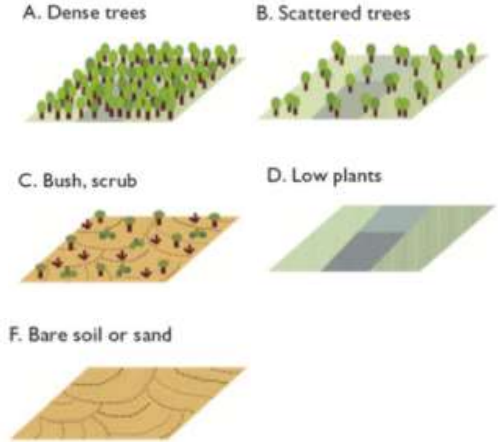






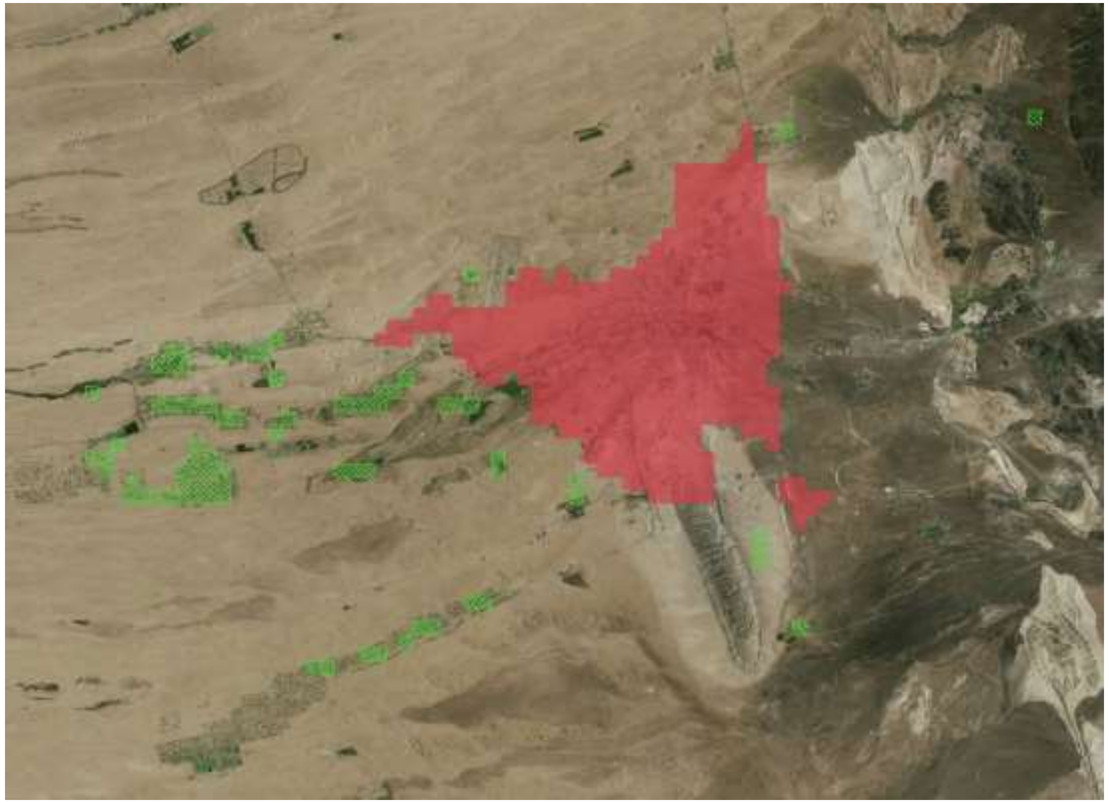


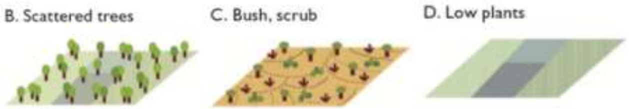




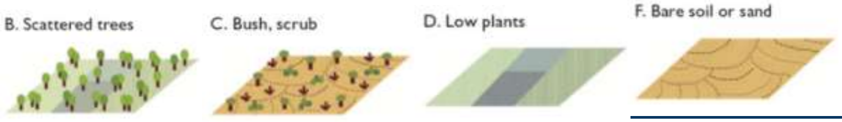
Natural Buffer - Examples

Rural (LCZ B + C + D)



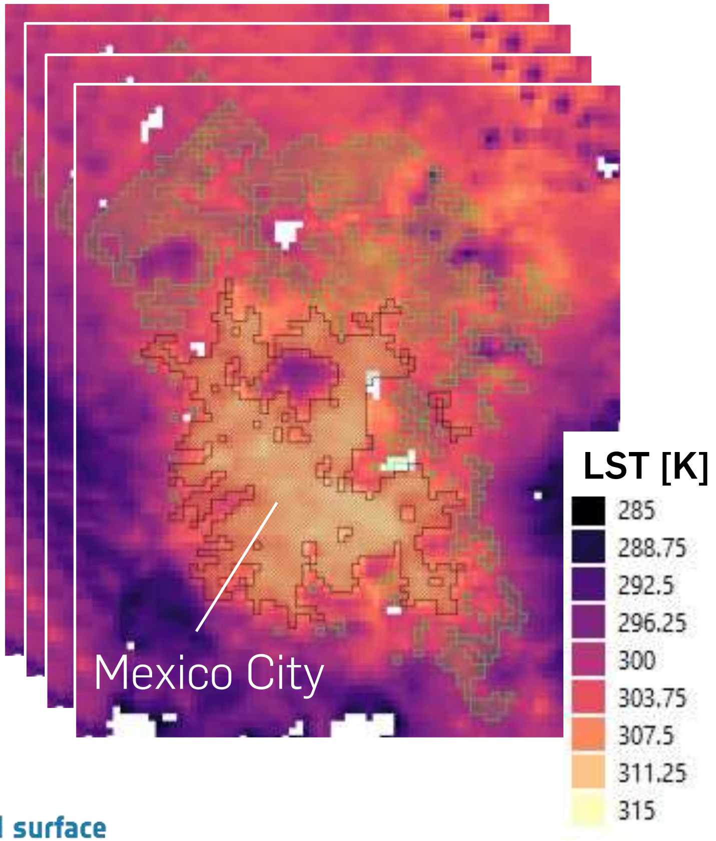


Rural + Bare Soil (LCZ B + C + D + F)



LST Means & SUHI Intensity

2000-2018 Daily LST
(Daytime or Nighttime)



$$\textcolor{orange}{\text{SUHII}} = \overline{\text{LST}}_{\text{urban}} - \overline{\text{LST}}_{\text{rural}}$$

For each day:

Urban Pixels → Quality Filtering → Urban Spatial Mean → Calculate SUHII

Rural Pixels → Quality Filtering → Rural Spatial Mean → Calculate SUHII

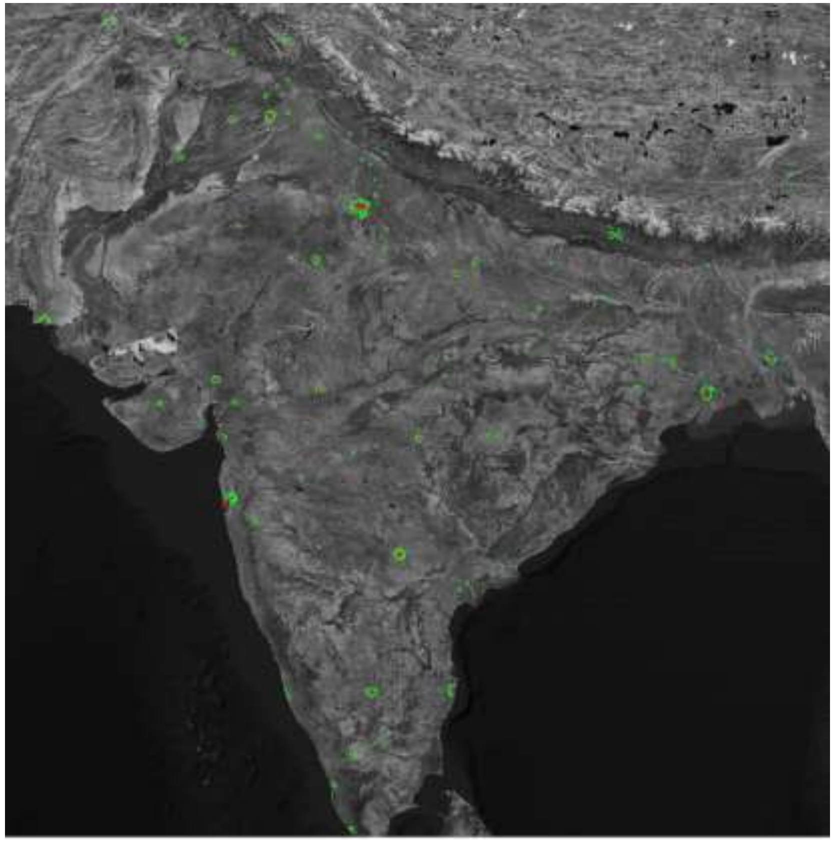
Outputs (1/2)

	UID	datetime_UTC	lc_class	lst_mean	lst_sem	lst_std	lst_min	lst_max	pxl_perc	satze_median	satze_range	soltime_median	soltime_range
1	BRA199518	2018-12-30 13:07:12	0	315.8814	0.2488	1.1312	313.15	317.77	100	22.01	0.35	10.1	0.01
2	BRA199518	2018-12-28 13:20:00	0	314.7046	0.129	0.4851	313.49	315.63	61.9	-4.72	0.31	10.3	0
3	BRA199518	2018-12-14 13:07:12	0	320.0141	0.326	1.3442	317.12	321.62	80.95	22	0.36	10.1	0.01
4	BRA199518	2018-12-14 13:07:12	2	312.9933	0.1853	0.321	312.54	313.24	20	22.16	0.45	10.1	0.01
5	BRA199518	2018-12-12 13:20:00	0	319.8812	0.2283	0.9413	317.46	321.37	80.95	-4.75	0.45	10.3	0.01
6	BRA199518	2018-12-10 13:32:48	0	315.6266	0.2886	1.3223	312.72	317.78	100	-29.98	0.33	10.52	0
7	BRA199518	2018-12-10 13:32:48	2	311.048	0.3531	1.3676	309.19	313.26	100	-29.89	0.73	10.52	0
8	BRA199518	2018-12-09 12:50:08	0	309.6176	0.2286	1.0476	307.41	310.9	100	50.01	0.18	9.8	0
9	BRA199518	2018-12-09 12:50:08	2	306.15	0.4843	1.7463	303.6	309.52	86.67	50.04	0.41	9.8	0
10	BRA199518	2018-12-05 13:12:32	0	316.9709	0.2626	0.8711	315.45	318.56	52.38	9.06	0.46	10.22	0.01
11	BRA199518	2018-11-28 13:07:12	0	311.6623	0.3514	1.2869	309.35	314.14	61.9	21.66	0.29	10.11	0.01
12	BRA199518	2018-11-28 13:07:12	2	309.145	0.1662	0.235	308.91	309.38	13.33	21.335	0.05	10.11	0
13	BRA199518	2018-11-12 13:07:12	0	314.5895	0.1821	0.8144	313.13	315.79	95.24	20.985	0.41	10.1	0.01
14	BRA199518	2018-11-12 13:07:12	2	311.8233	0.2668	0.4621	311.24	312.37	20	21.39	0.46	10.09	0
15	BRA199518	2018-11-03 13:15:44	0	316.3635	0.1303	0.5829	314.61	317.19	95.24	7.55	0.39	10.23	0
16	BRA199518	2018-10-23 13:32:48	0	314.21	0.1558	0.6231	312.98	315.33	76.19	-31.375	0.3	10.53	0.01
17	BRA199518	2018-10-22 12:50:08	0	309.1316	0.203	0.8847	307.03	310.52	90.48	49.14	0.23	9.81	0
18	BRA199518	2018-10-22 12:50:08	2	307.89	0	0	307.89	307.89	6.67	49.11	0	9.81	0
19	BRA199518	2018-10-21 13:45:36	0	306.115	0.251	0.355	305.76	306.47	9.52	-49.06	0.02	10.73	0
20	BRA199518	2018-10-21 13:45:36	2	304.5	0	0	304.5	304.5	6.67	-48.87	0	10.73	0
21	BRA199518	2018-10-20 13:02:56	0	304.4431	0.6266	2.2591	299.53	306.62	61.9	31.81	0.28	10.02	0.01
22	BRA199518	2018-10-20 13:02:56	2	301.7375	0.2468	0.4936	301.24	302.5	26.67	32.12	0.1	10.02	0
23	BRA199518	2018-09-25 13:07:12	0	310.3507	0.1876	0.702	308.78	311.36	66.67	19.995	0.35	10.11	0
24	BRA199518	2018-09-25 13:07:12	2	309.204	0.3305	0.739	308.47	310.56	33.33	20.11	0.58	10.11	0.01
25	BRA199518	2018-09-24 13:29:57	0	308.6747	0.0878	0.4481	307.6	309.18	100	-65.4	0.12	11.04	0.01
26	BRA199518	2018-09-24 13:29:57	2	308.621	0.1565	0.495	307.92	309.18	66.67	-65.345	0.12	11.04	0.01
27	BRA199518	2018-09-23 13:20:00	0	311.0829	0.1997	0.9153	309.18	312.35	100	-6.95	0.43	10.32	0.01
28	BRA199518	2018-09-23 13:20:00	2	309.3587	0.2487	0.9633	306.99	310.57	100	-6.83	0.87	10.32	0.01
29	BRA199518	2018-09-12 13:39:12	0	305.3495	0.1436	0.6092	304.35	306.57	85.71	-41.47	0.27	10.62	0
30	BRA199518	2018-09-12 13:39:12	2	304.0558	0.2445	0.8469	302.78	305.88	80	-41.285	0.58	10.62	0
31	BRA199518	2018-09-09 13:07:12	0	304.0976	0.134	0.6139	302.95	305.09	100	19.86	0.37	10.11	0
32	BRA199518	2018-09-09 13:07:12	2	302.8393	0.3689	1.3802	301.07	305.44	93.33	19.955	0.82	10.11	0
33	BRA199518	2018-09-08 13:29:57	0	300.5965	0.0812	0.363	299.93	301.12	95.24	-65.45	0.07	11.04	0
34	BRA199518	2018-09-08 13:29:57	2	300.1061	0.1823	0.6573	299.39	301.2	86.67	-65.4	0.13	11.04	0.01
35	BRA199518	2018-09-07 13:20:00	0	303.3881	0.1674	0.7672	301.87	304.29	100	-7.1	0.42	10.33	0
36	BRA199518	2018-09-07 13:20:00	2	302.9493	0.2199	0.8517	300.95	304.19	100	-7	0.91	10.33	0.01
37	BRA199518	2018-09-06 13:10:02	0	298.4	0	0	298.4	298.4	4.76	60.31	0	9.61	0
38	BRA199518	2018-09-06 13:10:02	2	297.8467	0.1711	0.2963	297.46	298.18	20	60.41	0.05	9.61	0.01
39	BRA199518	2018-09-05 13:32:48	2	293.42	0	0	293.42	293.42	6.67	-31.5	0	10.52	0
40	BRA199518	2018-09-03 13:45:36	0	308.9433	0.1124	0.4355	307.9	309.58	71.43	-49.38	0.21	10.74	0.01
41	BRA199518	2018-09-03 13:45:36	2	308.4983	0.1411	0.3457	307.76	308.83	40	-49.165	0.22	10.74	0
42	BRA199518	2018-09-02 13:02:56	0	308.1072	0.2125	0.9739	306.11	309.44	100	31.36	0.31	10.03	0.01
43	BRA199518	2018-09-02 13:02:56	2	307.18	0.2454	0.9182	305.63	308.81	93.33	31.44	0.67	10.03	0.01
44	BRA199518	2018-09-01 13:24:58	0	309.338	0.0611	0.2366	308.86	309.66	71.43	-61.03	0.13	10.92	0.01
45	BRA199518	2018-09-01 13:24:58	2	309.4363	0.1124	0.3178	308.95	309.85	53.33	-61.085	0.23	10.925	0.01

- Datetime (UTC)
- LST mean, min, max, std, sem
- % missing pixels
- Median VZA
- Median Local Solar Time

Outputs (2/2)

The urban and natural polygons as vectors.



