Session 1.4

In the Cool of the Day: The role of urban forests in improving microclimate and reducing the heat island effect

Chair: Cynnamon Dobbs

World Forum on Urban Forests

2nd World Forum on Urban Forests

Washington DC, 2023

Addressing interactions between landcover and urban heat at local and regional scales

Presented by

Peter Ibsen PhD

United States Geological Survey – Climate Research and Development Program

Geoscience and Environmental Change Science Center

USGS science for a changing world

Statewide Tree Planting Programs to Combat Urban Heat

Baltimore's Heat Islands Are a Problem, but New Tree Planting Efforts Could Help

Volunteers and staff with Baltimore Tree Trust planted 18 trees at Mary Ann Winterling Elementary School in Baltimore.
BALTIMORE TREE TRUST

PORTLAND STATE STUDY DEMONSTRATES HOW PLANTS, TREES AND REFLECTIVE MATERIALS CAN REDUCE EXTREME HEAT IN CITY NEIGHBORHOODS

By John Kirkland | July 8, 2019 Share

Tucson launches 'Million Trees' tree-planting effort

Mayor Regina Romero says new trees will help cool the fast-warming city.

Trees battle Houston's brutal heat, but many poorer areas are left unshaded

FEATURES: Jul. 16, 2021 DEMOGRAPHICS | HEALTH | HOUSING

ANDY OLIN

LA needs 90,000 trees to battle extreme heat. Will residents step up to plant them?

by Jaimie Ding

ENVIRONMENT

Proposal would create a $30 million fund to plant trees in areas suffering from heat

Brandon Loomis
Arizona Republic
Published 6:15 a.m. MT April 21, 2022

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16 Photos VIEW FULL GALLERY

Nationwide Tree Planting Program to Combat Urban Heat

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Washington DC, 2023

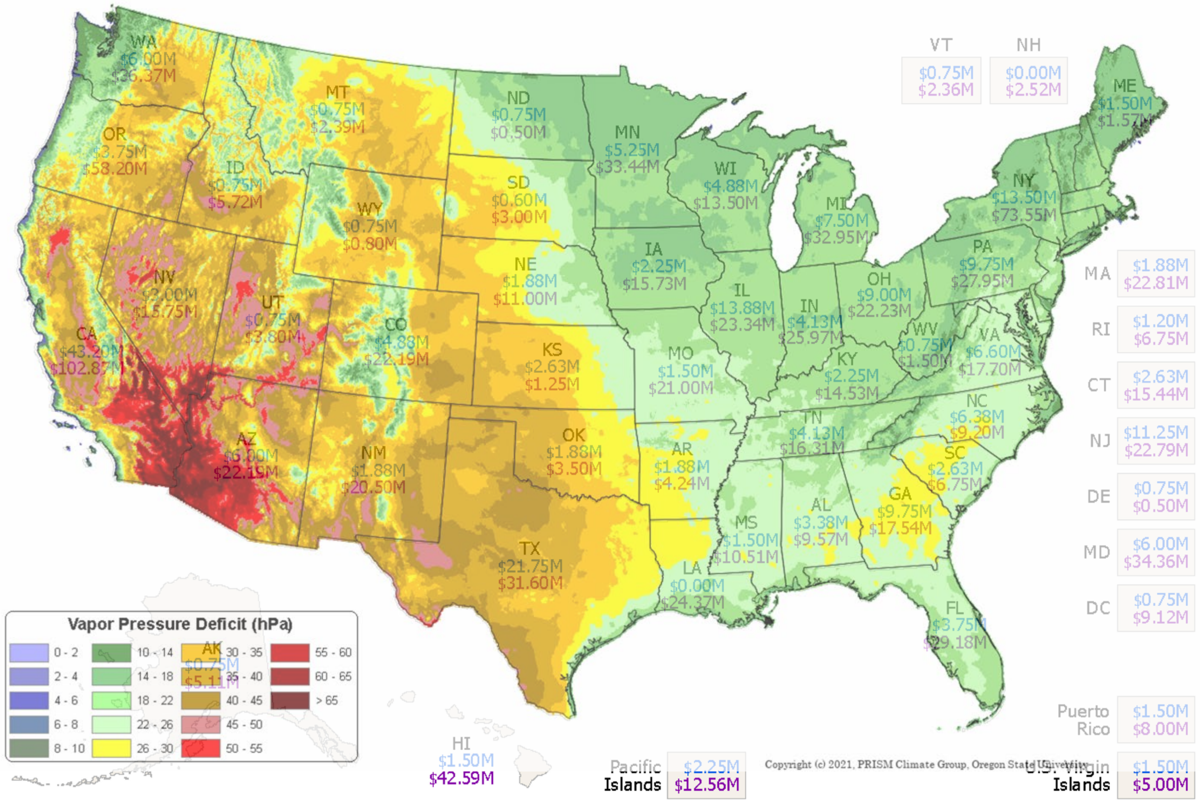
USDA
Forest Service
U.S. DEPARTMENT OF AGRICULTURE

URBAN AND COMMUNITY FORESTRY GRANTS

USDA is an equal opportunity provider, employer, and lender.

The USDA Forest Service's Urban and Community Forestry Program awarded more than $1 billion to fund projects that support urban communities through equitable access to trees and the benefits they provide. The funding was made possible by the Inflation Reduction Act.

Urban and Community Forestry FY 2023 IRA Grant Allocations in Millions of Dollars



FY 2023 IRA State Allocation - $250 Million Total
FY 2023 IRA Notice of Funding Opportunity Grants - $1.13 Billion Total

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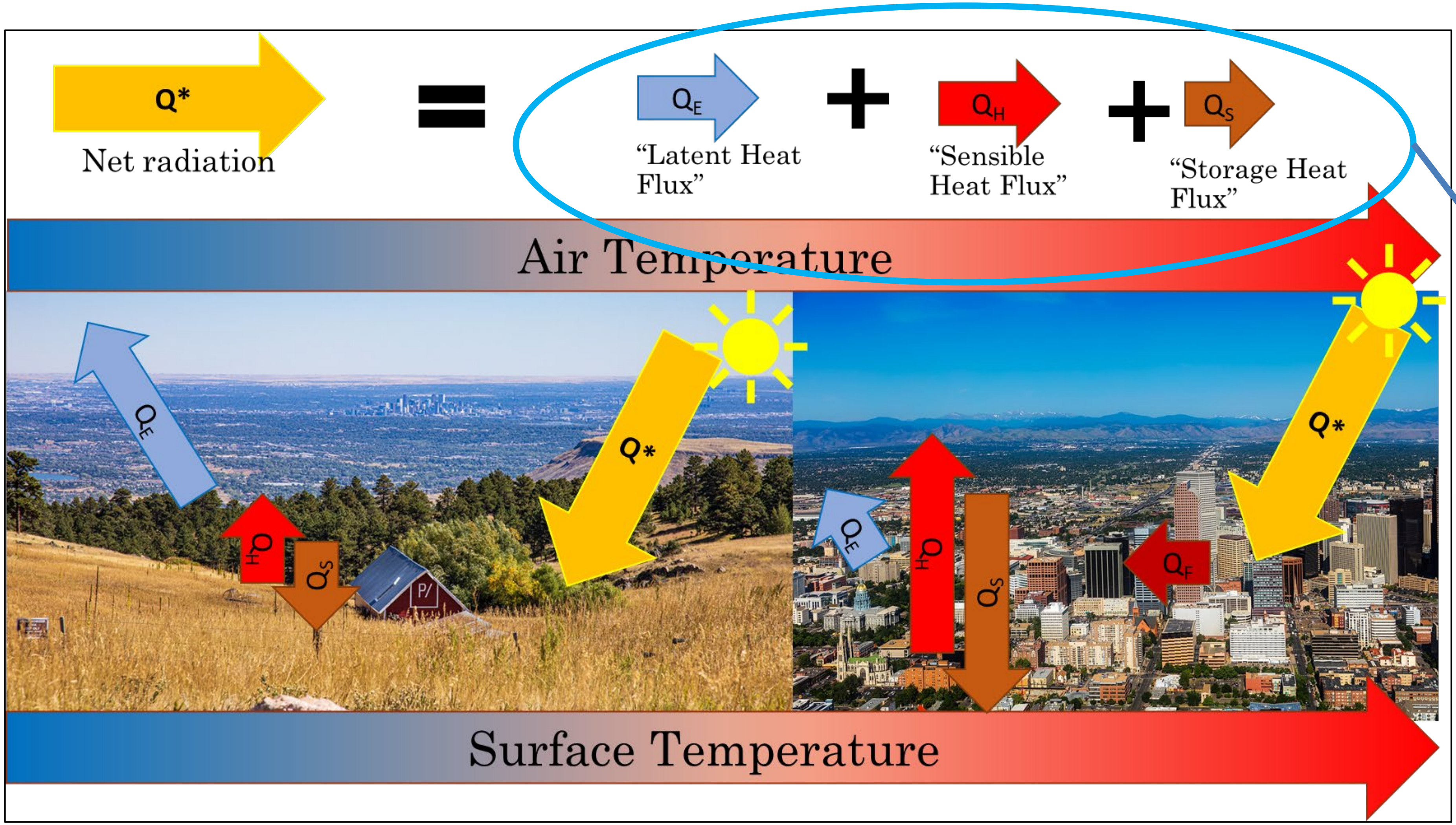
Land Cover and Heat Mitigation Can Be Dependent of Regional Climate

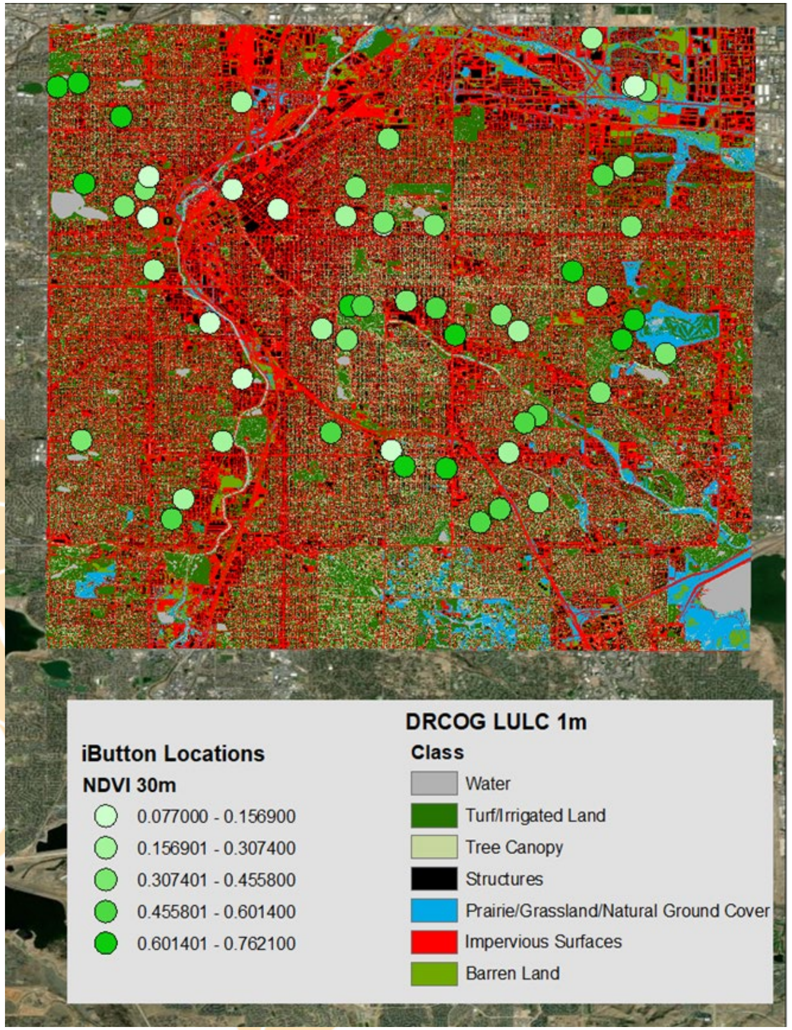


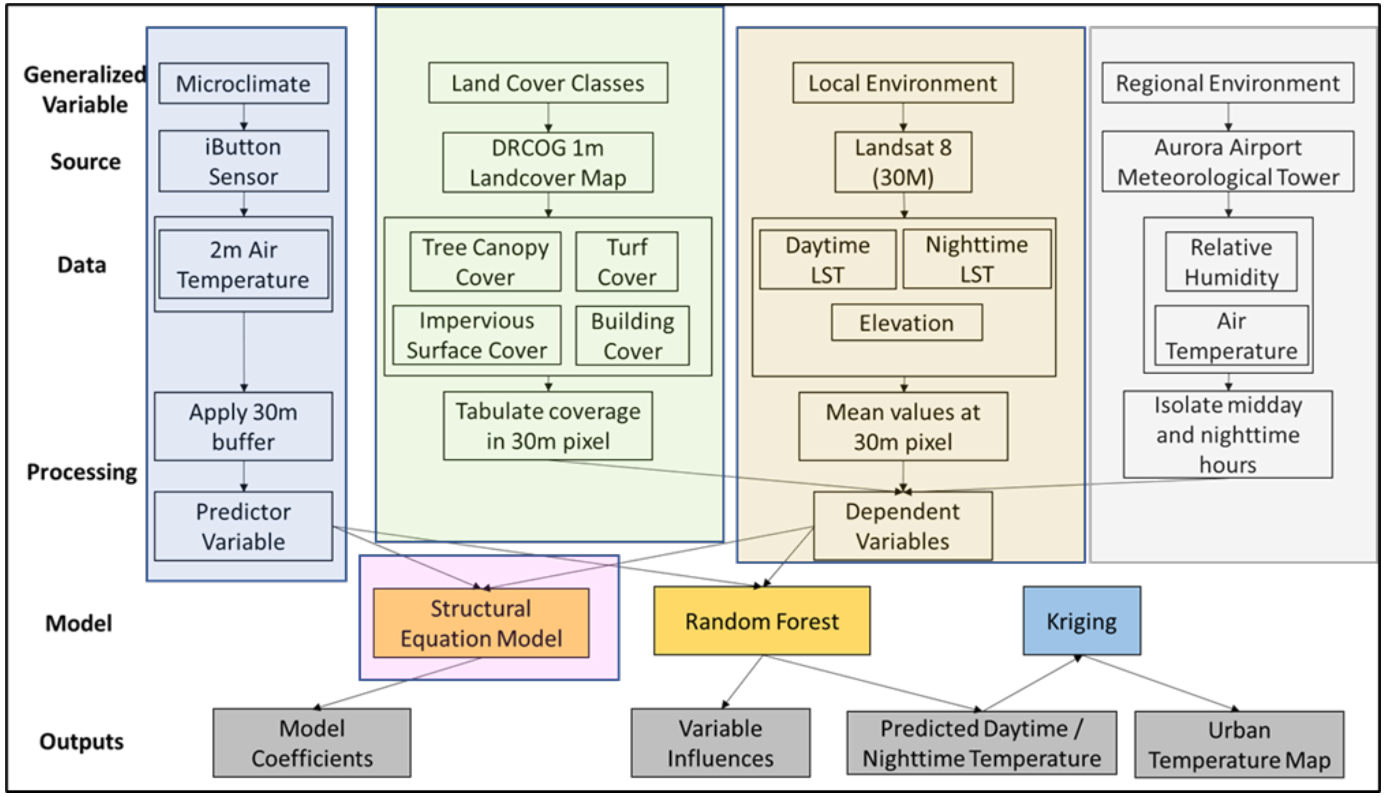
Climate underlies the biophysical mechanisms relating urban vegetation to cooling

USGS Climate Research and Development Program Urban Heat Study – Research Questions

1. How do highly heterogenous land covers influence daytime and nighttime urban temperatures?
2. Does the influence of urban land cover on urban heat vary in different regional climates?
3. Does the relative influence of urban land cover on air temperature vary during heat waves?
4. How does urban land covers' heat mitigating properties affect urban residents?

USGS Climate Research and Development Program Urban Heat Study – Citywide Scale





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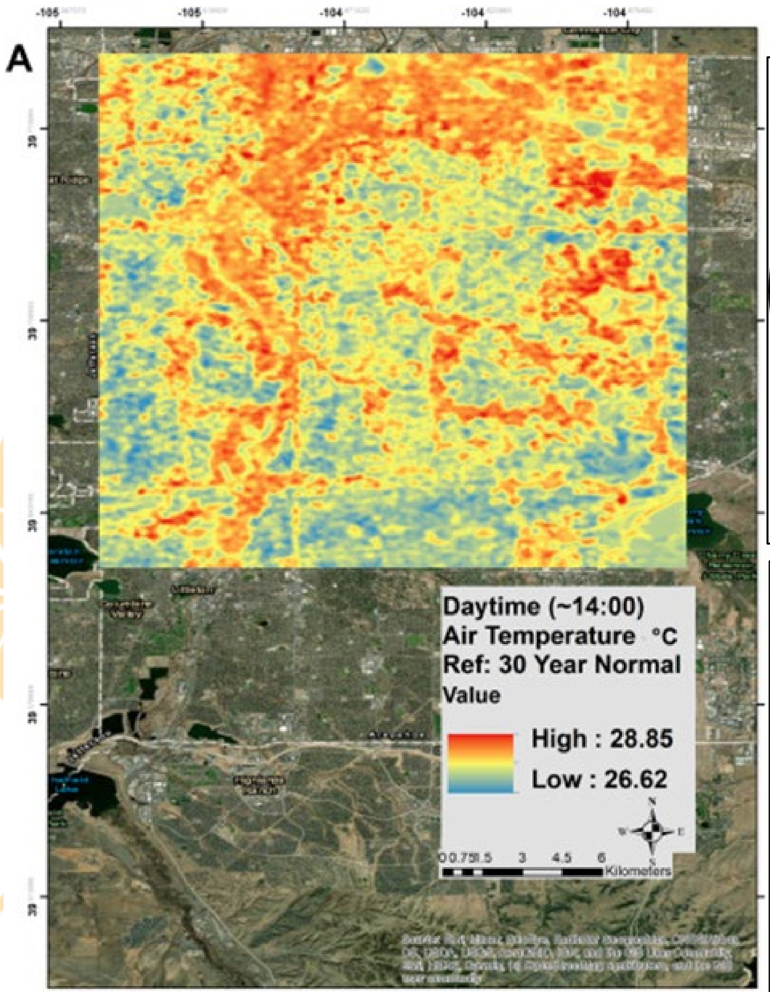
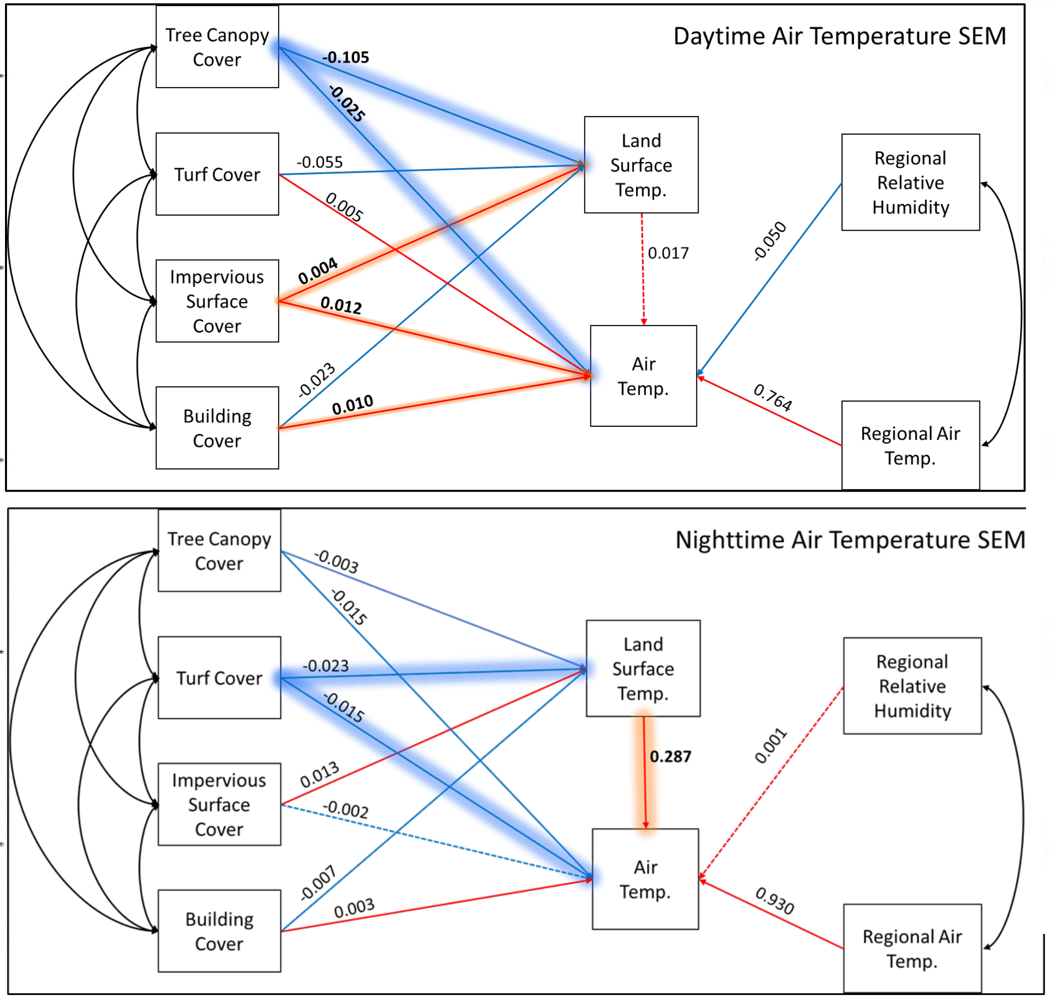
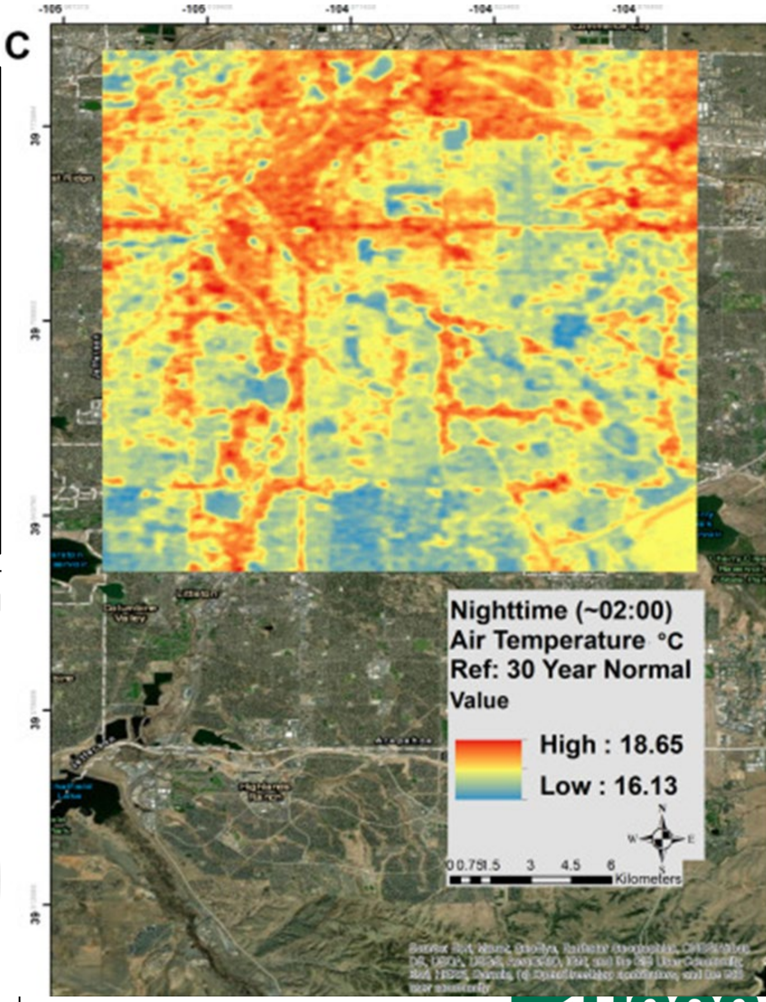
USGS Climate Research and Development Program Urban Heat Study – Citywide Scale







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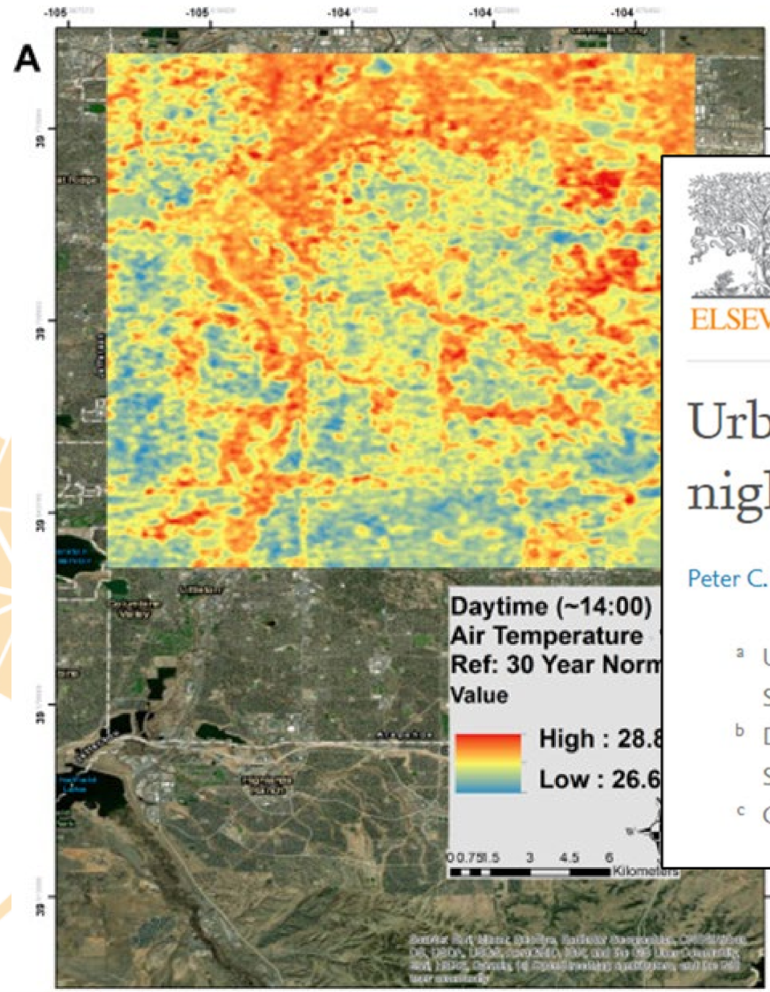
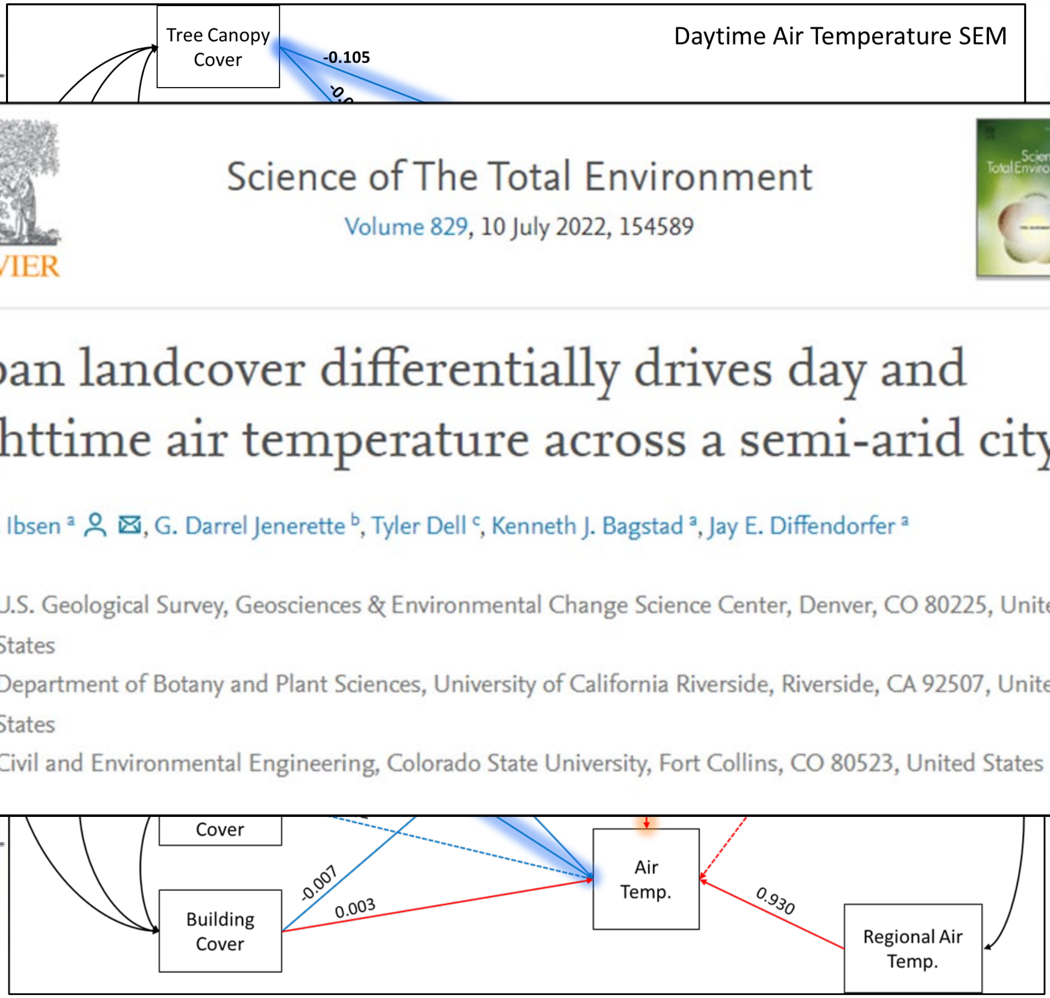
USGS Climate Research and Development Program Urban Heat Study – Citywide Scale



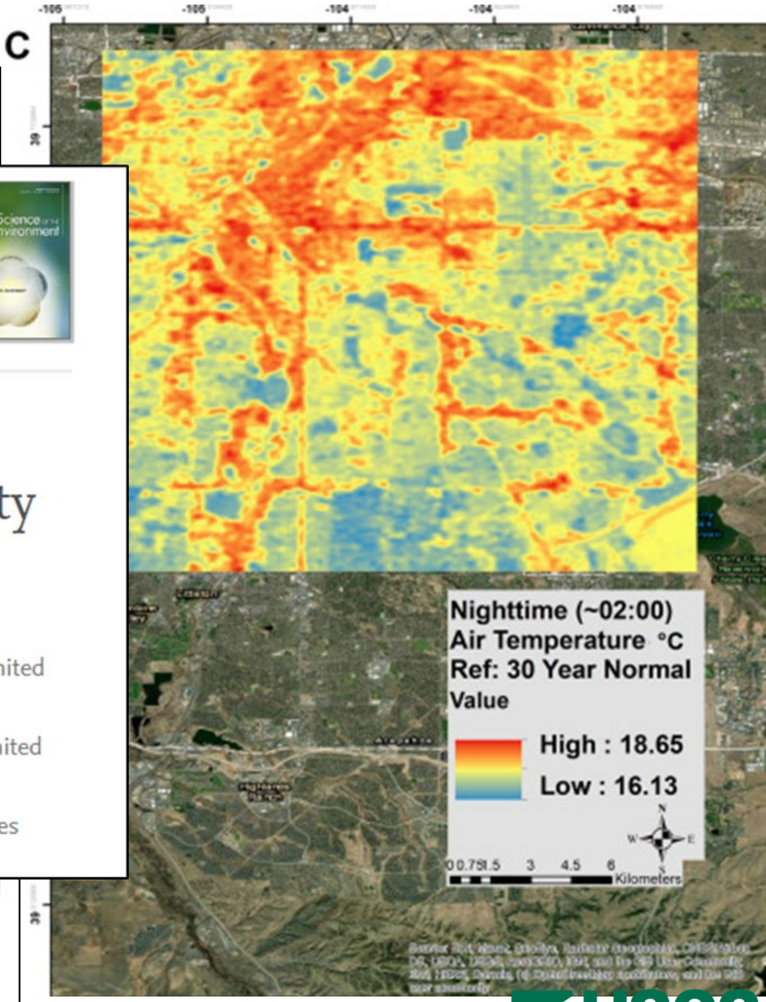


Science of The Total Environment
Volume 829, 10 July 2022, 154589

Urban landcover differentially drives day and nighttime air temperature across a semi-arid city

Peter C. Ibsen [a], G. Darrel Jenerette [b], Tyler Dell [c], Kenneth J. Bagstad [a], Jay E. Diffendorfer [a]

[a] U.S. Geological Survey, Geosciences & Environmental Change Science Center, Denver, CO 80225, United States
[b] Department of Botany and Plant Sciences, University of California Riverside, Riverside, CA 92507, United States
[c] Civil and Environmental Engineering, Colorado State University, Fort Collins, CO 80523, United States



