# Impact of weather patterns on Urban Thermal Field Variance Index distributions derived from Landsat time series: Assessments in small to medium-sized municipalities in Hesse, Germany

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## CoolTown

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MARTIN-LUTHER-UNIVERSITÄT HALLE-WITTENBERG

GEO ECOLOGY

HLNUG Für eine lebenswerte Zukunft

FACHZENTRUM KLIMAWANDEL UND ANPASSUNG

# Background

- cities alter the energy balance of the surface
  (Oke et al., 2017)

→ **Urban Heat Island (UHI) effect**

- increased health risks for vulnerable groups
  (Heaviside et al., 2017)

- mitigation via Urban Green Spaces, green roofs, bright surfaces, ...
  (Budzik et al., 2024)

- → *Where are the thermal hot spots?*

**satellite based Land Surface Temperature (LST)**

- enables mapping of

→ **Surface UHI (SUHI)**

**SUHI ≠ UHI**

- common index for SUHI analysis:
  **Urban Thermal Field Variance Index (UTFVI)**

# Urban Thermal Field Variance Index

- method to quantify thermal stress in urban areas
- normalization of LST data

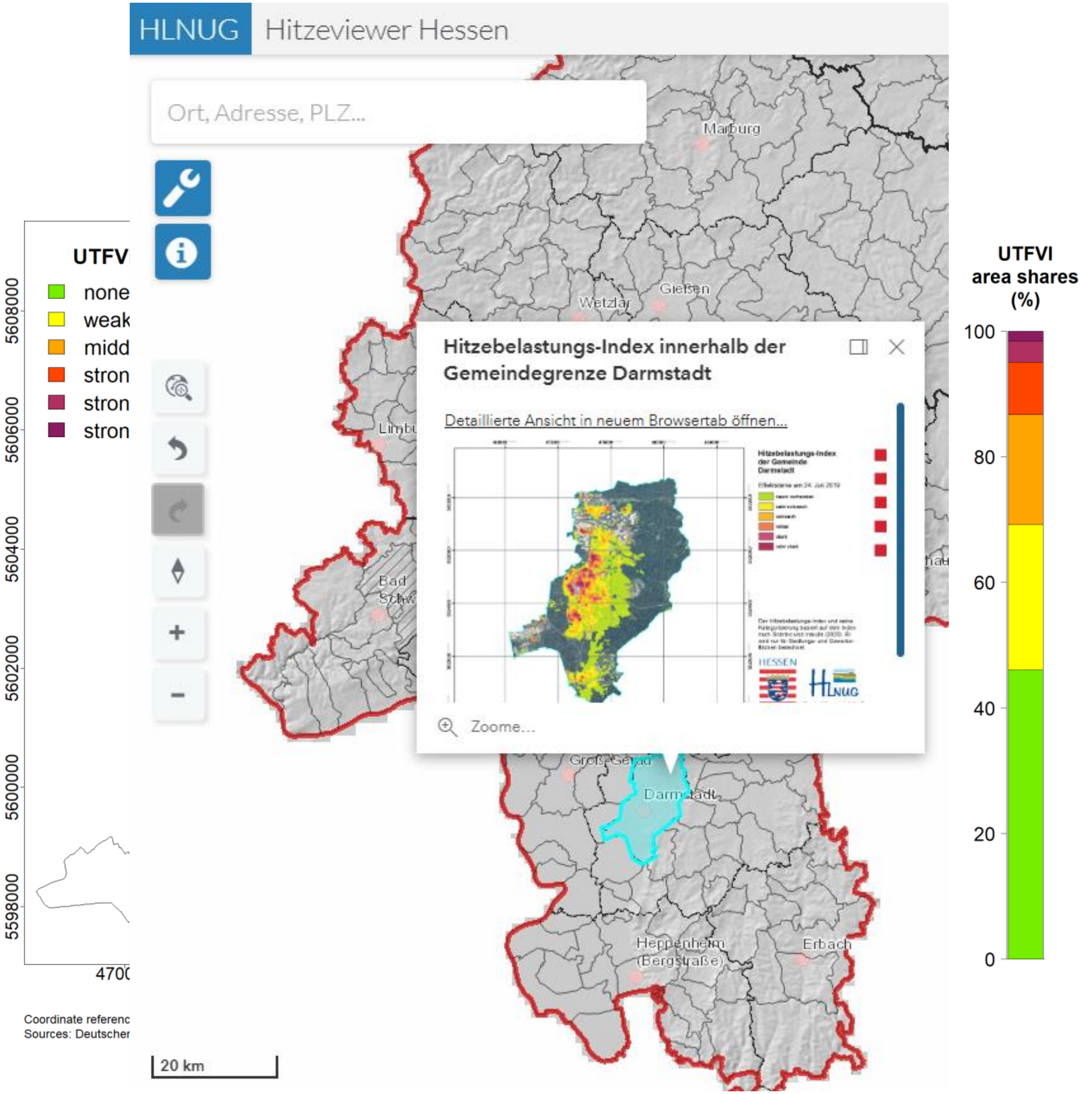
$$UTFVI = \frac{LST_i - LST_{mean}}{LST_{mean}}$$