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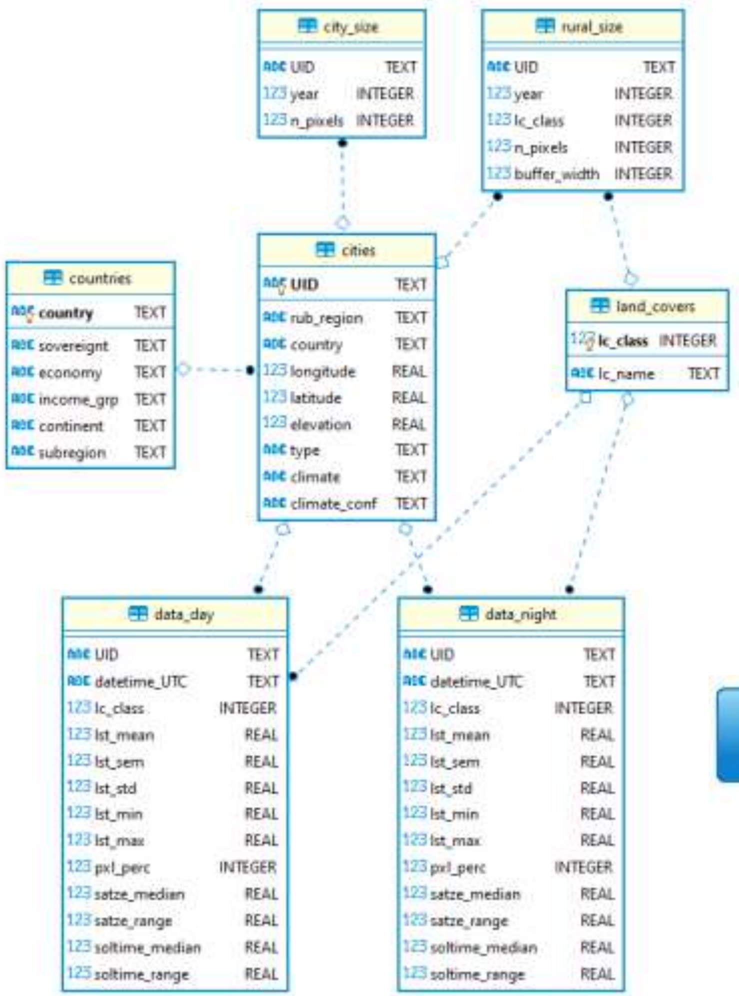
CHI19951	1,995	2	50.4050616615	4
CHI19951	1,995	3	50.4050616615	4
CHI19951	1,995	4	50.4050616615	4
CHI19952	1,995	1	52.4656549469	4
CHI19952	1,995	2	52.4656549469	4
CHI19952	1,995	3	52.4656549469	4
CHI19952	1,995	4	52.4656549469	4
CHI19953	1,995	1	14.8200509031	4
CHI19953	1,995	2	14.8200509031	4
CHI19953	1,995	3	18.5267232096	4
CHI19953	1,995	4	18.5267232096	4
CHI19955	1,995	1	35.4400293406	5
CHI19955	1,995	2	36.371866115	5
CHI19955	1,995	3	35.4400293406	5
CHI19955	1,995	4	36.371866115	5
CHI19956	1,995	1	28.9139533687	4
CHI19956	1,995	2	28.9139533687	4
CHI19956	1,995	3	28.9139533687	4
CHI19956	1,995	4	28.9139533687	4
CHI19957	1,995	1	110.5782754765	8
CHI19957	1,995	2	118.0685795404	7
CHI19957	1,995	3	111.5165267497	8
CHI19957	1,995	4	119.0068308136	7
CHI19958	1,995	1	36.5601307981	4
CHI19958	1,995	2	36.5601307981	4
CHI19958	1,995	3	36.5601307981	4
CHI19958	1,995	4	36.5601307981	4
CHI19959	1,995	1	26.252423563	4
CHI19959	1,995	2	26.252423563	4
CHI19959	1,995	3	30.0007060054	4
CHI19959	1,995	4	30.0007060054	4
CHI199510	1,995	1	31.8892963701	9
CHI199510	1,995	2	[illegible]	9

- Area
- Median Elevation
- Year of first detection
- Coastal /inland
- Number of buffer expansions

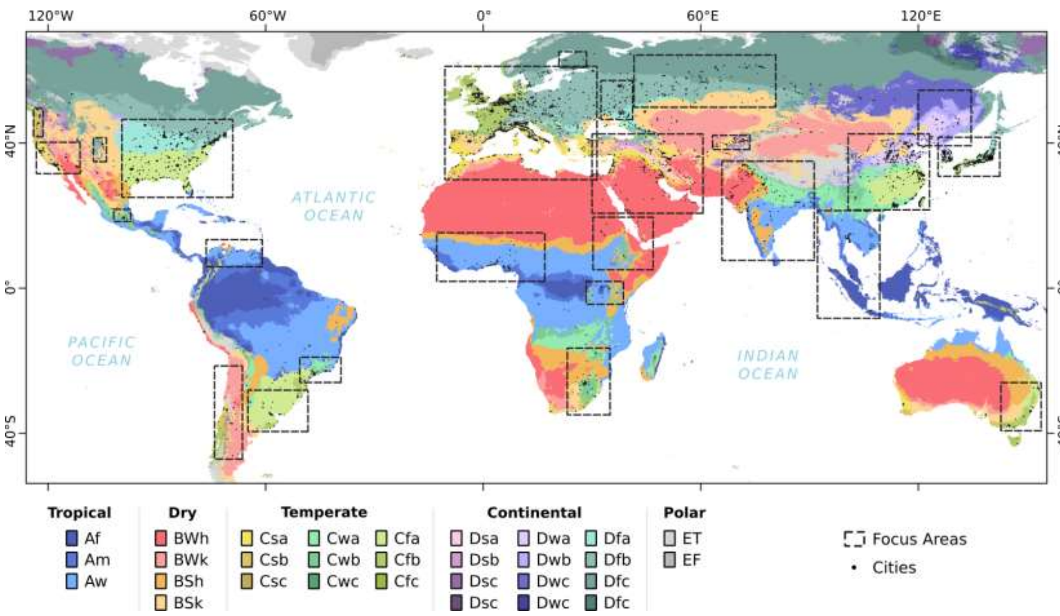
Analysis-ready Data

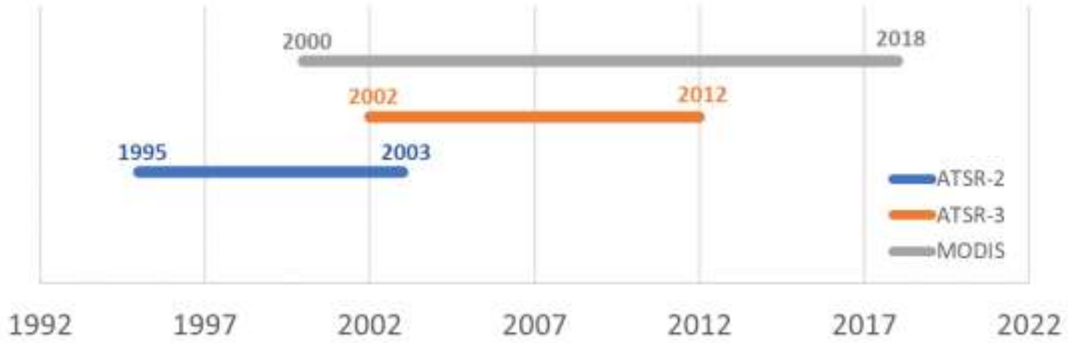
- File Format:
  - SQLite is a self-contained, file-based SQL database.
  - Stable, cross-platform, and backwards compatible.
  - Well-supported by both Python and R.
- Ancillary data
  - Timestamp (UTC & Local Solar Time)
  - City properties (area, polygon geometry, Köppen-Geiger climate class, lat/lon, elevation, coastal/inland etc.)
  - Socioeconomic data (country, economy, etc.)
  - The urban and natural polygons (as separate geojson files)



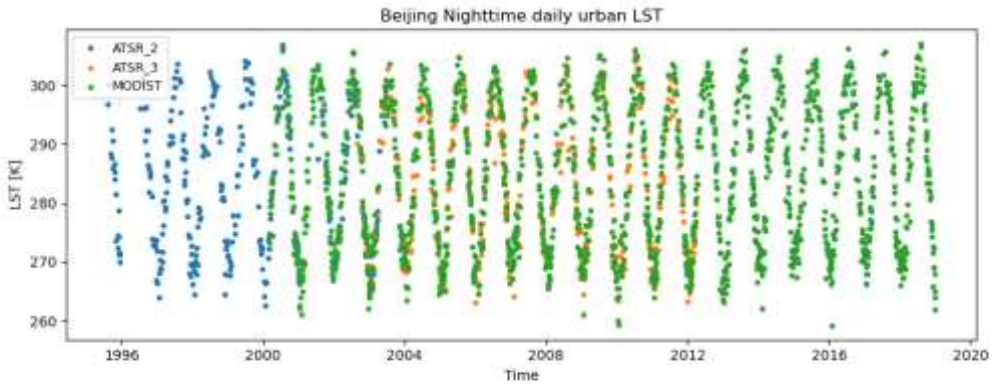
Wealth of Information

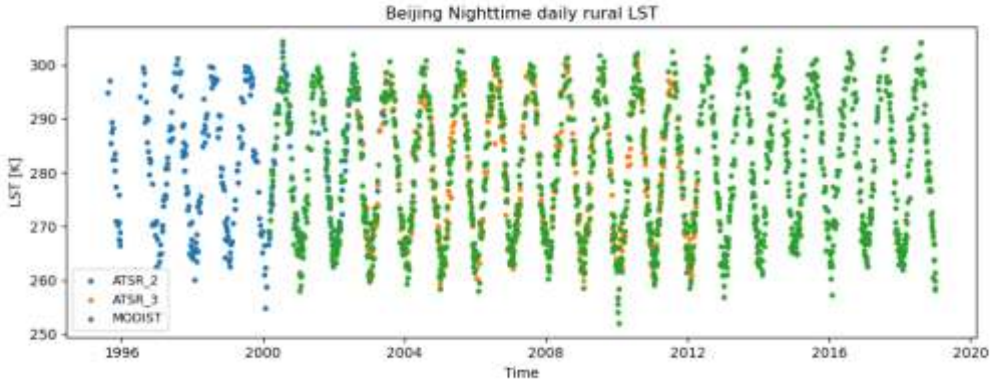
~65 million observations



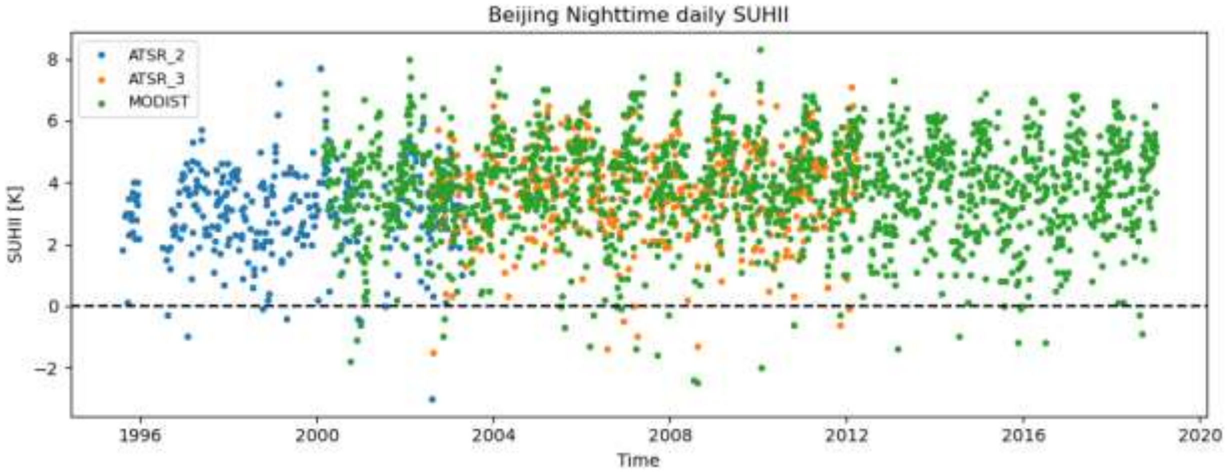


Example: Beijing, China

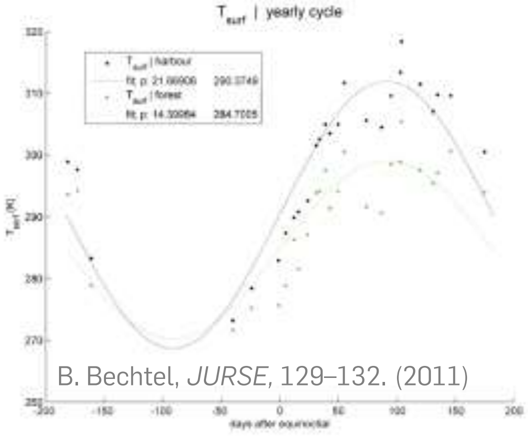




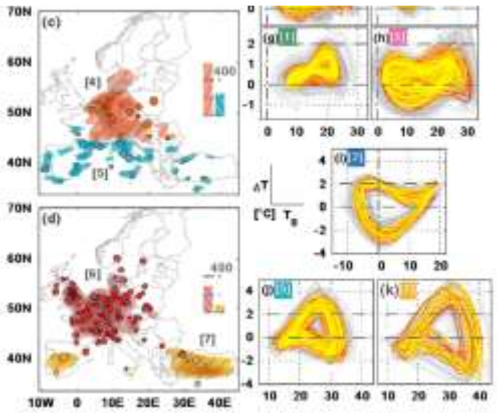
$$\mathrm{SUHII}(d) = \overline{\mathrm{LST}}_{\mathrm{urban}}(d) - \overline{\mathrm{LST}}_{\mathrm{rural}}(d)$$