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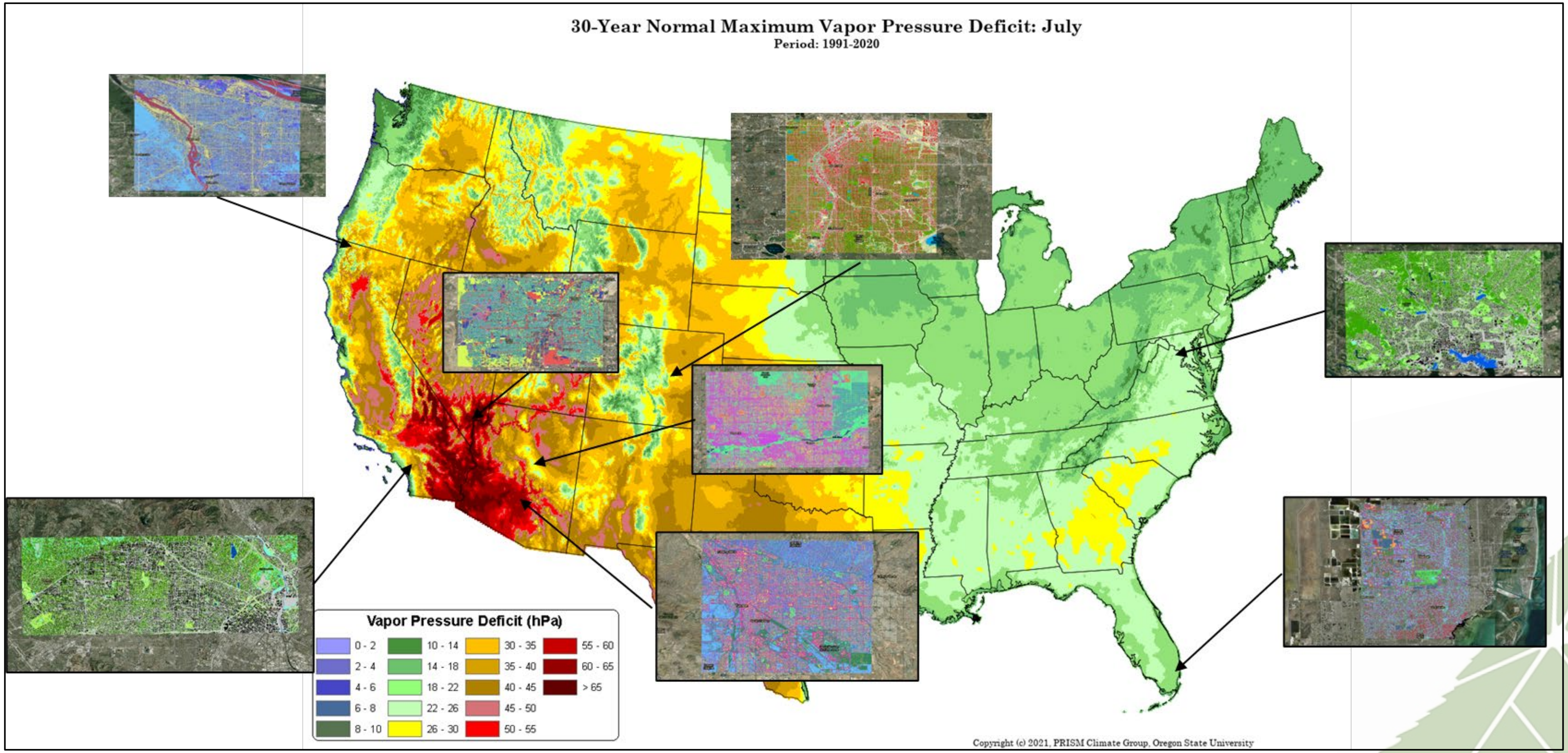
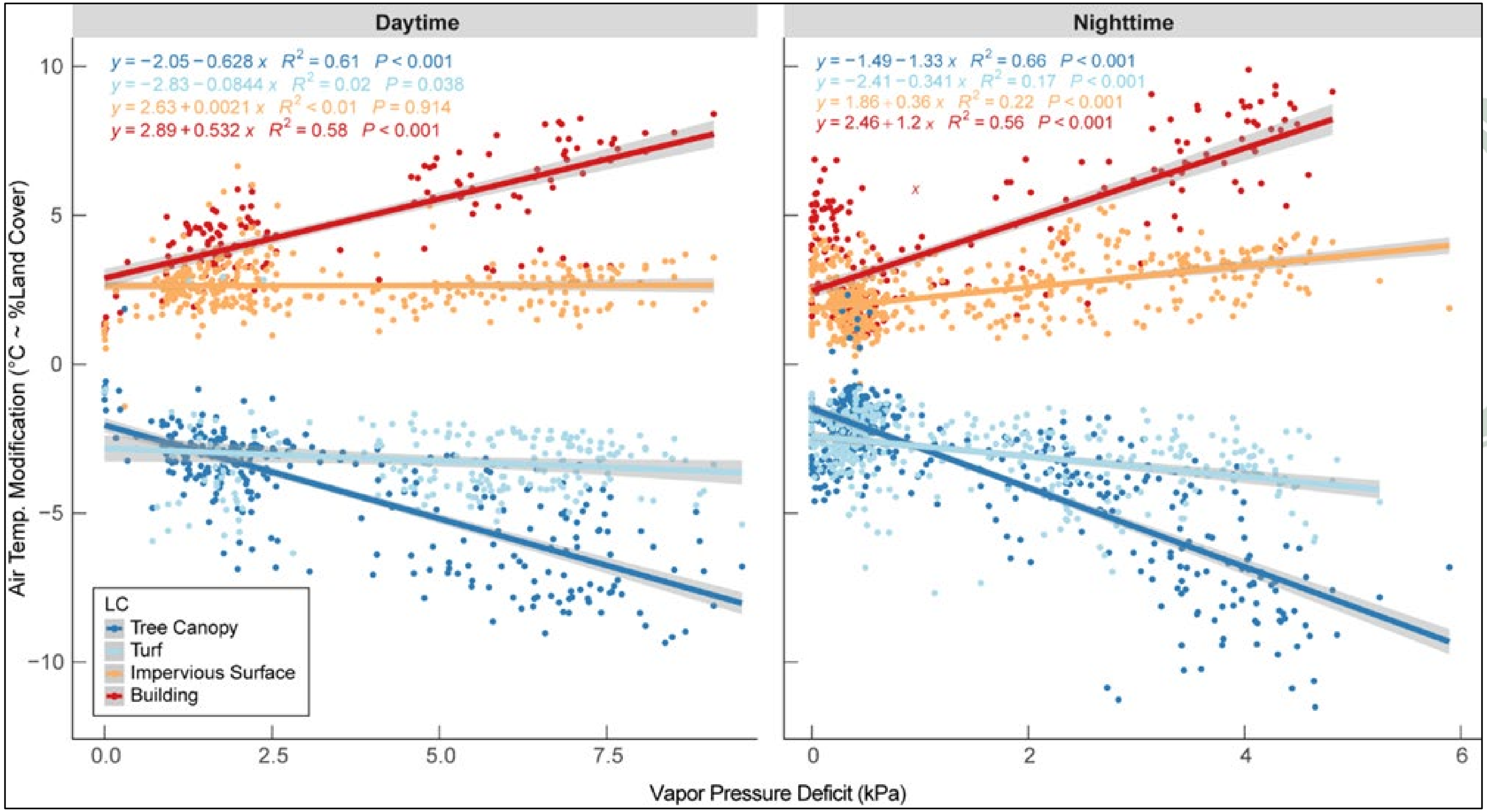
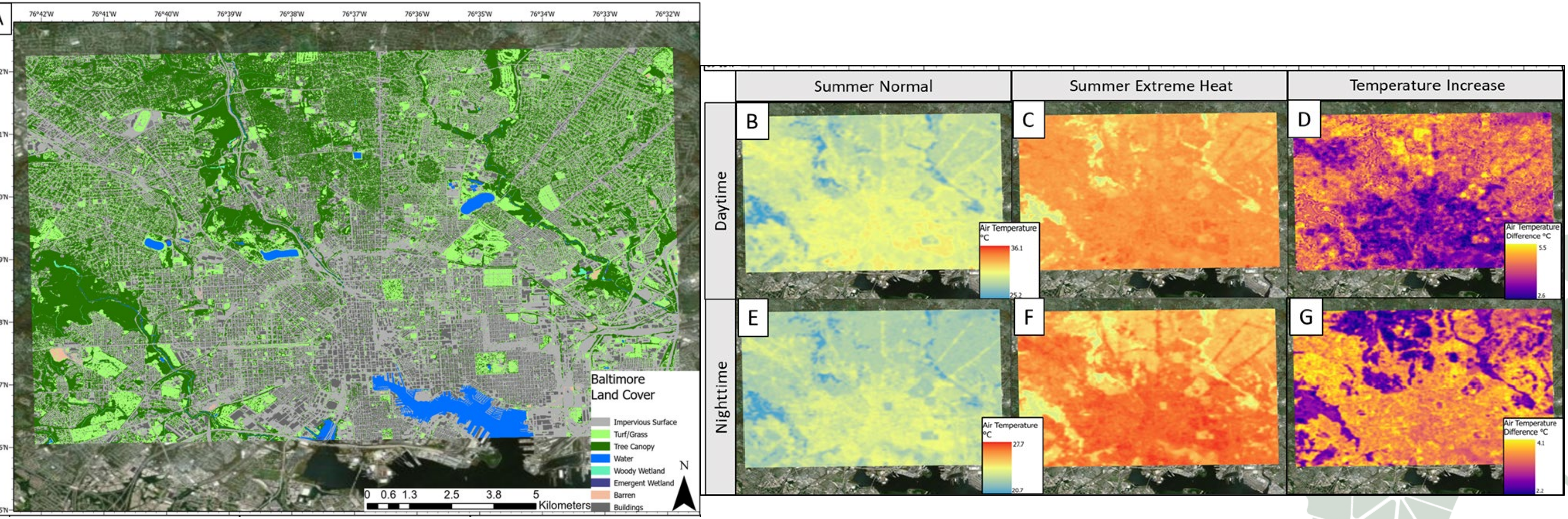
USGS Climate Research and Development Program Urban Heat Study – Nationwide Scale



USGS Climate Research and Development Program Urban Heat Study – Nationwide Scale



USGS Climate Research and Development Program Urban Heat Study – Nationwide Scale



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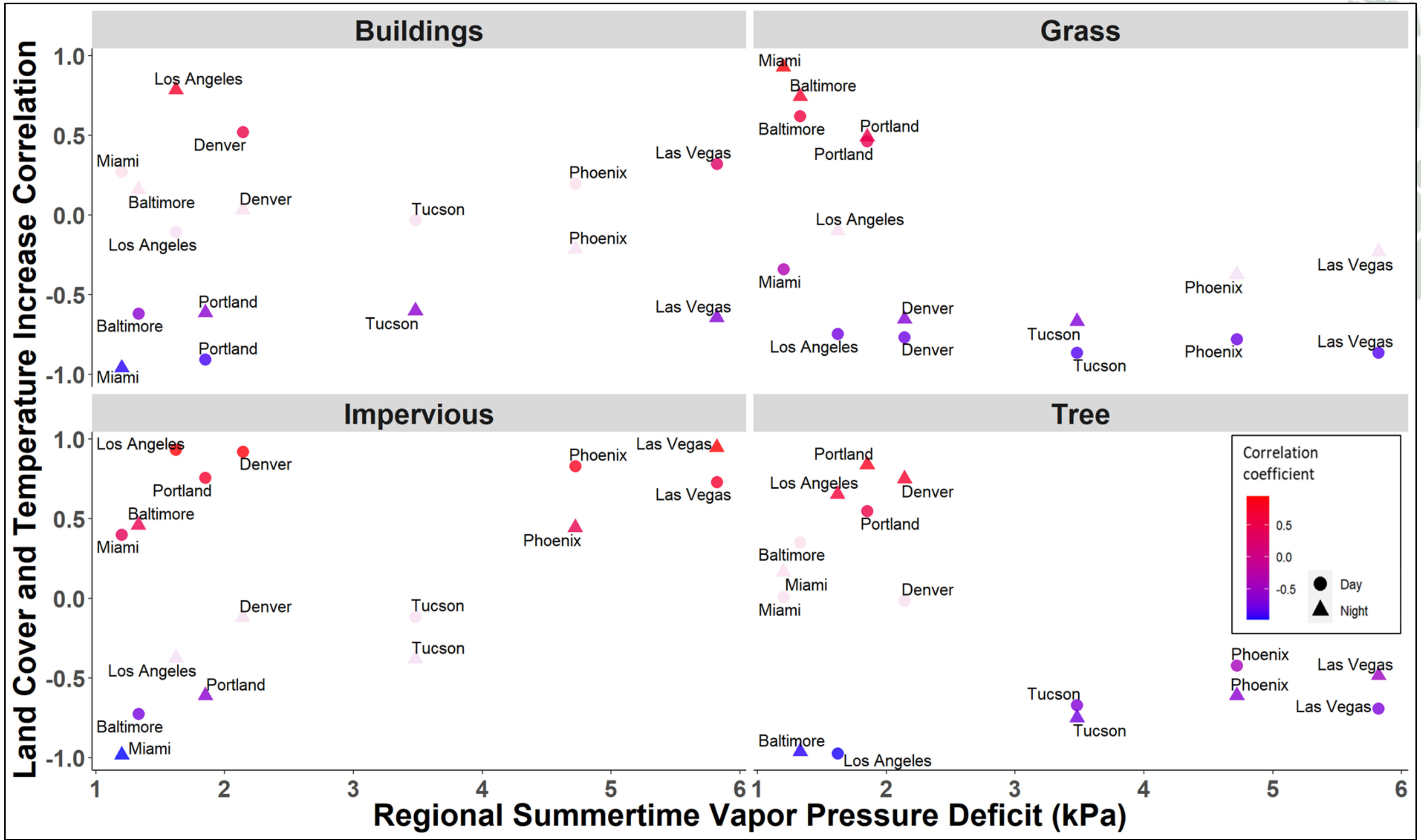
USGS Climate Research and Development Program Urban Heat Study – Nationwide Scale



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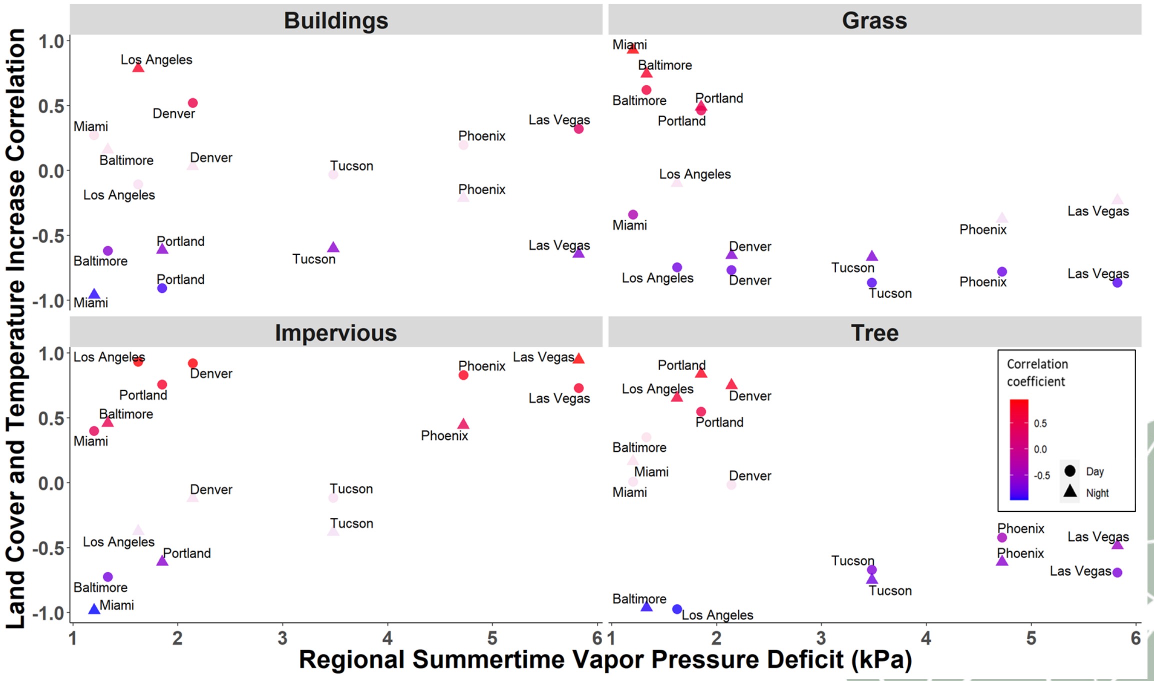
USGS Climate Research and Development Program Urban Heat Study – City & Nationwide Scale

Main Takeaways

- Vegetation-derived cooling ecosystem services have a significant interaction with regional climate
- Hotter/Drier cities experience greater vegetation-derived cooling benefits – Primarily driven by tree canopy
- Buildings’ effect on urban warming also scales with regional heat/aridity
- During heatwaves, vegetation in arid cities consistently increases cooling potential, while land use in more humid cities responds variably to heat waves, which can inform city-specific heat mitigation planning



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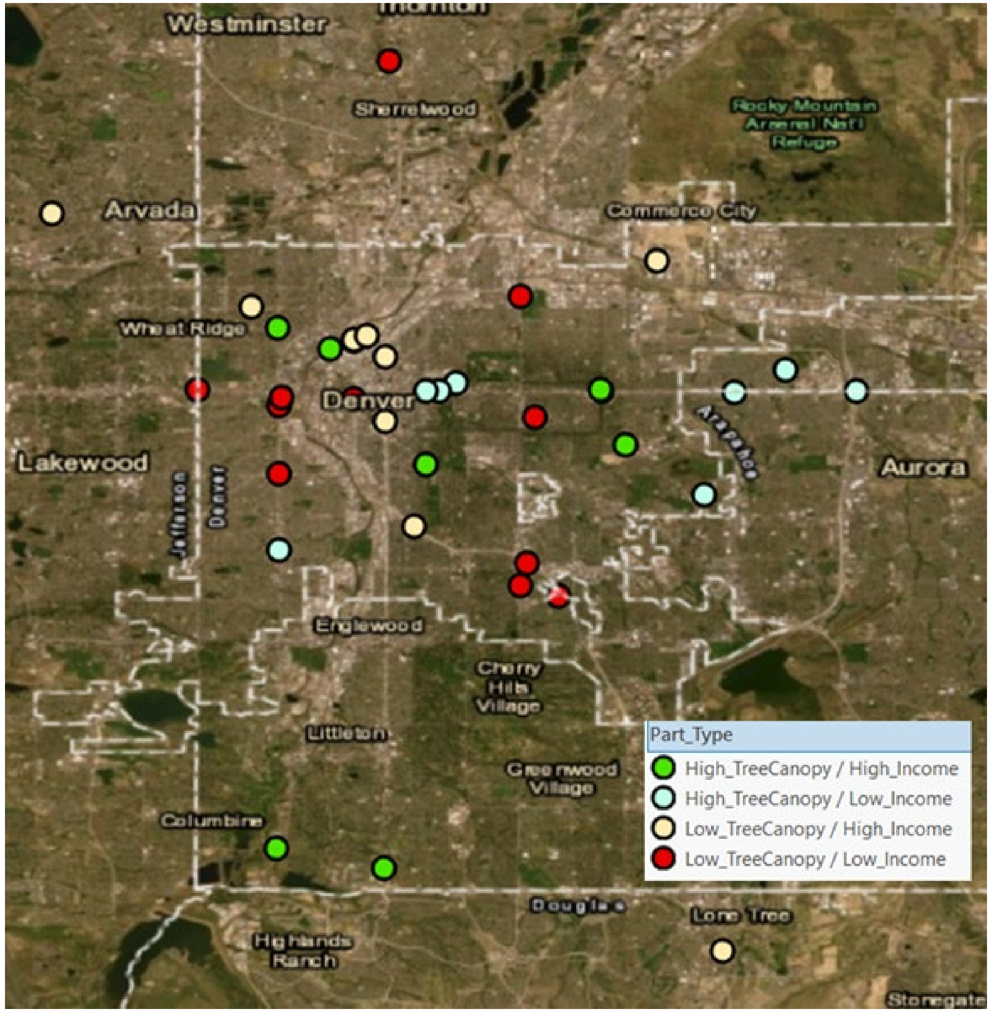
USGS Climate Research and Development Program Urban Heat Study – Local Scale



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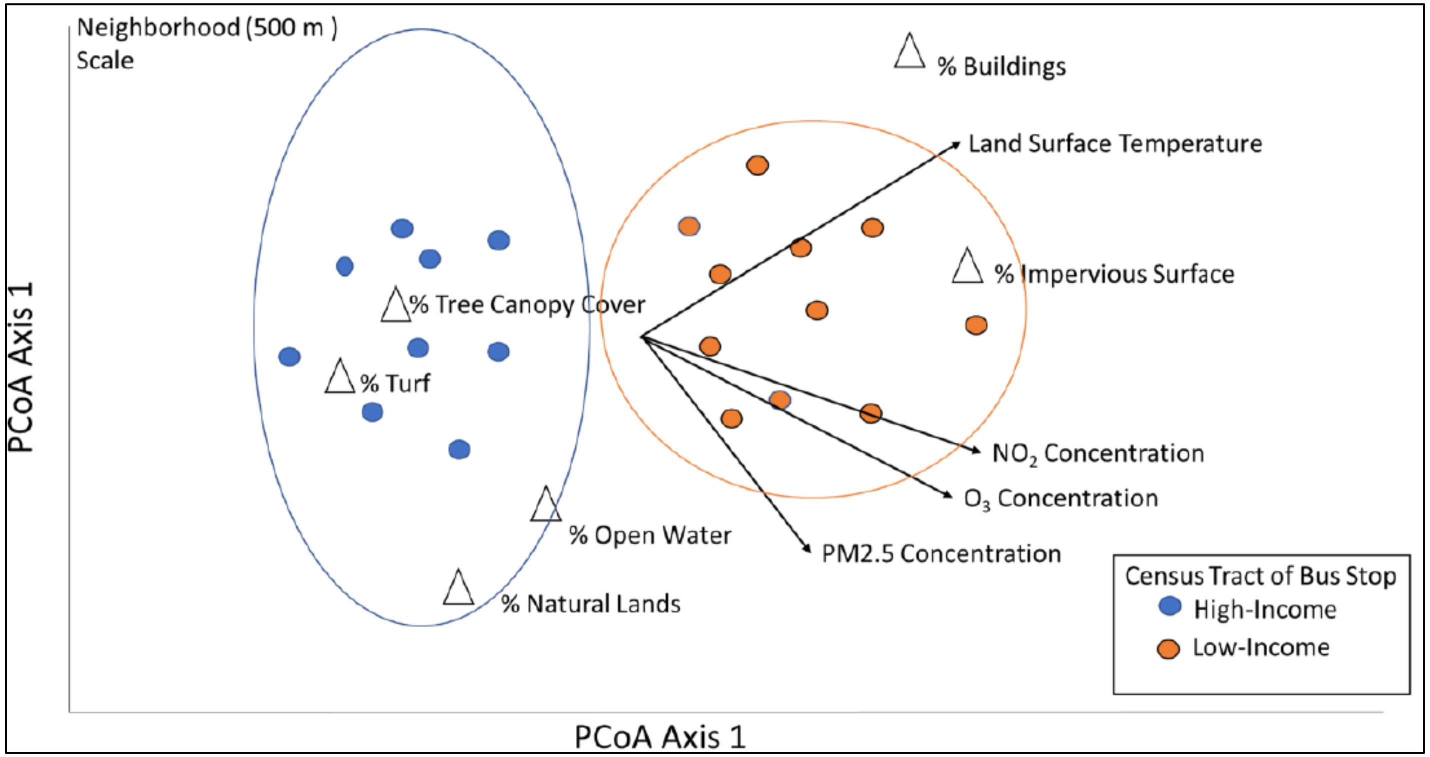
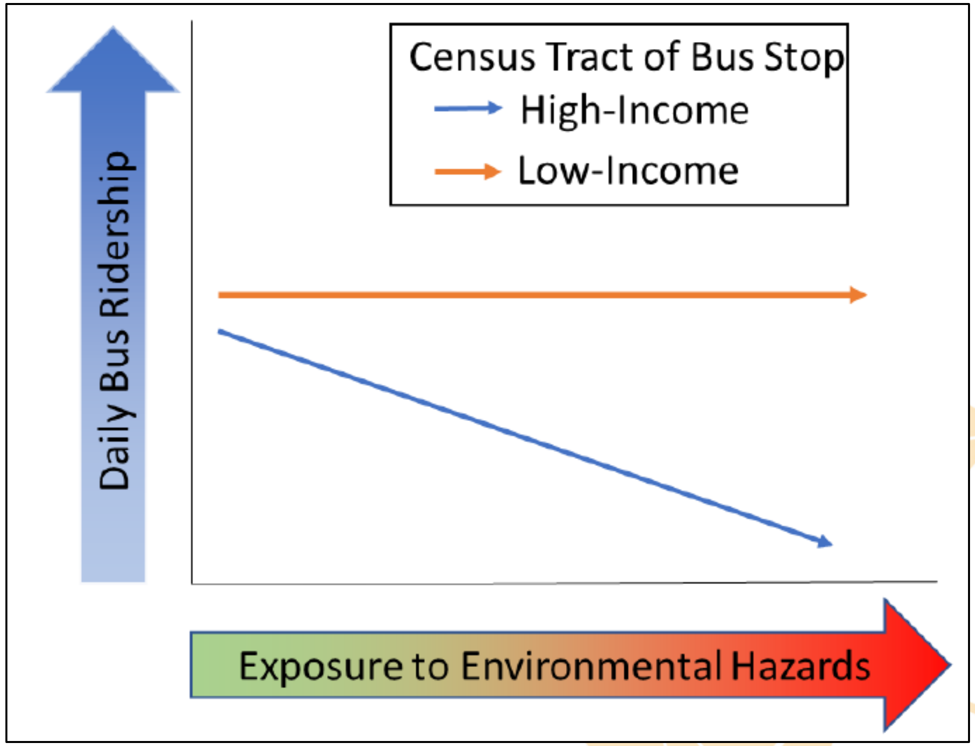
USGS Climate Research and Development Program Urban Heat Study – Local Scale





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Thank you

Peter Ibsen | United States Geological Survey
Climate Research & Development Program

pibsen@ usgs.gov

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Washington DC, 2023

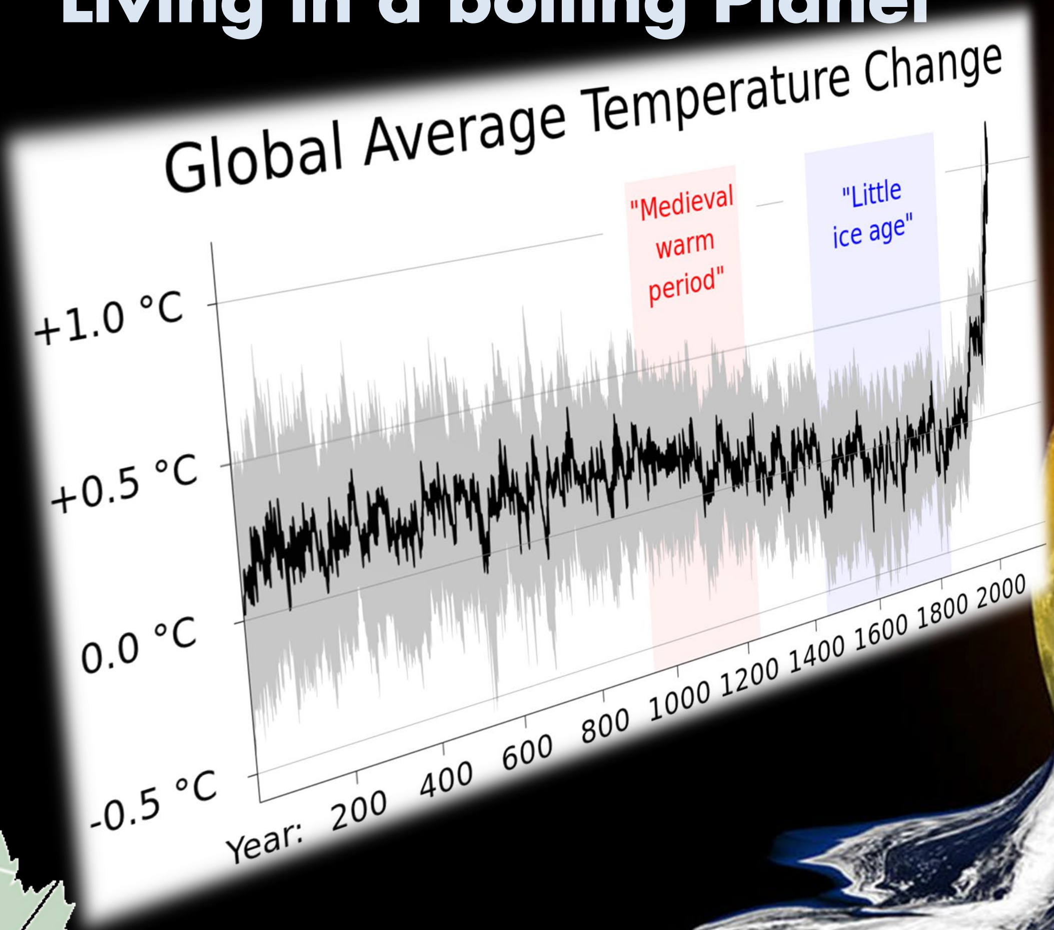
Greener & Cooler. Earth observation and AI to check the performance of Urban Forest in contrasting heat islands

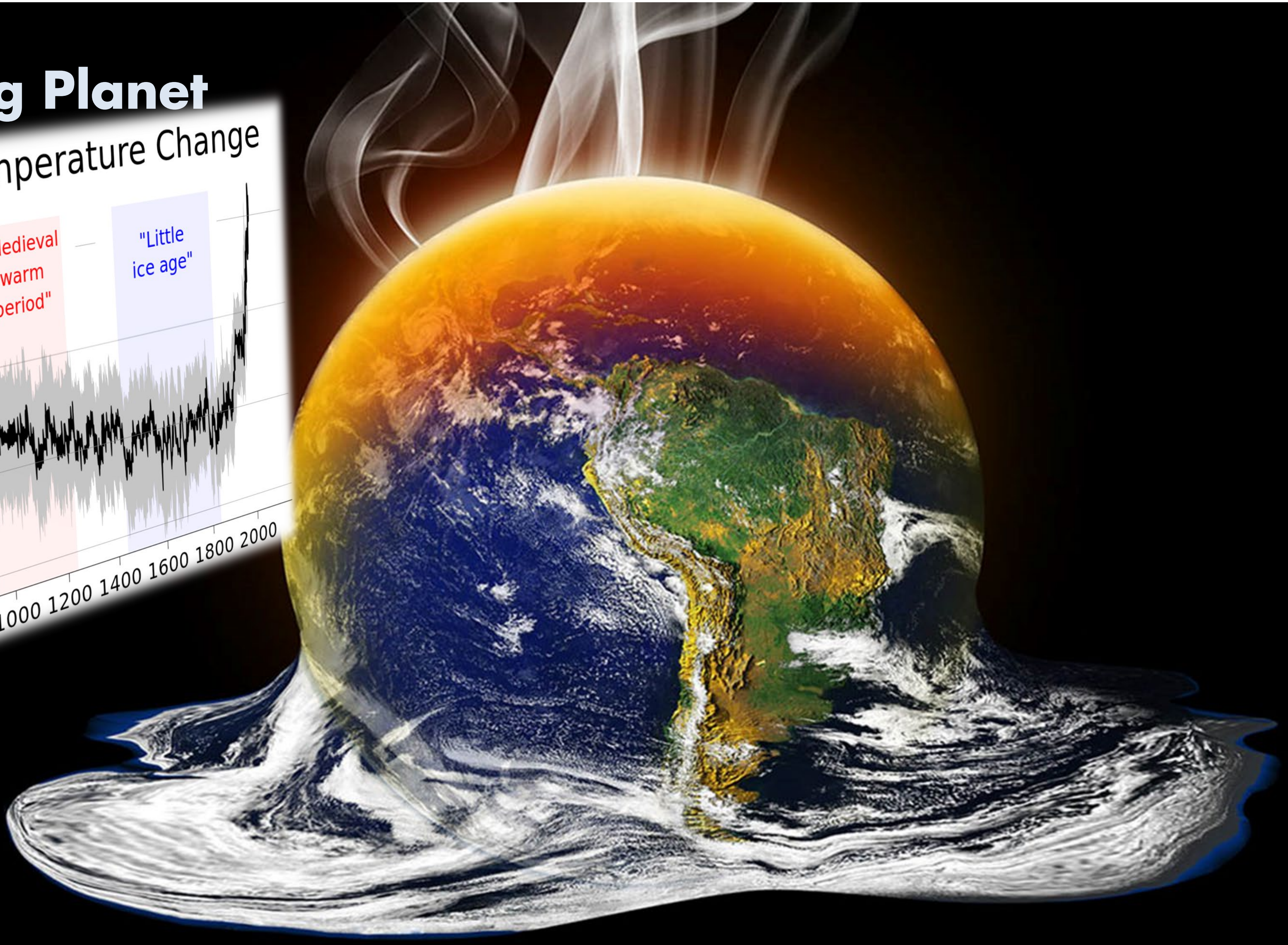
Presented by

Fabio Salbitano, Mondanelli, L., Francini, S., Cocozza, C., Chirici, G., Clementini, C., Marchetti, M., Manaresi, M., Speak, A.F.