*Tab 1: Threshold values of the UTFVI categories.*

| Threshold | Category |
|---|---|
| < 0.000 | None |
| 0.000 – 0.005 | Weak |
| 0.005 – 0.010 | Middle |
| 0.010 – 0.015 | Strong |
| 0.015 – 0.020 | Stronger |
| > 0.020 | Strongest |

- provided by governmental administrations, e.g., Hitzeviewer Hessen
  - https://umweltdaten.hessen.de

- commonly applied to show the consequences of urban growth and densification on the temporal development of urban heat stress



# Background

### Previous studies

- used only few scenes over large periods of time (e.g. 4 scenes in 30 years)
- focused on large cities (population > 500 k)
- didn‘t consider weather effects

### Research gaps

- long-term UTFVI time series
- small to medium-sized municipalities
- impact of weather patterns on the UTFVI

### Questions

- Is a single point in time sufficient to reliably assess the heat stress of a city?
- Do weather patterns influence the distribution of the individual UTFVI categories?

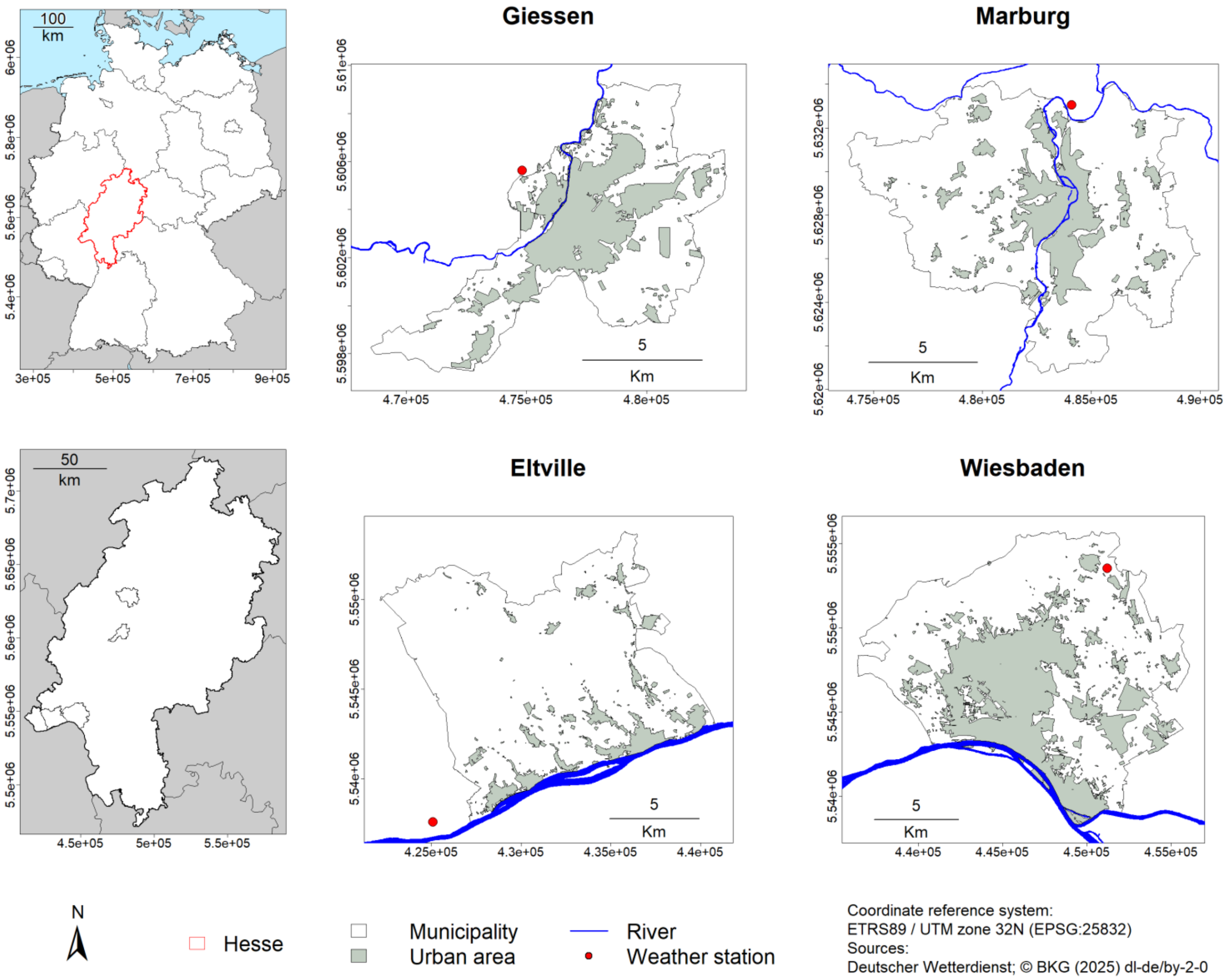
### Objectives

1. to statistically describe the **long-term variability** of the UTFVI distributions
2. to analyze the **within-season comparability** of UTFVI distributions under different LST levels
3. to analyze the **impact of the prevailing weather patterns** on the specific UTFVI distributions