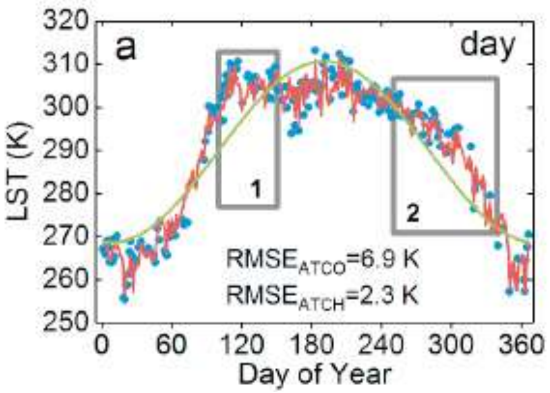
Investigating SUHI seasonality



B. Bechtel, *JURSE*, 129–132. (2011)



Zhou et al. 2013, GRL



Z. Liu *et al.*, *ISPRS Journal of Photogrammetry and Remote Sensing*. **151**, 189–206 (2019).

2011

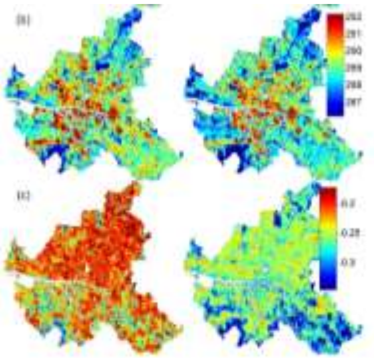
2013

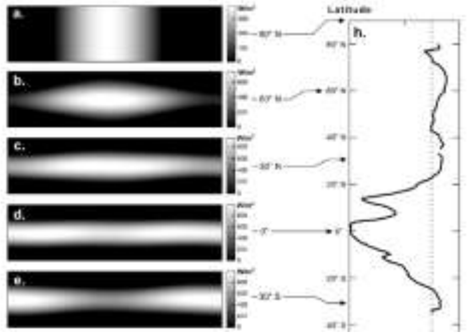
2019

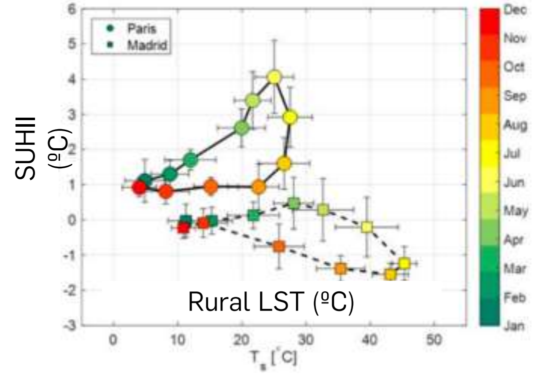
2012

2018

2020







B. Bechtel, *Geoscience and Remote Sensing Letters, IEEE*. **9**, 876–880 (2012).

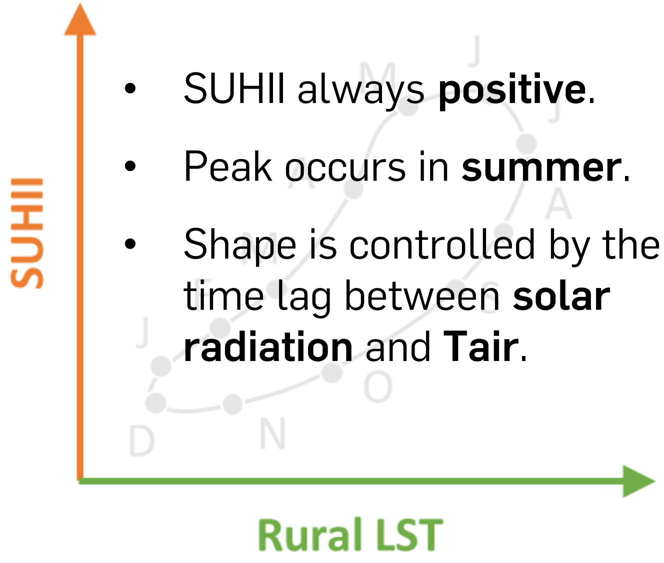
- B. Bechtel, P. Sismanidis, in *Remote Sensing: Time Series Image Processing*, Q. Weng, Ed. (2018).

Manoli et al. (2020), PNAS

SUHII Seasonal Hysteresis

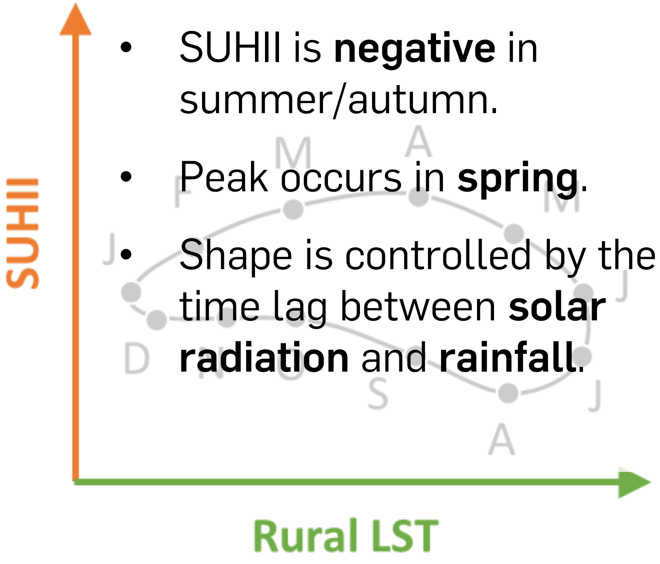
- The seasonal variation of SUHII exhibits a rate dependent hysteresis that strongly depends on local climate conditions.

Wet Climates: Concave-Up Loop



- SUHII always **positive**.
- Peak occurs in **summer**.
- Shape is controlled by the time lag between **solar radiation** and **Tair**.

Dry Climates: Concave-Down Loop



- SUHII is **negative** in summer/autumn.
- Peak occurs in **spring**.
- Shape is controlled by the time lag between **solar radiation** and **rainfall**.

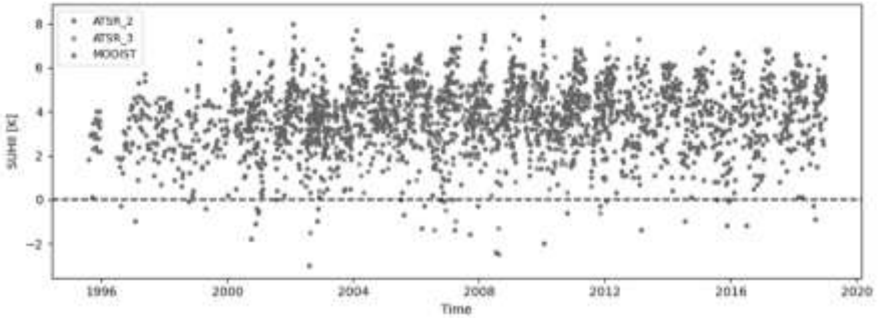
$$\text{SUHII} = \overline{\text{LST}}_{\text{urban}} - \overline{\text{LST}}_{\text{rural}}$$

Manoli et al. (2020); Bechtel et al. (2019); Zhou et al. (2013)

Data Analysis

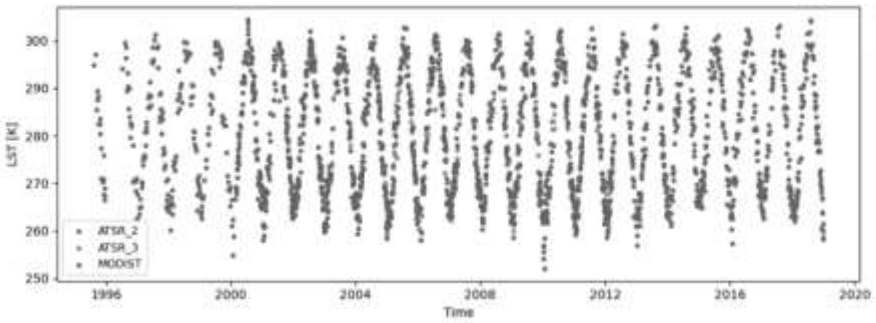
For each City:

Daily SUHII



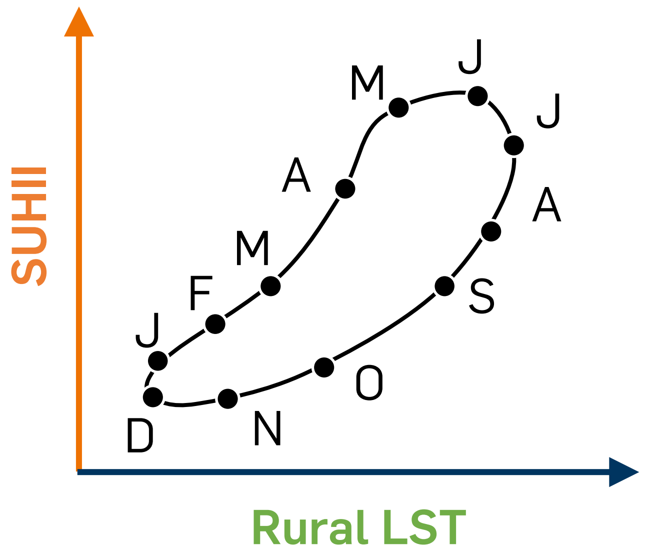
Calculate Monthly Means for all years

Daily Rural LST



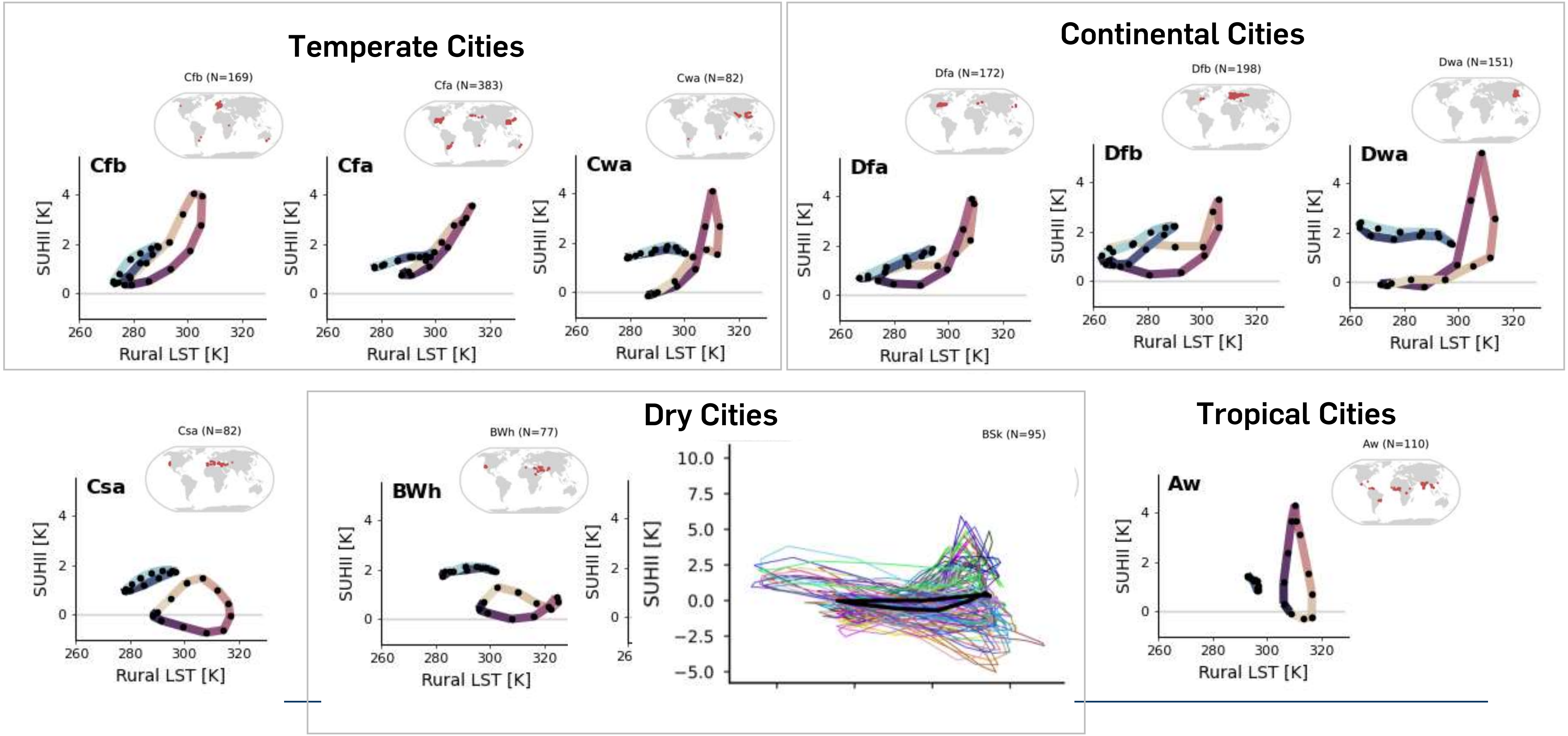
Calculate Monthly Means for all years

Hysteresis Loop



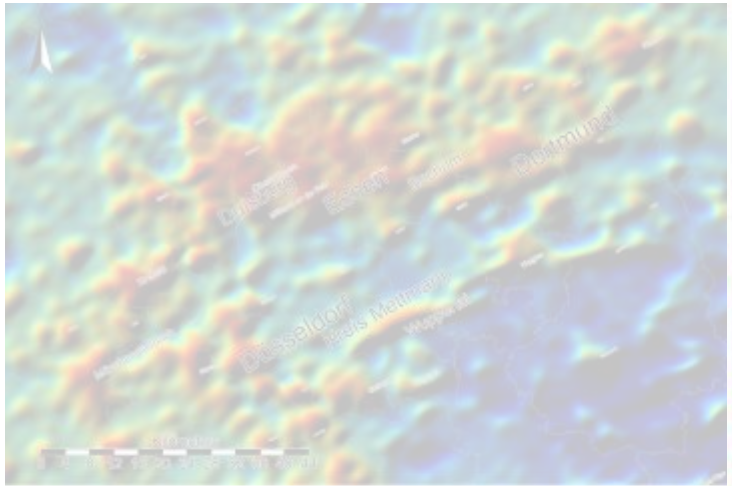
Results

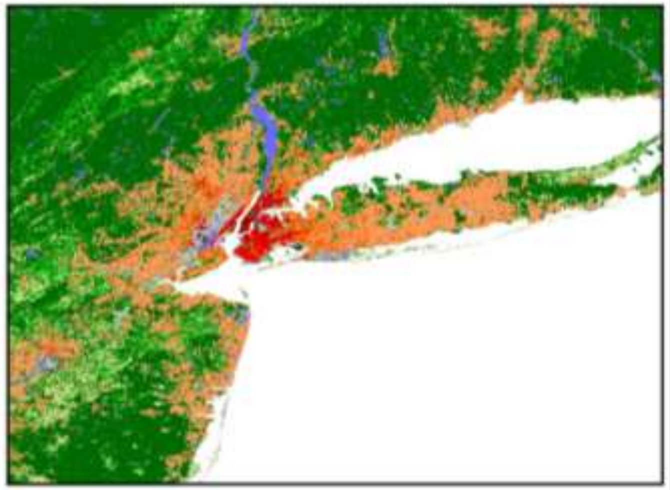
Spring Equinox (SE)
SE + 12 Months
Nighttime
Daytime