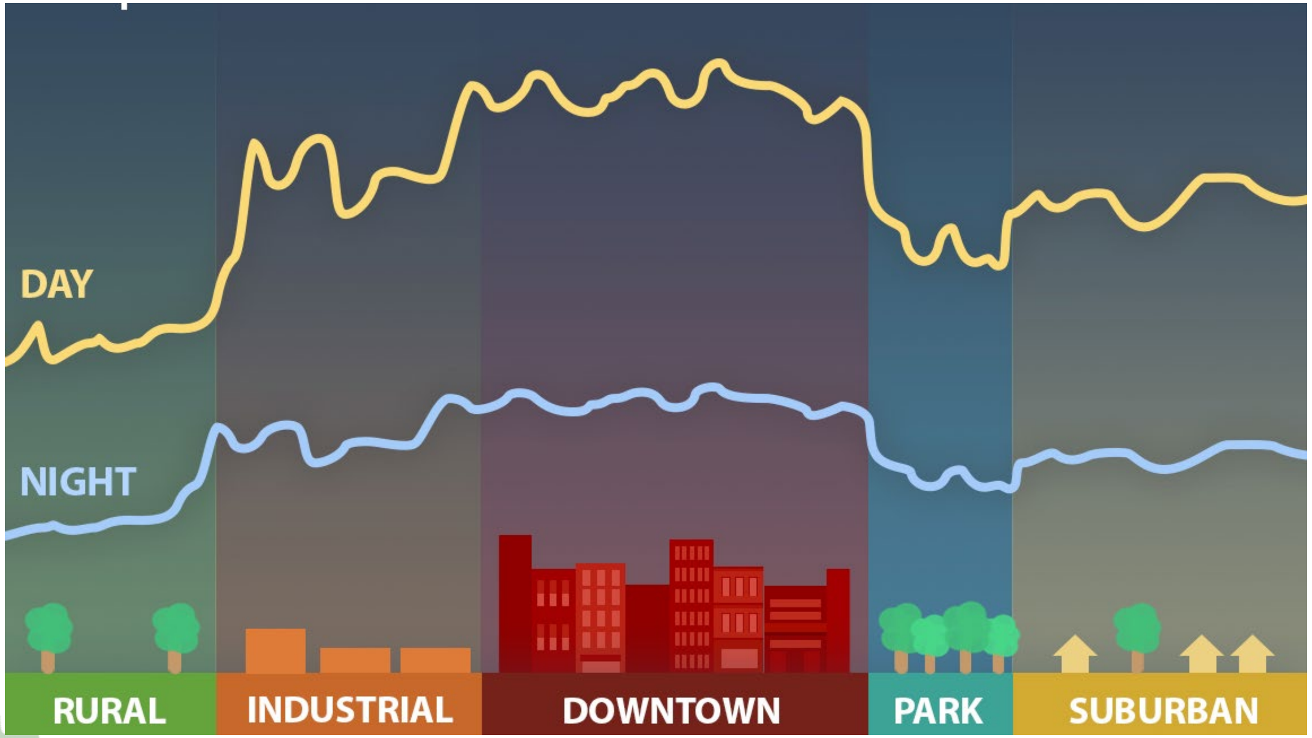
October 18, 2023

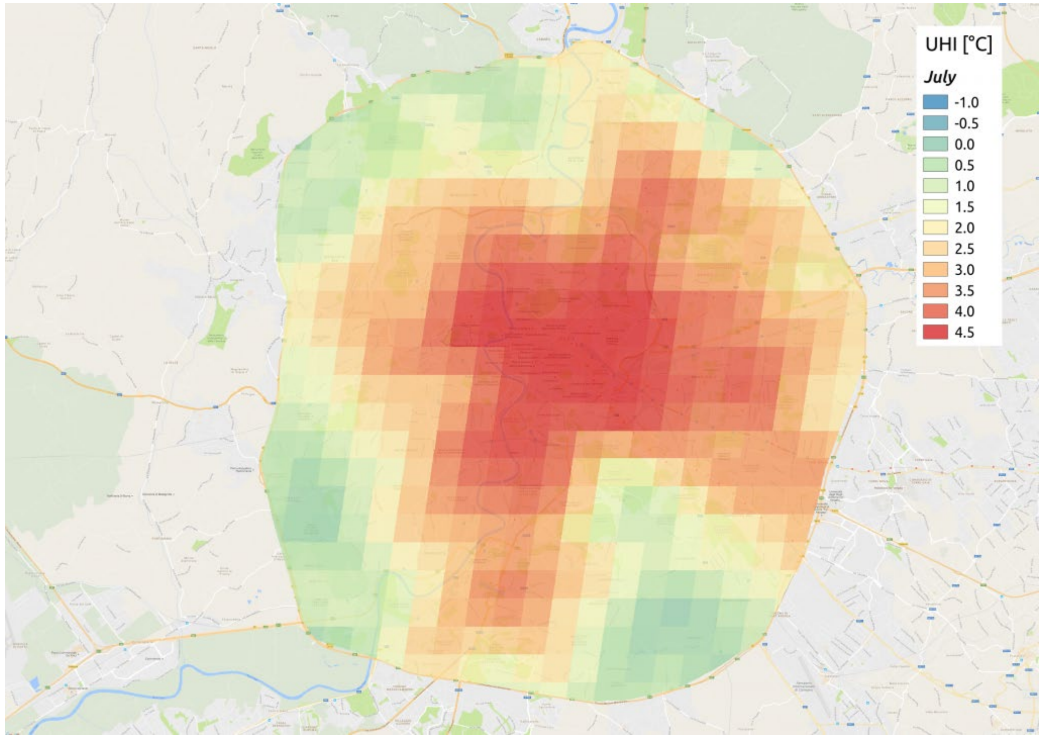
Living in a boiling Planet

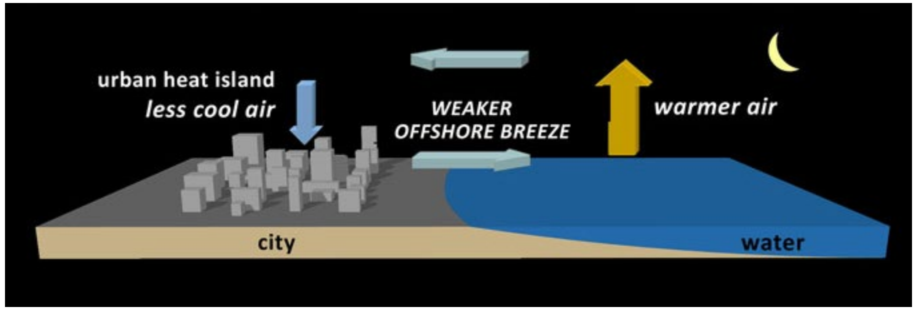


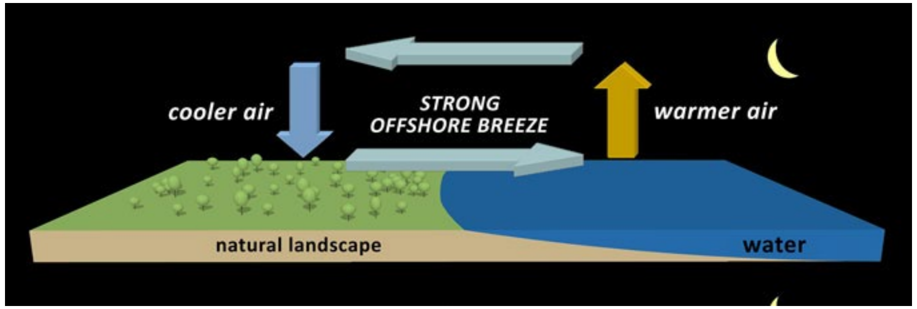


The Urban Heat Island

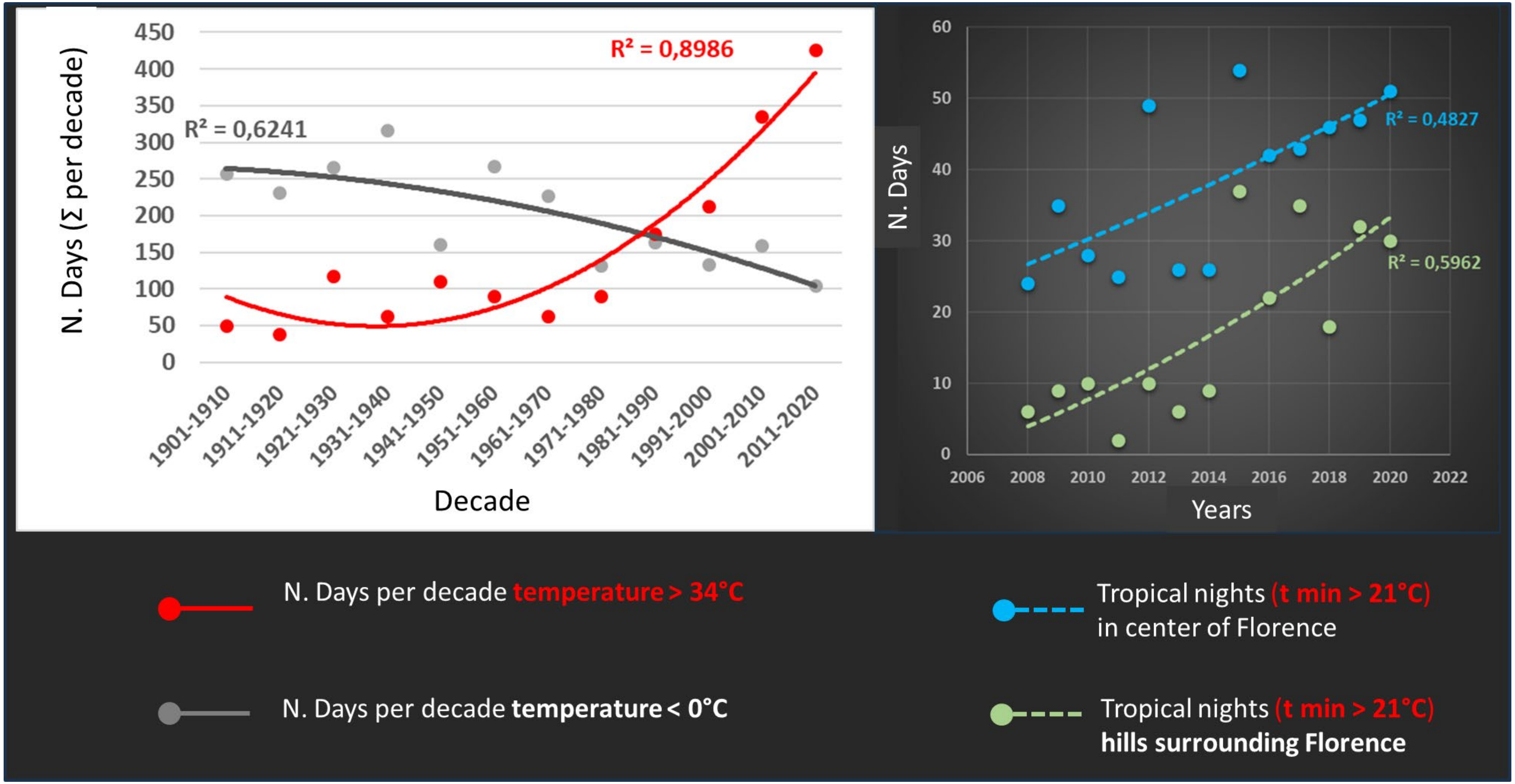






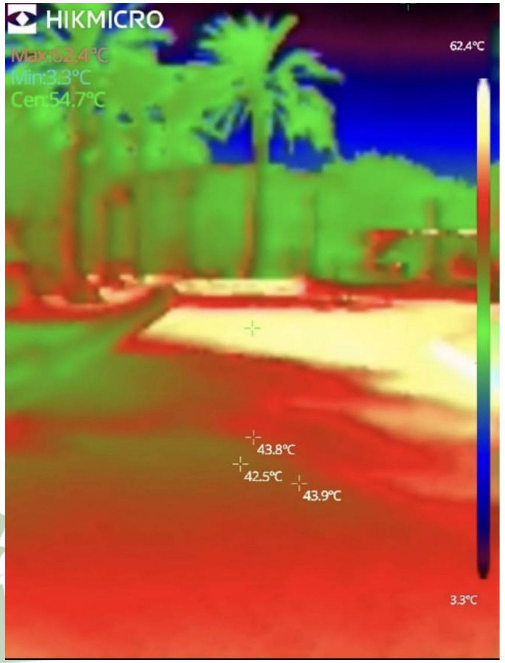


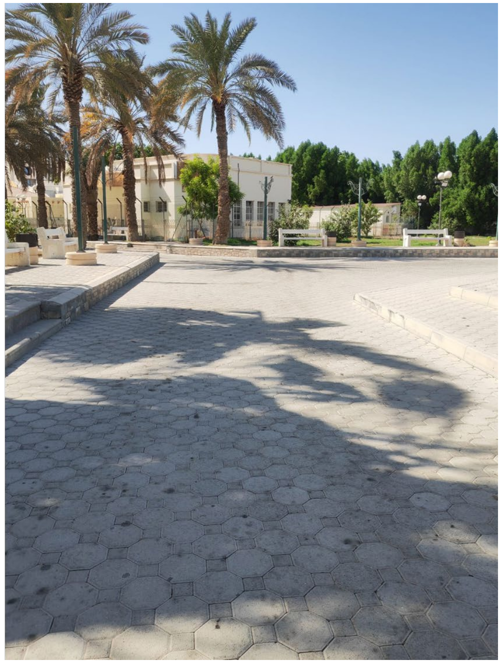
Climate change & Temperature



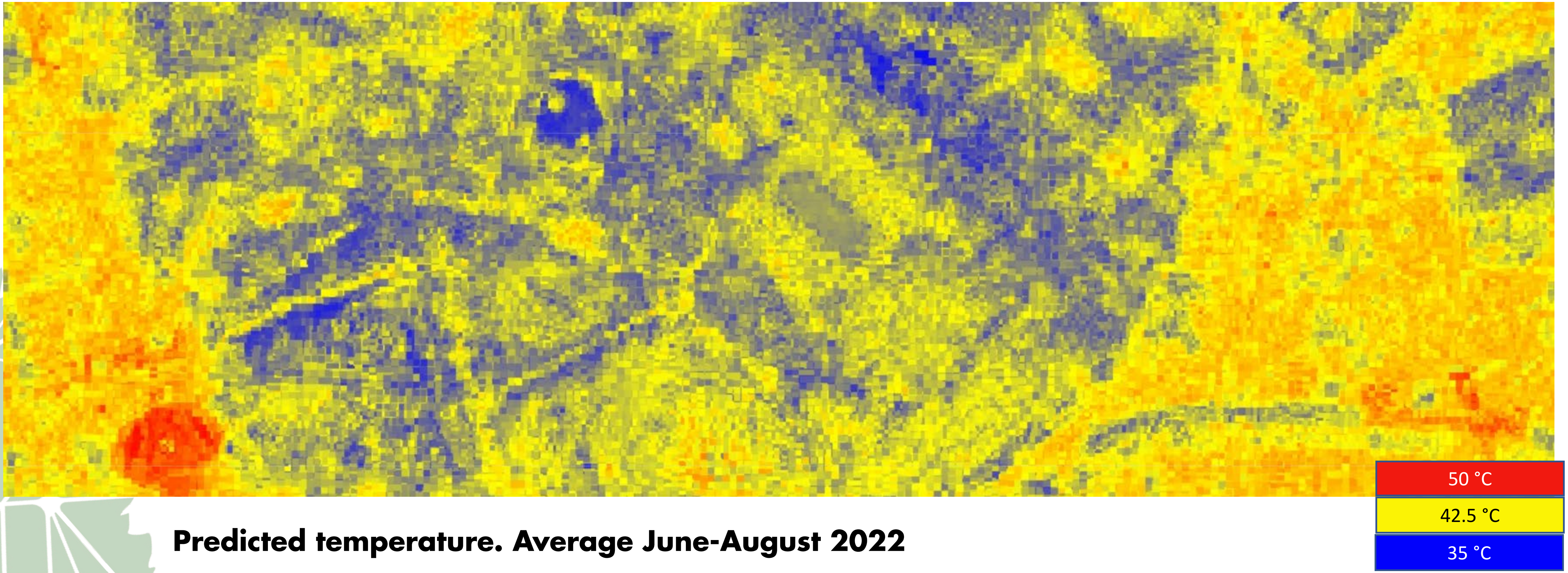
Air temperature and urban heat islands

Quantified by in situ measurements: a homogeneously distributed network of sensors and can be time-consuming and expensive.





Remote sensing data is known to be a relevant source of information for large-scale monitoring of Land Surface Temperature (LST)

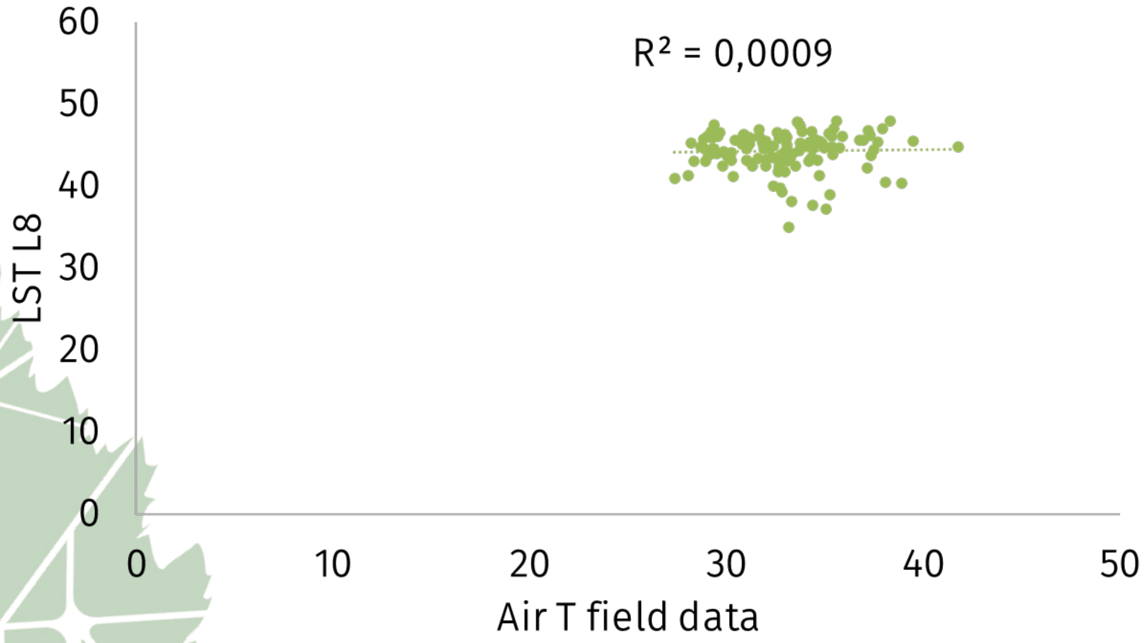


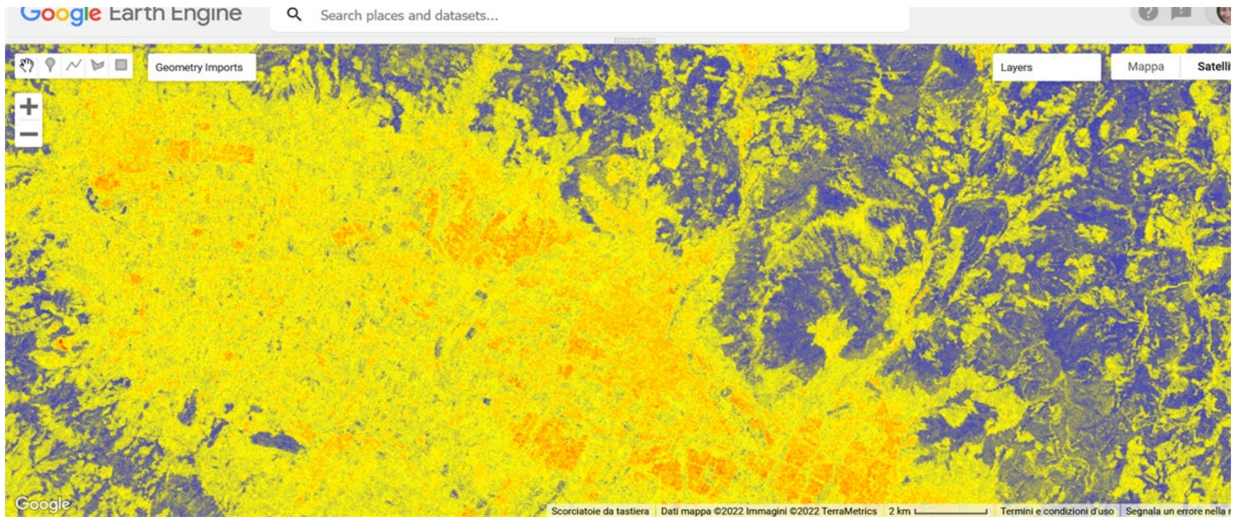
Predicted temperature. Average June-August 2022

Assessing LST in the urban context is essential for understanding the capability of urban forests and trees in mitigating climate and avoiding urban heat islands, and so improving human thermal comfort

- Landsat provides LST data at 30 meters, but LST urban monitoring requires data at a finer resolution.
- Urban forests are often characterized by very small patches that are challenging to analyze using 30-meter resolution data.
- Little knowledge was developed in up-scaling the LST products by using Sentinel-2 data.
- Combining MODIS and Landsat LST data, studies combining MODIS LST and Sentinel-2 data, and studies combining Sentinel-3 LST and Sentinel-2 data.
- Almost any study focuses on upscaling Landsat LST data by using Sentinel-2 data.

What is the level of accuracy and admissibility of satellite remote sensing applications to understand the multiscalarity of thermal comfort in urban environments?

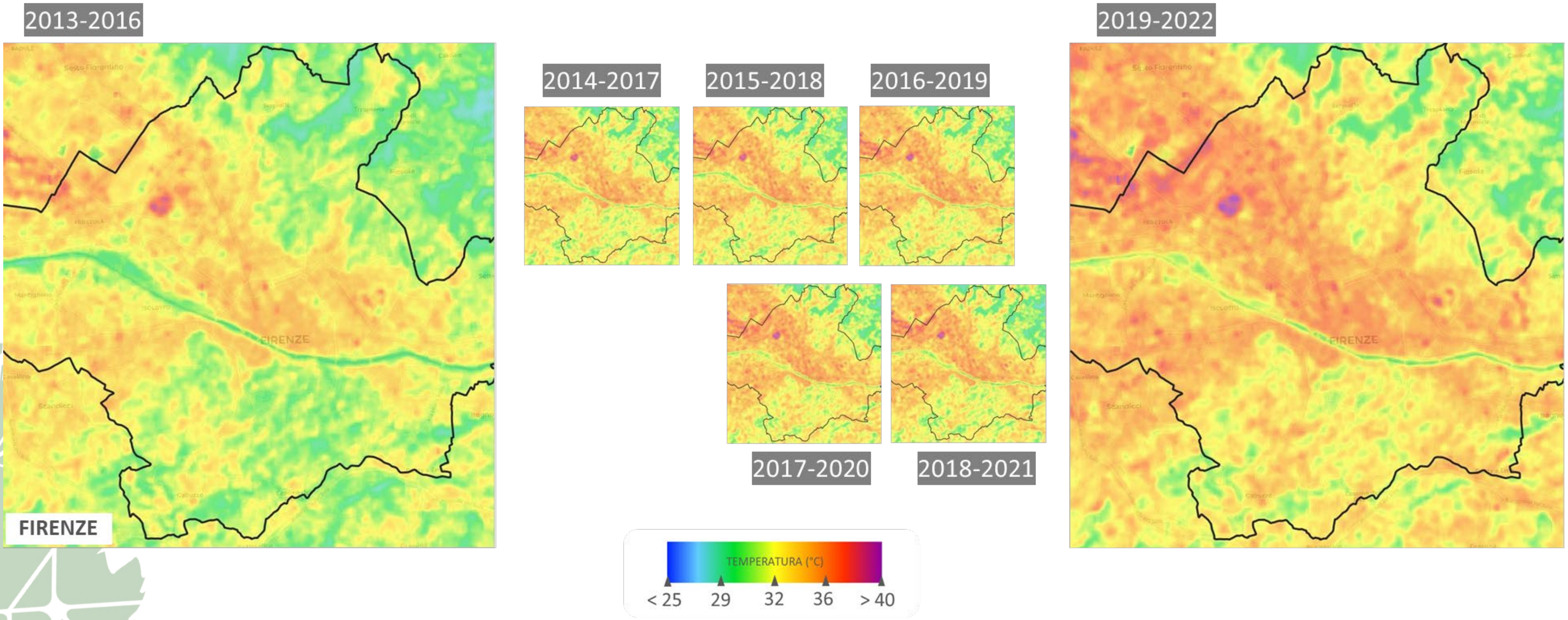




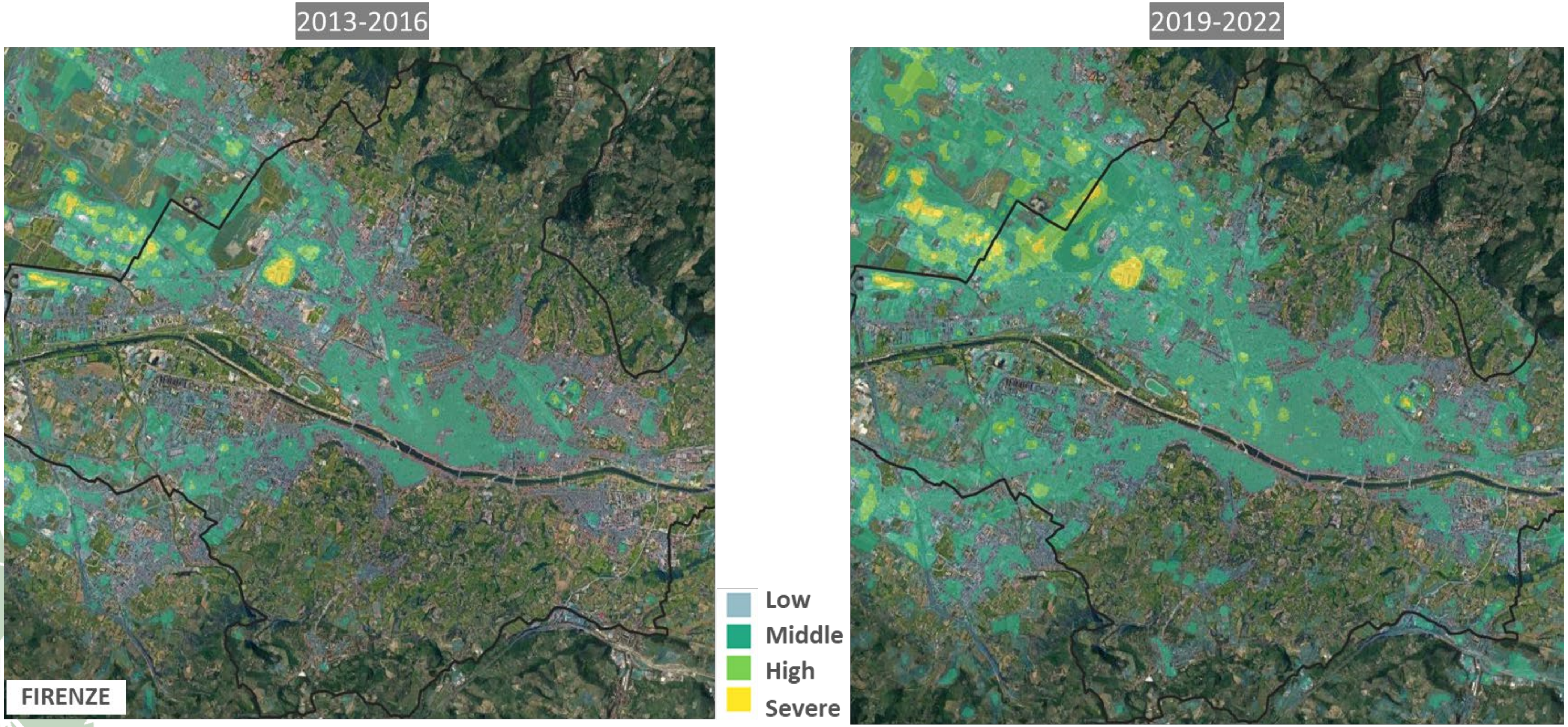
A dataset of air temperatures (Wet and Dry Bulb Temperature, and Globe Thermometer temperature) measured on-field during the summer of 2020

A model to predict LST as acquired by the Landsat sensor (30-resolution) using random forests and the four Sentinel-2 bands at 10-meters resolution, blue, green, red, and nir.

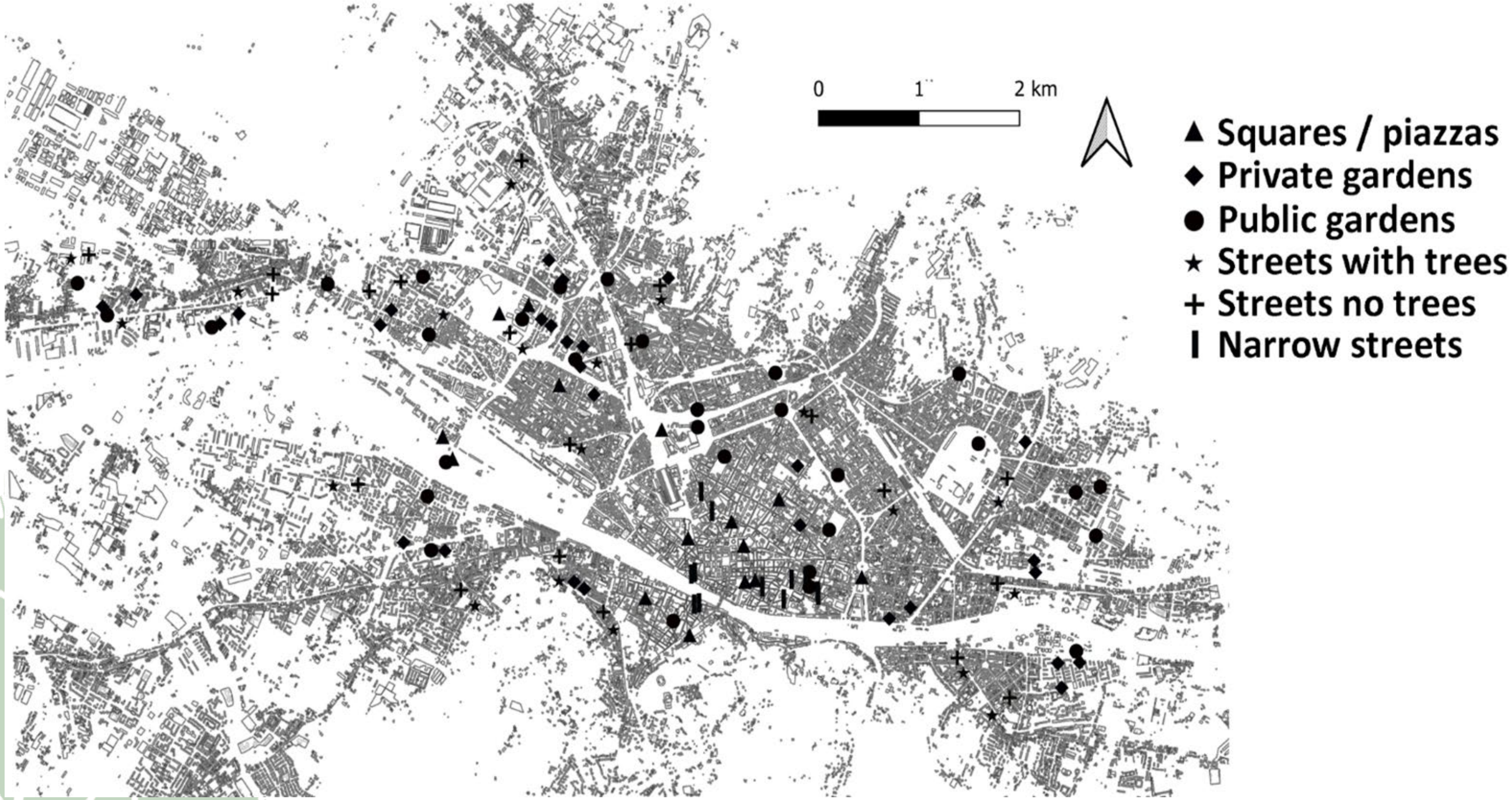
4 yrs. series of Temperature using combined Sentinel 2 data

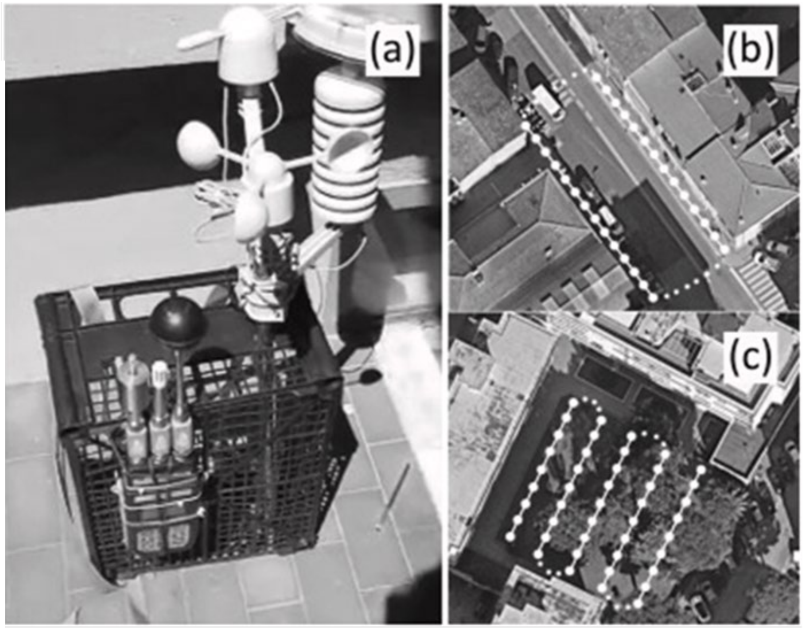


Surface urban heat island

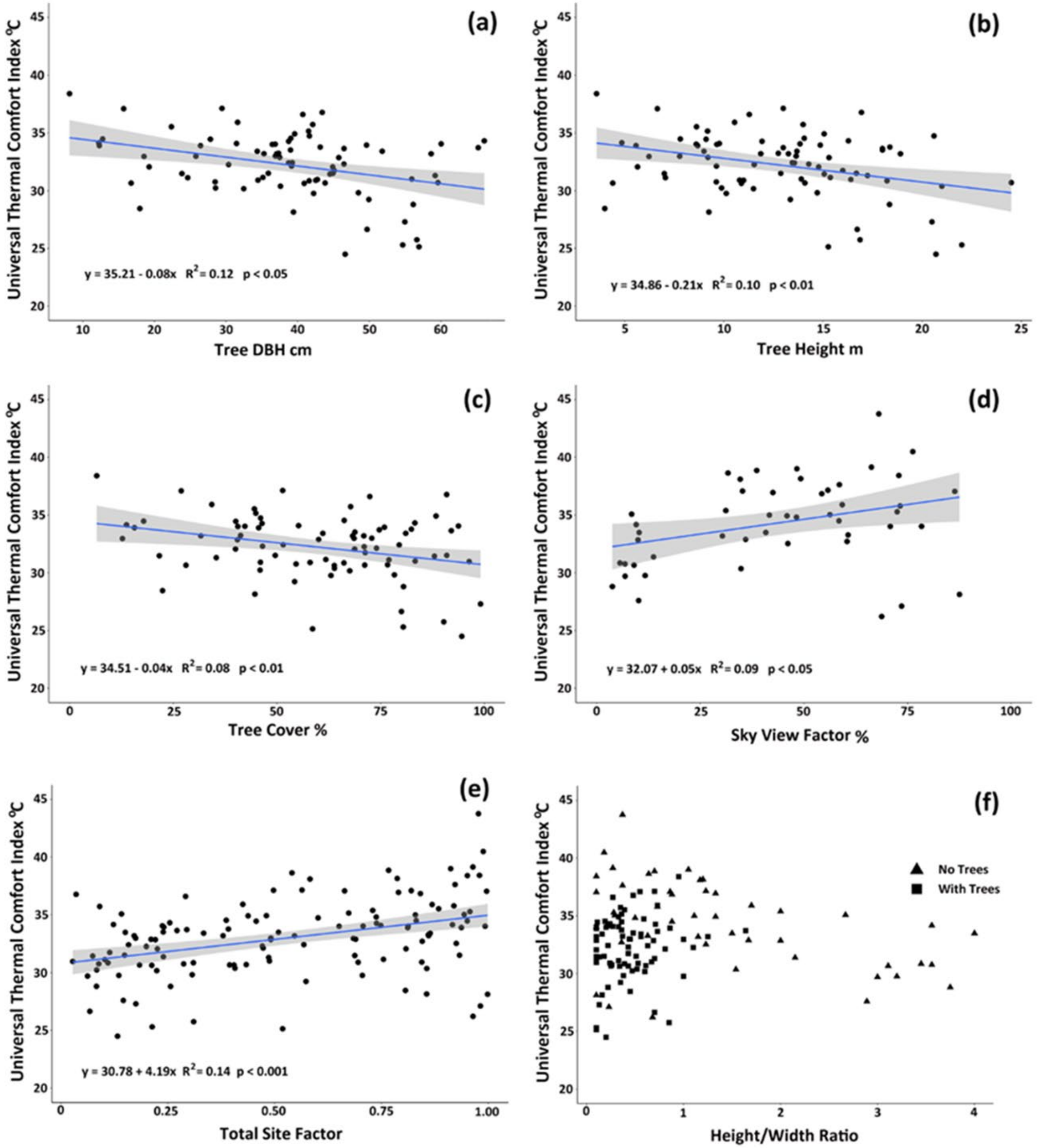


The micrometeorological and thermal comfort mobile study in Florence





a) Mobile meteorological monitoring station for measuring wet bulb, dry bulb and globe temperature alongside humidity and wind speed, and schematic diagrams of the walking paths taken in b) streets and c) gardens, parks and piazzas. Speak, A. F., & Salbitano, F. (2022). Summer thermal comfort of pedestrians in diverse urban settings: A mobile study. *Building and Environment*, *208*, 108600.