# Study Area

- 4 Hessian municipalities
  (~ 40 k - 300 k)

- urban areas delineated using
  ATKIS Basis-DLM* data

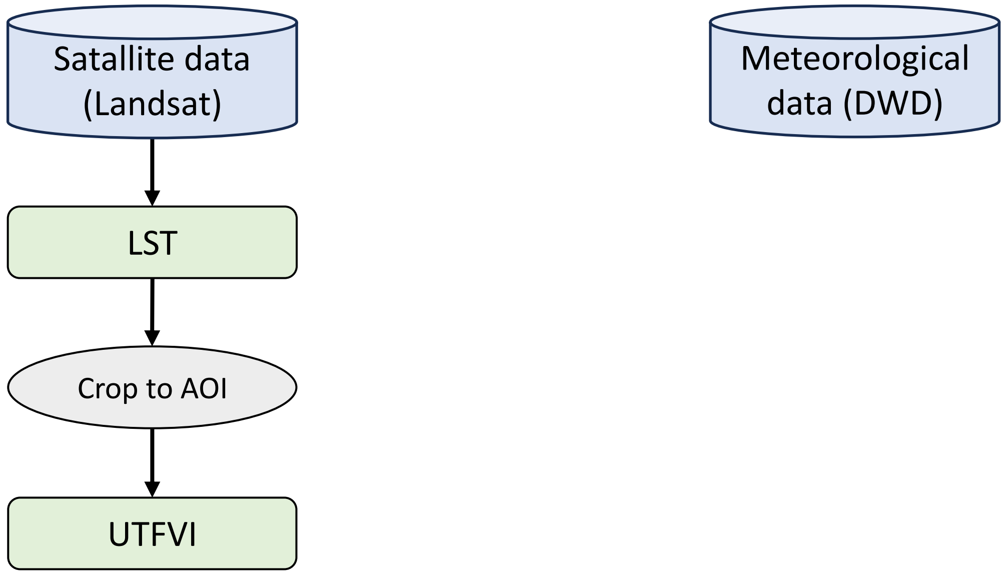



* Amtliches Kartographisch-Topographisches Informationssystem Basis-Digitales Landschaftsmodell

# Data

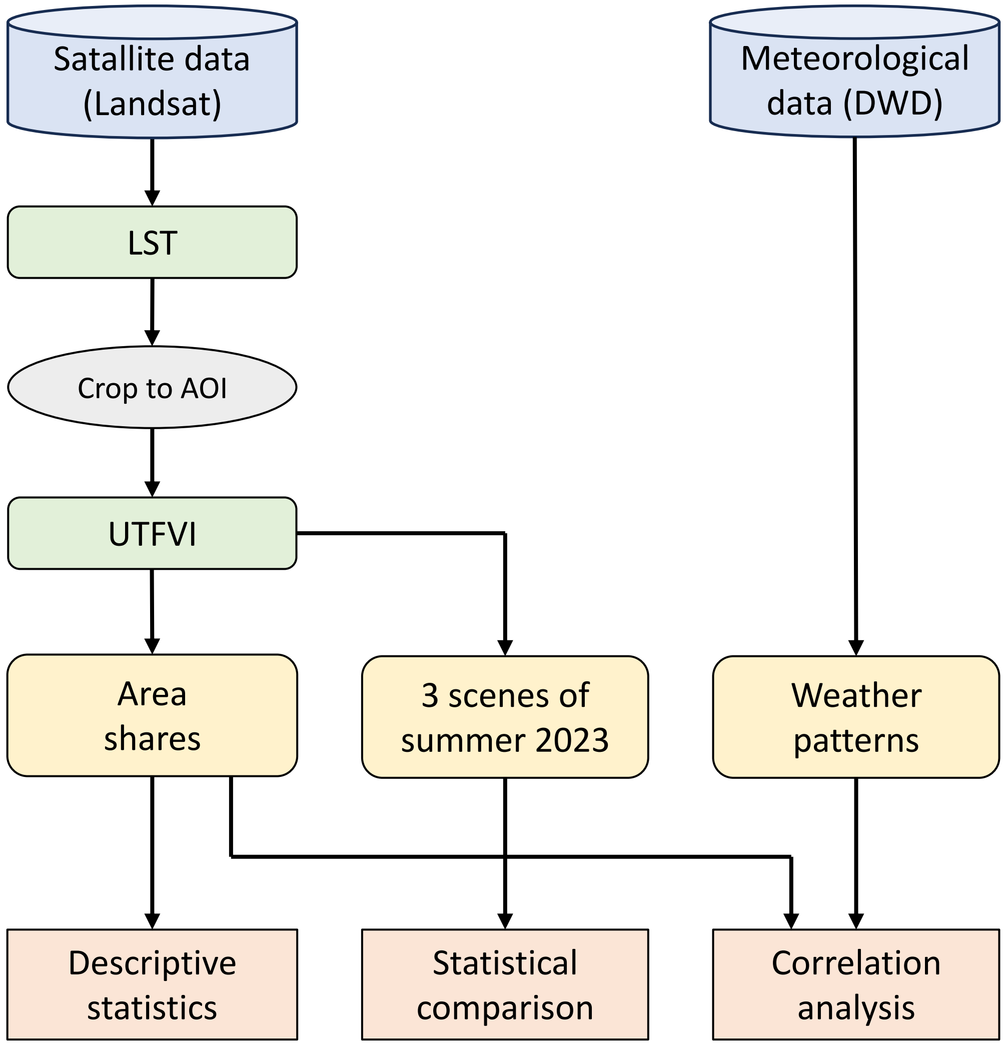
- **Landsat LST time series (1984 to 2024)**
  - Landsat 4-5, 7, 8-9, Level 2, Tier 1, 30 m, cloud free images (N > 100)
  - cropped to urban area
    (Sobrino & Irakulis 2020)
  - UTFVI calculated