Temperate Cities
Cfb (N=169)
Cfb
Cfa (N=383)
Cfa
Cwa (N=82)
Cwa
Continental Cities
Dfa (N=172)
Dfa
Dfb (N=198)
Dfb
Dwa (N=151)
Dwa
Csa (N=82)
Csa
Dry Cities
BWh (N=77)
BWh
BSk (N=95)
Tropical Cities
Aw (N=110)
Aw
SUHII [K]
Rural LST [K]
260
280
300
320
0
2
4
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0

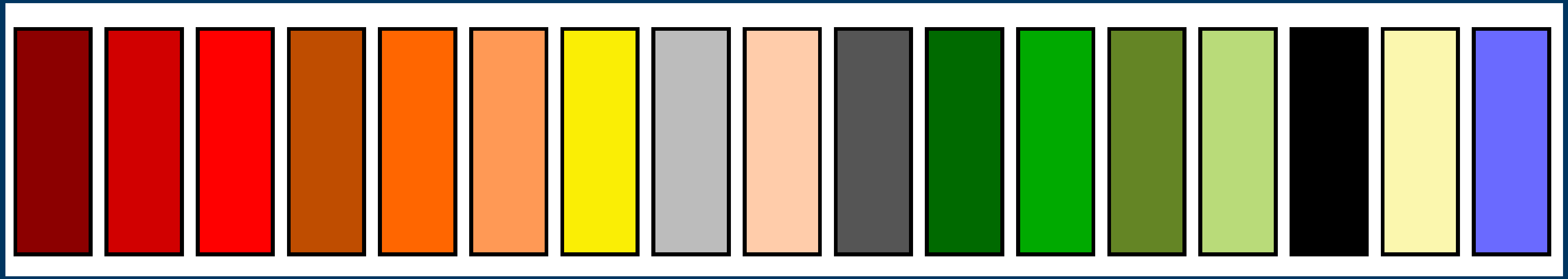
3. Urban structure and modelling

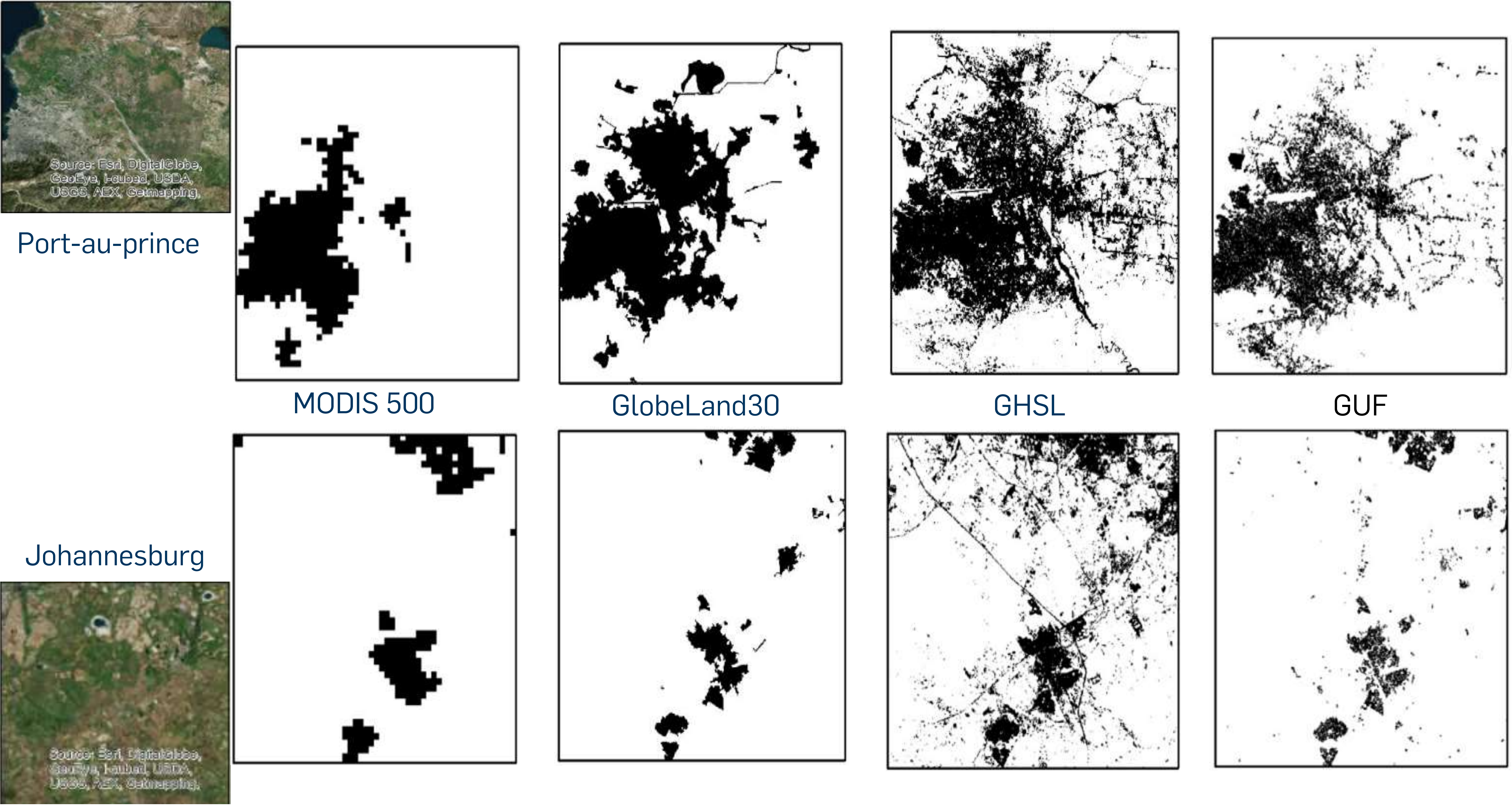




Quelle

Intra-urban differences

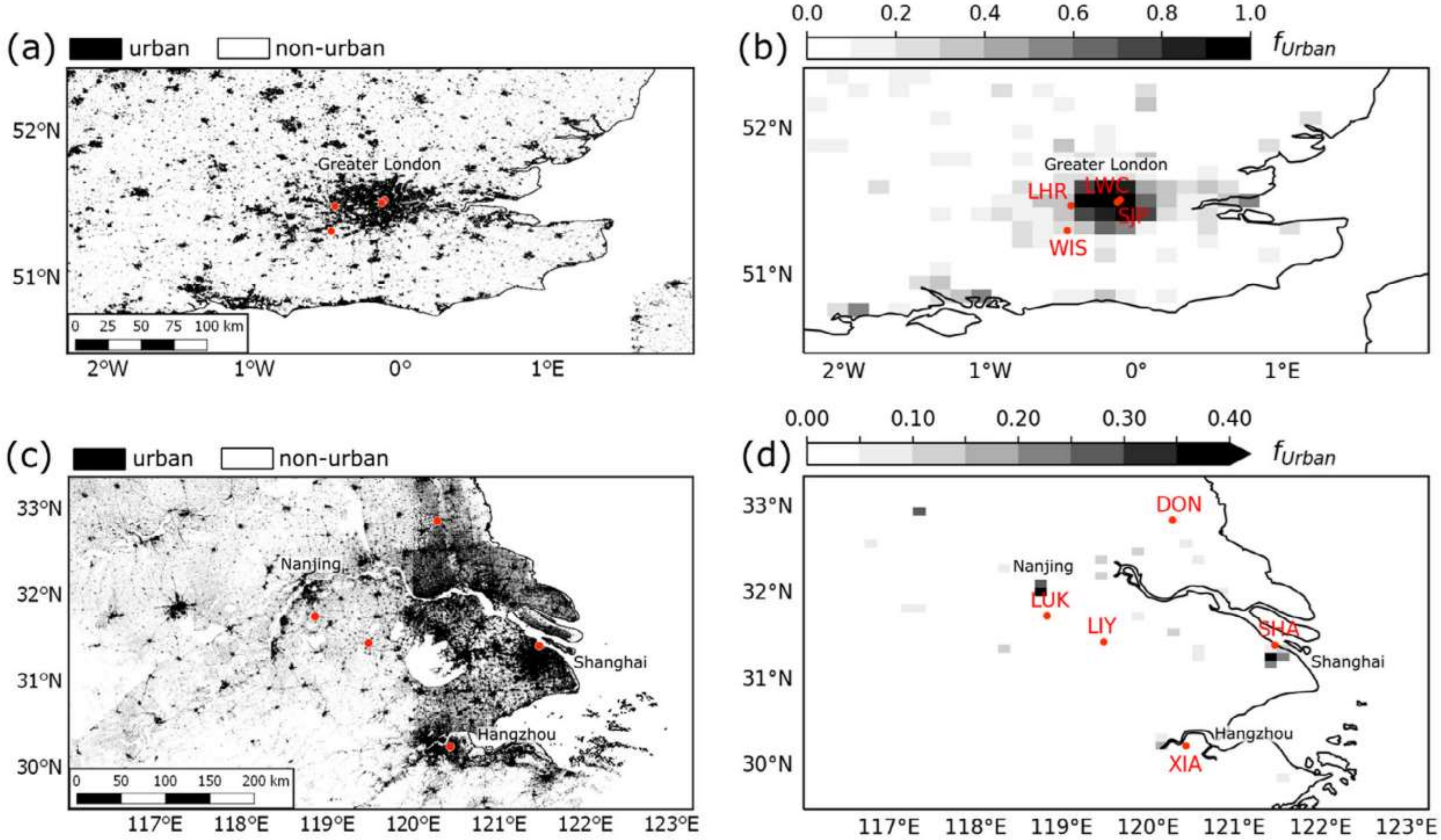




Esch et al. 2017

Context

GUF HadGEM3–PRIMAVERA ~0.1°



Hertwig D, Ng M, Grimmond S, Vidale PL, McGuire PC. High-resolution global climate simulations: Representation of cities. Int J Climatol. 2021;41(5):3266-3285. doi:10.1002/joc.7018,

WUDAPT?

WUDAPT

An Urban Weather, Climate, and Environmental Modeling Infrastructure for the Anthropocene

J. Ching, G. Mills, B. Bechtel, L. See, J. Feddema, X. Wang, C. Ren, O. Brousse, A. Martilli, M. Neophytou, P. Mouzourides, I. Stewart, A. Hanna, E. Ng, M. Foley, P. Alexander, D. Aliaga, D. Niyogi, A. Shreevastava, P. Bhalachandran, V. Masson, J. Hidalgo, J. Fung, M. Andrade, A. Baklanov, W. Dai, G. Milcinski, M. Demuzere, N. Brunsell, M. Pesaresi, S. Miao, Q. Mu, F. Chen, and N. Theeuwes

World **U**rban **D**atabase and **A**ccess **P**ortal **T**ools

WUDAPT is an international community-generated urban canopy information and modeling infrastructure to facilitate urban-focused climate, weather, air quality, and energy-use modeling application studies

Ching et al. (2018)

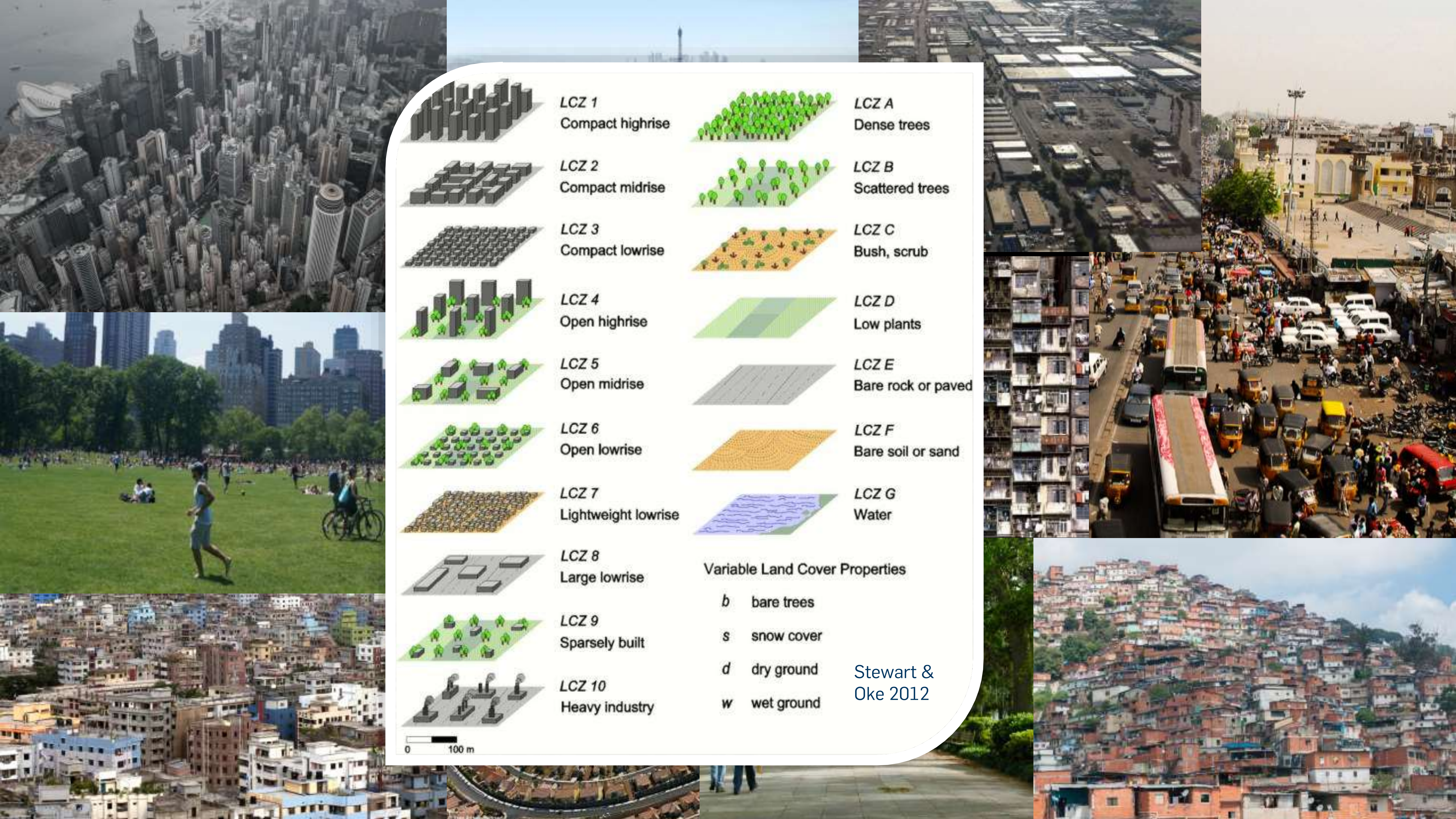
WUDAPT?

WUDAPT Levels 0, 1 & 2 features and their potential applications.