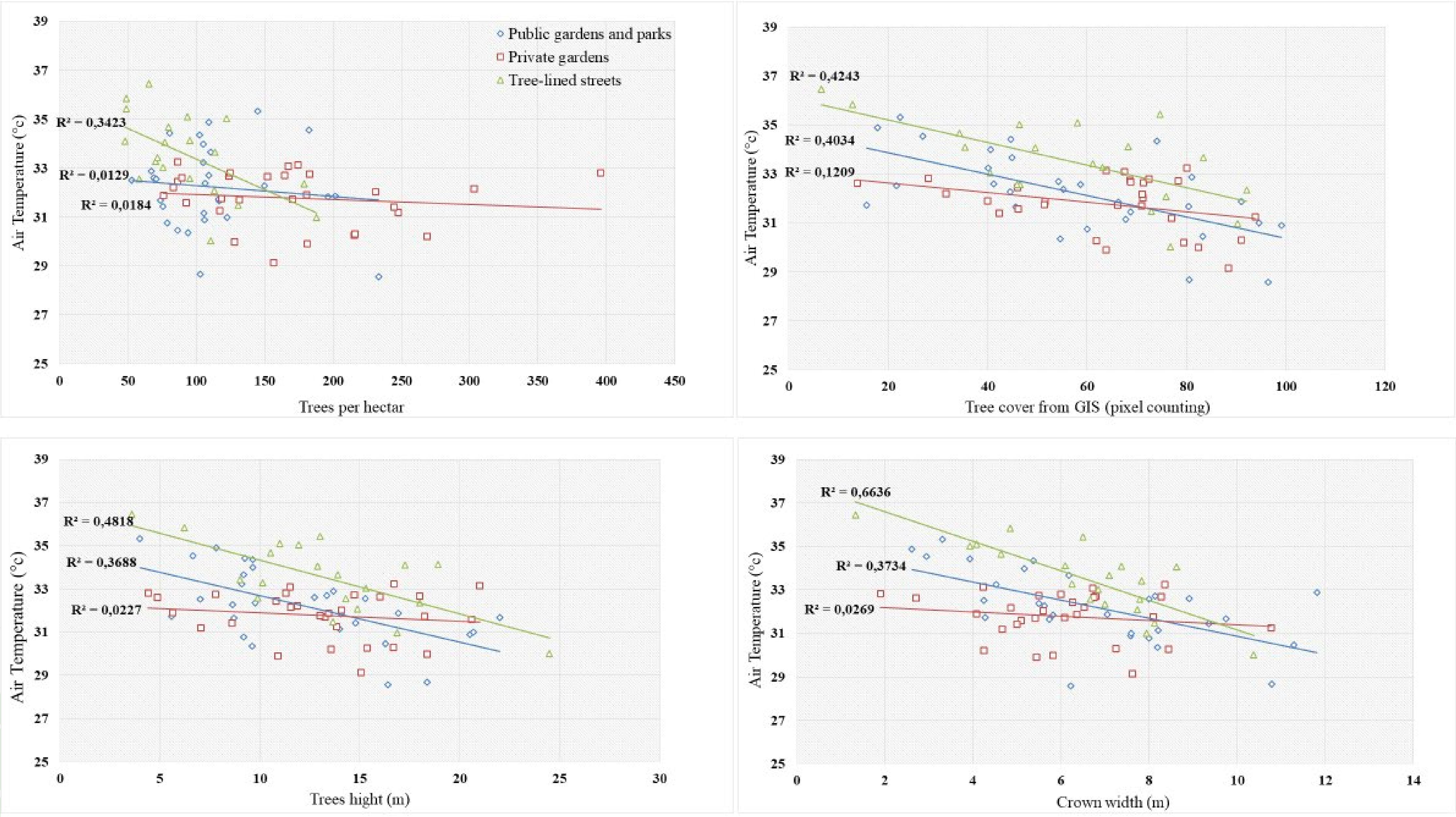


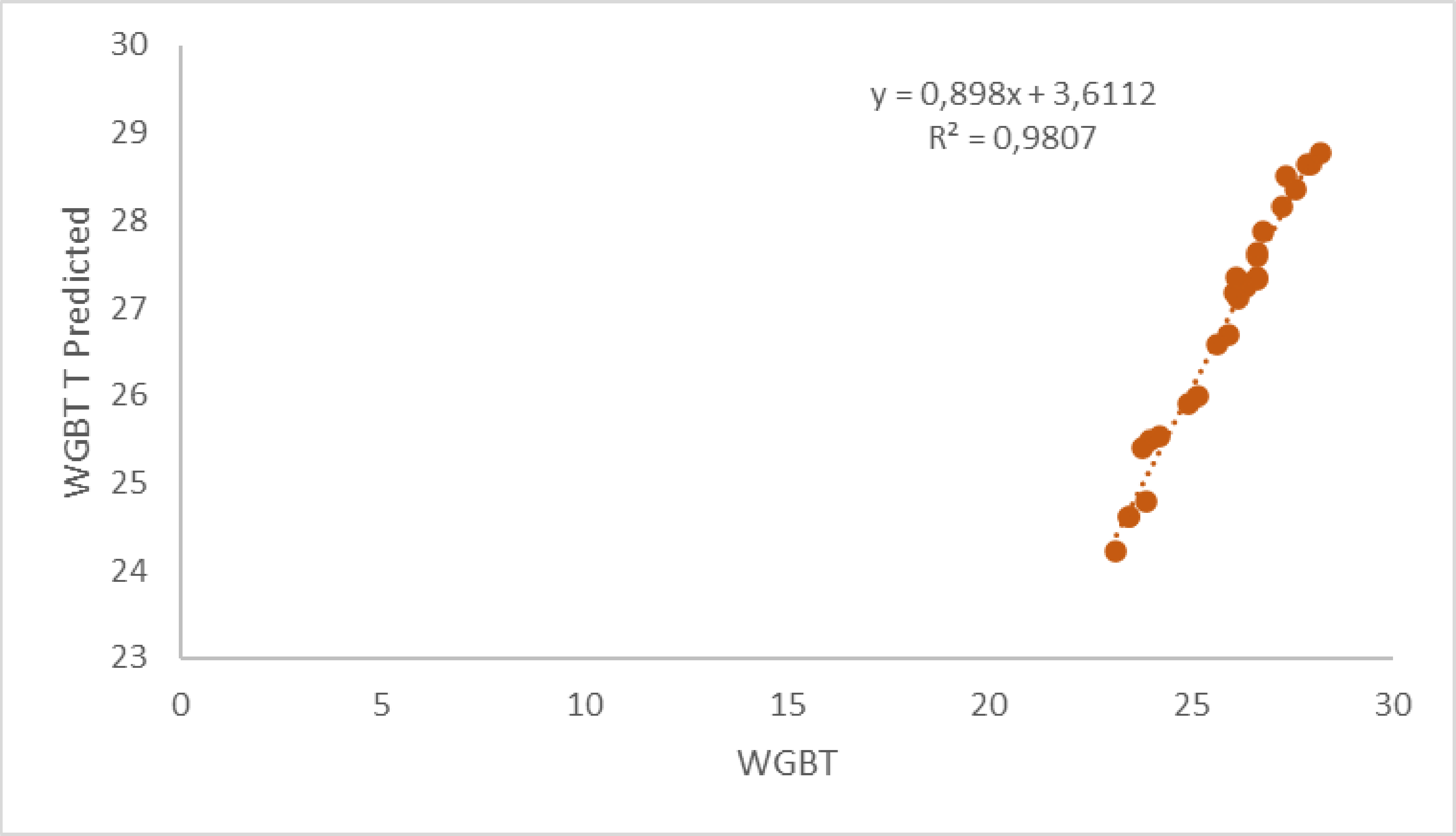
Variation of the thermal index UTCI by

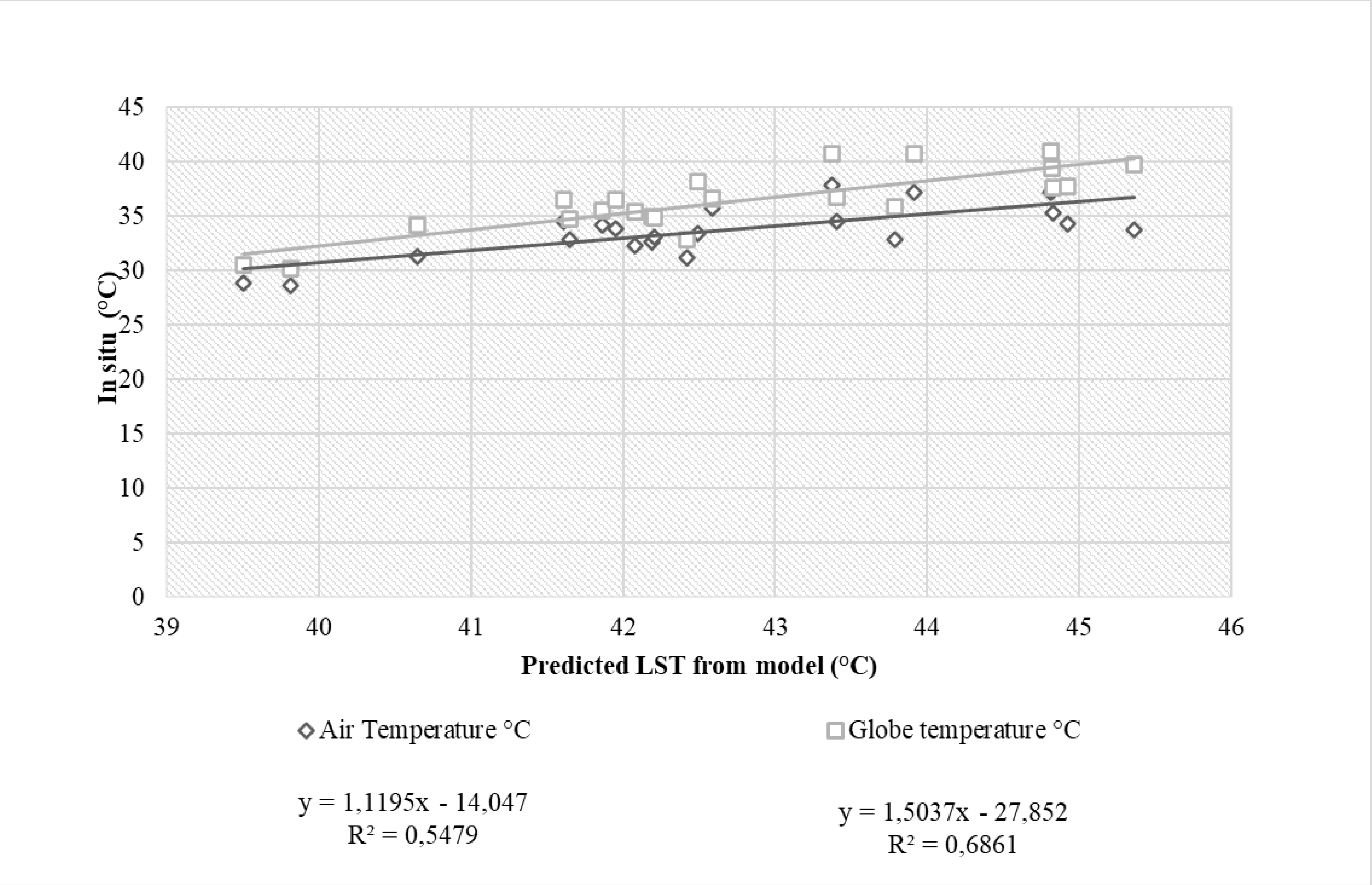
a. **average tree diameter,**
b. **average tree height,**
c. **tree canopy cover,**
d. **sky view factor,**
e. **total site factor, and**
f. **Height/width ratio.**

a) to c) represent data from green sites only, d) from non-green sites only and e) to f) using all data.

F. Salbitano et al. Greener & Cooler.




y = 0,898x + 3,6112
R² = 0,9807
WGBT T Predicted
30
29
28
27
26
25
24
23
0
5
10
15
20
25
30
WGBT


In situ (°C)
45
40
35
30
25
20
15
10
5
0
39
40
41
42
43
44
45
46
Predicted LST from model (°C)
Air Temperature °C
Globe temperature °C
y = 1,1195x - 14,047
R² = 0,5479
y = 1,5037x - 27,852
R² = 0,6861

Some conclusion

- ☺ There is a greater correlation between LST_S2 and Globe T compared to LST_S2 and Air T
- ☺ There is correlation only when considering ground surveys and remote sensing images referring to the same day, otherwise very weak R^2.
- ☹ There is no correlation between remote sensing data and the average of ground data in the nearest two days.
- ☹ The alleys of the center: micro-canyon effect difficult to define from satellite
- ☺ High correlation between LST_S2 and Sky view factor: looks promising to interpret the tree cover effect
- 😐 Correlations between LST_S2 and other vegetation parameters need to be explored

Thank you!

Fabio Salbitano

fsalbitano@ uniss.it

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Washington DC, 2023

Beyond Canopy Coverage : The impact of Shrubs and Evaporative Cooling on Human Thermal Comfort in Urban Forests

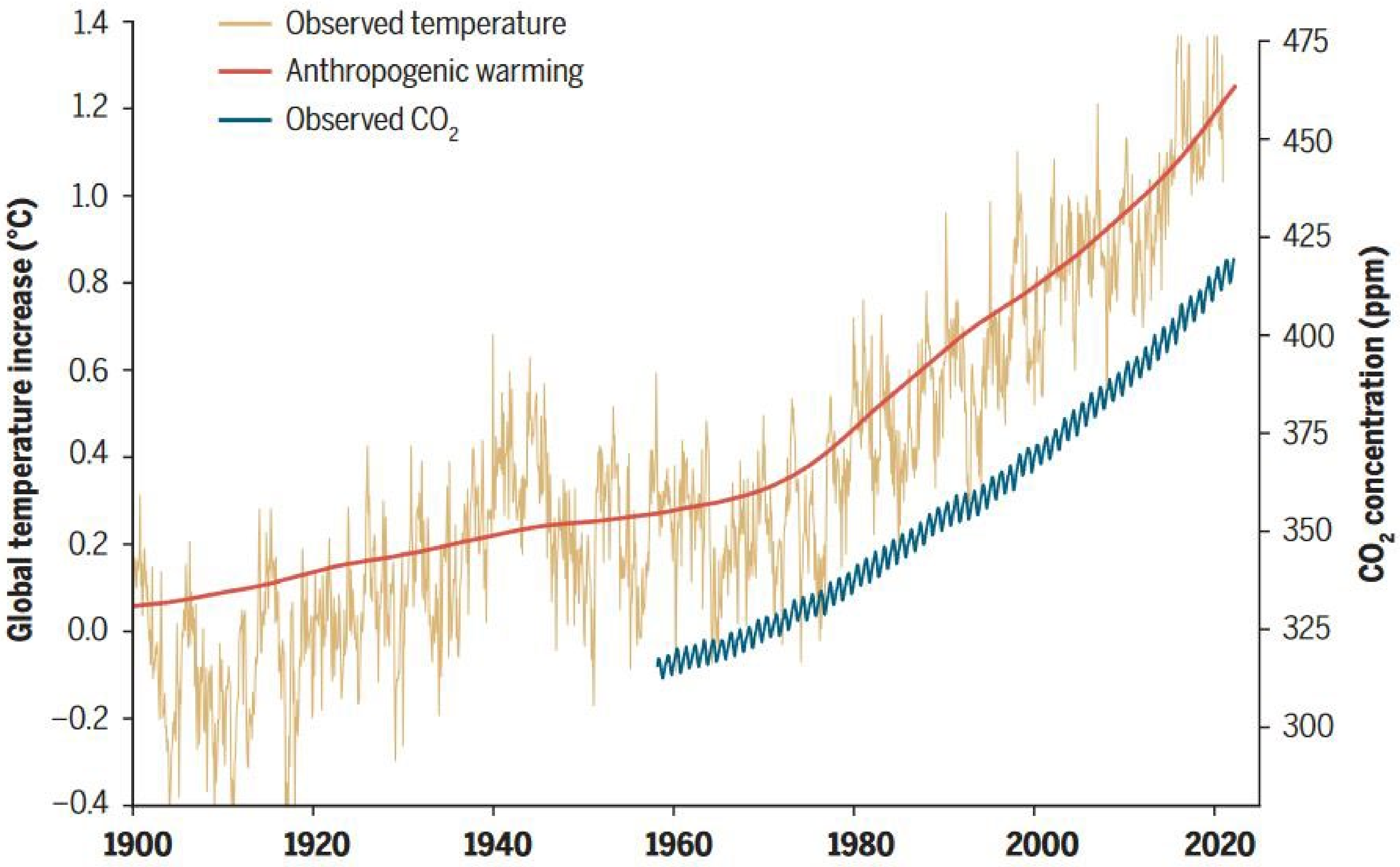
Nayanesh Pattnaik, Mohammad A. Rahman, Stephan Pauleit

Presented by

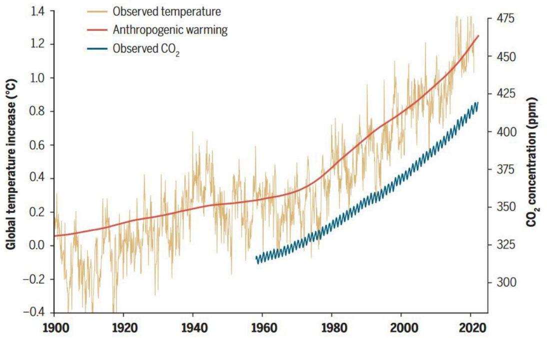
Nayanesh Pattnaik

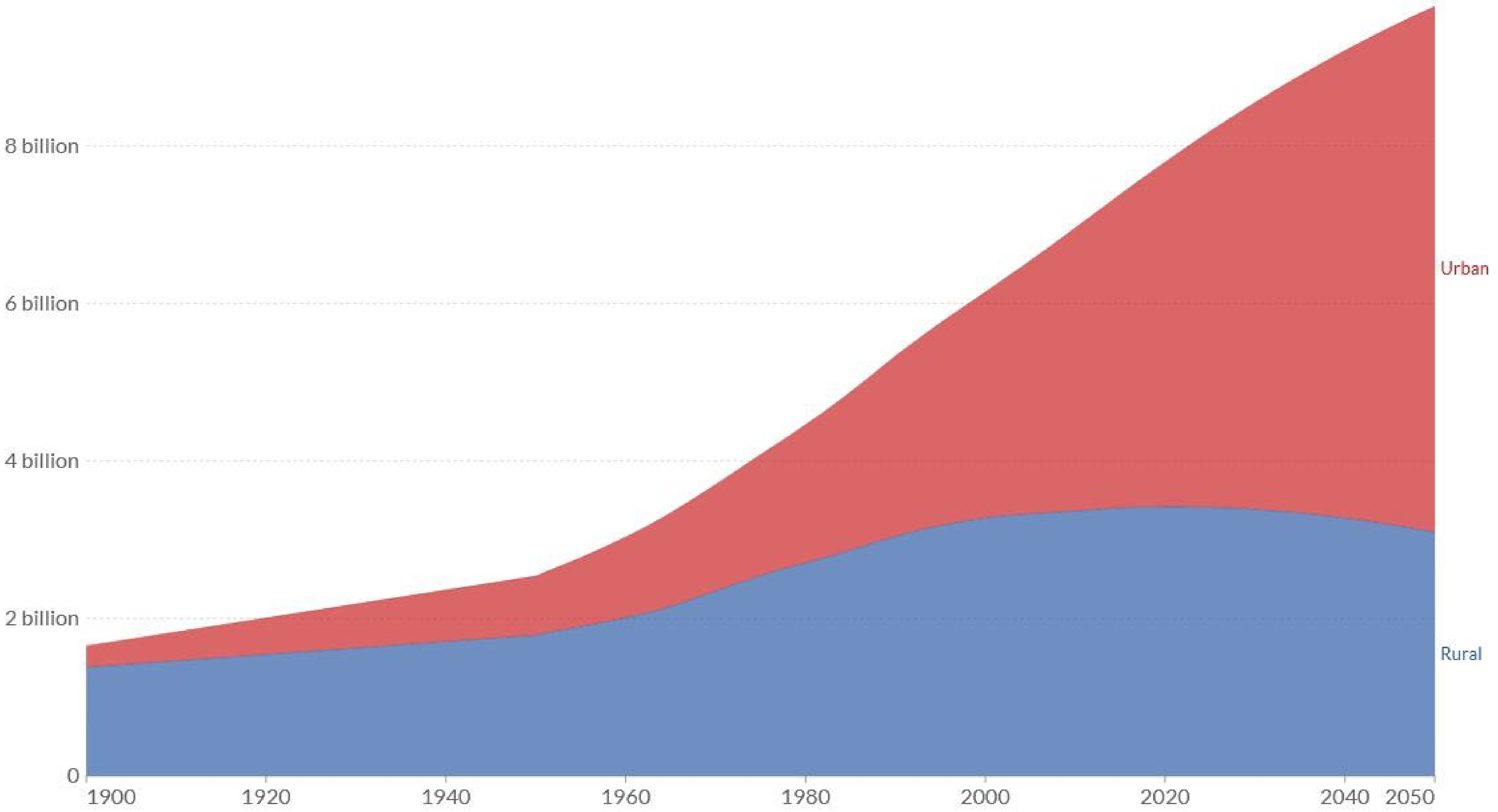
Chair for Strategic Landscape Planning and Management

Technical University of Munich

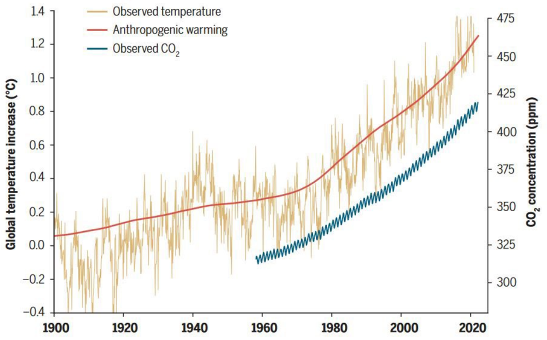


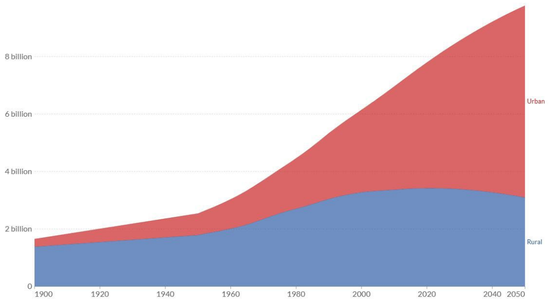
Source – Matthews et al., 2022

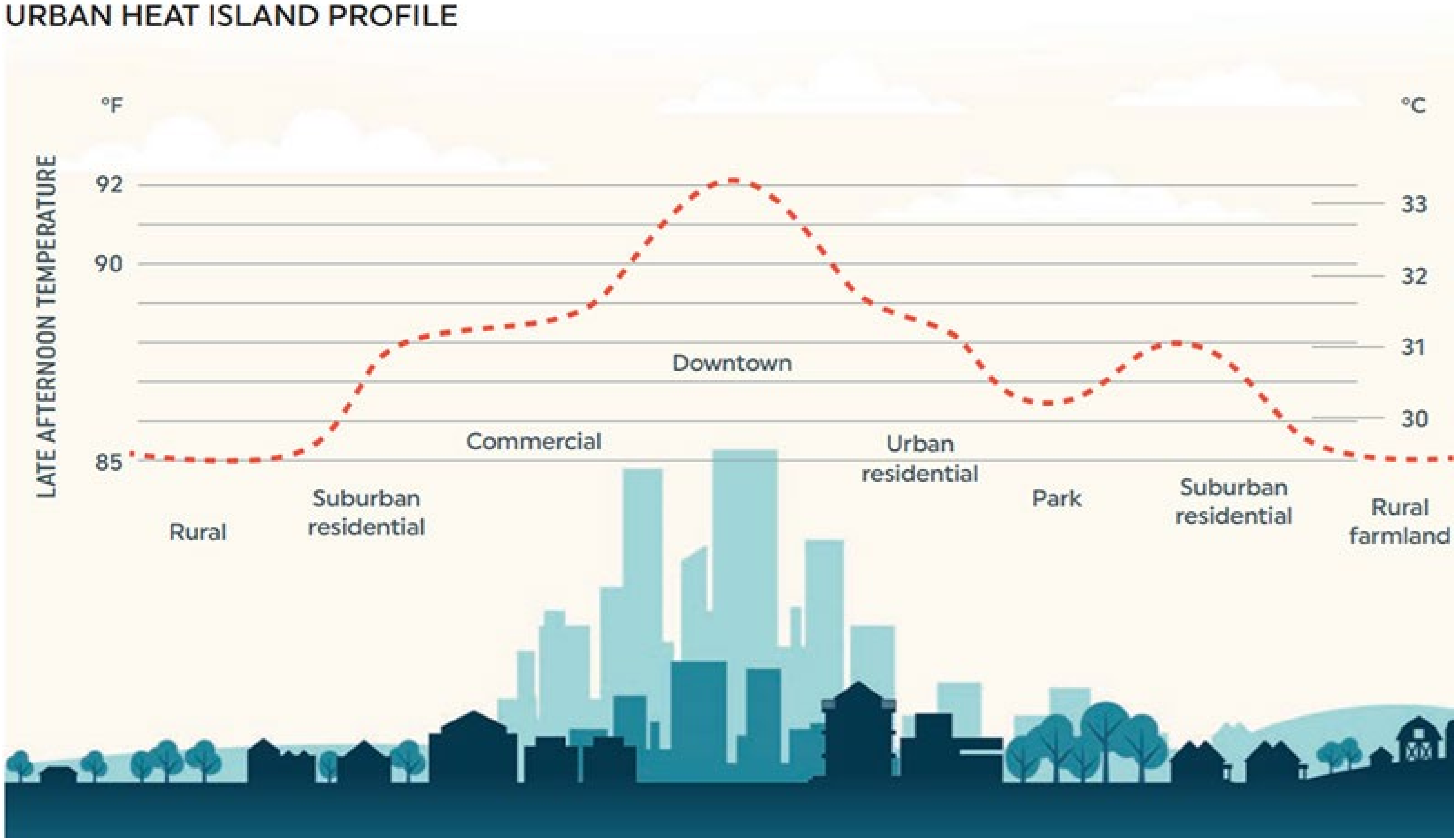




Source – UN World Urbanization Prospects, 2018







Source – https://urbanland.uli.org/public/four-approaches-to-reducing-the-urban-heat-island-effect

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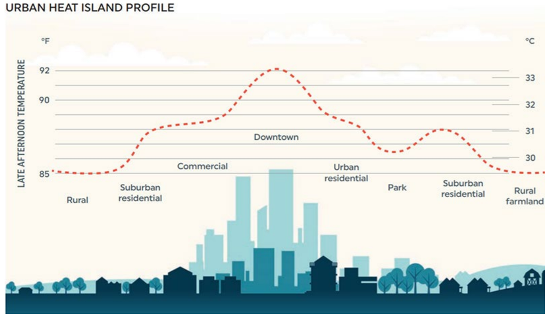
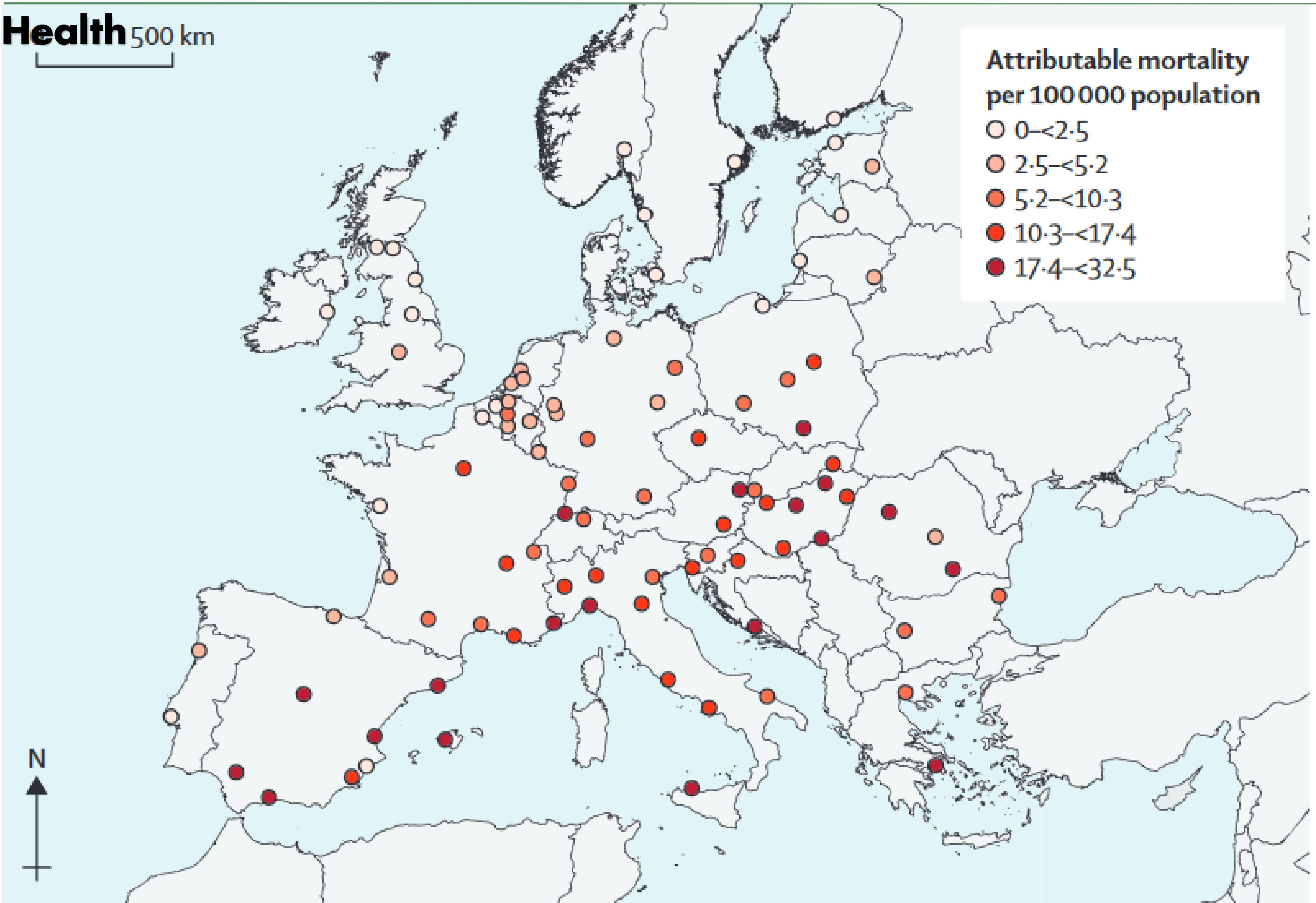
Urban Heat and Health





Source – Iungman et al., 2023

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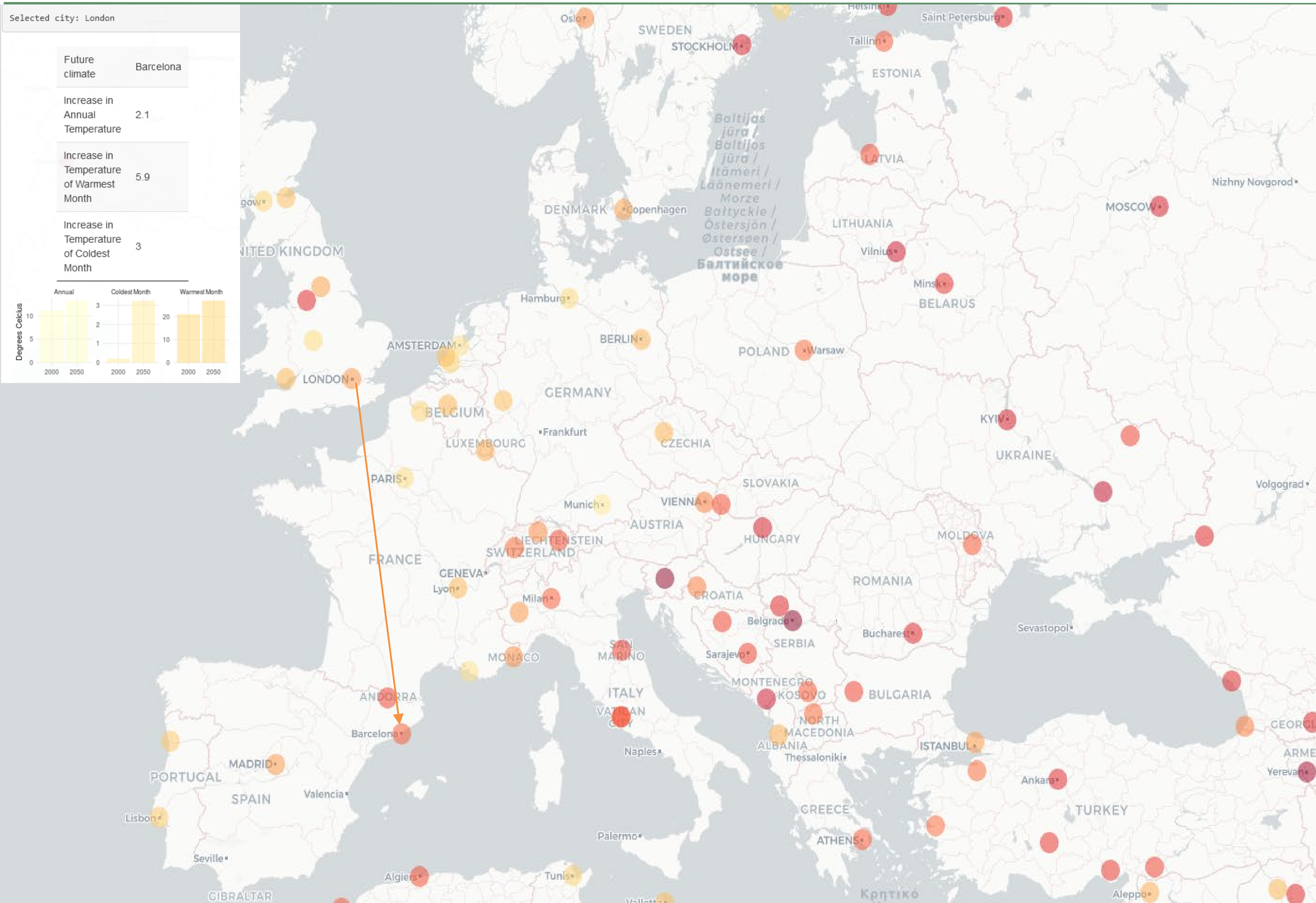
London will feel like Barcelona!