- **Meteorological data from DWD stations**
  - air temperature
  - precipitation
  - relative humidity



# Methods

1. **UTFVI time series**
    - calculation of area shares
    - descriptive statistics (coefficient of variation)
2. **UTFVI variability**
    - statistical comparison of scenes of the same summer (2023) with different LST levels using Friedman & Wilcoxon tests (Friedman, 1939, 1937; Wilcoxon, 1945)
3. **Relationship between UTFVI area shares and weather patterns**
    - calculation of weather patterns
        - meteorological variables averaged over 1, 2, 3, 7, 14, 21 d prior to Landsat acquisition
    - correlation matrix using Spearman's rank correlation coefficient



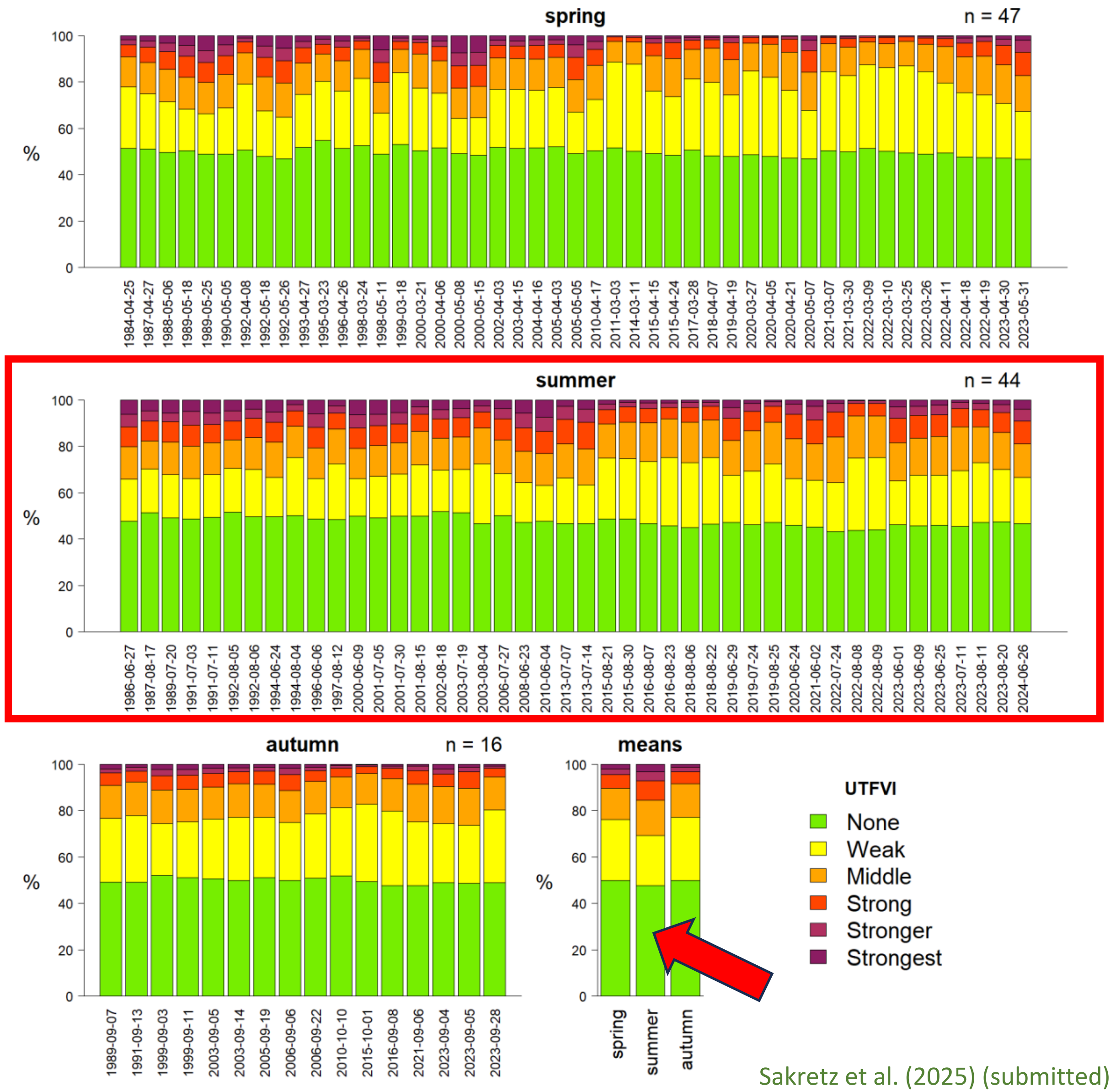
# 1) Long term variability

## Results

- high variation in Weak and Strong to Strongest
- spring and summer show more variation than autumn
- compared to spring and autumn, the summer average shows higher shares of Strong to Strongest and less shares in Weak

*Tab 2: Coefficients of variation of the UTFVI categories.*

| Season | None | Weak | Middle | Strong | Stronger | Strongest |
|---|---|---|---|---|---|---|
| spring | 3.68 | 23.85 | 14.32 | 42.78 | 67.47 | 95.12 |
| summer | 4.53 | 19.69 | 11.75 | 19.52 | 36.29 | 58.23 |
| autumn | 2.73 | 11.03 | 6.13 | 22.14 | 32.04 | 43.57 |