Product	Level 0	Level 1	Level 2
Coverage	Over 120 cities and regions	Data gathering methods; and testing to refine Level 0 based on crowdsourcing APPS and Buidling Typology approaches as in MApUCE	Any city by using our new 3-D mapping technology, DSC
Data source	Landsat + Google Earth + local data & expert evaluation	Landsat + Google Earth + local data & expert evaluation	World-view Stereo Data + Terra-SAR data
Resolution	100–500 m	100–500 m	2 m
Format	kml, tiff	GIS shapefiles	GIS shapefiles
Applications	Environment and Energy (Weather Research and Forecasting (WRF) Modeling, Urban heat island) Urban and Regional planning (population density)	Environment and Energy (weather and climate, urban air flows, urban radiation, mean radiant temperature, urban energy consumption, air pollution, CO2 and GHG emission) Ecology (biodiversity) Urban and Regional planning (master plan, land use plan, green master plan, new town plan)	Environment and Energy (building energy cost) Building and community design (visibility analysis, building development) Disaster and risk management (Flooding, heatwave) Pedestrian and citizen's mobility (walkability, thermal comfort) Public health (polluted areas)

Local Climate Zone maps

Ching et al.


LCZ 1
Compact highrise
LCZ 2
Compact midrise
LCZ 3
Compact lowrise
LCZ 4
Open highrise
LCZ 5
Open midrise
LCZ 6
Open lowrise
LCZ 7
Lightweight lowrise
LCZ 8
Large lowrise
LCZ 9
Sparsely built
LCZ 10
Heavy industry
0
100 m
LCZ A
Dense trees
LCZ B
Scattered trees
LCZ C
Bush, scrub
LCZ D
Low plants
LCZ E
Bare rock or paved
LCZ F
Bare soil or sand
LCZ G
Water
Variable Land Cover Properties
b bare trees
s snow cover
d dry ground
w wet ground
Stewart & Oke 2012

LCZ database?

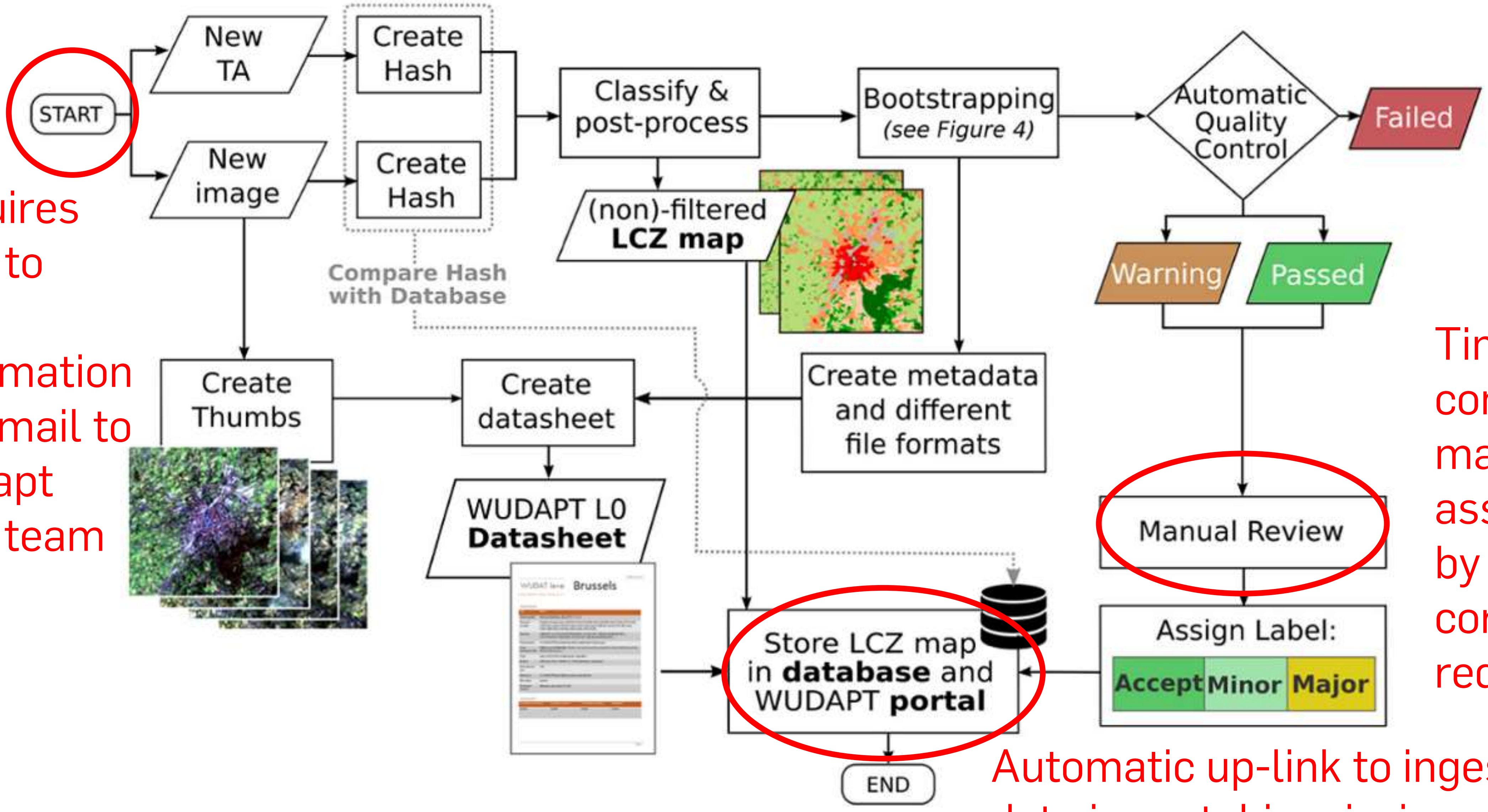


Fig. 2. The LCZ production and quality assessment workflow.

Requires user to send information via email to wudapt core team

Time-consuming manual assessment by wudapt core team required

Automatic up-link to ingest data in portal is missing.

LCZ Generator

https://lcz-generator.rub.de/

User input → **LCZ classification & quality control** → **Output**

User input

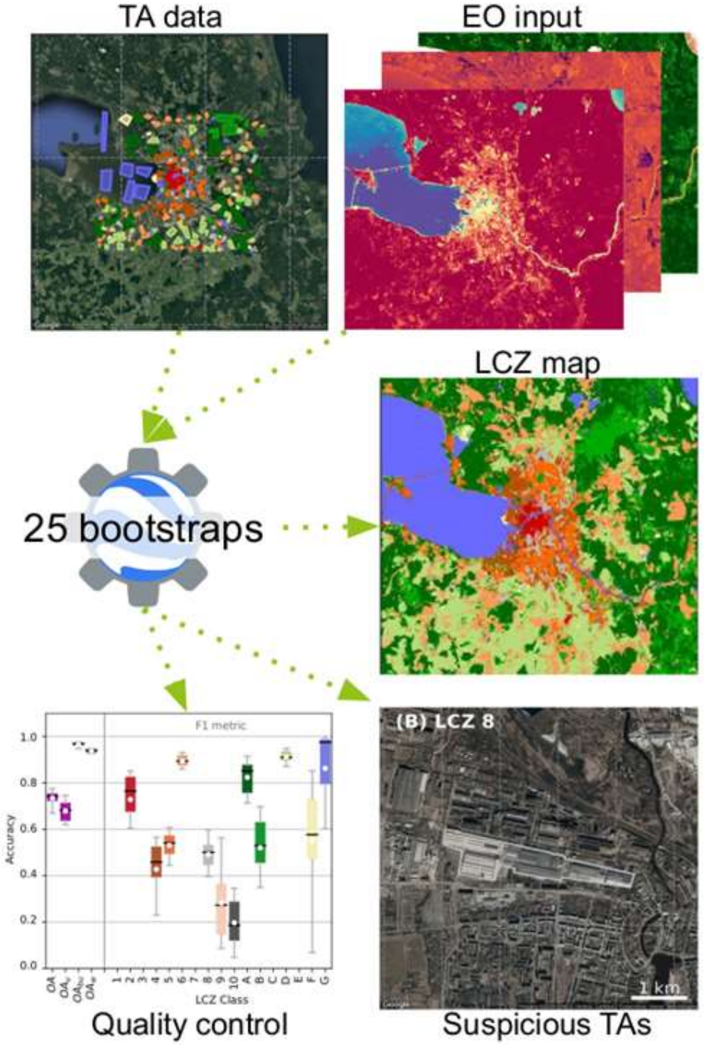
1. **Personal information**

- First Name
- Last Name
- E-mail Address

2. **Training area information**

- Continent
- Country
- City Name
- **Upload training area file**
- Representative Date
- Reference
- Remarks

LCZ classification & quality control



Output

1. **Compressed results (e-mail)**

- Factsheet
- LCZ map
- QGIS/ArcGIS colormaps
- data/
  - *ID.kml*
  - *ID_TA_statistics.csv*
  - *ID_auto_qc_polygon.shp*
  - *ID_auto_qc_point.shp*
  - *ID_cm_average_formatted.csv*
- figures/
  - *ta_freq.png*
  - *lcz_map.jpg*
  - *lcz_oa.jpg*

2. **Online submission table**

Improve training area data

LCZ Generator

https://lcz-generator.rub.de/

Welcome to the LCZ Generator!

Fast and easy Local Climate Zone mapping

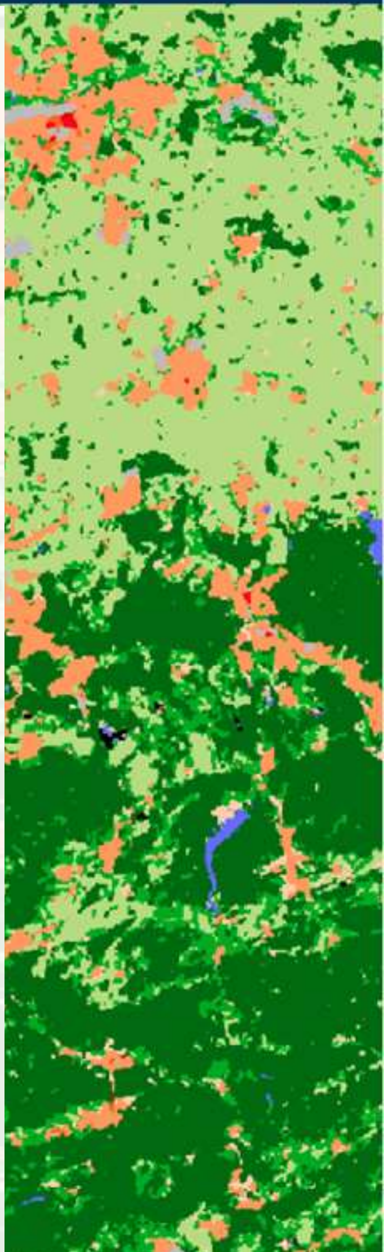
Getting started:

1. Read Demuzere et al. (2021) it serves as the primary user guide
2. Download the Training Area Template kml file
3. Create your Training Areas following the guidelines
4. Once finished, use the submission form to submit your file.
5. Fill out the fields in the submission form; fields with an asterisk (*) are required.
   ▸ Show detailed information
6. Submit the form. If you see a green box appear on the top of the page after clicking the submit button, your submission was successful and will be processed. If a red box appears, there was a problem with your Training Area file. Check out the FAQ for more information.
7. You will be notified via email once the processing has finished. Depending on the current load of the system it should take ~20 minutes.
8. After you received the email, your submission is also available in the submission table.

Submit your Training Area | Show generated LCZ maps

Please cite the tool using:

Demuzere, M., Kittner, J., Bechtel, B. (2021). LCZ Generator: a web application to create Local Climate Zone maps. Frontiers in Environmental Science 9:637455. https://doi.org/10.3389/fenvs.2021.637455



LCZ Generator https://lcz-generator.rub.de/

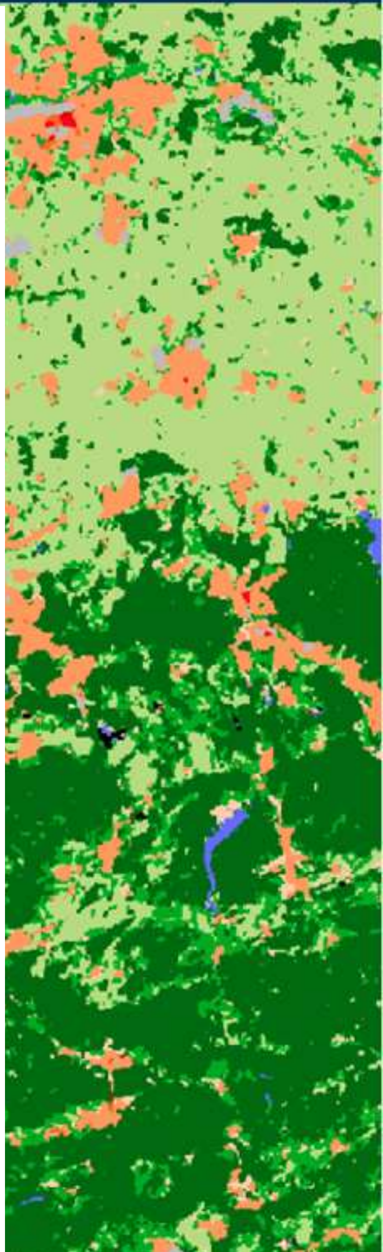
LCZ Generator Home Training area submission Available LCZ maps FAQ