Selected city: London

Future climate	Barcelona
Increase in Annual Temperature	2.1
Increase in Temperature of Warmest Month	5.9
Increase in Temperature of Coldest Month	3



Source : Bastin et al. (2019)

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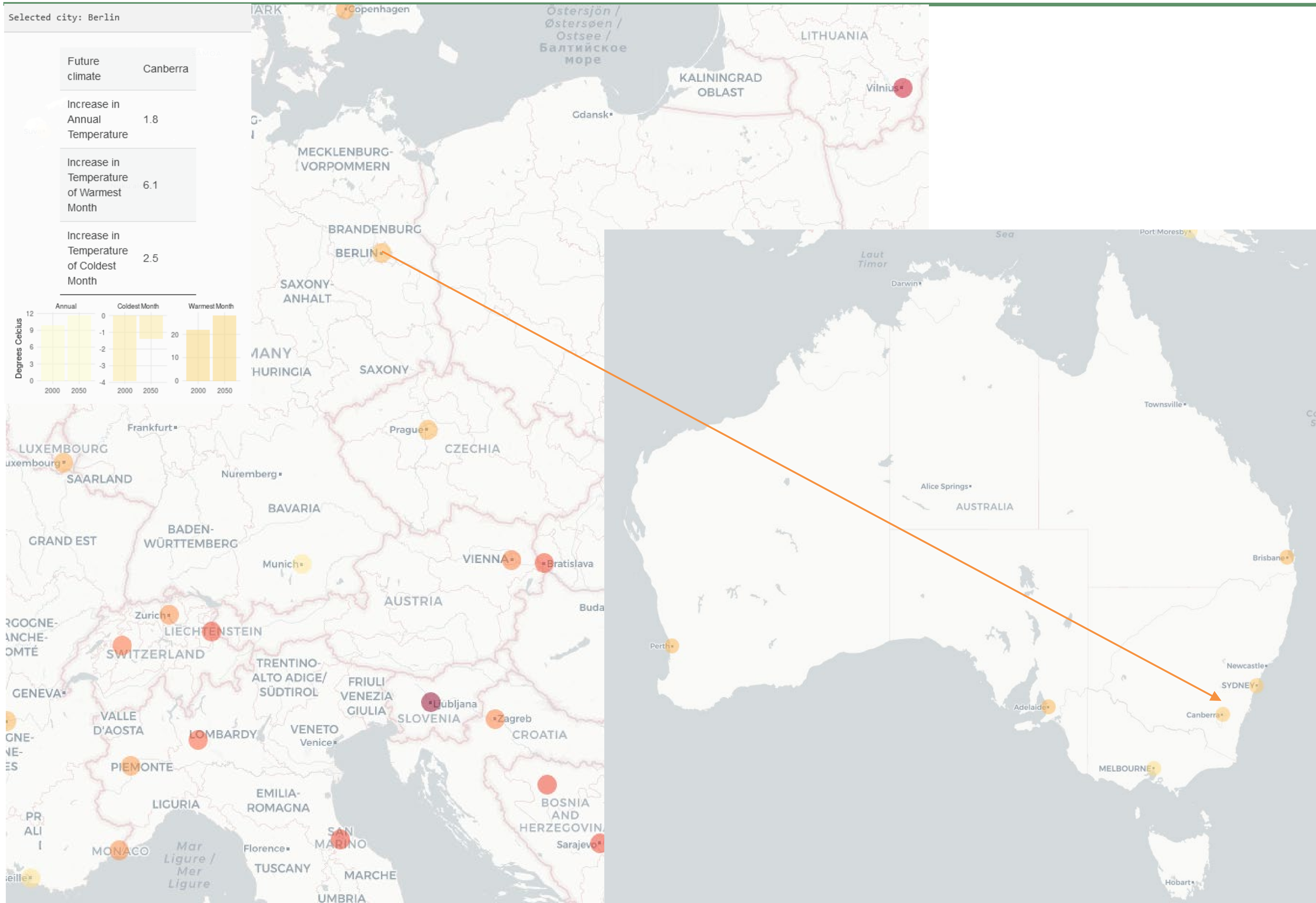
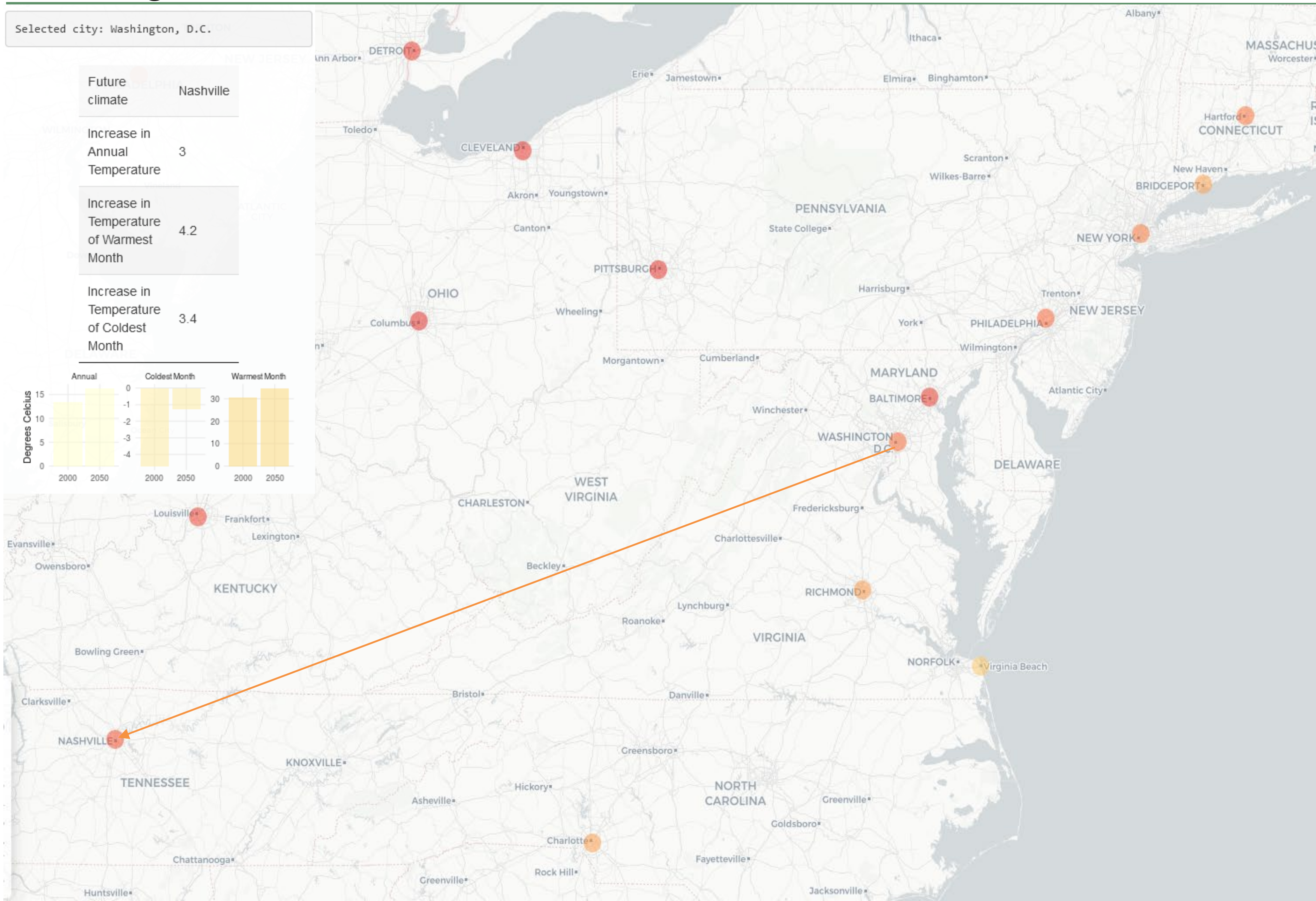
Berlin will feel like Canberra!



Source : Bastin et al. (2019)

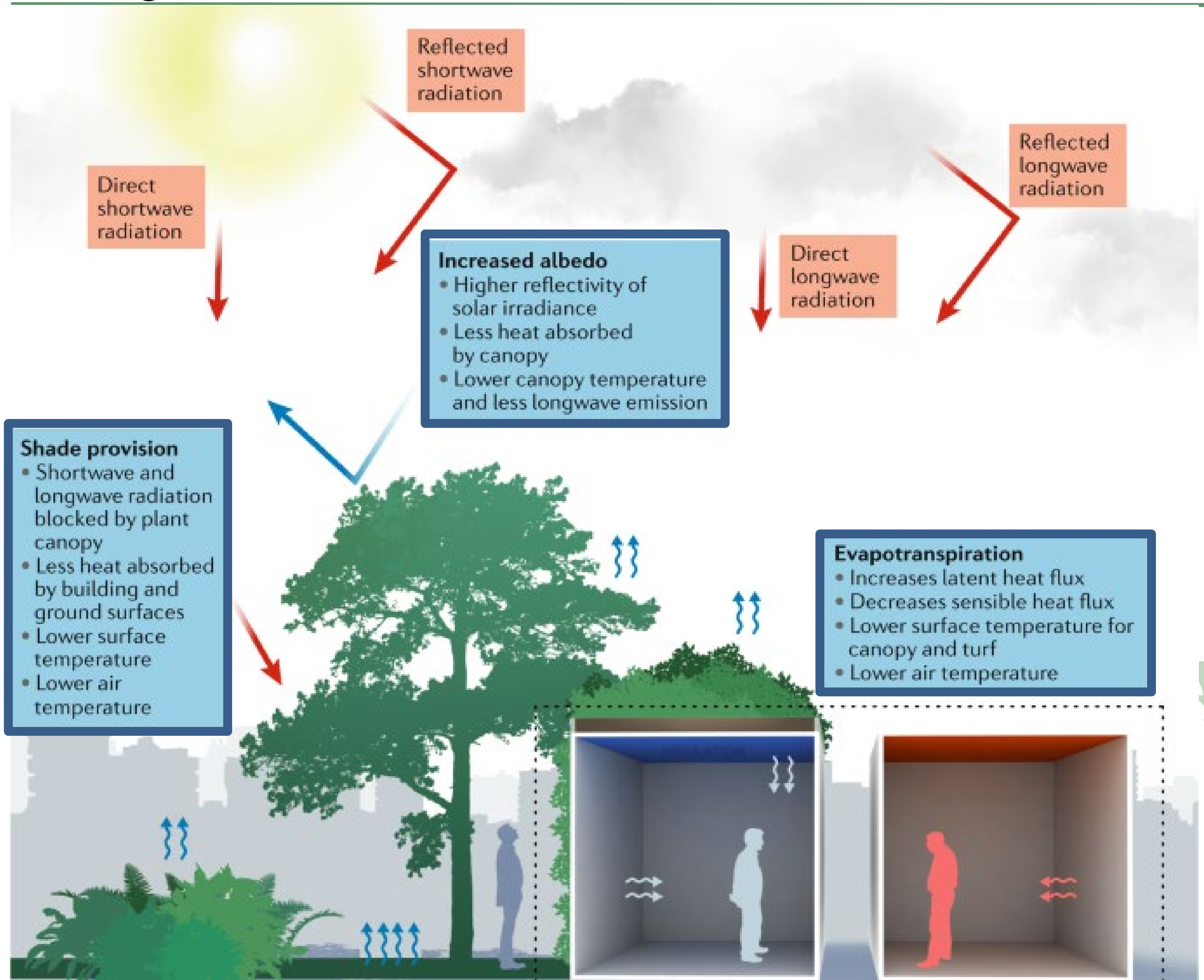
Washington will feel like



Source : Bastin et al. (2019)

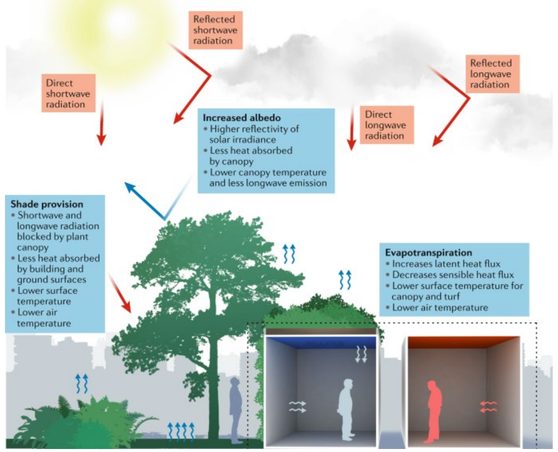

O2 Arena
Holešovice district
Prague
Vltava River
Industrial zone
Land surface temperature
18 June 2022

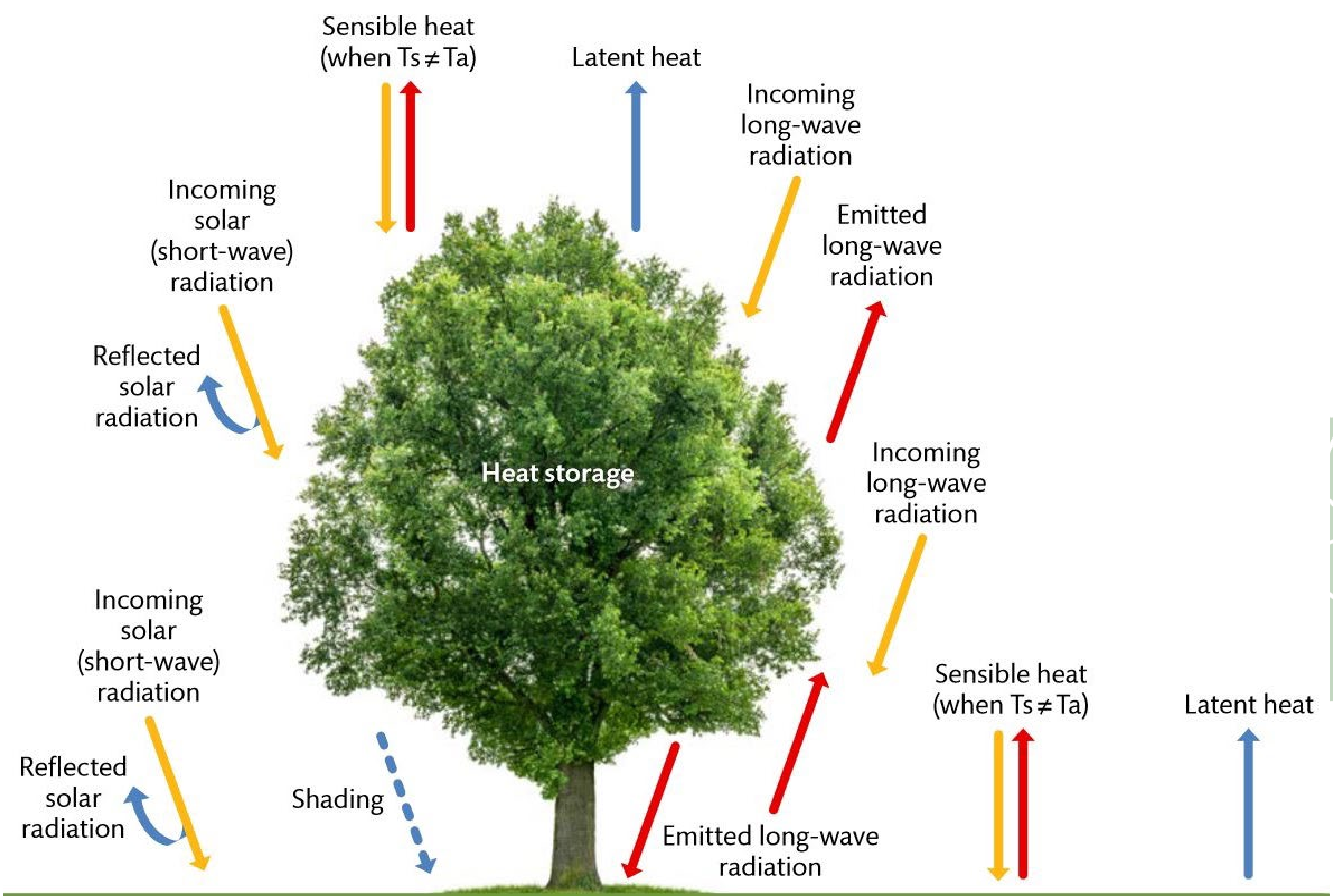
Cooling Mechanisms



Source : Wong et al. (2021)

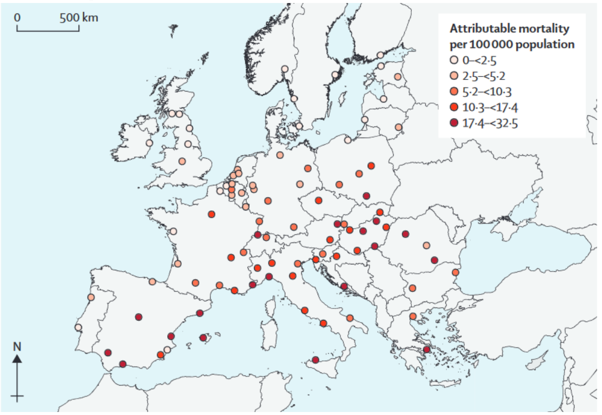
Emphasis on Trees

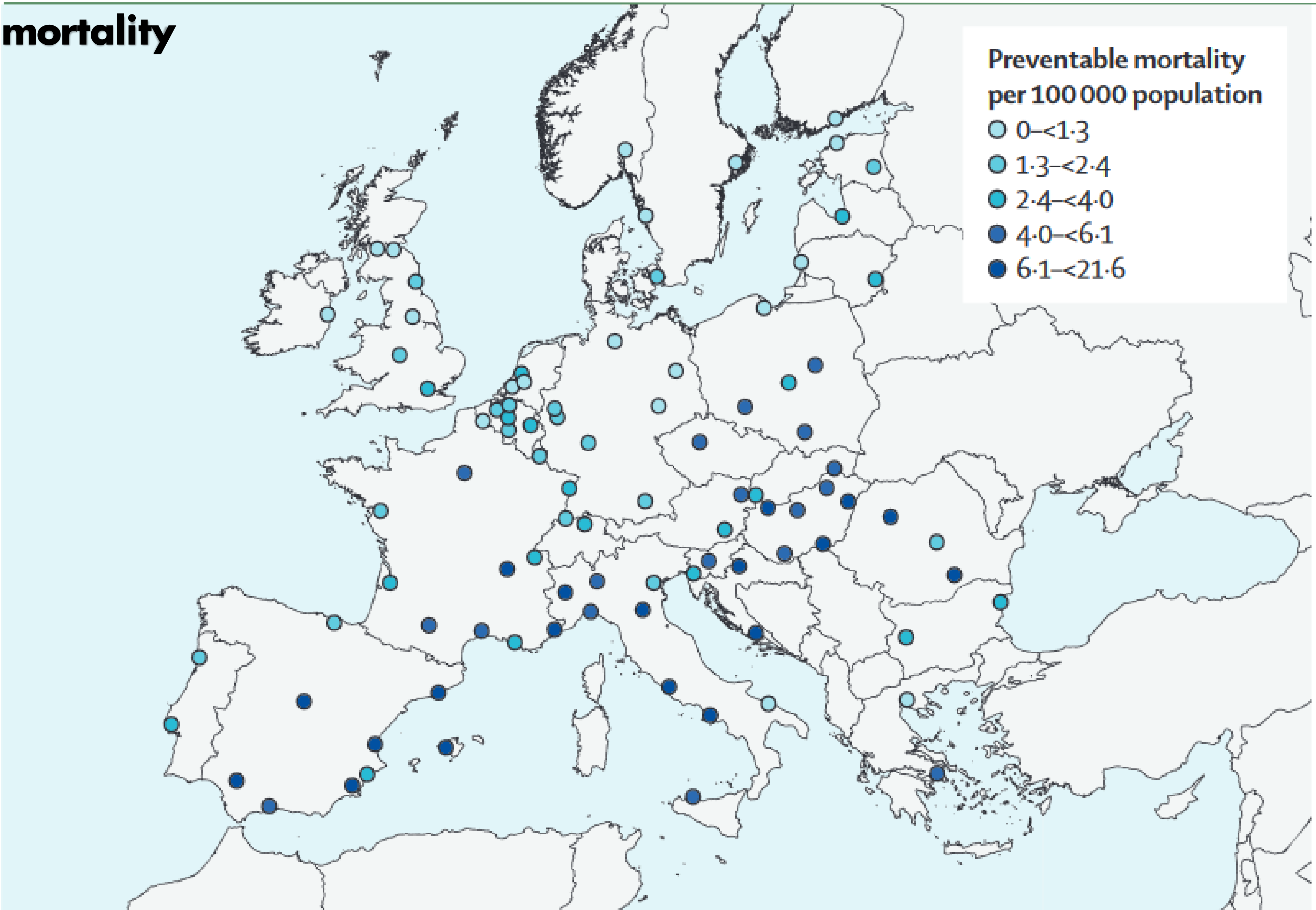




Source – Monteiro et al., 2019

Tree Cover decreases heat-related mortality



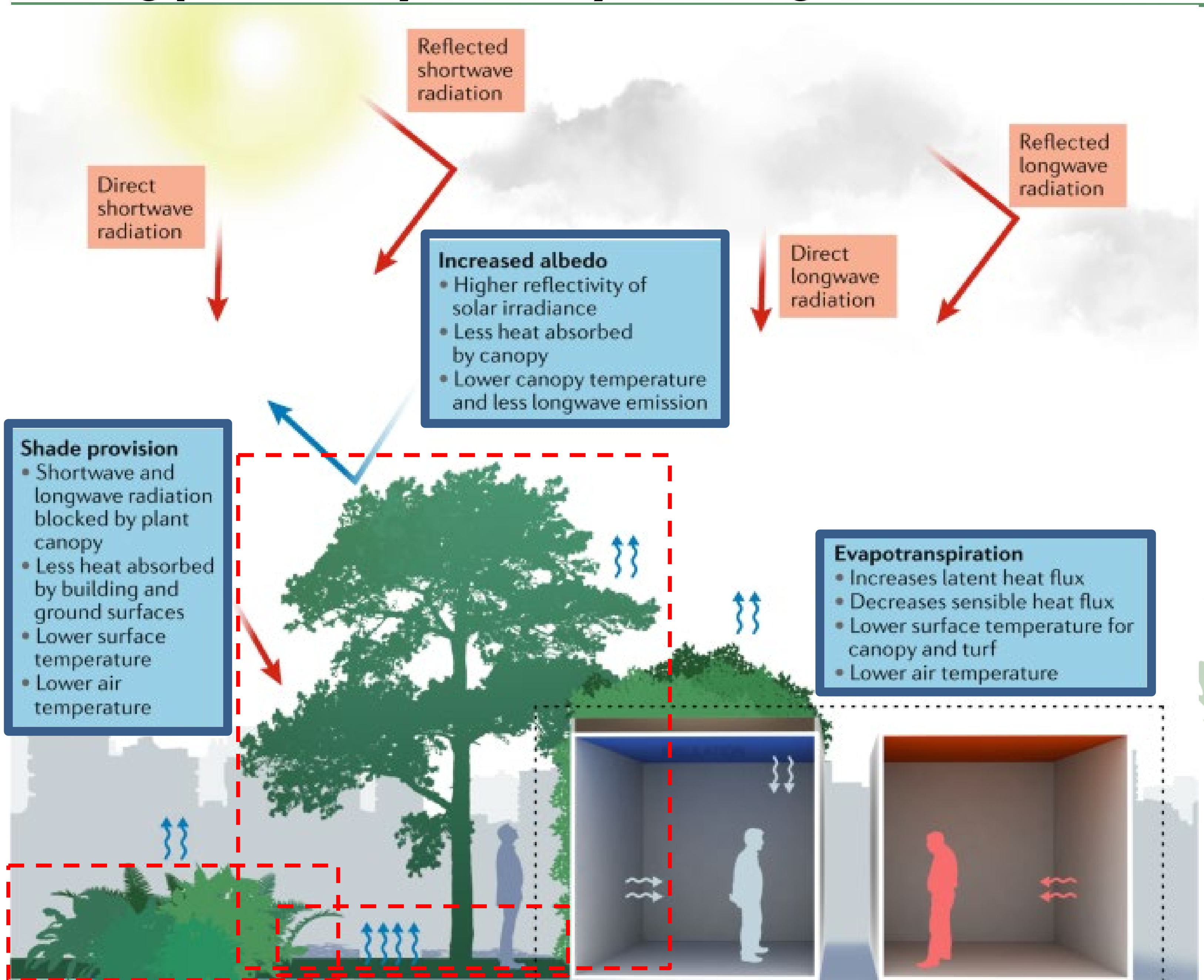


Source – Iungman et al., 2023

Urban vegetation is more than just

Cooling provided by other layers of vegetation

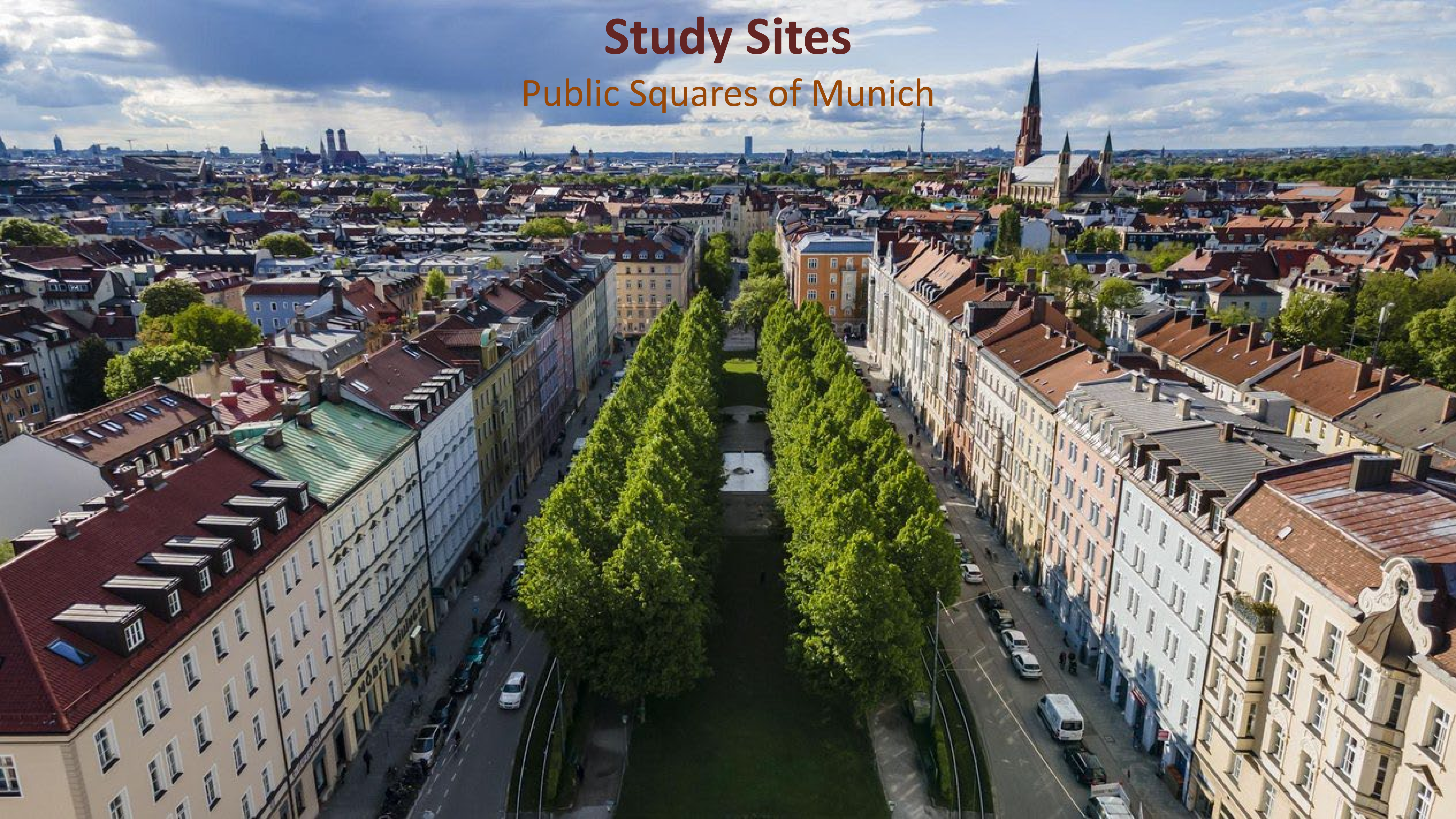
Cooling benefits between the different layers of the vegetation?



Source : Wong et al. (2021)

Study Sites

Public Squares of Munich



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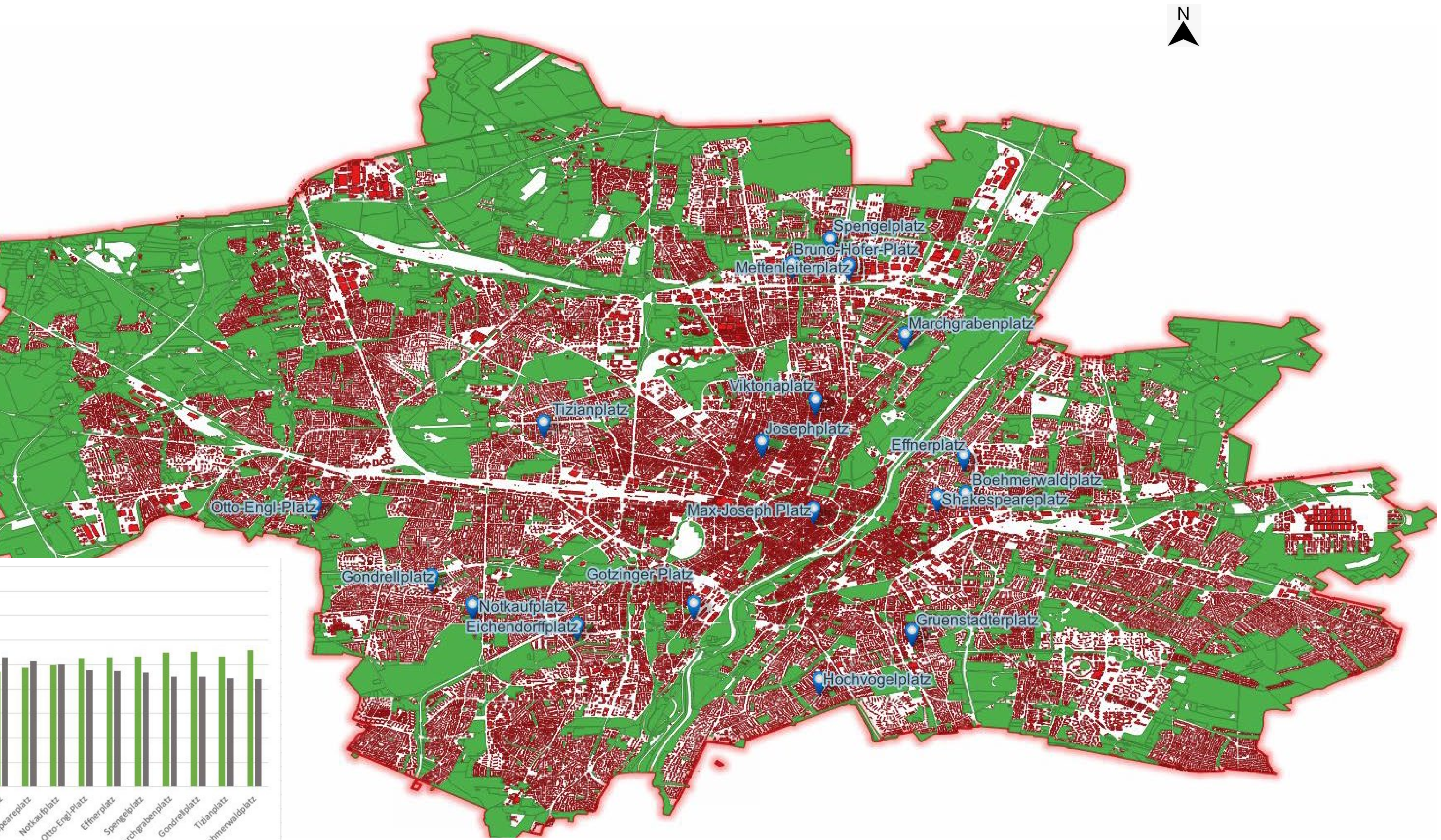
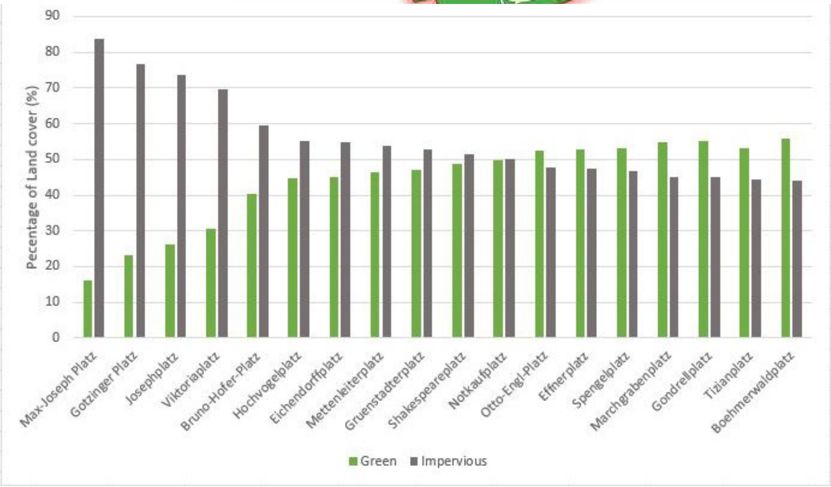
Study Sites

- SCENARIOS
  - Completely Sealed
  - Mixed LC
  - Grass Dominated
  - Tree Dominated





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Experimental Design

Microclimate Measurements

- Air Temp, Relative Humidity, Radiation, Surface Temperature, Wind Speed, Black Globe
- July and August (Three Repeations)
- Sunny, Cloudless and warm days
- From 11 a.m. to 4 p.m

Ecophysiological Measurements

- Stomatal Conductance, Transpiration, Net Assilimation Rate
- Soil Moisture and Soil Temperature

Measured Shrub Species

Cornus sanguinea (Common Dogwood)

- Ornamental
- Non-Native
- Wood Anatomy – Diffused Porous
- Shrub height between 0.8 to 1.3m

Carpinus betulus (European Hornbeam)

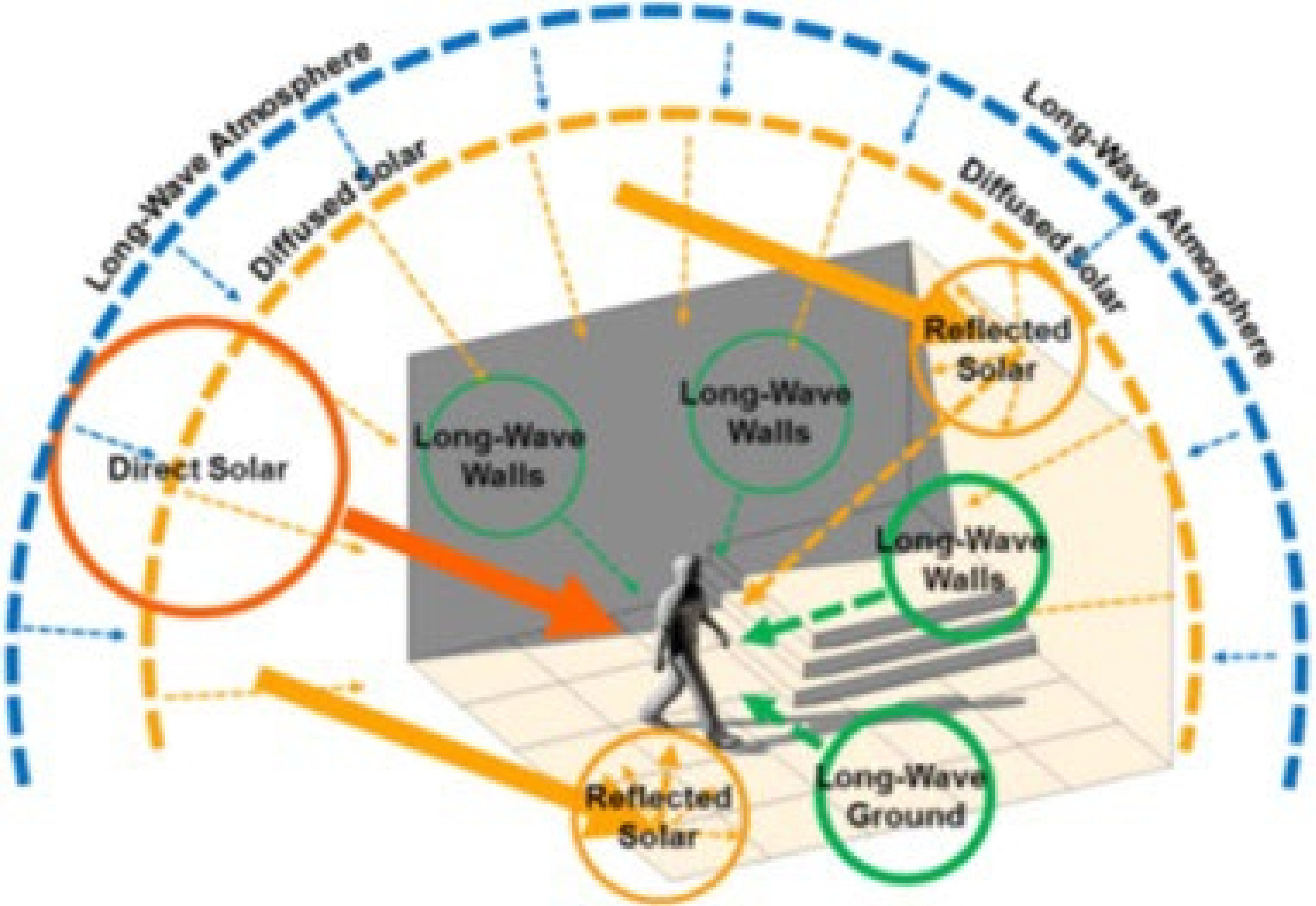
Syringa vulgaris (Common Lilac)

- Ornamental
- Non-Native
- Wood Anatomy – Diffused Porous
- Shrub height between 0.8 to 1.3m

Forsythia virdissima (Green-Stemmed forsythia)

Mean Radiant Temperature (Tmrt)

- Tmrt summarizes the effects of all radiant heat fluxes
- Tmrt between 55°C to 60 °C = Moderate Heat Stress
- Tmrt > 60 °C = Extreme Heat Stress