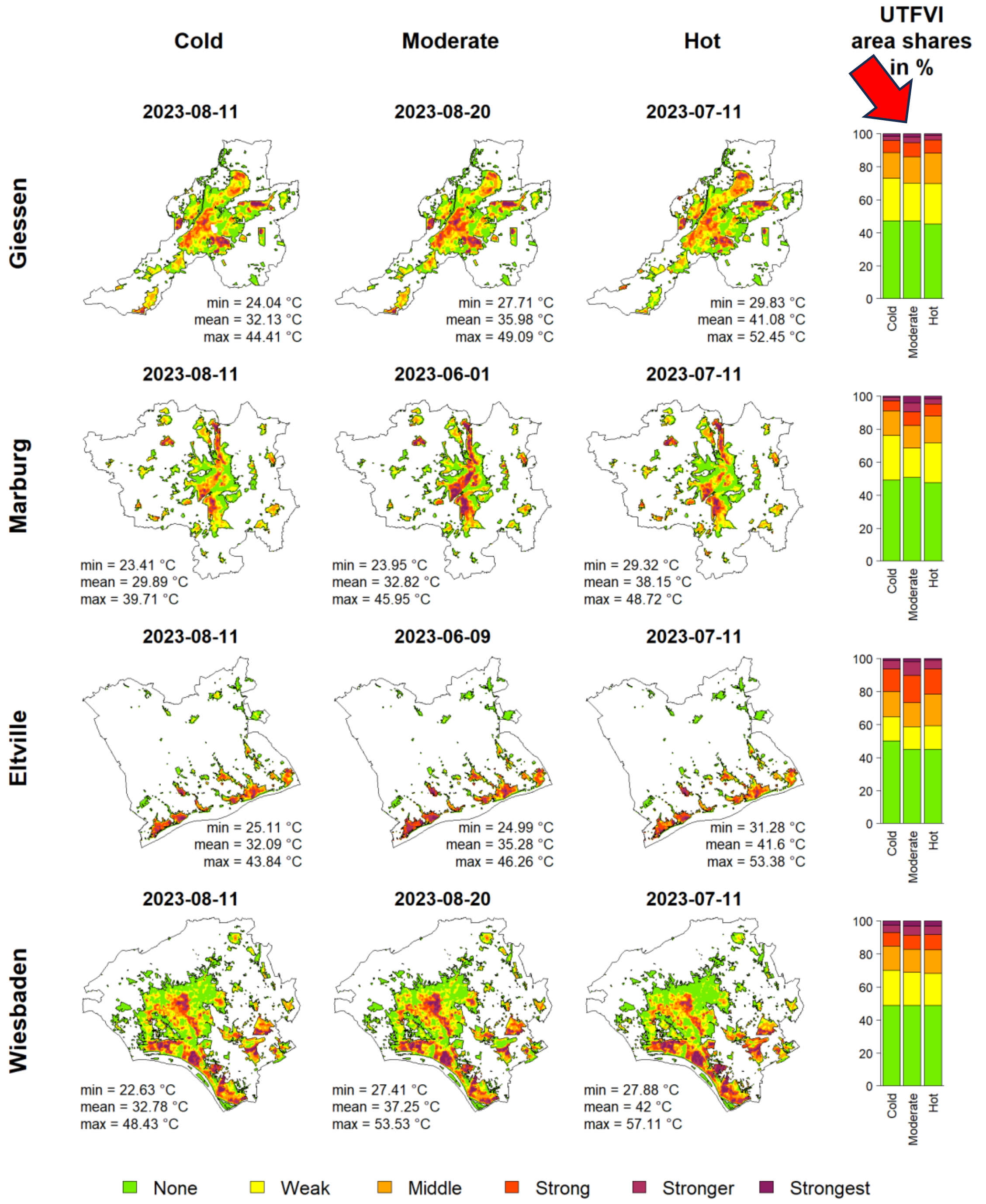



Sakretz et al. (2025) (submitted)

# 2) within-season comparability

## Results

- visually, only slight differences recognizable
- area shares show more significant changes
  - moderate scene shows higher proportions of high categories