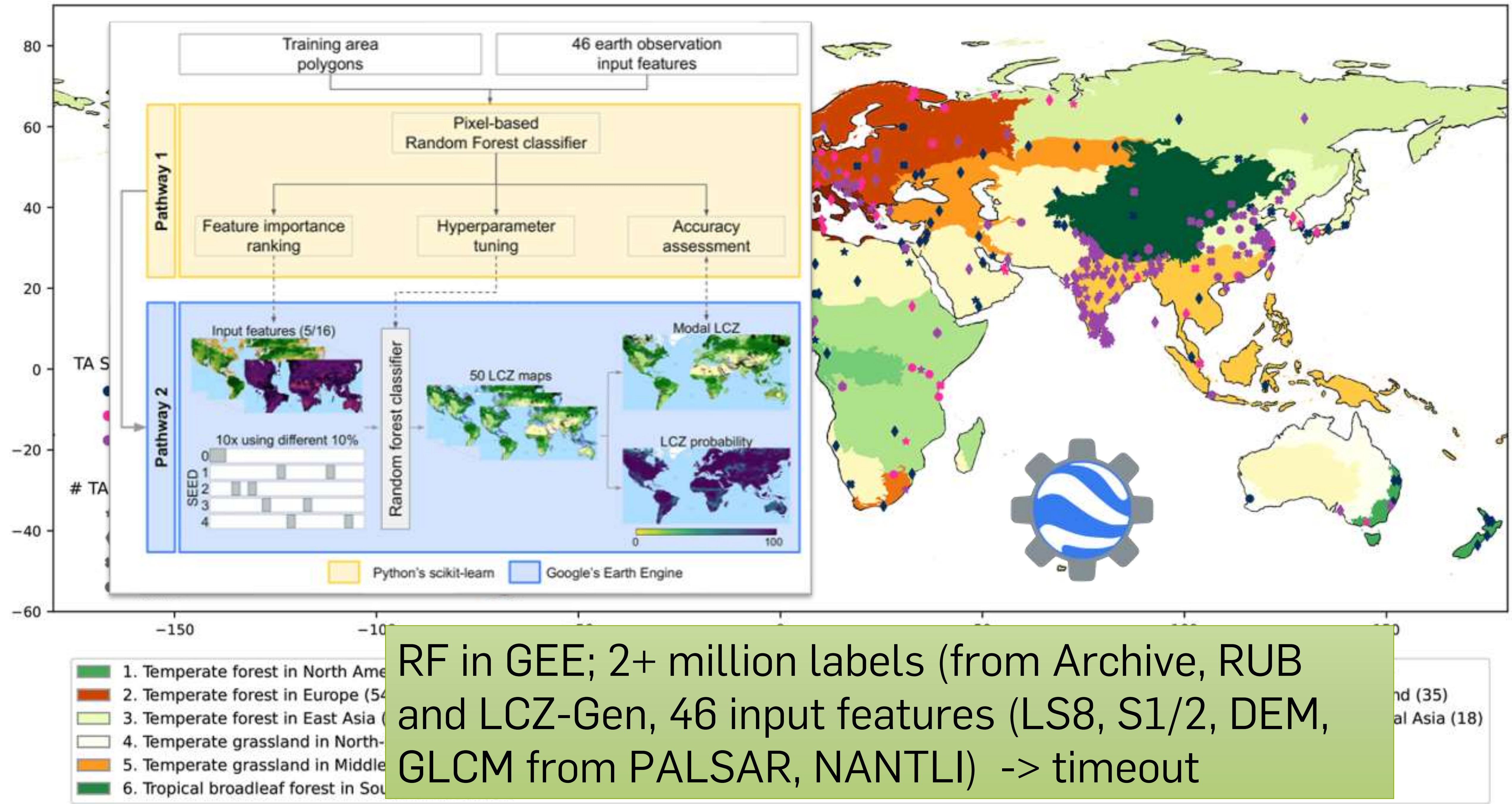
Download Selected Show best submissions Search:

☐	City	Country	Continent	Date Submitted	Author	Accuracy	
☐	Barcelona	Spain, Kingdom of	Europe	2022-06-08 07:26:11	Majdi Hunter-Batal	0.69	Show Factsheet
☐	NANJING	China, People's Republic of	Asia	2022-06-08 00:26:51	Yokey Tang	0.81	Show Factsheet
☐	Salt Lake City	United States of America	North America	2022-06-07 17:53:05	Natalie White	0.52	Show Factsheet
☐	SÃO PAULO	Brazil, Federative Republic of	South America	2022-06-07 14:42:41	Sara Lopes De Moraes	0.65	Show Factsheet
☐	Piatra Neamt	Romania	Europe	2022-06-07 11:58:14	Dragos Butnaru	0.70	Show Factsheet
☐	Bhubaneswar	India, Republic of	Asia	2022-06-07 11:40:03		0.43	Show Factsheet
☐	São Paulo	Brazil, Federative Republic of	South America	2022-06-07 11:00:13	Sara Lopes De Moraes	0.65	Show Factsheet
☐	nanjing	China, People's Republic of	Asia	2022-06-07 01:53:29	Yokey Tang	0.82	Show Factsheet
☐	São Paulo	Brazil, Federative Republic of	South America	2022-06-06 16:31:53	Sara Lopes De Moraes	0.65	Show Factsheet
☐	Yazd	Iran, Islamic Republic of	Asia	2022-06-06 15:48:24		0.69	Show Factsheet

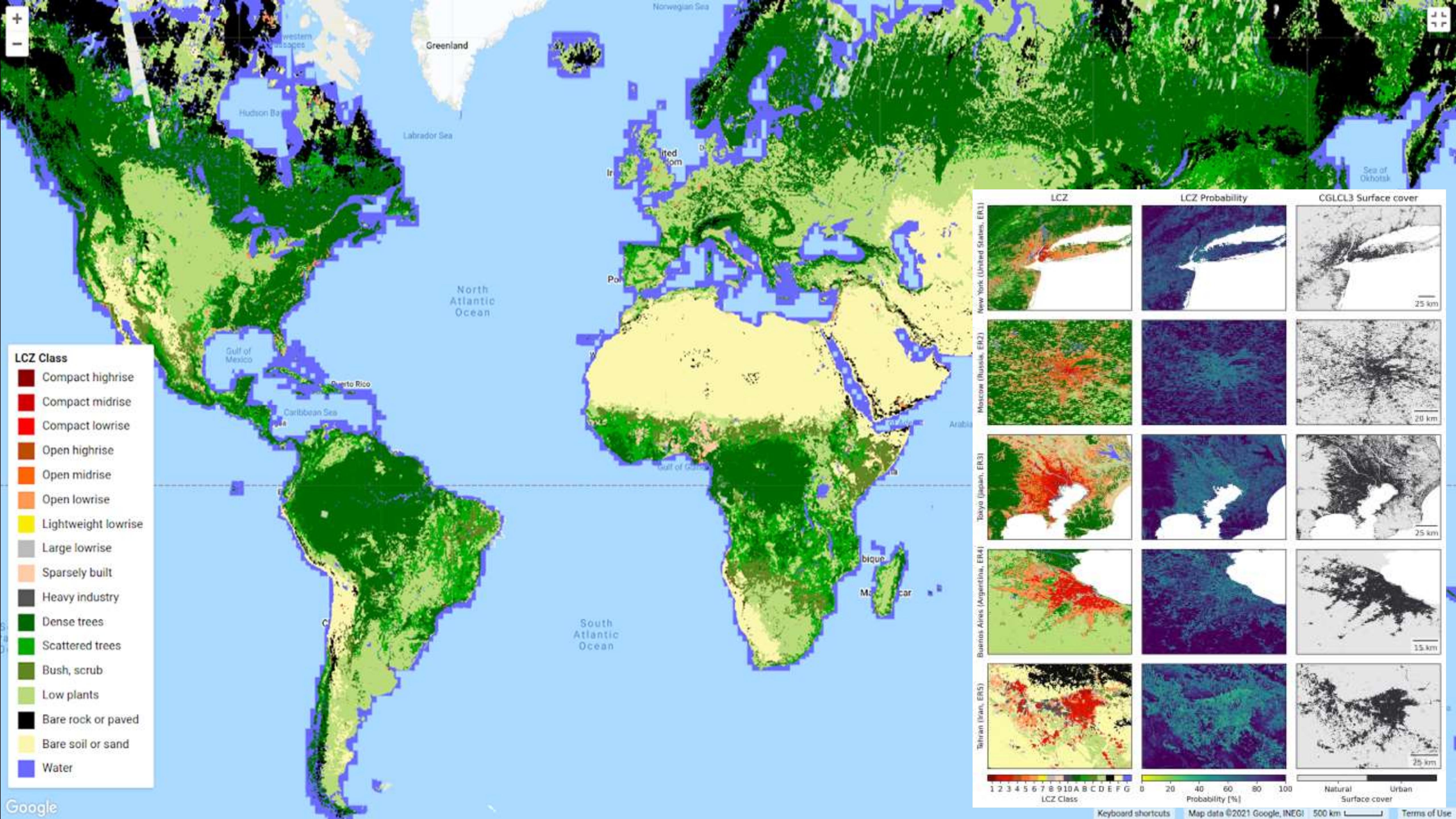
Showing 1 to 10 of 2,175 entries

First Previous 1 2 3 4 5 ... 218 Next Last





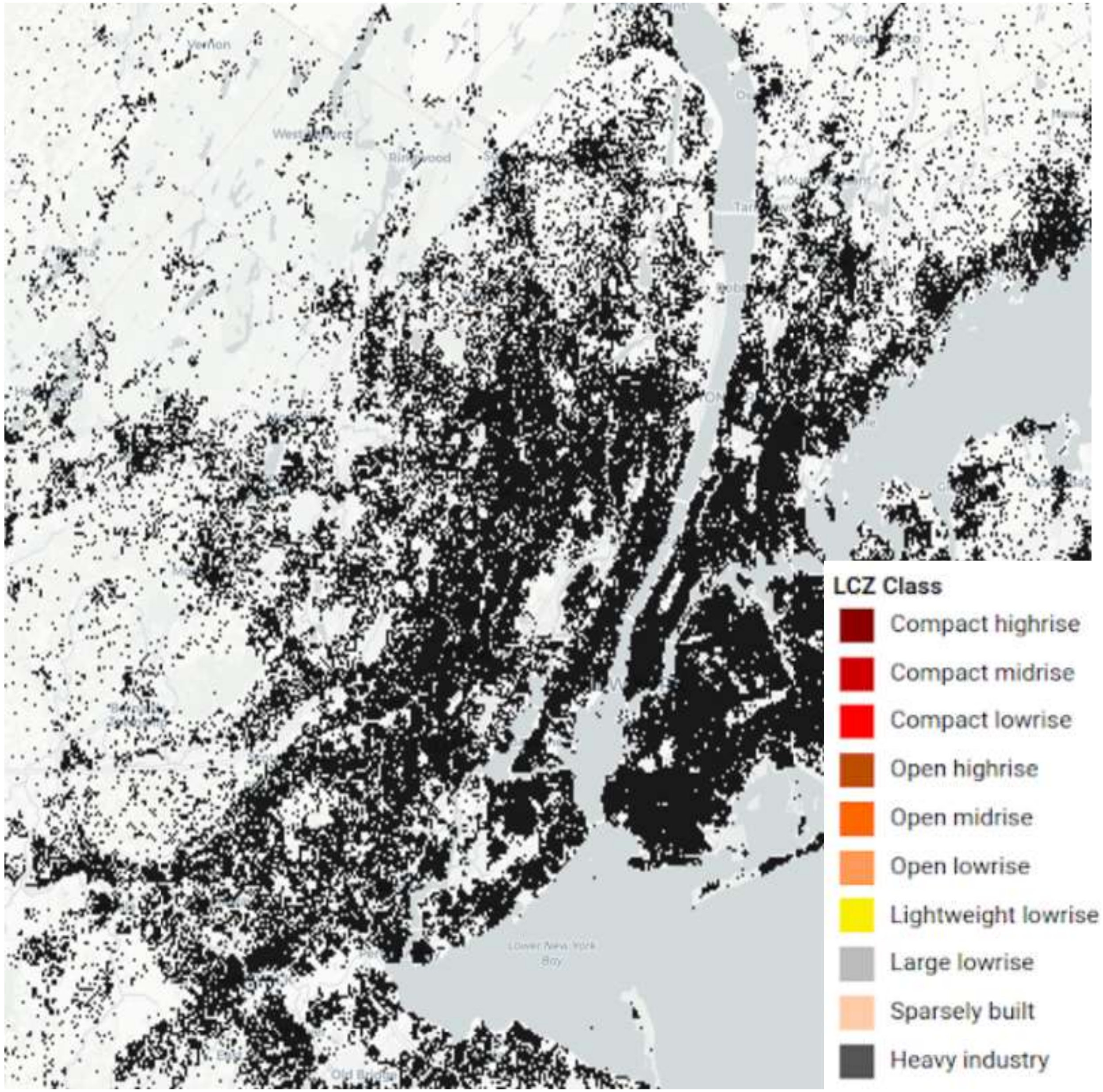
RF in GEE; 2+ million labels (from Archive, RUB and LCZ-Gen, 46 input features (LS8, S1/2, DEM, GLCM from PALSAR, NANTLI) -> timeout



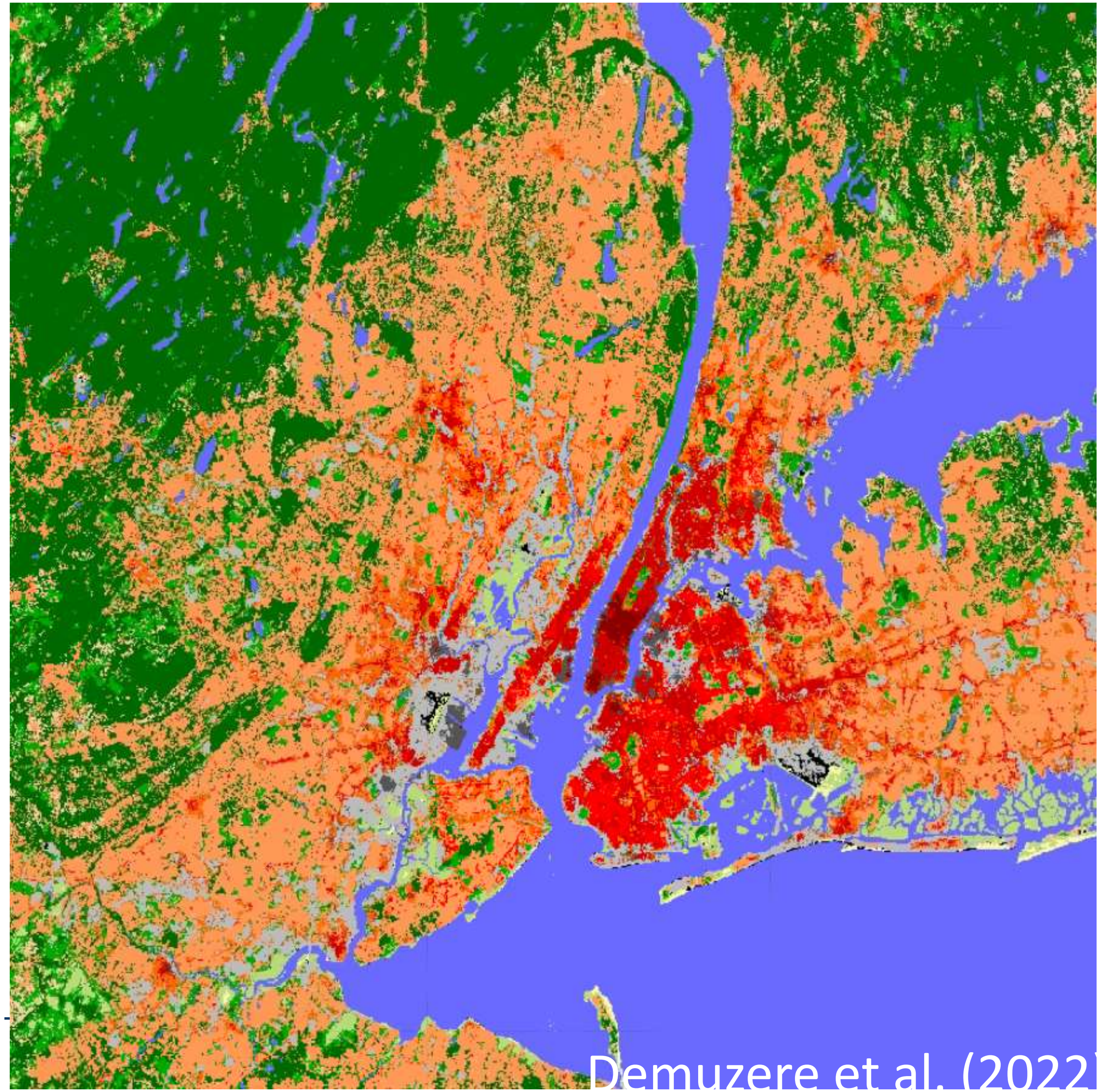
Greenland
Hudson Bay
Labrador Sea
Norwegian Sea
North Atlantic Ocean
Gulf of Mexico
Caribbean Sea
Puerto Rico
South Atlantic Ocean
Sea of Okhotsk
LCZ Class
Compact highrise
Compact midrise
Compact lowrise
Open highrise
Open midrise
Open lowrise
Lightweight lowrise
Large lowrise
Sparsely built
Heavy industry
Dense trees
Scattered trees
Bush, scrub
Low plants
Bare rock or paved
Bare soil or sand
Water
LCZ
LCZ Probability
CGLCL3 Surface cover
New York (United States, ER1)
Moscow (Russia, ER2)
Tokyo (Japan, ER3)
Buenos Aires (Argentina, ER4)
Tehran (Iran, ER5)
25 km
20 km
25 km
15 km
25 km
1 2 3 4 5 6 7 8 9 10 A B C D E F G
LCZ Class
0 20 40 60 80 100
Probability [%]
Natural
Urban
Surface cover
Google
Keyboard shortcuts
Map data ©2021 Google, INEGI
500 km
Terms of Use

Global map of LCZs

WSF



LCZ



LCZ maps ~ climate modelling?