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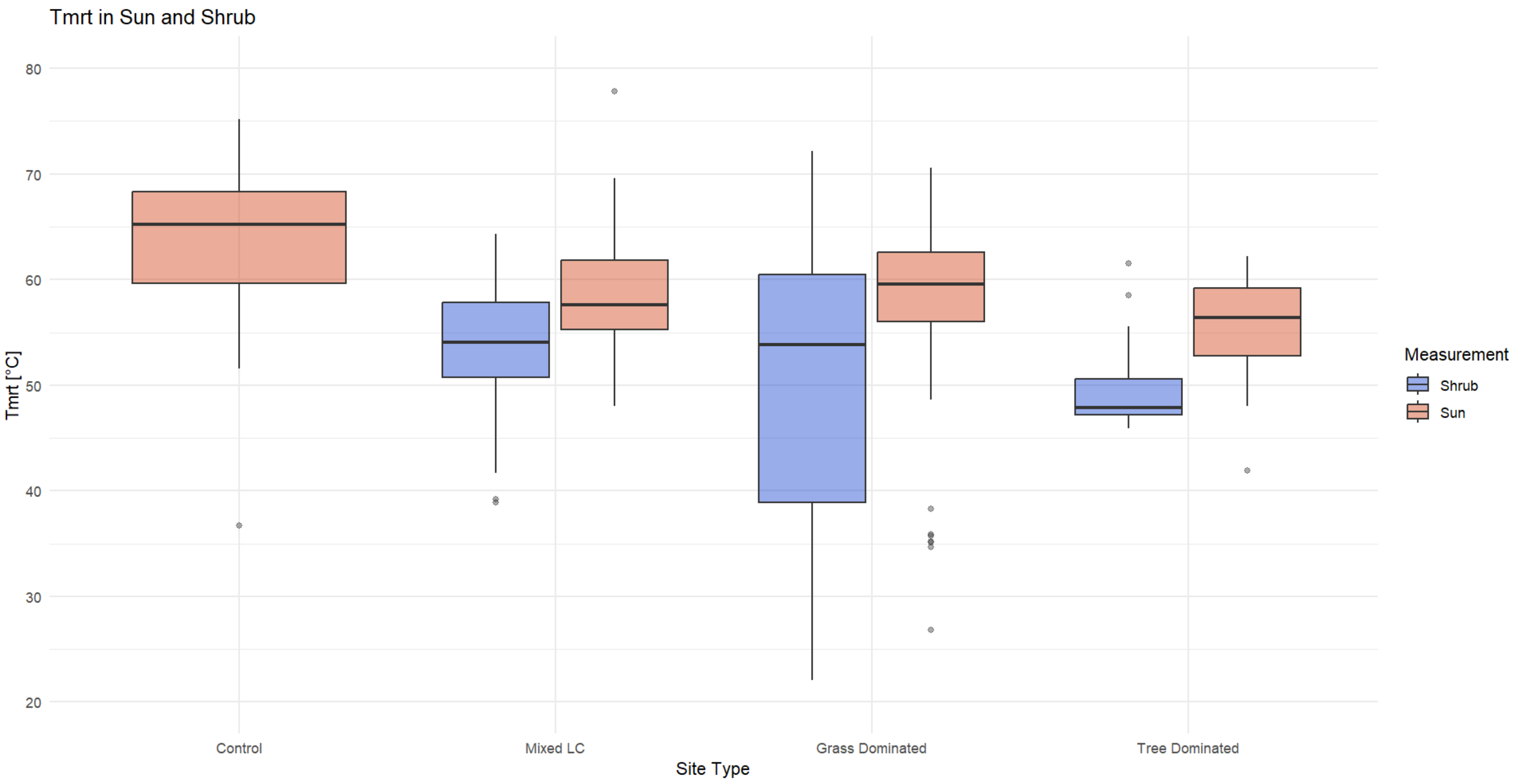
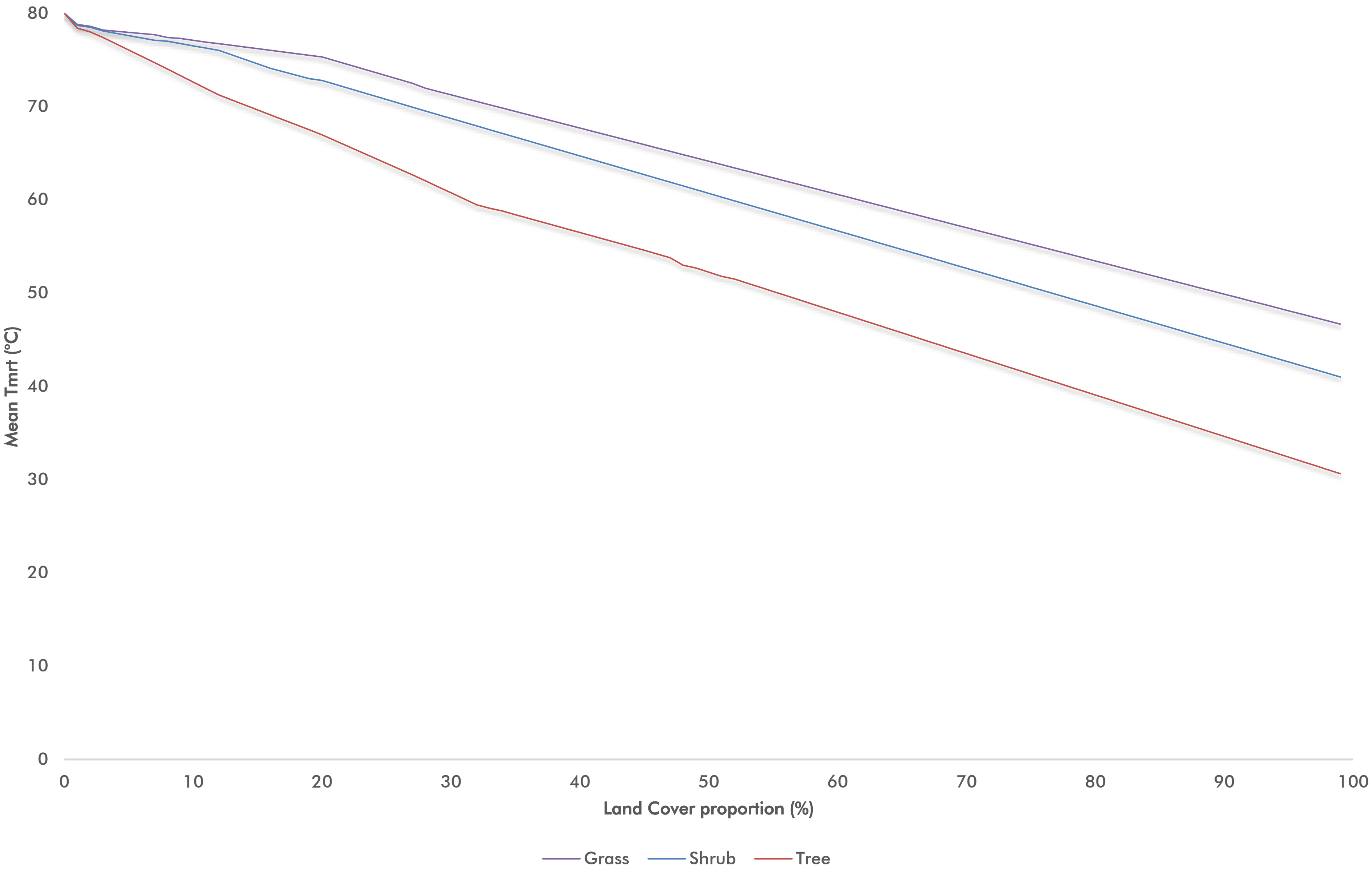
Differences in Tmrt



Mean ▲ = 6.2 °C

Vegetation Structure

Moderate Heat Stress reduced by
- 35% Tree Cover
- 60% Shrub Cover
- 75% Grass Cover

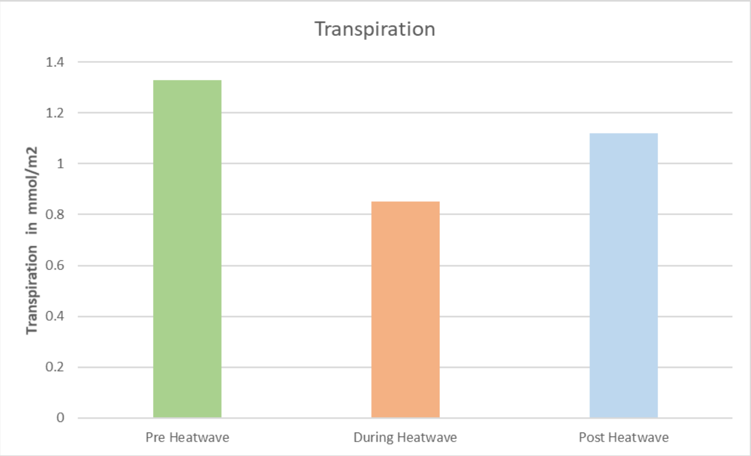


Microclimate Vegetation Feedbacks

Pre Heatwave

During Heatwave

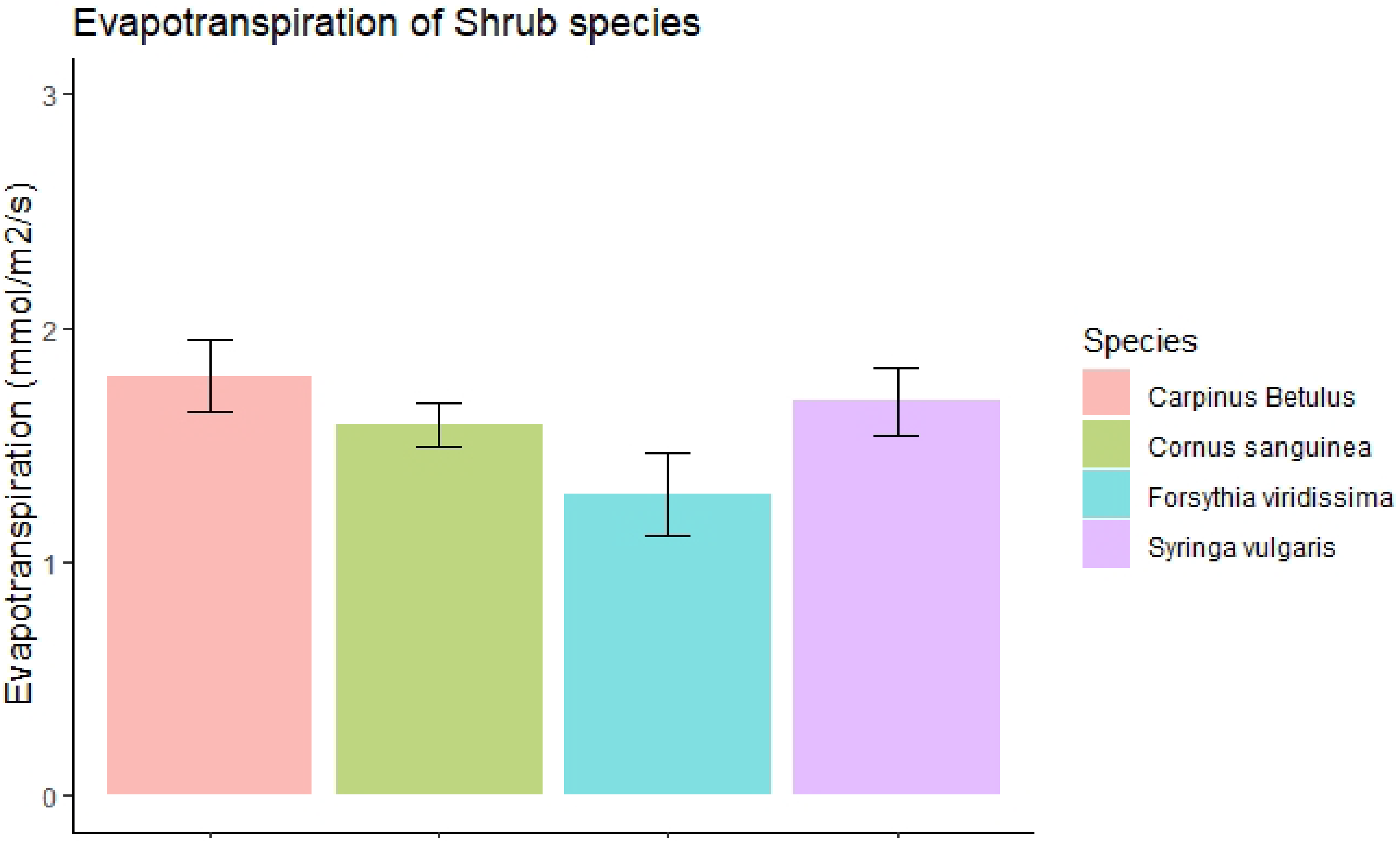
Post Heatwave



~40% decrease in transpiration

Species Level Differences

~ 1/3rd of latent heat as compared to tree



Thank you

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Monitoring urban surface temperatures using UAV-derived thermal imagery

Presented by

Katrina Henn

Dr. Alicia Peduzzi, Assistant Professor

Sudhir Payare

Warnell School of Forestry and Natural Resources, UGA

Precision Forestry Lab

University of Georgia

Warnell School of Forestry & Natural Resources

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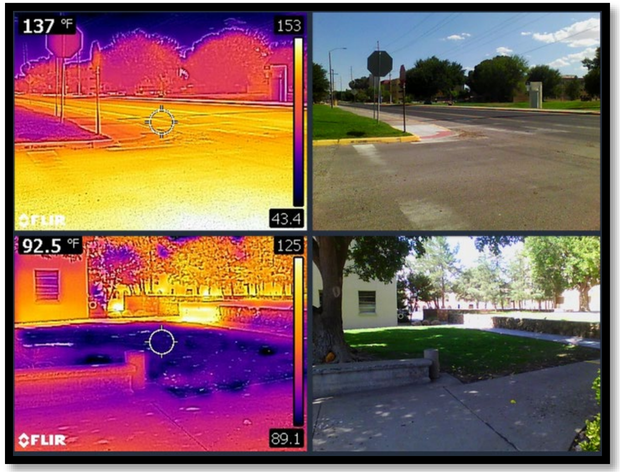
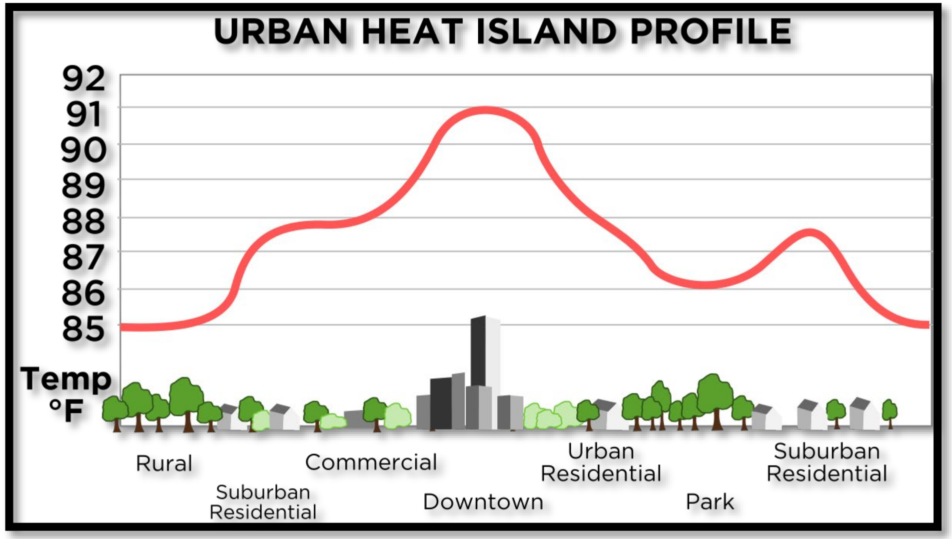
Background: Why is urban heat important?



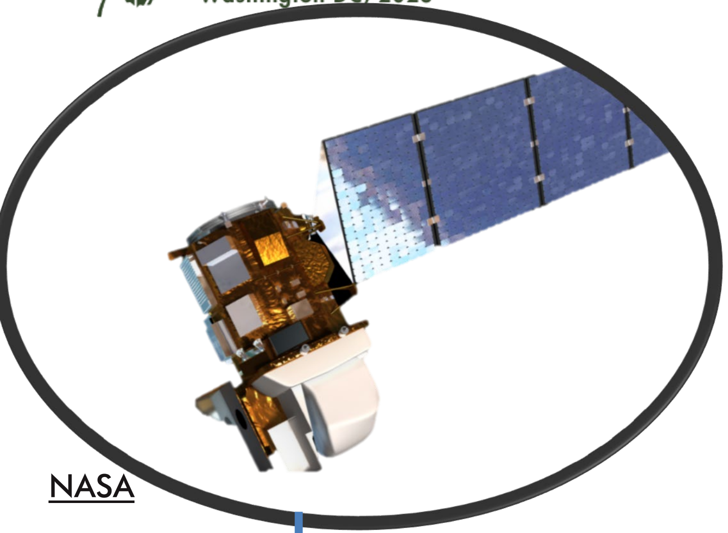
Heat.gov

- Urban area hotter than surrounding rural area
- Day- & night-time effects
- Marginalized communities more affected



Royal Meteorological Society

One Tree Planted

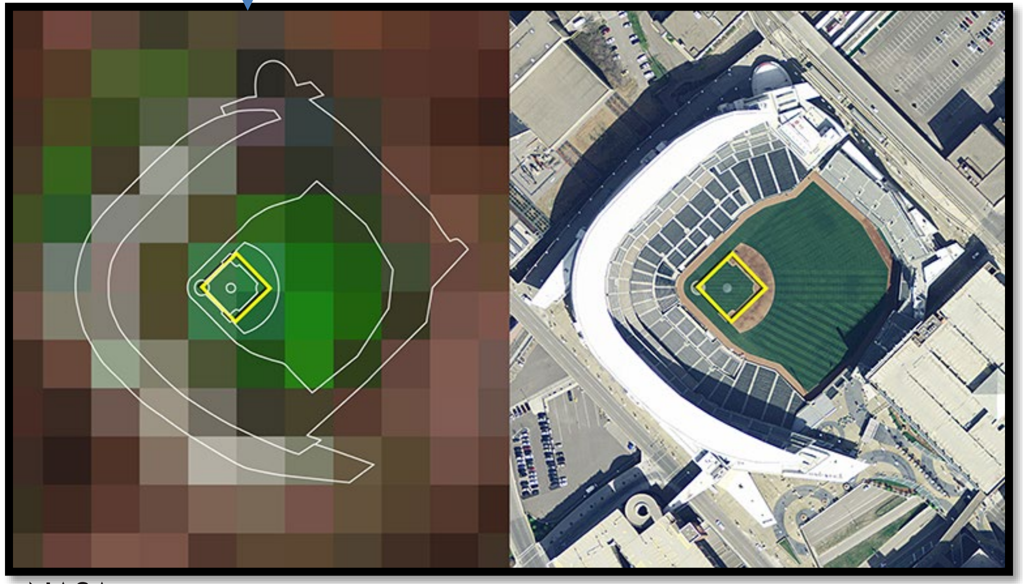


NASA

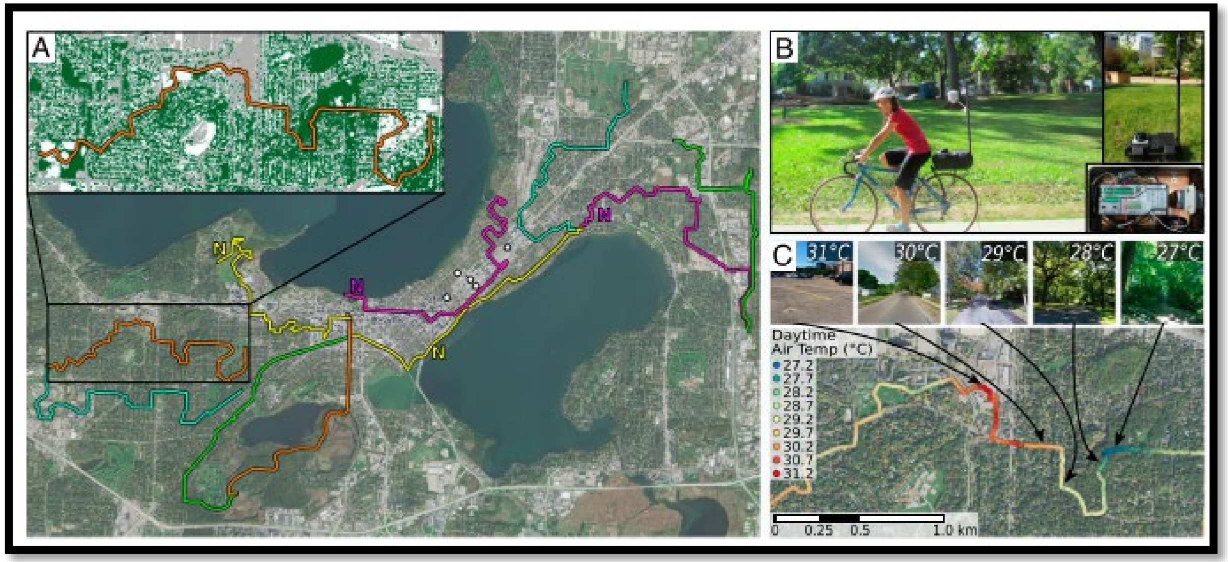
Background: How are we currently measuring urban heat?

- Levels
  - Satellite (spaceborne) level
  - Ground
- Surface vs. air temperature
- Resolution

Plane?
UAV?



NASA



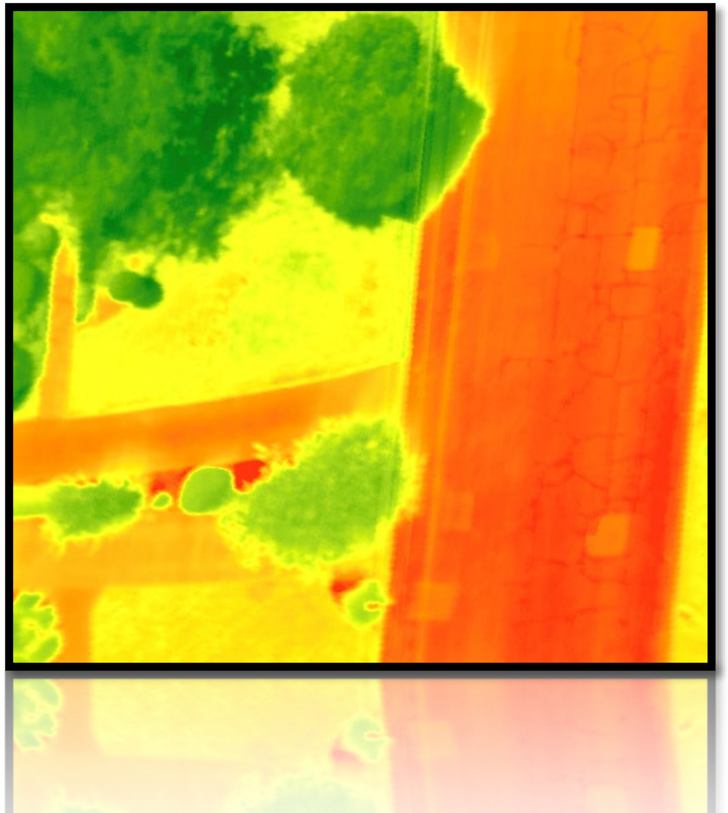
Ziter et al., 2019

Objectives: Two-pronged approach

1. Demonstrate UAV and thermal application in urban environment

Drone life

2. Analyze urban surface differences, shaded & non-shaded



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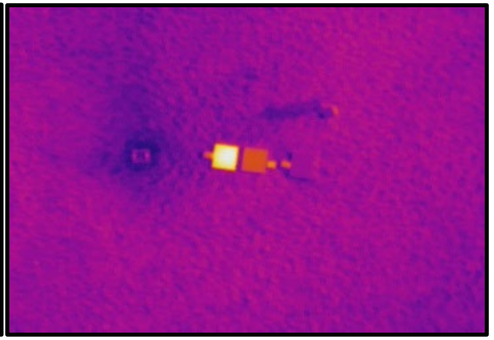
Methods: Initial testing

UAV with FLIR camera (±5°C)

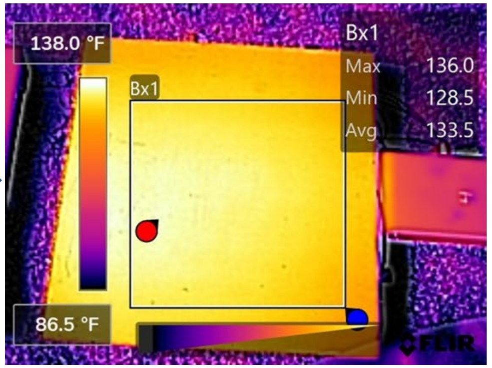
Freerangestock, FLIR

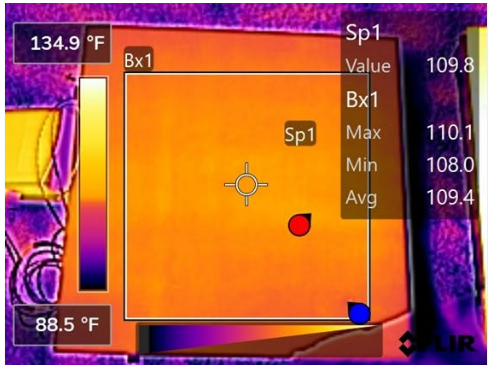
Surface thermal imagery from UAV

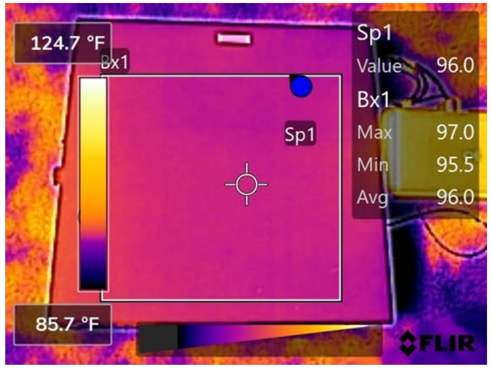


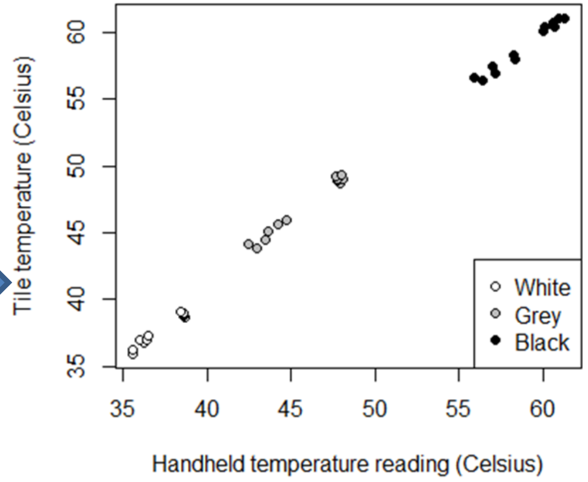
Ground check: Tile, handheld, & UAV

FLIR







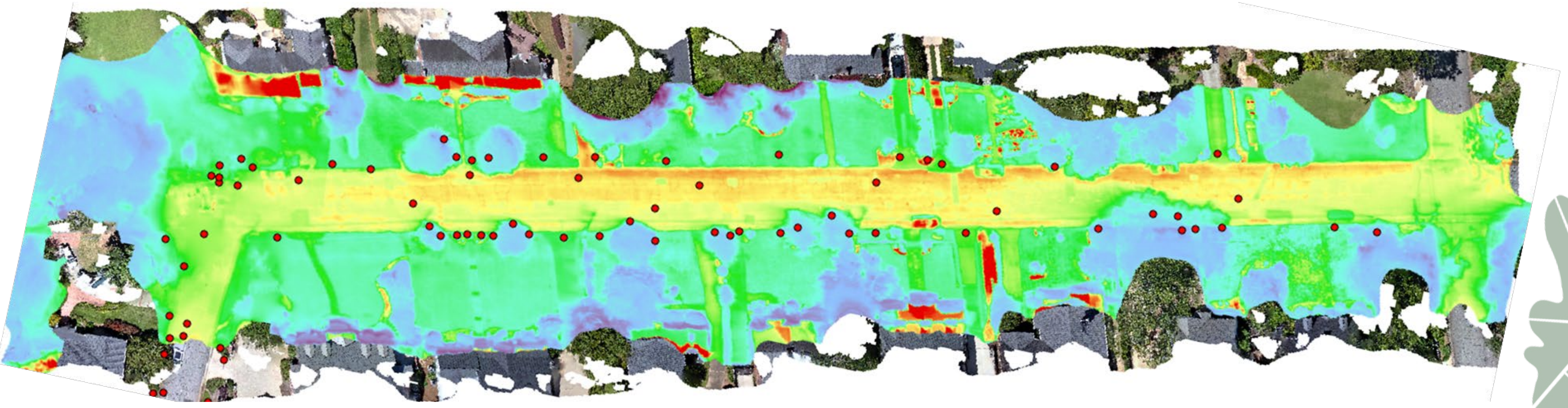


Methods: UAV application

- Transects = balance between safety and practical application
  - Regulations + courtesy
- Both sides of street. Low enough for detail, high enough for image overlap.
  - 165-175 ft & 80% overlap

Methods: Ground data collection

- Ground data collected at same time as flight
  - Surface type & Shaded or unshaded
  - Audio recording during collection
- GPS point taken for each point
- Handheld reading compared to UAV reading



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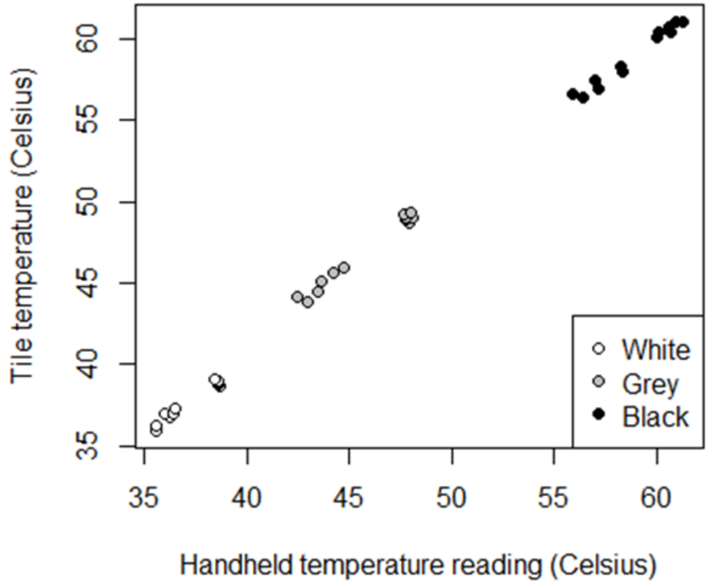
Results: Handheld and UAV accuracy

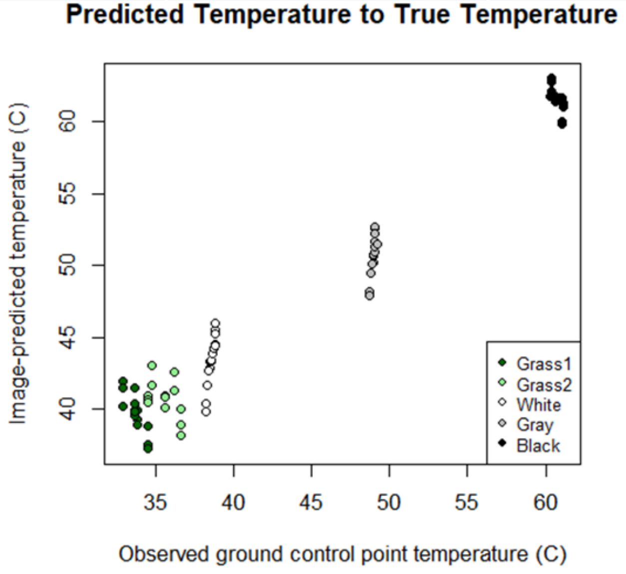
- Handheld = accurate (n = 36)

White		Gray		Black		Measurement Error (%)
Handheld FLIR	Average Tile Reading	Handheld FLIR	Average Tile Reading	Handheld FLIR	Average Tile Reading	White Gray Black
37.3	37.8	45.7	46.9	58.9	58.9	1.3% 2.6% 0.1%



- Majority of UAV thermal image readings fell within FLIR-specified ±5° C
  - (n = 38/45, or 84%) for tiles, worse for grass (7/30, or only 23%)
  - For neighborhoods so far: 222/278 (80%)

White Measurement Error (%)	Gray Measurement Error (%)	Black Measurement Error (%)
12.5	3.61	1.32



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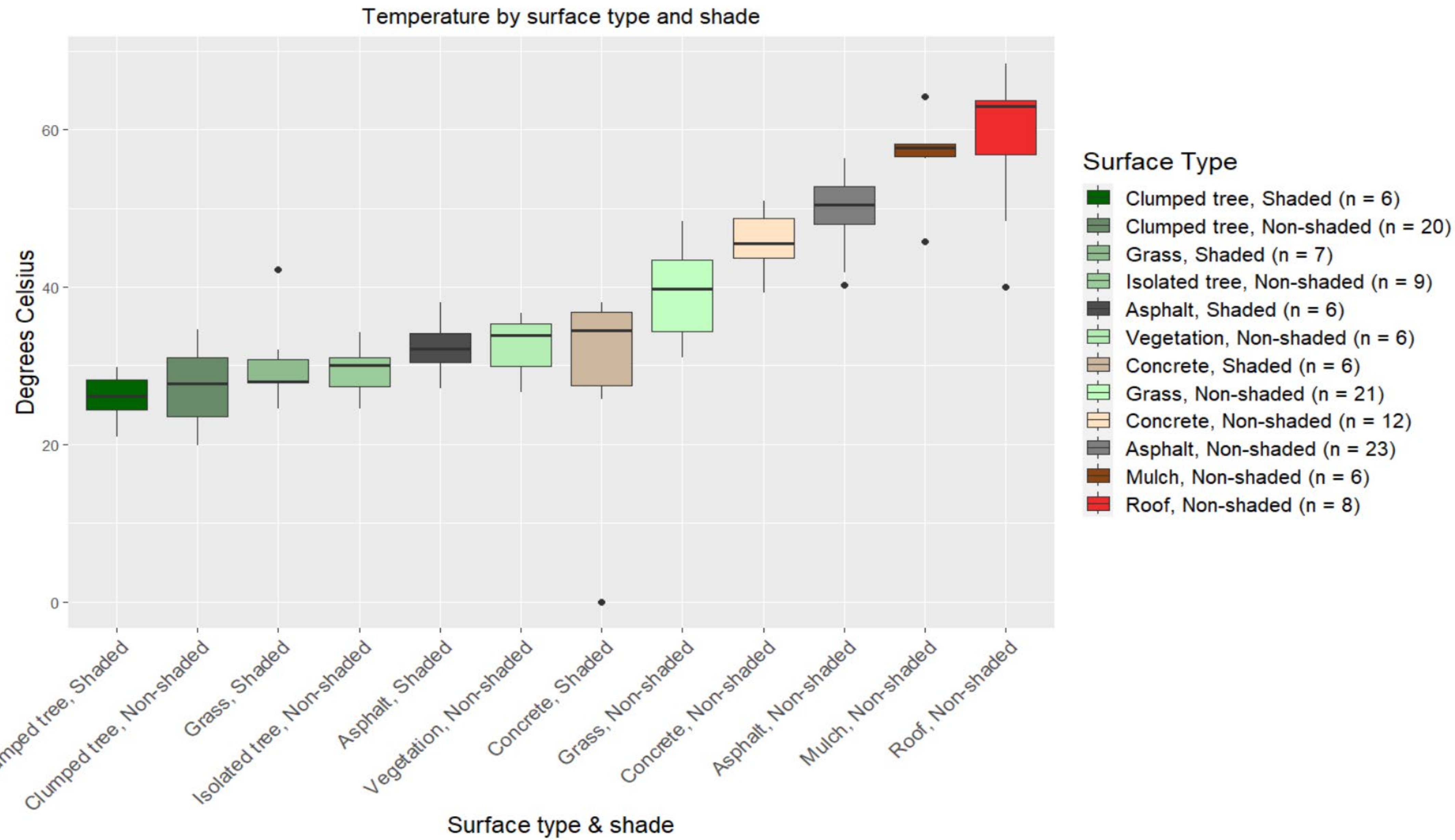
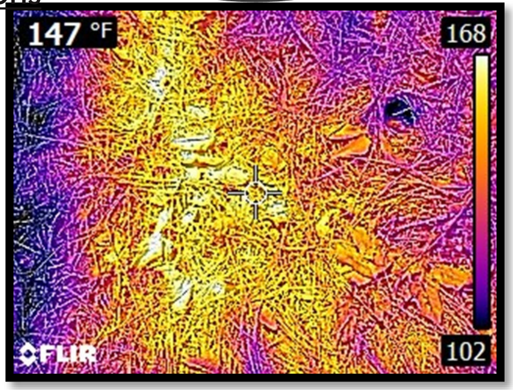
Results: Urban surface temperatures

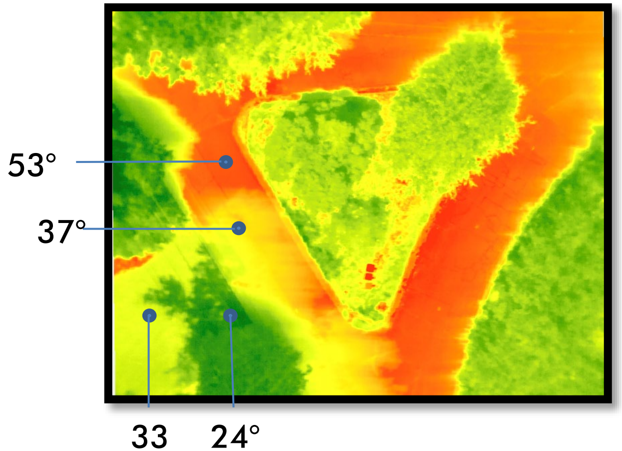


Takeaways

- UAV can measure urban temperatures
  - There is a way to fly urban areas while minimizing risk
  - Person with technical knowledge needed
- Even non-shaded greenery = some of the coolest surfaces
  - Non-green natural surfaces appear hotter—comparable?
- Tree configuration (clumped vs. isolated) might show temperature differences in canopy temperature (Alonzo et al., 2021)
  - Does configuration make a difference in surrounding surface temps?