- statistical tests: significant differences
  - ($p < 0.01$; exception: Wiesbaden Moderate-Hot)
- differences vary in intensity across municipalities

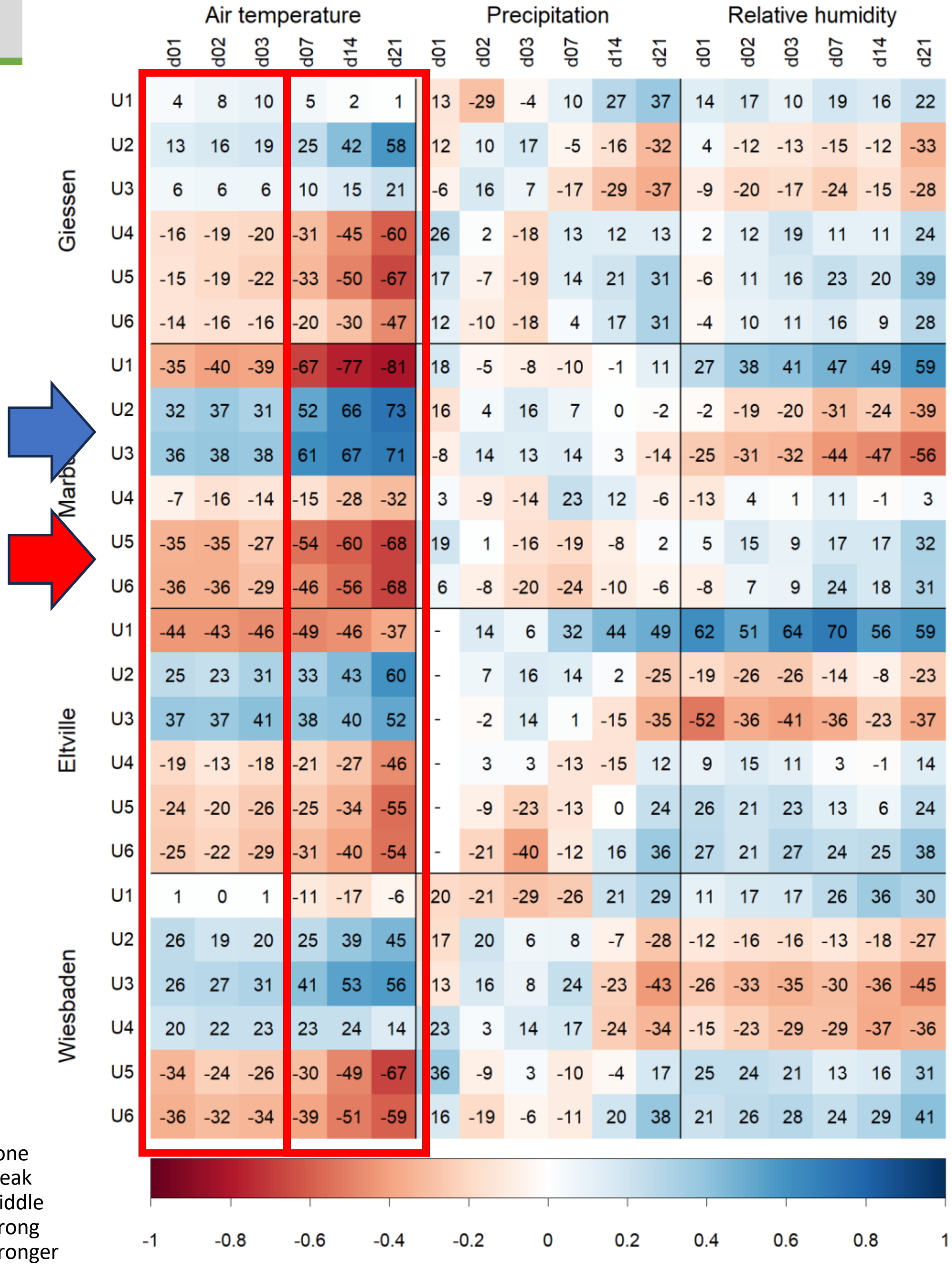



Sakretz et al. (2025) (submitted)