Table: LCZ-class specific urban canopy parameter values

LCZ	λ_B	λ_I	λ_V	H	SVF	AHF	IMD
1. Compact high-rise	40–60	40–60	<10	>25	0.2–0.4	50–300	>80
2. Compact midrise	40–70	30–50	<20	10–25	0.3–0.6	<75	>70
3. Compact low-rise	40–70	20–50	<30	3–10	0.2–0.6	<75	>60
4. Open high-rise	20–40	30–40	30–40	>25	0.5–0.7	<50	50–80
5. Open midrise	20–40	30–50	20–40	10–25	0.5–0.8	<25	50–80
6. Open low-rise	20–40	20–50	30–60	3–10	0.6–0.9	<25	40-90
7. Lightweight low-rise	60–90	<20	<30	2–4	0.2–0.5	<35	>60
8. Large low-rise	30–50	40–50	<20	3–10	>0.7	<50	>70
9. Sparsely built	10–20	<20	60–80	3–10	>0.8	<10	10-40
10. Heavy industry	20–30	20–40	40–50	5–15	0.6–0.9	>300	>40
A. Dense trees	<10	<10	>90	3–30	<0.4	0	<20
B. Scattered trees	<10	<10	>90	3–15	0.5–0.8	0	<20
C. Bush, scrub	<10	<10	>90	<2	0.7–0.9	0	<20
D. Low plants	<10	<10	>90	<1	>0.9	0	<20
E. Bare rock or paved	<10	>90	<10	<0.25	>0.9	0	>90
F. Bare soil or sand	<10	<10	>90	<0.25	>0.9	0	<20
G. Water	<10	<10	>90	–	>0.9	0	<20

+ Radiative and thermal properties such as emissivity, albedo, heat capacity, heat conductivity etc …

LCZ maps ~ climate modelling?

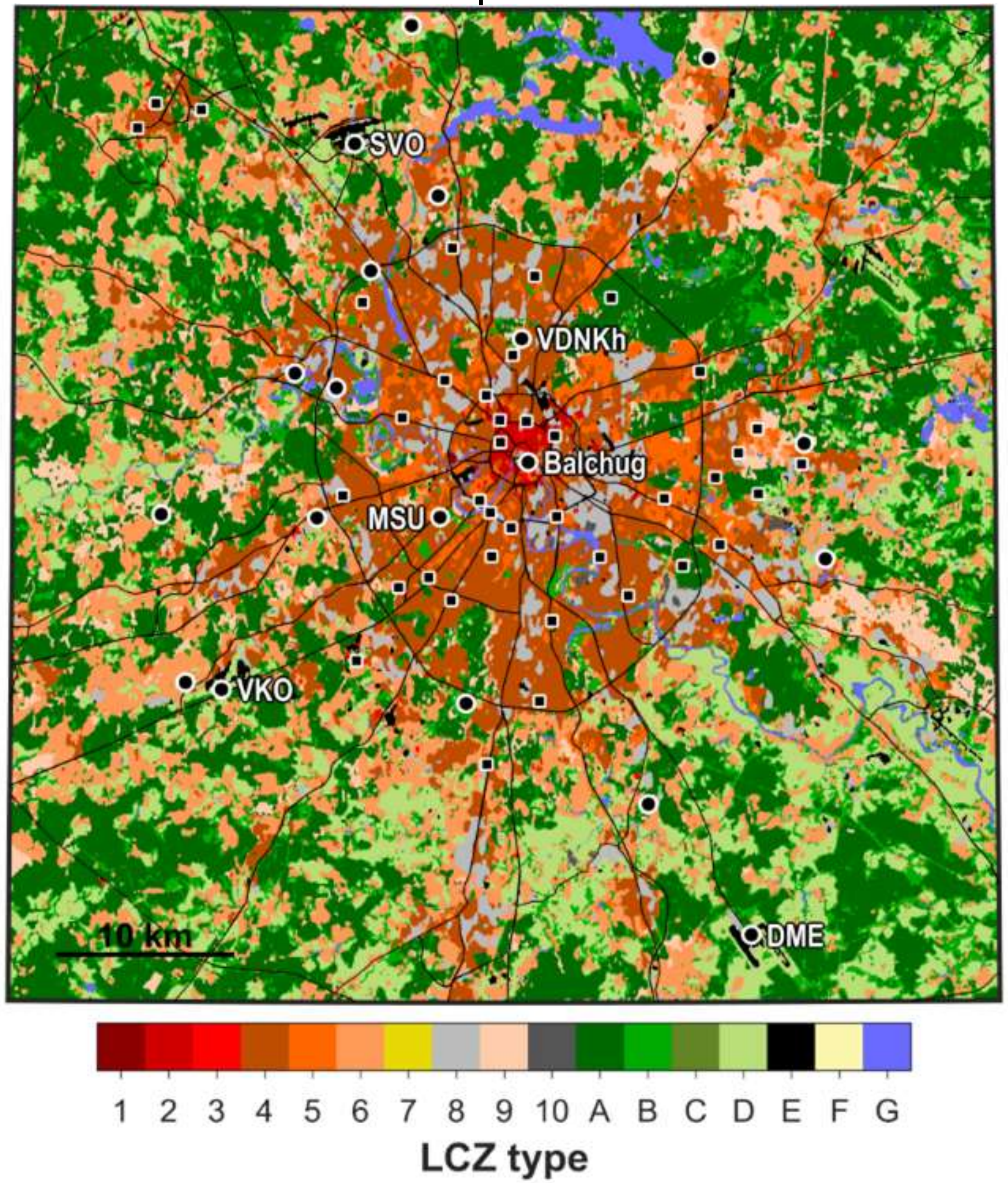
Table: LCZ-class specific urban canopy parameter values

LCZ	λ_B	λ_I	λ_V	H	SVF	AHF	IMD
1. Compact high-rise	40–60	40–60	<10	>25	0.2–0.4	50–300	>80
2. Compact midrise	40–70	30–50	<20	10–25	0.3–0.6	<75	>70
3. Compact low-rise	40–70	20–50	<30	3–10	0.2–0.6	<75	>60
4. Open high-rise	20–40	30–40	30–40	>25	0.5–0.7	<50	50–80
5. Open midrise	20–40	30–50	20–40	10–25	0.5–0.8	<25	50–80
6. Open low-rise	20–40	20–50	30–50	3–10	0.6–0.9	<25	40-90
7. Lightweight low-rise	60–90	<20	<30	2–4	0.2–0.5	<35	>60
8. Large low-rise	30–50	40–50	<20	3–10	>0.7	<50	>70
9. Sparsely built	10–20	<20	60–80	3–10	>0.8	<10	10-40
10. Heavy industry	20–30	20–40	40–50	5–15	0.6–0.9	>300	>40
A. Dense trees	<10	<10	>90	3–30	<0.4	0	<20
B. Scattered trees	<10	<10	>90	3–15	0.5–0.8	0	<20
C. Bush, scrub	<10	<10	>90	<2	0.7–0.9	0	<20
D. Low plants	<10	<10	>90	<1	>0.9	0	<20
E. Bare rock or paved	<10	>90	<10	<0.25	>0.9	0	>90
F. Bare soil or sand	<10	<10	>90	<0.25	>0.9	0	<20
G. Water	<10	<10	>90	–	>0.9	0	<20

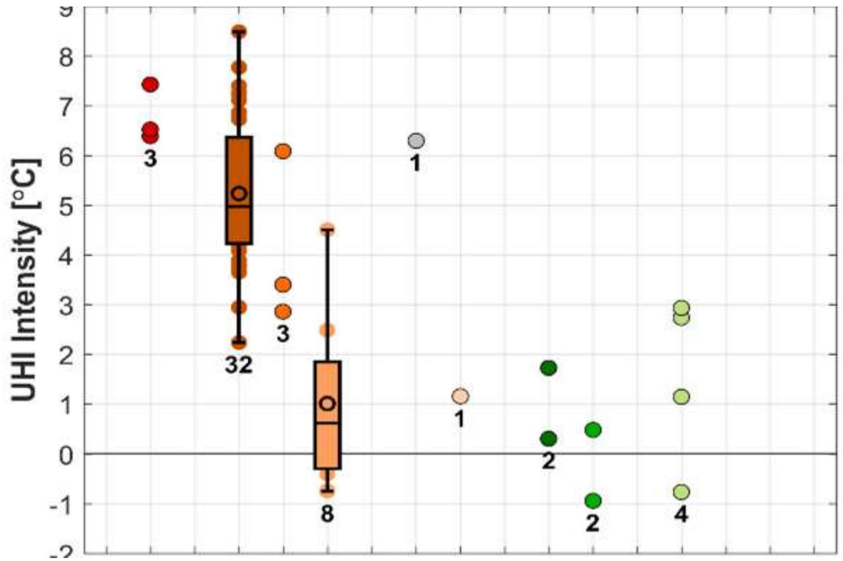
+ ~~Radiative and thermal properties such as emissivity, albedo, heat capacity, heat conductivity etc …~~

> The global LCZ map describes all the cities of the world,
> in the same, universal language,
> but interested users can read it in their own dialect

LCZ map Moscow

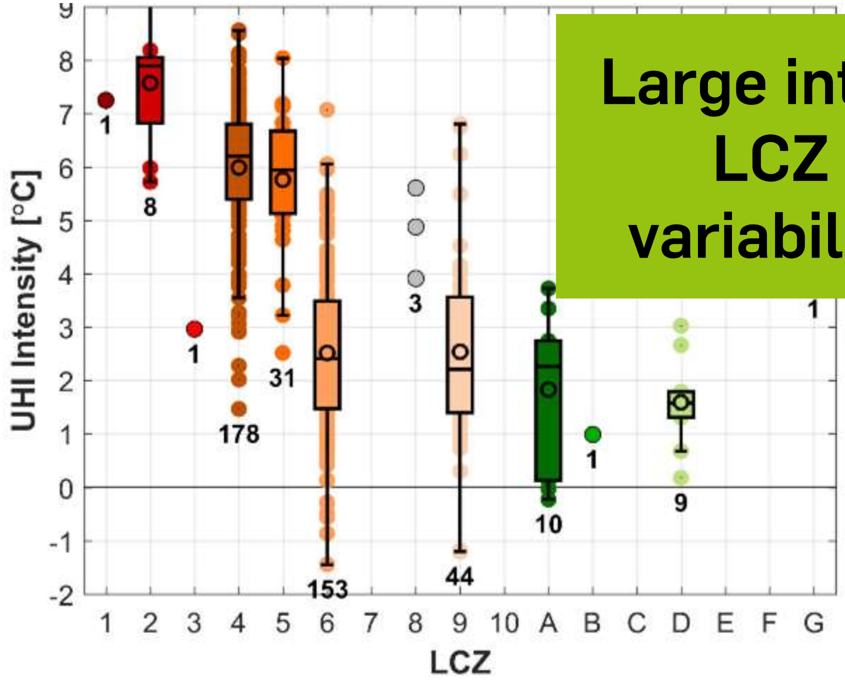


Reference weather stations



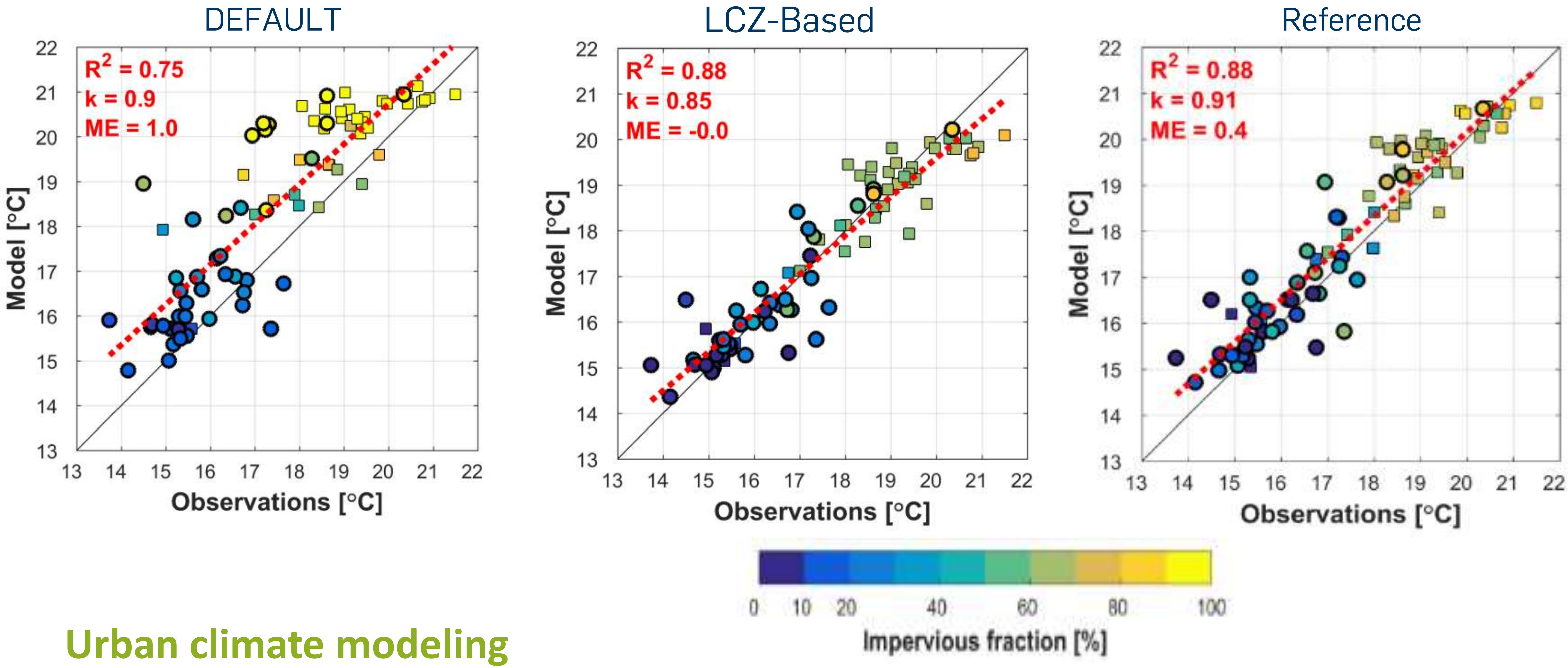
Summer 2019

Citizen weather stations (netatmo)