Wikimedia Commons



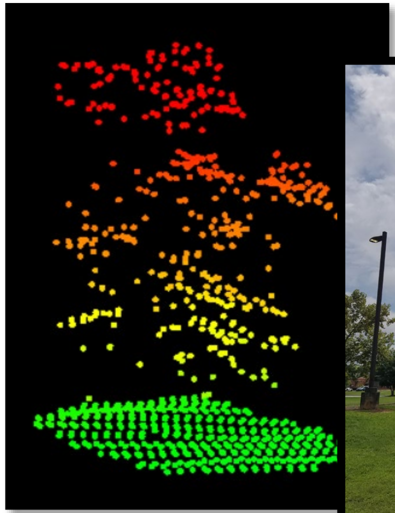


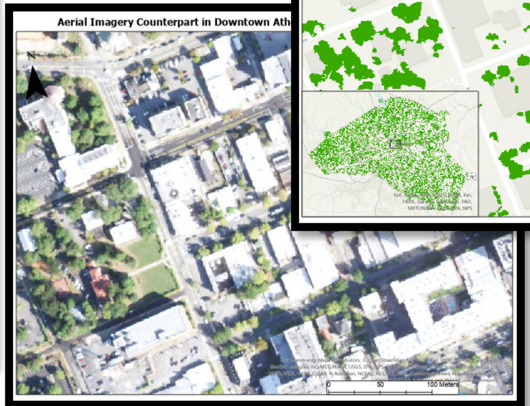
Takeaways (continued)

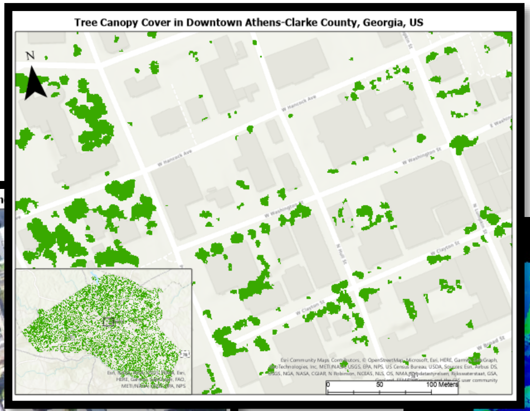
- More work required in:
  - Tree characteristics effects and spatial configurations of trees (Cai et al., 2022; Davis et al., 2016; Rafiee et al., 2016)
  - Relationships among canopy temperature, air temperature, and surface temperature (Cheung et al., 2021)
  - Spatial configurations of surrounding environment & trees (da Rocha et al., 2017; Oke & Stewart, 2012; Yu et al., 2019)
- Higher resolution thermal imagery from UAV makes more detailed data fusion possible

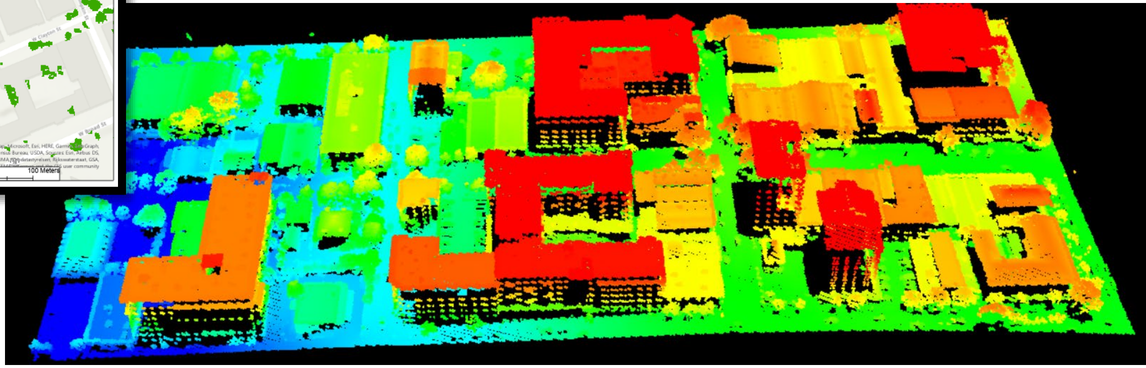
Accounting for 3-dimensionality

Cheung et al., 2021









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Thank you

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Session 1.4 - In the Cool of the Day

Impacts of water restriction on the development of urban trees and their associated climate services.

Presented by

Dorine Canonne, Sabine Demotes-Mainard,
Marc Saudreau, Julien Thierry, Bénédicte Dubuc,
Lydie Ledroit, Denis Cesbron, Camille Lebras, Lydia Brialix,
Dominique Lemesle, Sophie Herpin, Pierre-Emmanuel Bournet

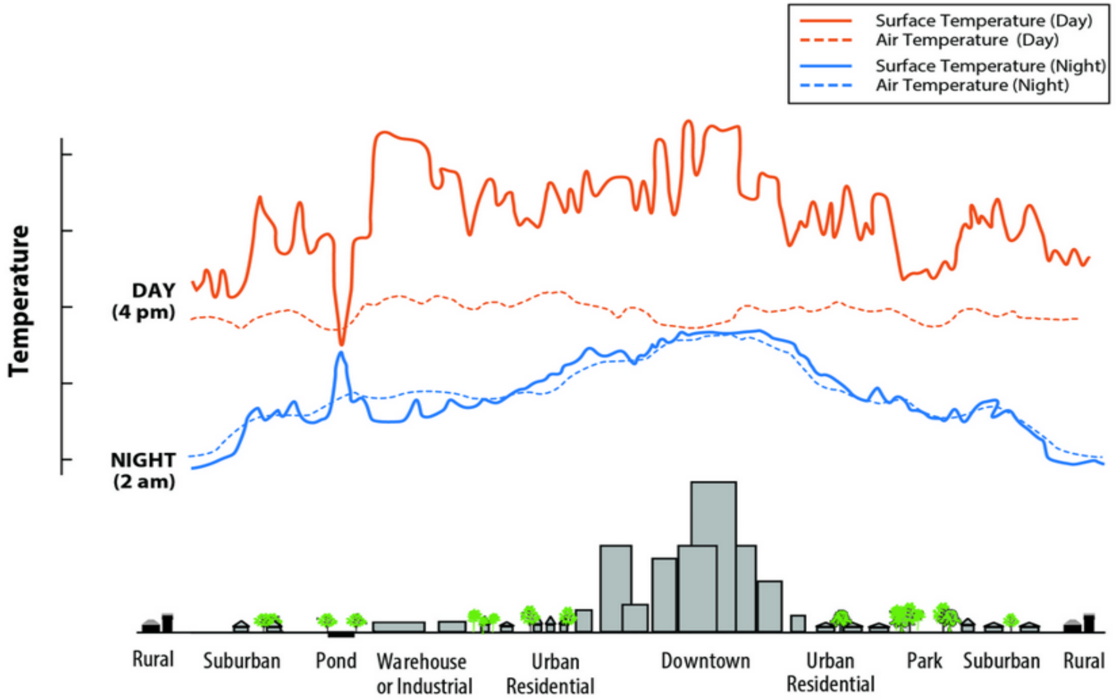
Introduction

Context & Objectives

- **Ongoing climate changes**, e.g. ↗ global average air temperature

IPCC, 2022

- **Urban Heat Island** (UHI) **intensification**



Oke, 1981; US EPA, 2014

↗ Human thermal stress in cities

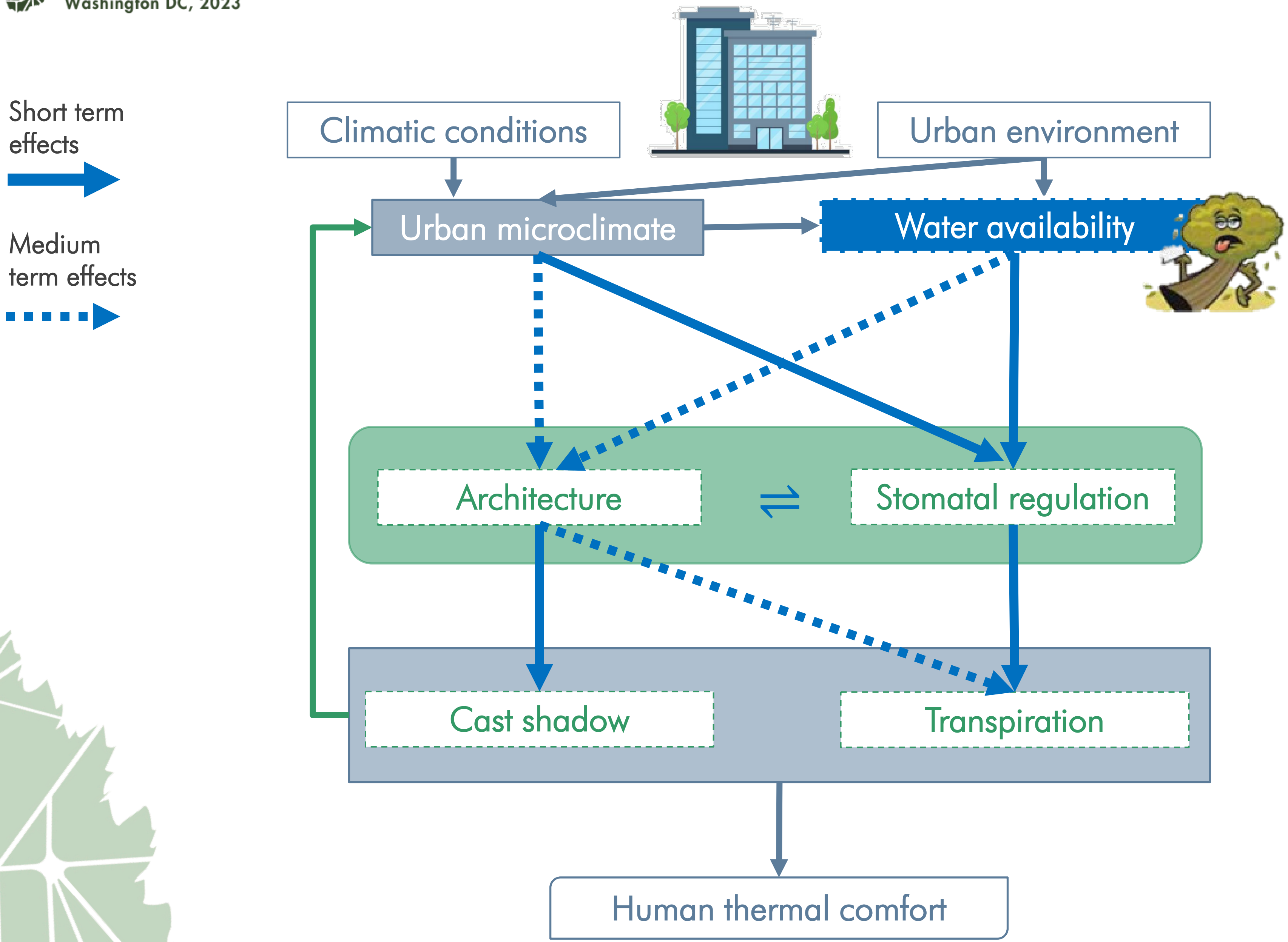
&

- Increasing **urbanization** trend, i.e. ↗ in the number of people exposed to these extreme climatic events

United Nations, 2019

⇒ Identify solutions for adapting to increasing heat: trees in cities are a promising line …
… but there is a need to account for increasing droughts

Bühler et al, 2006; Rahman et Ennos, 2016; Rötzer et al, 2021



Objectives

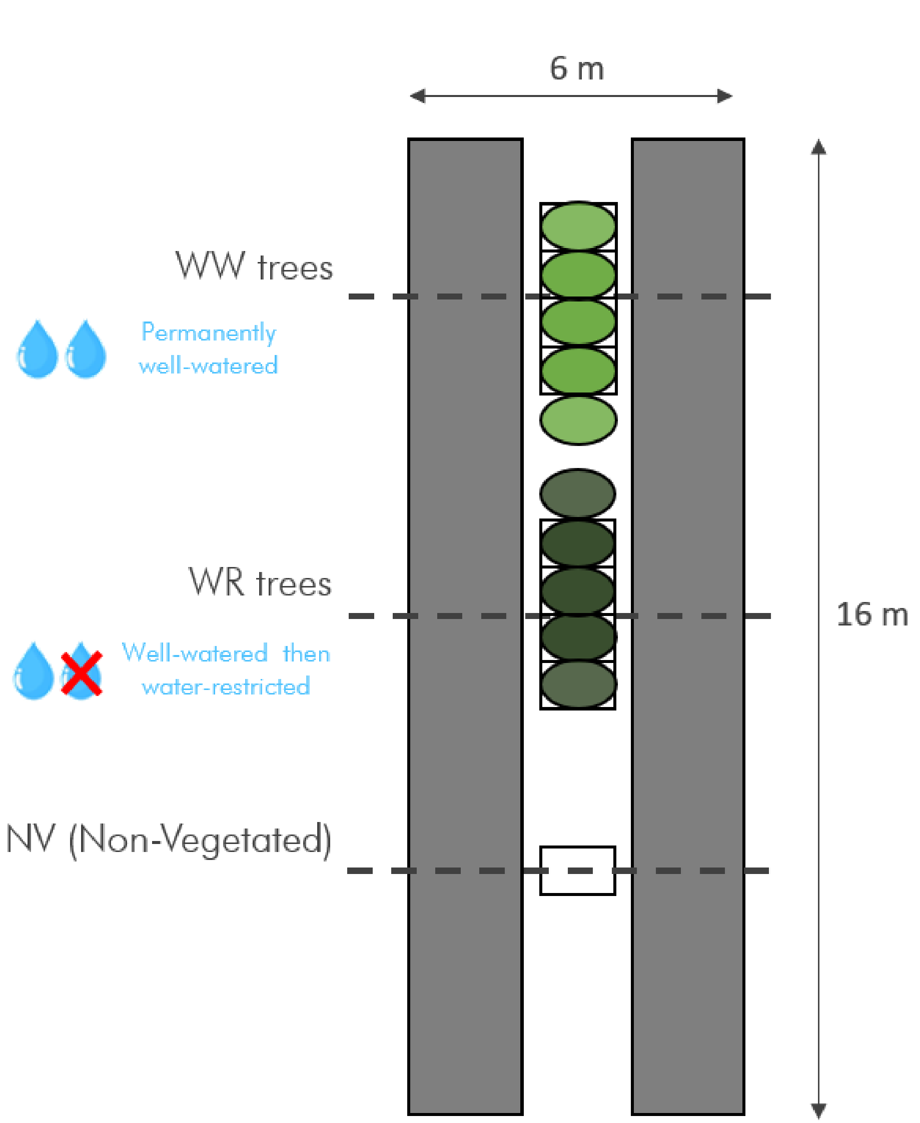
1. Analyze the effects of a drought period on the **architectural development** and the transpiration of alignment trees in a canyon street

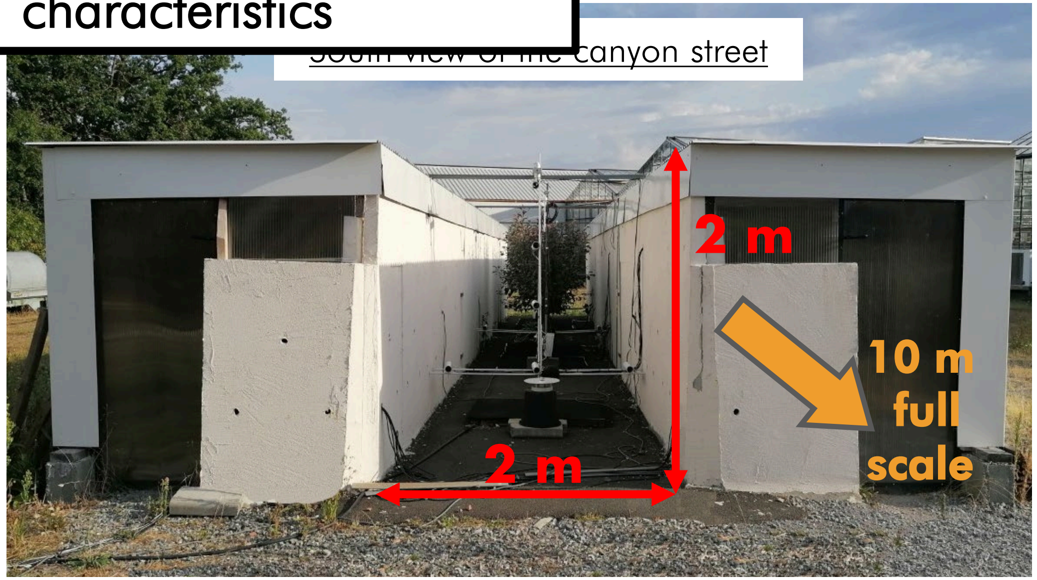
2. Characterize **their consequences on the cooling services**

Material & Methods

Facility & Measurements

Experimental facility characteristics






A WW tree on July 5th, 2022

- Width : 2 meters
- Height : 2 meters

- Aspect ratio : 1
- Scale : 1/5

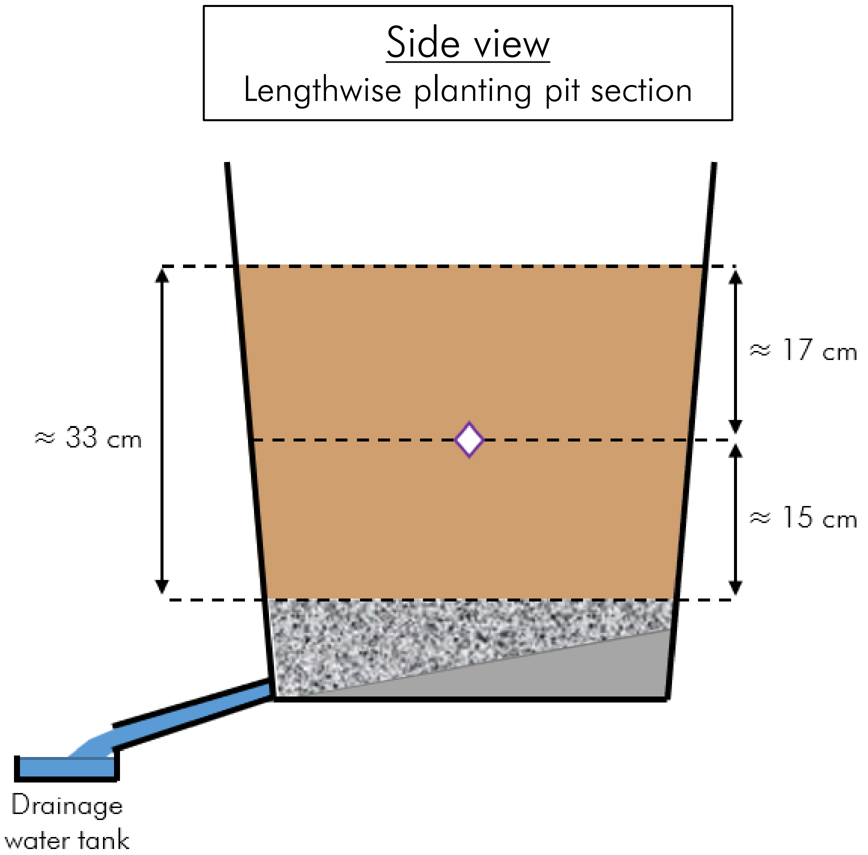
- 2 vegetated zones
- 1 non-vegetated zone

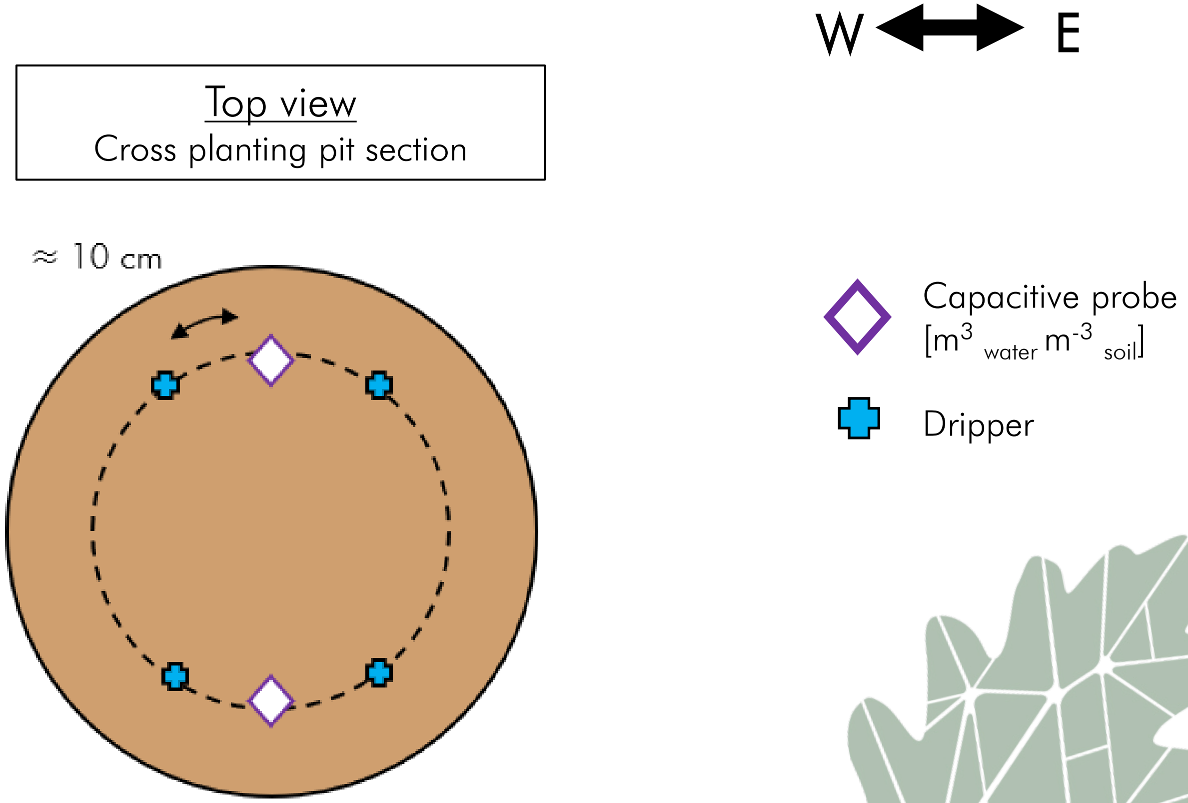
- 1 species *Malus Coccinella® 'Courtarou'*

Ground measurements

Bioclimatic sensors to characterize:

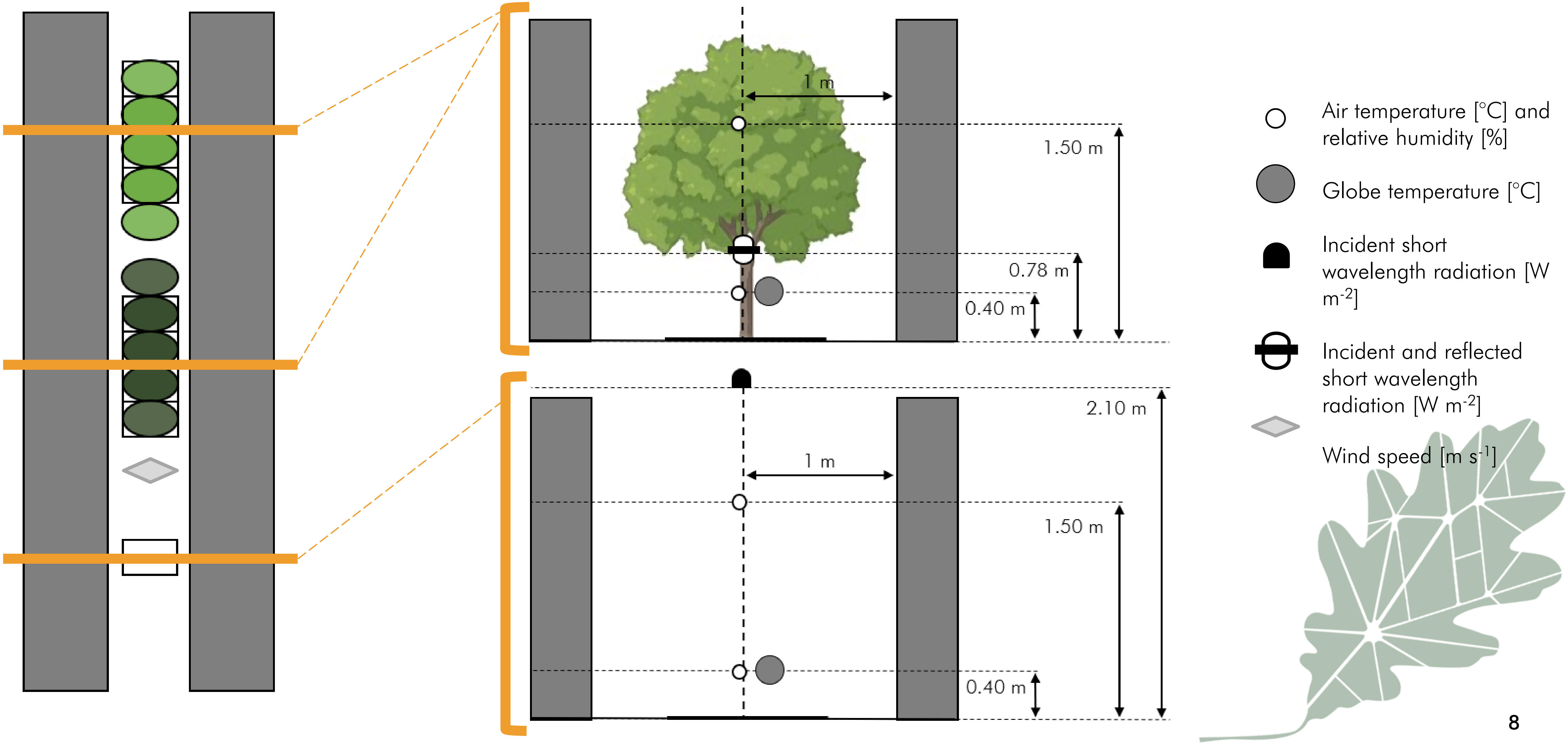
➢ Water availability in the soil





Climate measurements

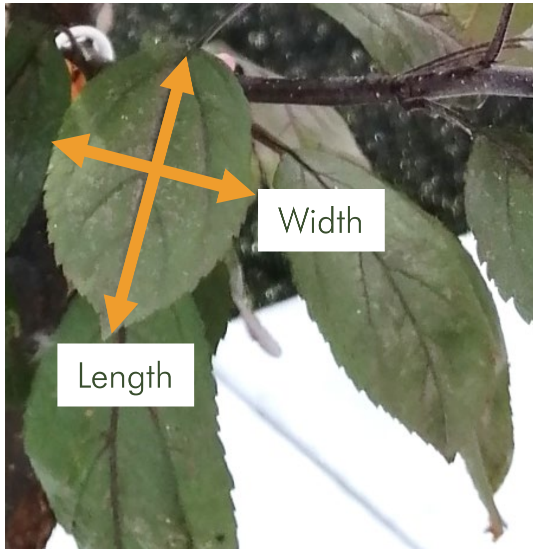
- **Climatic conditions** both in vegetated … the street & **tree climate services**

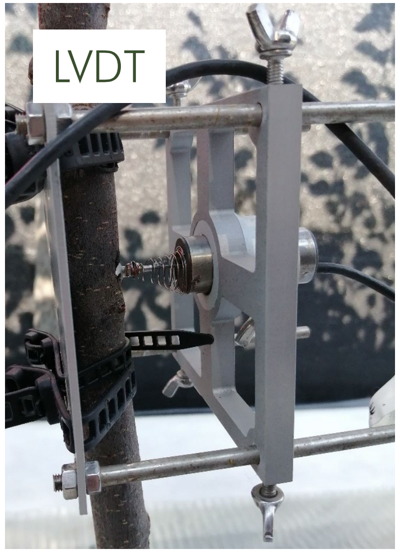


Ecophysiological measurements

Tree measurements

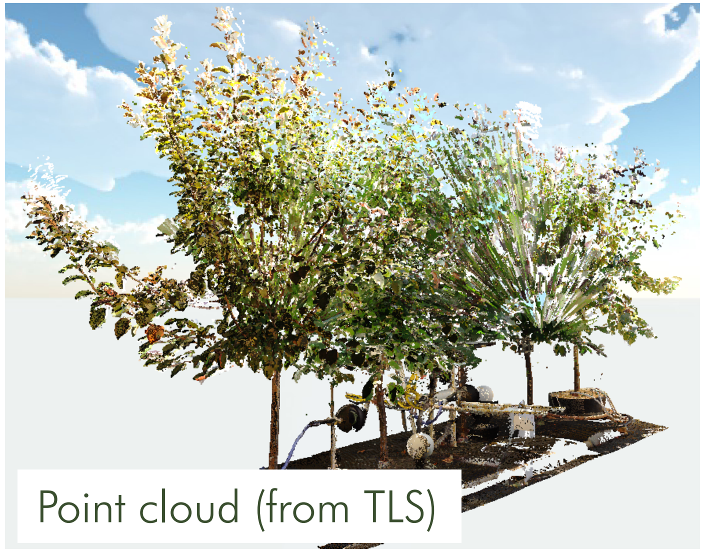
- Organ characteristics:
  - Leaf and stem numbers and dimensions (length & width) *by manual measurements*
  - Trunk diameter variations *using LVDT*





- Crown characteristics:
  - Tree leaf area using allometric relationships *based on manual measurements of leaf length, leaf width and total foliated length of the axes*
  - Crown geometry such as projected area, volume *using Terrestrial Laser Scanner*

  - Leaf Area Index (LAI), Leaf Area Density (LAD) *calculated from tree leaf area and crown geometry variables*



Results

Characterization of water regime

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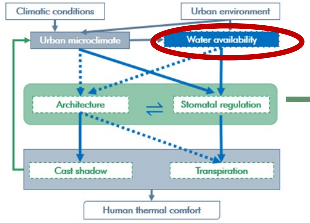
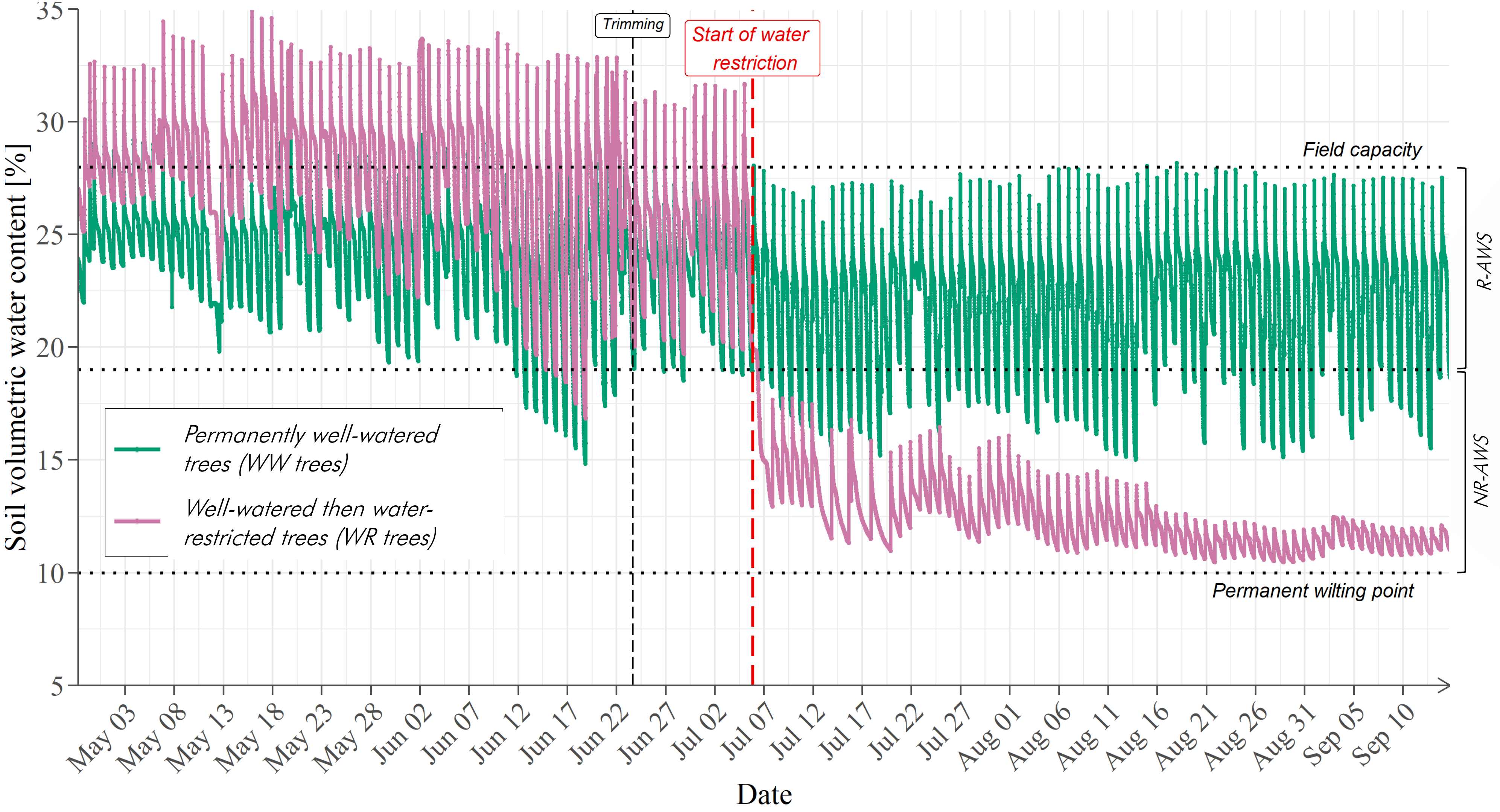
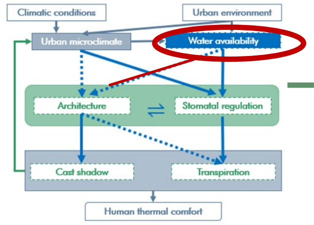