# 3) Impact of weather patterns

**results**

- temperature with the greatest influence, significant long-term effects
- categories None and Stronger to Strongest opposite to Weak and Middle
- negative dependence of high UTFVI categories (and None) on air temperature increases during longer weather periods
  - i.e., the longer a high air temperature prevails, the lower the occurrence of higher UTFVI classes



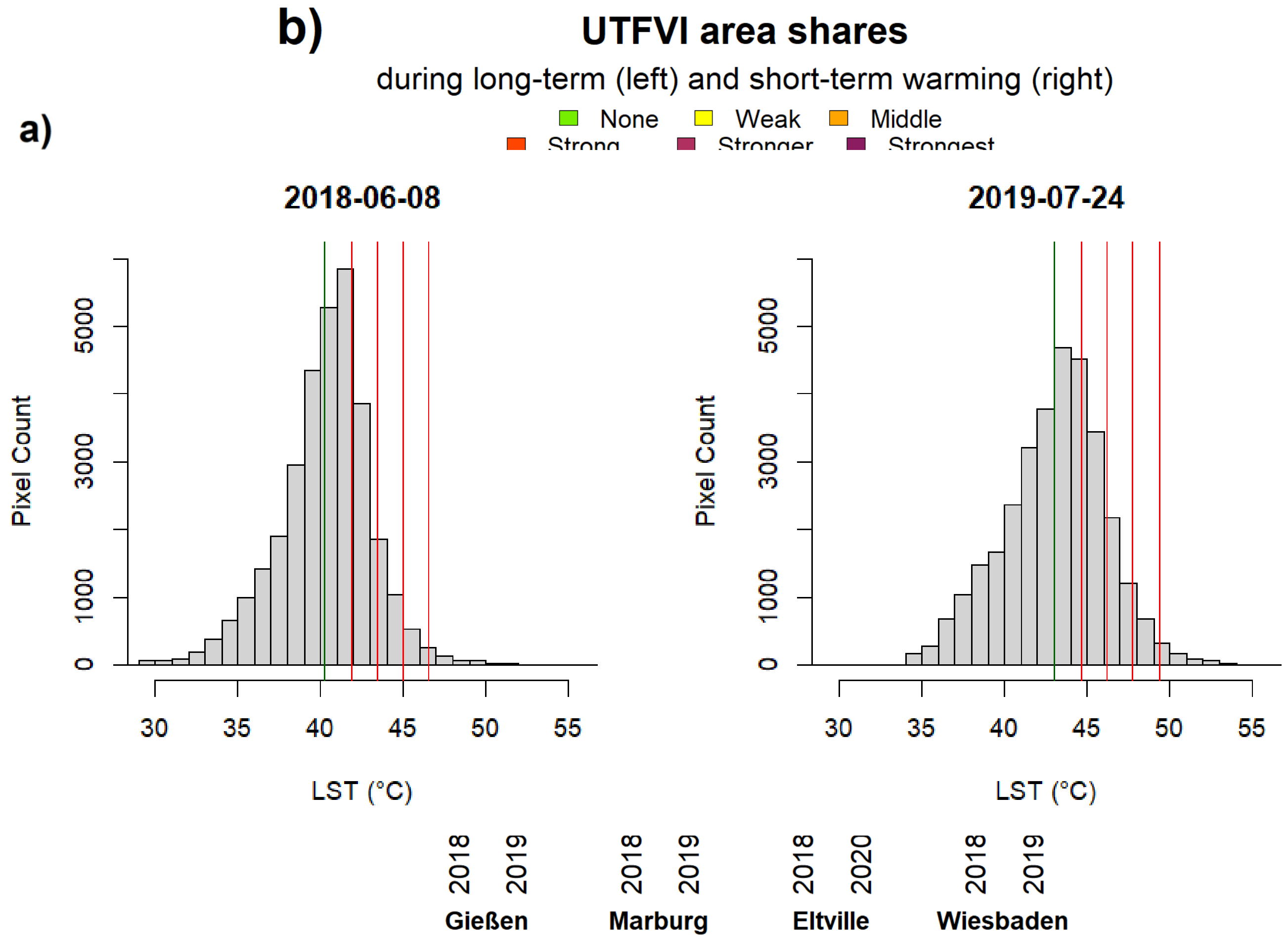

**UTFVI**
U1 = None
U2 = Weak
U3 = Middle
U4 = Strong
U5 = Stronger
U6 = Strongest

Sakretz et al. (2025) (submitted)