Large intra-LCZ variability

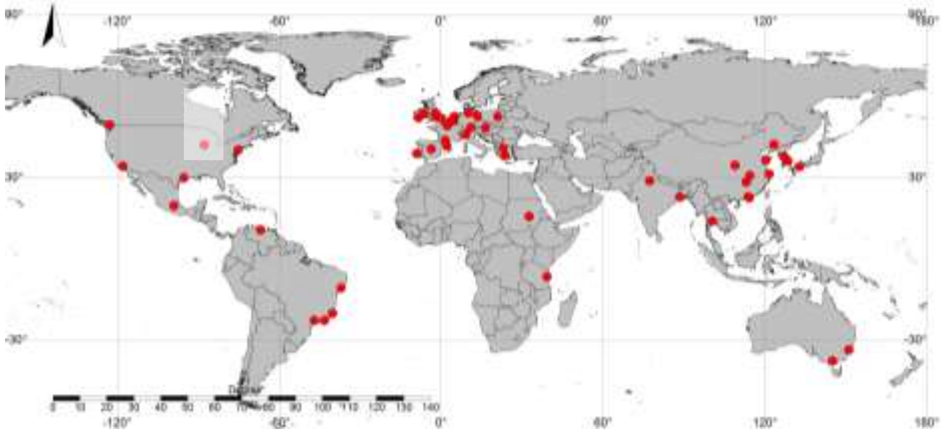
Evaluation of modelled (COSMO-CLM) nocturnal 2m air temperature averaged for August 2017

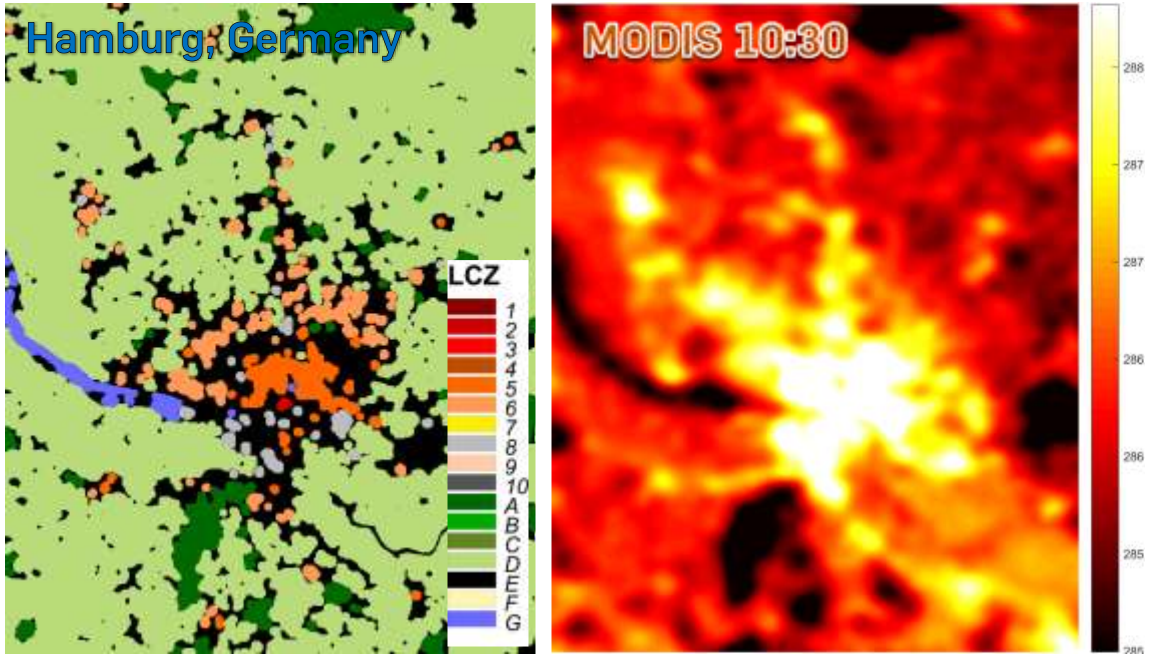


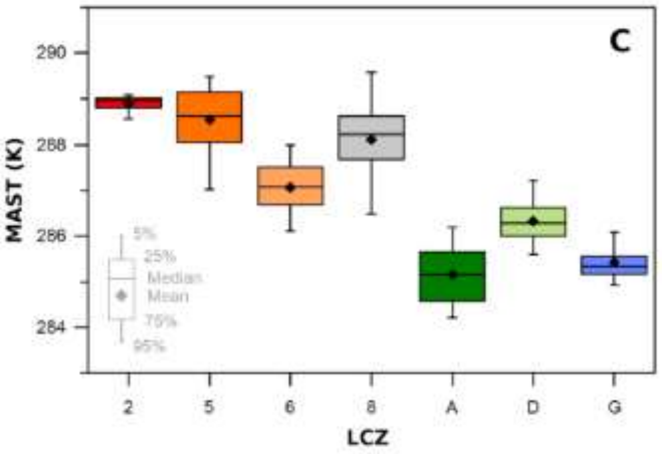
Urban climate modeling

Varentsov et al. 2020

Intra-Urban SUHII by LCZ

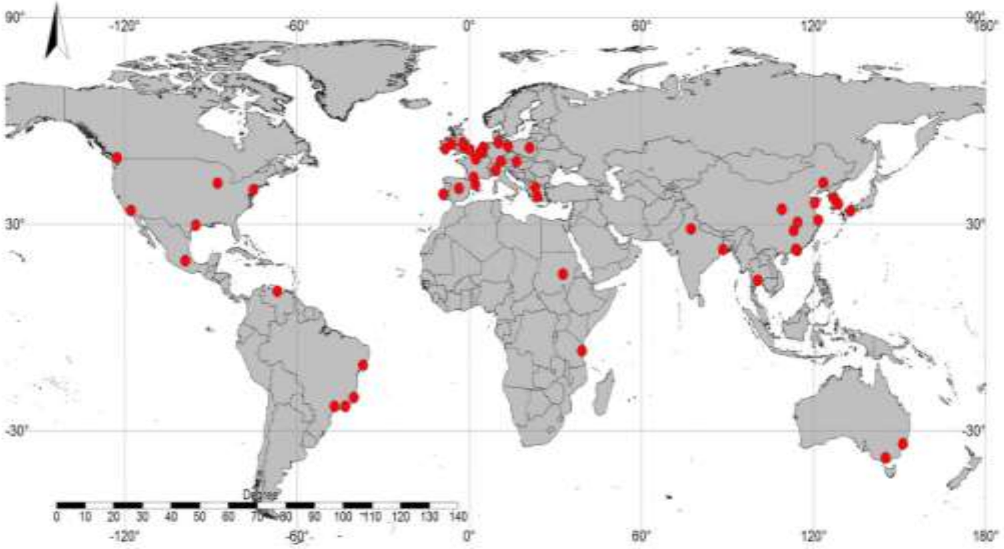






- B. Bechtel et al., Urban Climate. 28, 100451 (2019).

The LCZ approach provides a consistent and comprehensive framework for SUHI analysis.



Surface temperature

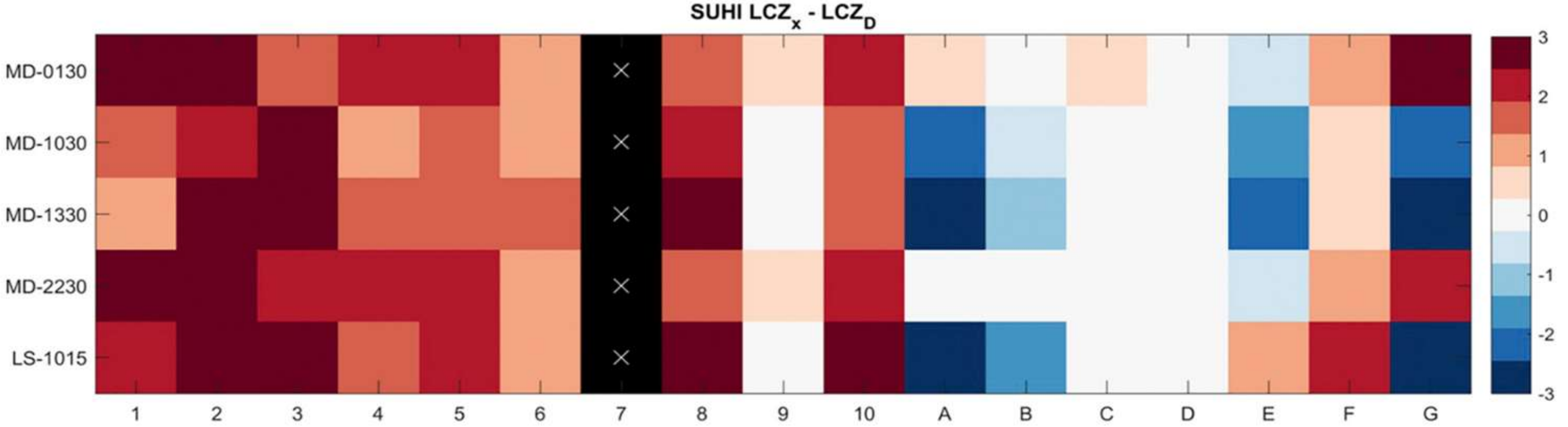
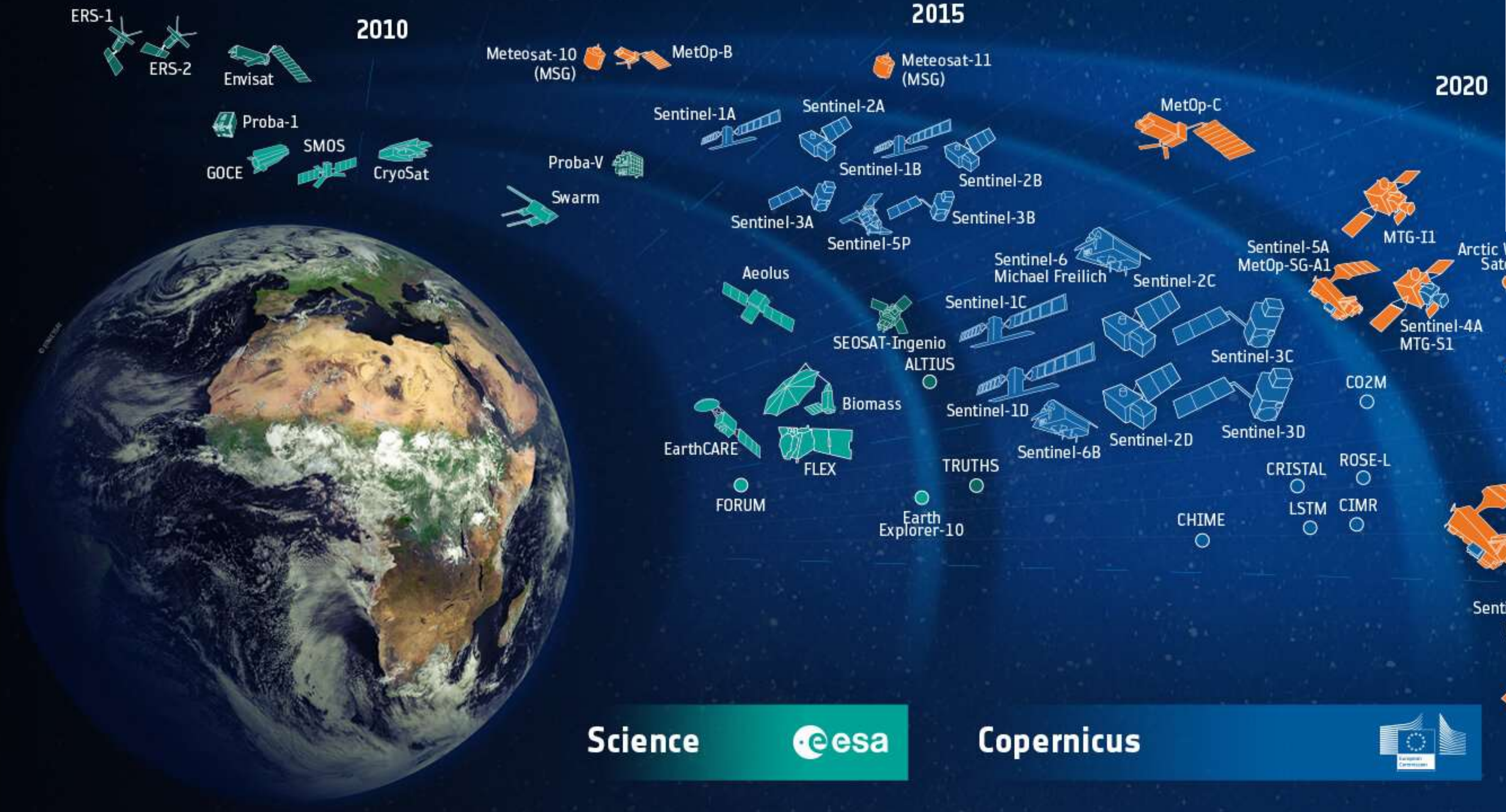
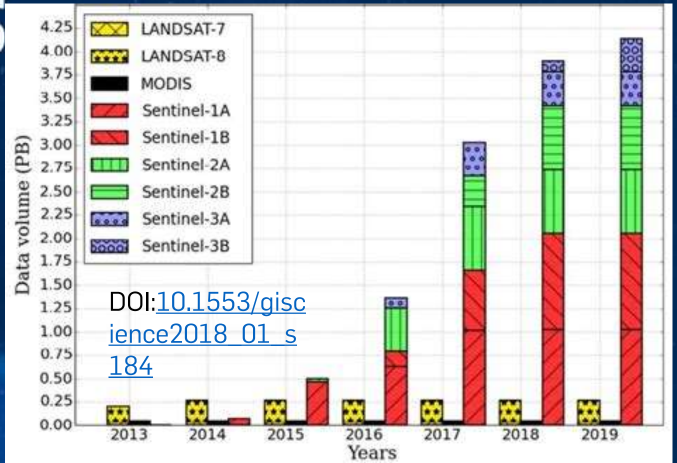


Fig. 11. Average SUHI intensity in K for all cities and LCZ compared to LCZ D for different acquisition times and sensors. Black with white x (LCZ 7) indicates that the LCZ type is not present in the study.

Bechtel et al. 2019

ESA-DEVELOPED EARTH OBSERVATION MISSIONS



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There are plenty of data out there? Who is going to make sense of it if not us?

https://medianexis.com/wp-content/uploads/2019/06/Data.jpg

innovative

impact

community

visible

international

Thank you!