# 3) Impact of weather patterns

- **Long-term warming**
  - high average air temperature over a longer weather period
  - accumulation of pixels in the Weak and Middle categories
- **Short-term warming**
  - rapid warming over a shorter weather period
  - accumulation of pixels in the None and Stronger to Strongest categories

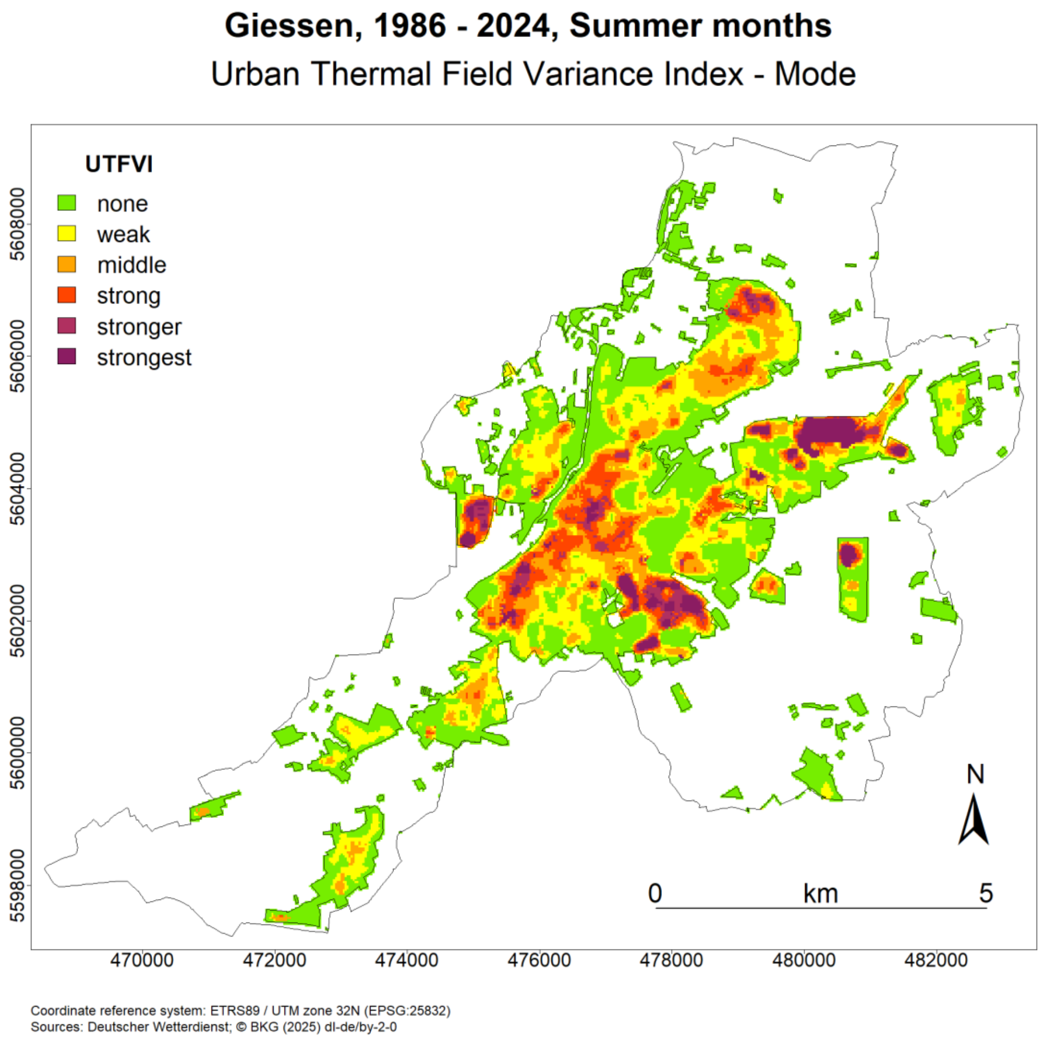
➢ **Homogenization effect of the LST during longer warming phases**
  - i.e. pixels are more closely distributed around the mean LST



# Take away messages

- significant differences between individual scenes, even with non-changing building structure
- temperature has the greatest influence on UTFVI distributions
- long warming phases (e.g., during heat waves) lead to a homogenization of the LST
- clear differences in the comparison of municipalities

- but: UTFVI enables a low-threshold assessment of heat distribution
- suggestion: use of a long-term UTFVI-mode




Mode = value that appears most often (per pixel)

# Thank you for your attention!

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# Lokal vs. (Über-)Regional

- Hessenweiter UTFVI-Modus
- Surface Urban Heat Island Intensity (basierend auf Local Climate Zones)
- Vergleichbarkeit schwierig
- Frage: Definition der ländlichen Umgebung
    - Welche Fläche eignet sich als Referenz
    - Gibt es unterschiede zwischen Nord und Süd-Hessen?
    - Welche Rolle spielen phänologische Effekte?
        - z.B. Landwirtschaftliche Bearbeitung (Mahd/Ernte Juli/August)