Evolution of average soil volumetric water content

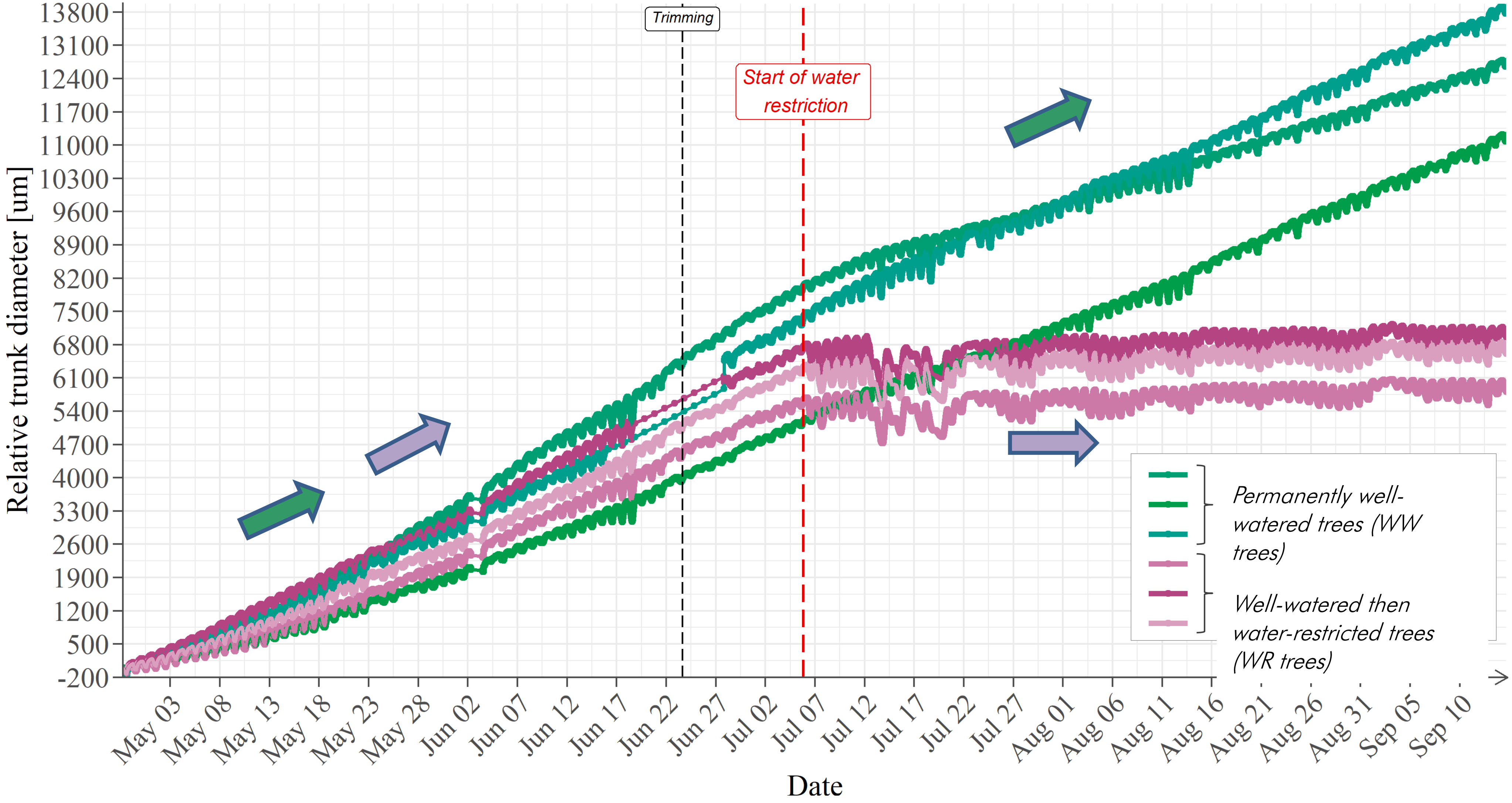


- <u>Before</u> WR starts: Soil volumetric water content in the readily available water storage (R-AWS) = **Well-watered conditions** for both WW trees & WR trees

- <u>After</u> WR starts:
  - Soil volumetric water content in the R-AWS = **Well-watered conditions** for WW trees
  - Soil water content in non-readily available water storage (NR-AWS) = **Water-restriction** for WR trees



Evolution of trunks' micrometric variations of the trees



- **Before WR starts:**
  Positive trunk secondary growth for both WW trees & WR trees
- **After WR starts:**
  - Still positive trunk secondary growth for WW trees
  - **No trunk secondary growth** for WR trees

Results

Impact of water restriction on tree architecture

2022.07.22

Trimming to maintain coherent tree dimensions, which resulted in new branches development rather than evolution of formely developed axes

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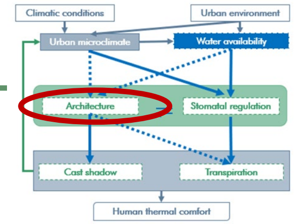
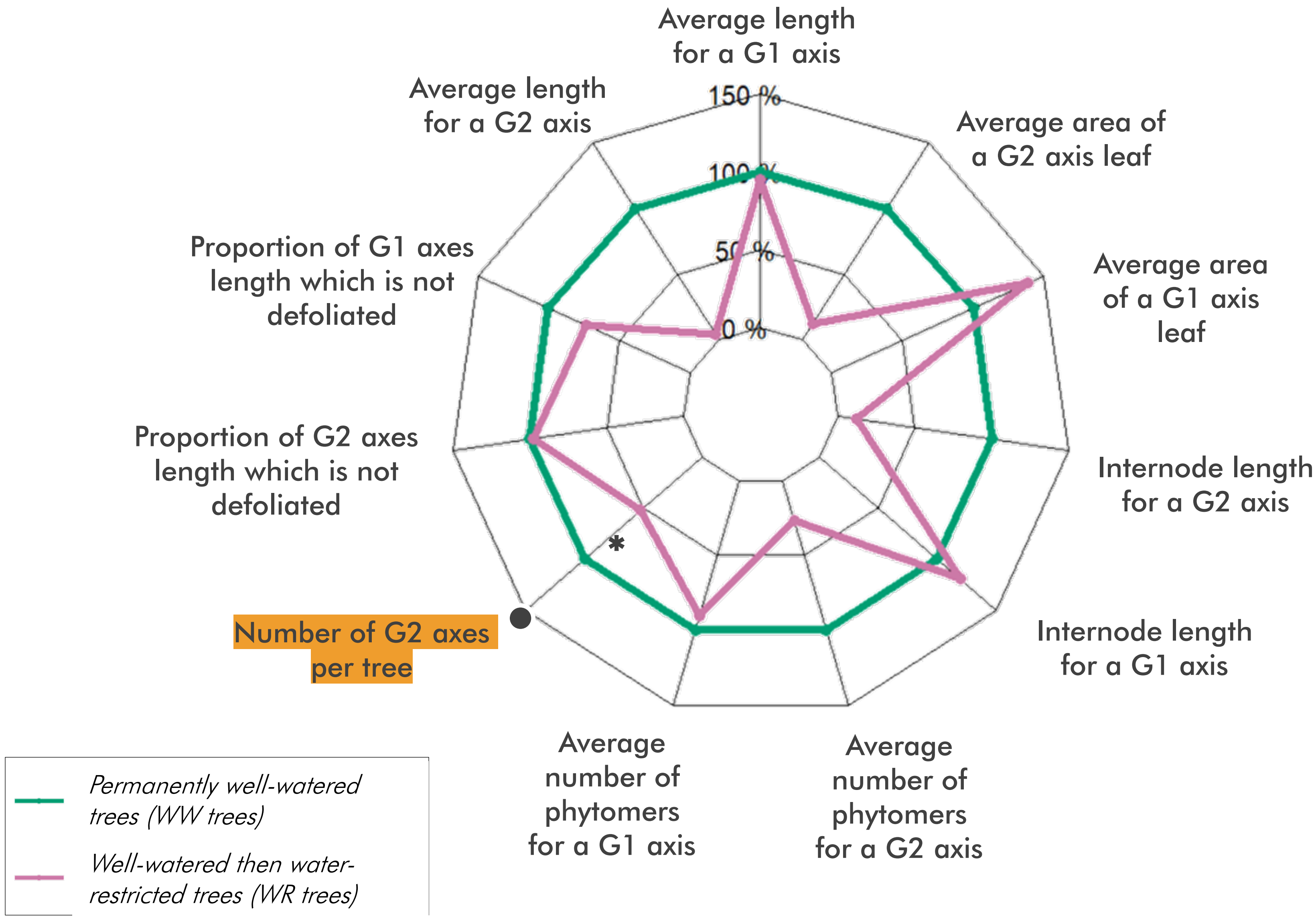
After 7 water-restricted weeks (for WR trees)



Architectural variables involved in crown structure (relative values)



Water restriction implies:

1) **Branching**: ↘ of the number of newly formed axis

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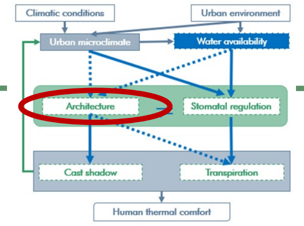
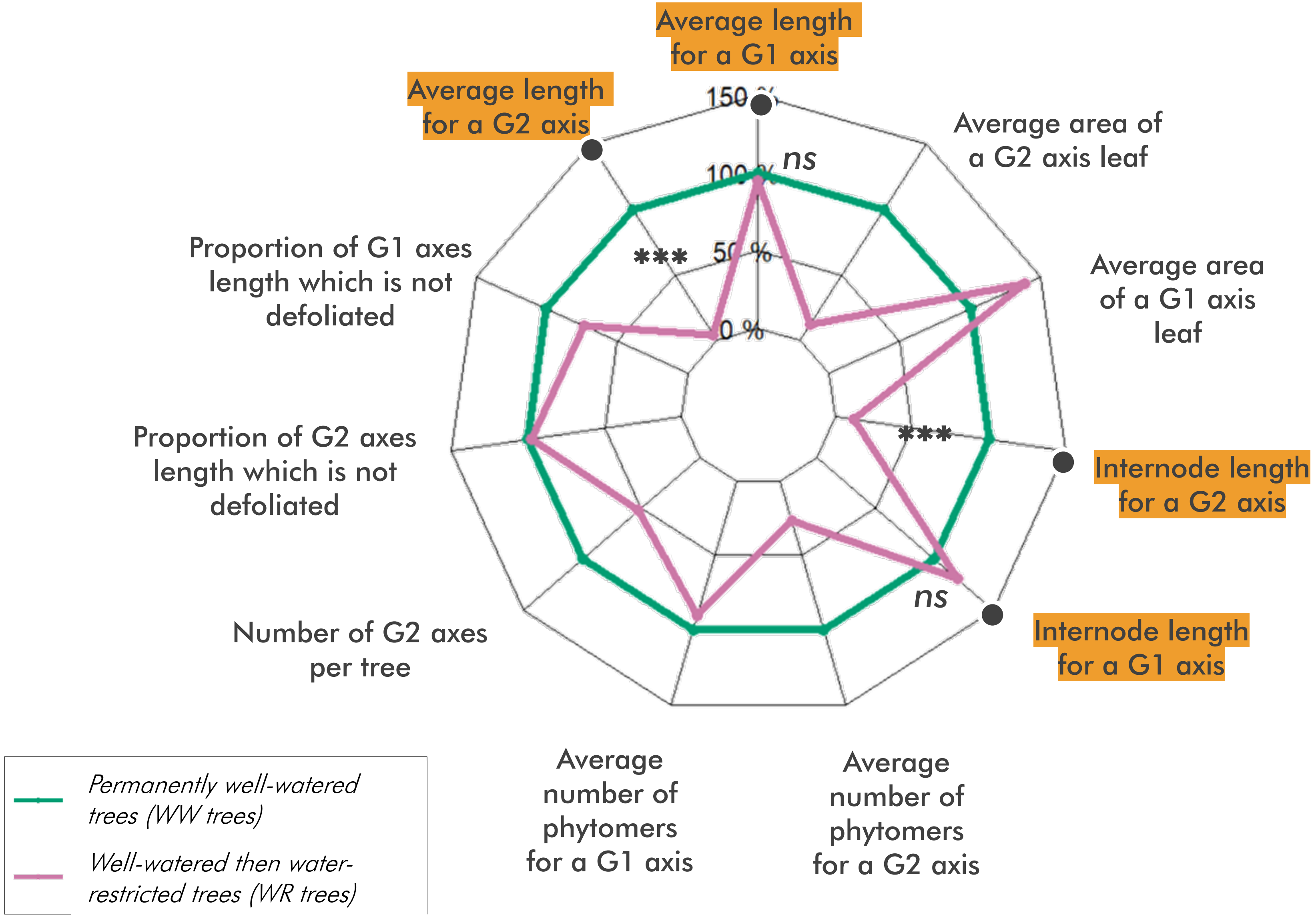
After 7 water-restricted weeks (for WR trees)



Architectural variables involved in crown structure (relative values)



Water restriction implies:

1) **Branching**: ↘ of the number of newly formed axis

2) **Elongation** of newly formed axis ↘

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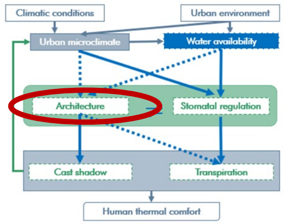
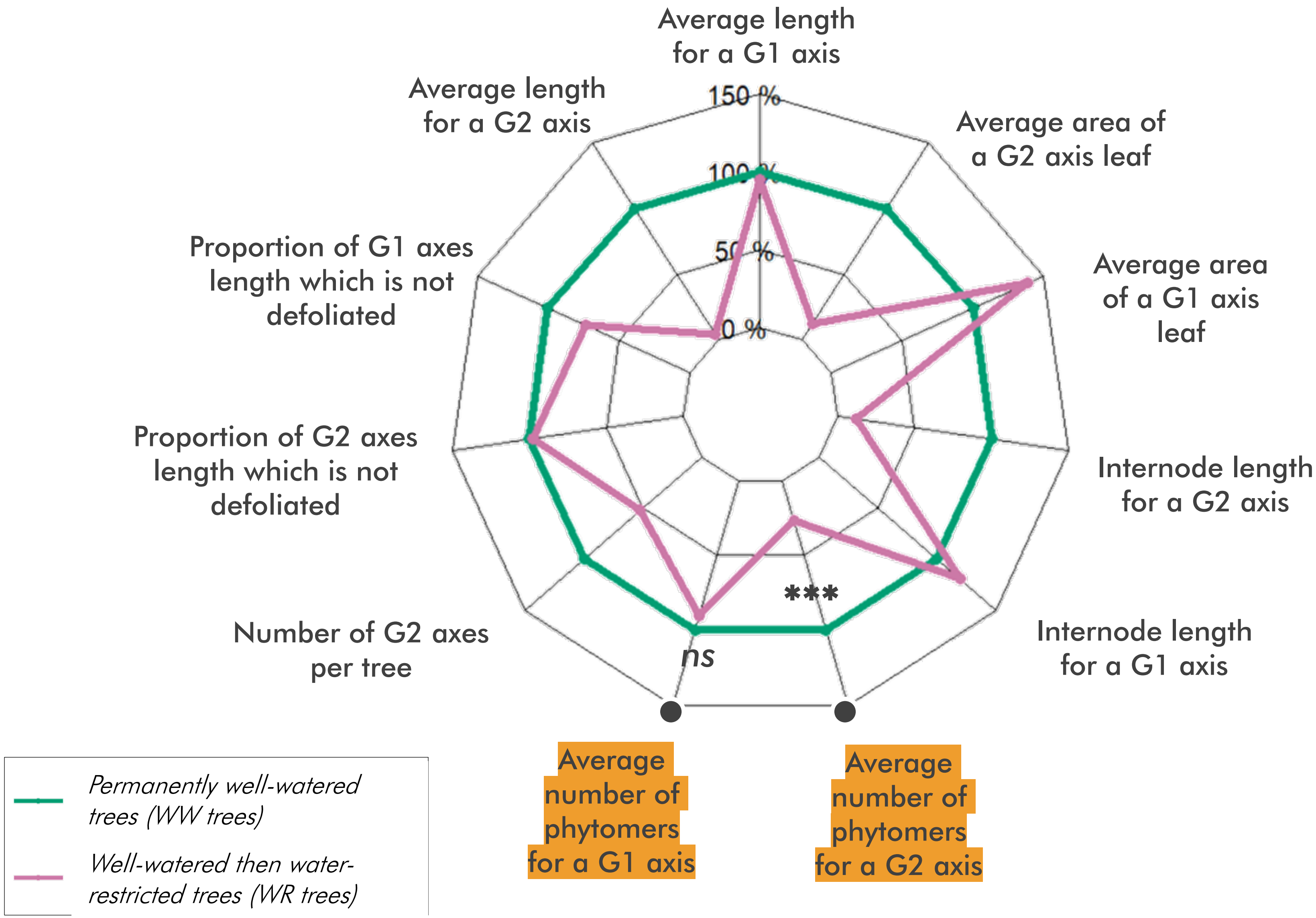
After 7 water-restricted weeks (for WR trees)



Architectural variables involved in crown structure (relative values)



Water restriction implies:

1) **Branching**: ↘ of the number of newly formed axis
2) **Elongation** of newly formed axis ↘
3) **Phytomer (and leaf) formation**: ↘ in newly formed axes

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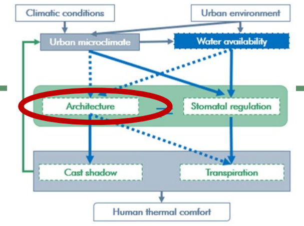
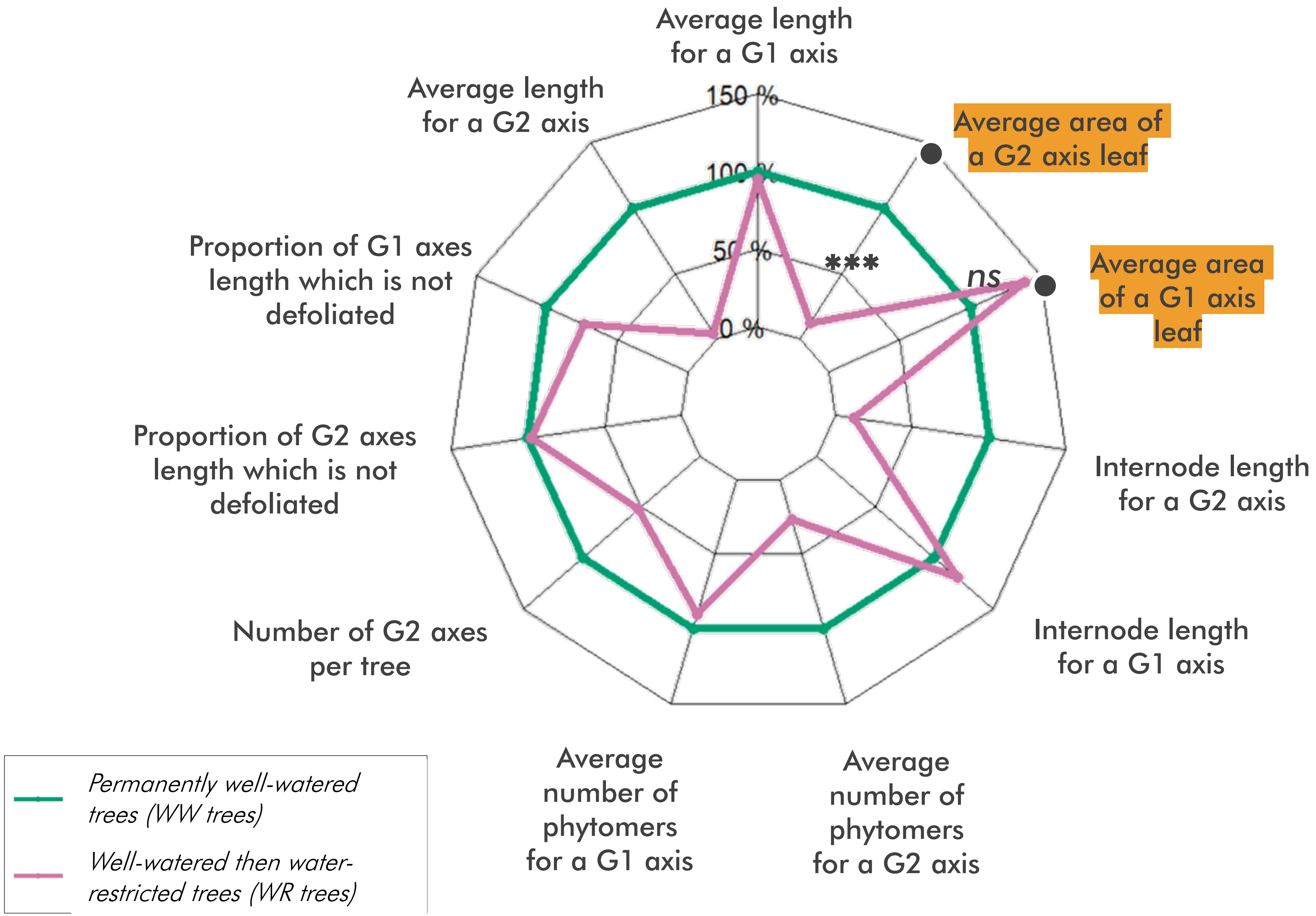
After 7 water-restricted weeks (for WR trees)



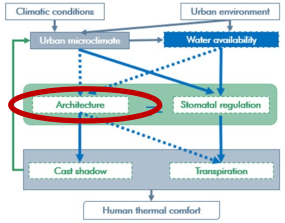
Architectural variables involved in crown structure (relative values)



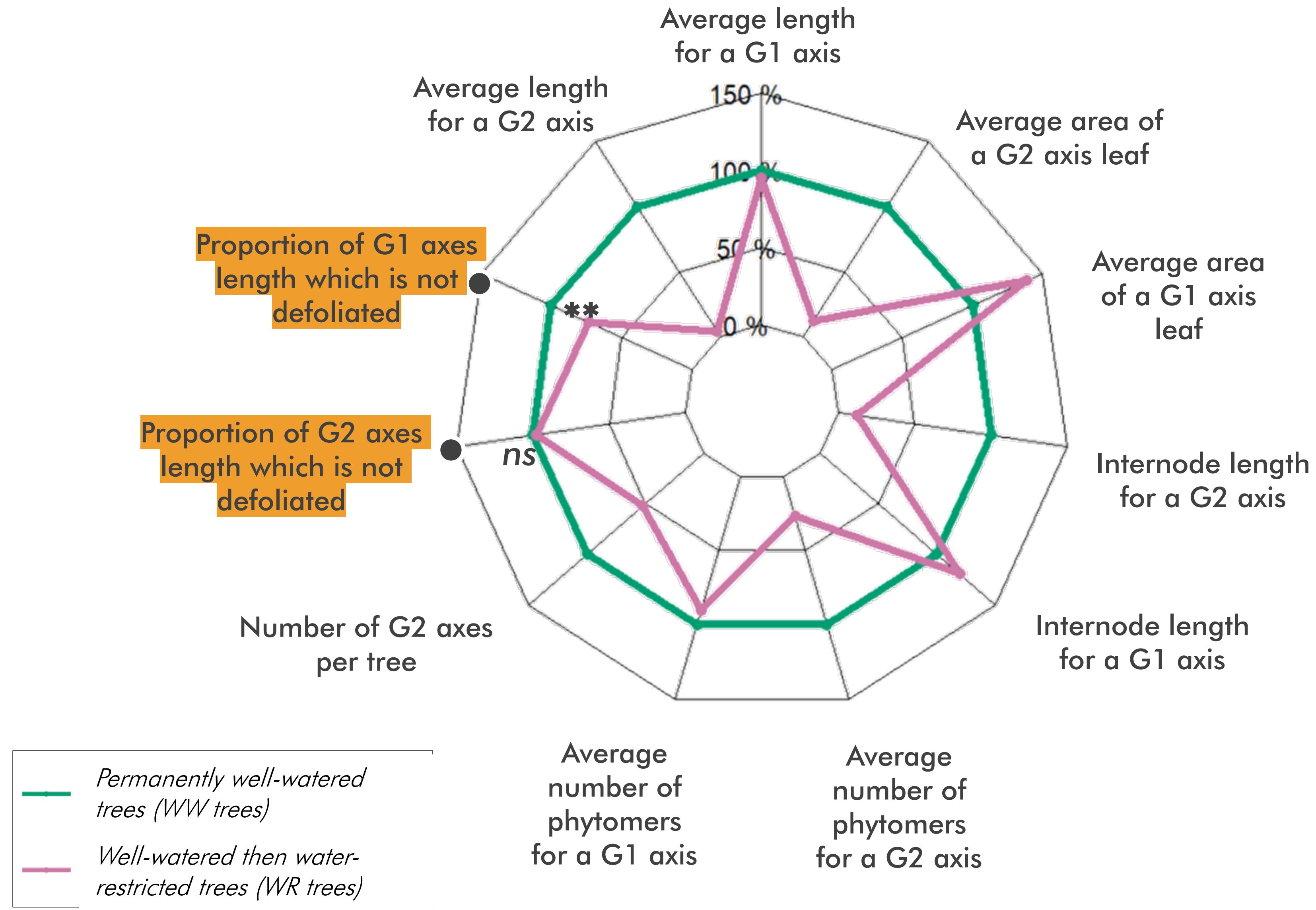
Water restriction implies:

1) **Branching**: ↘ of the number of newly formed axis
2) **Elongation** of newly formed axis ↘
3) **Phytomer (and leaf) formation**: ↘ in newly formed axes
4) **Foliar expansion** of leaves carried out by newly formed axis ↘

After 7 water-restricted weeks (for WR trees)



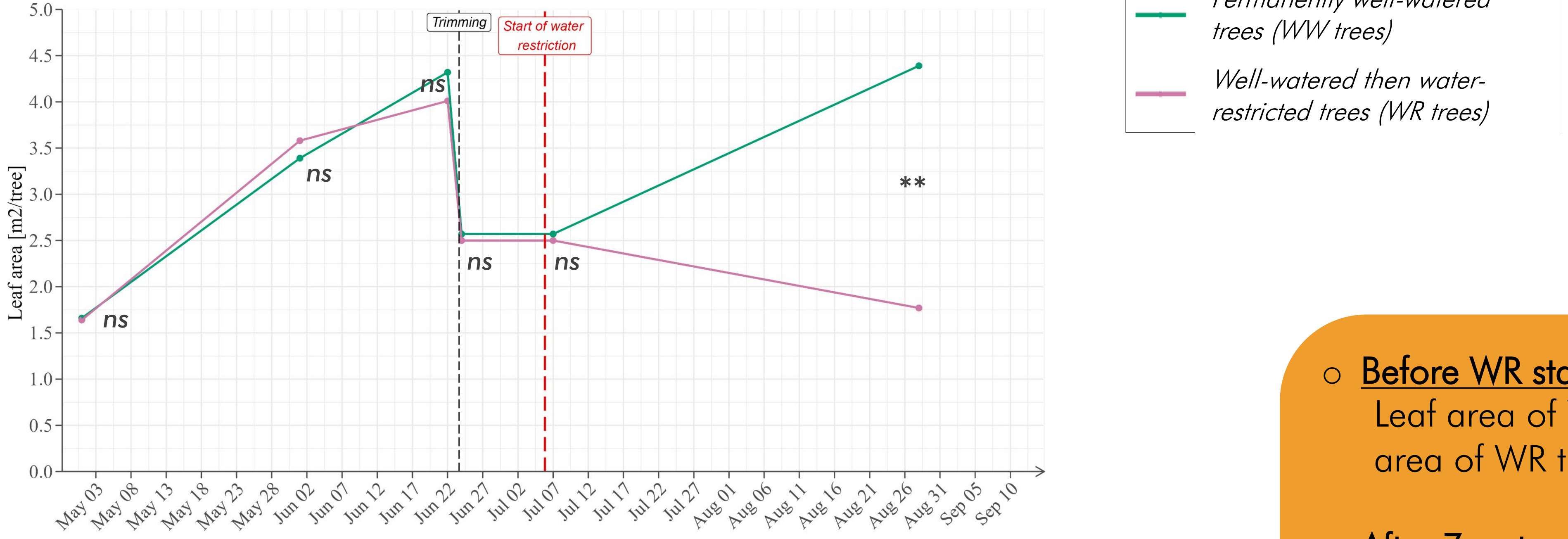
Architectural variables involved in crown structure (relative values)

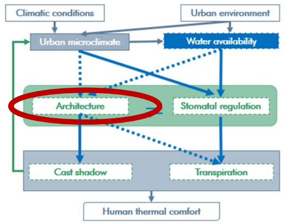


Water restriction implies:

1) **Branching**: ↘ of the number of newly formed axis
2) **Elongation** of newly formed axis ↘
3) **Phytomer (and leaf) formation**: ↘ in newly formed axes
4) **Foliar expansion** of leaves carried out by newly formed axis ↘
5) **Defoliation** of formely formed axes ↗

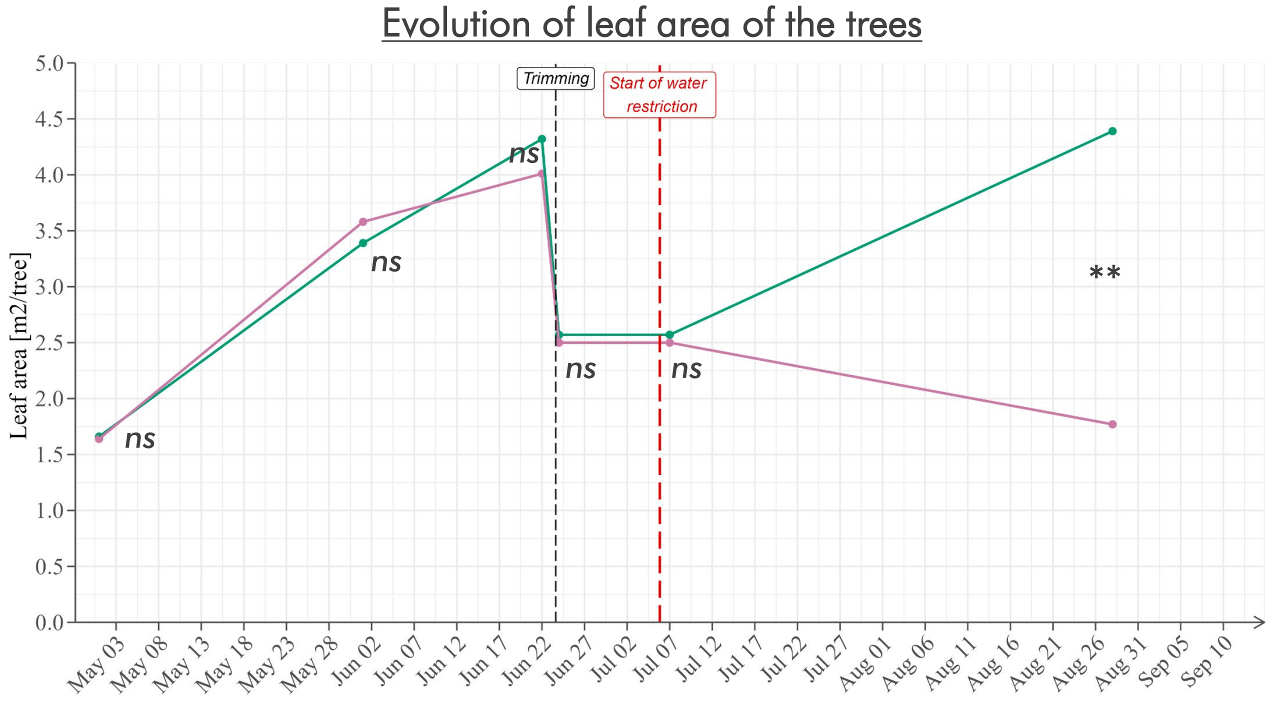
Evolution of leaf area of the trees

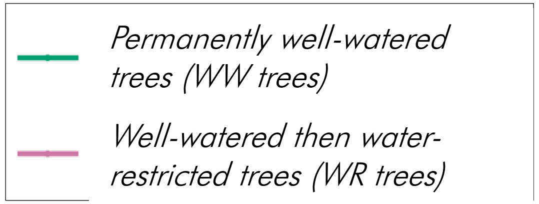


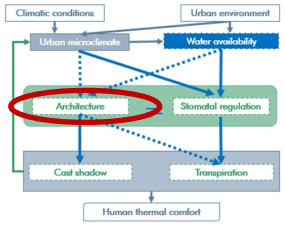


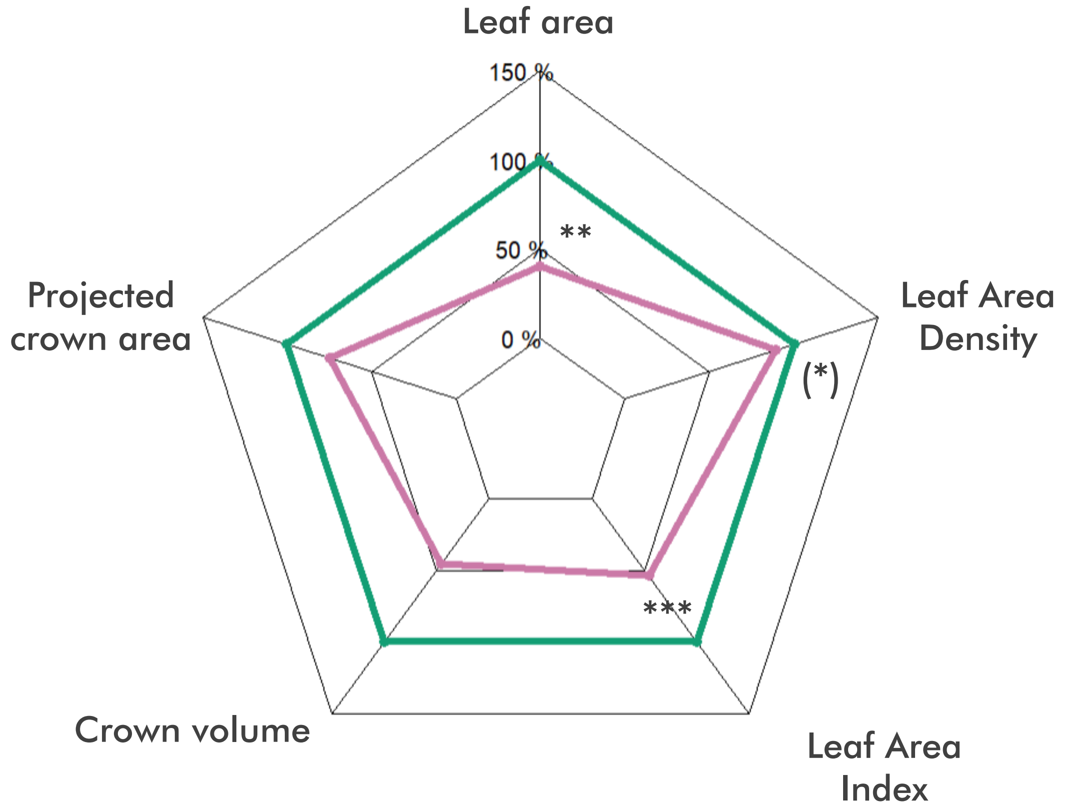
- **Before WR starts:**
  Leaf area of WW trees ≈ Leaf area of WR trees

- **After 7 water-restricted weeks:**
  Leaf area of WW trees >> Leaf area of WR trees, meaning **effects of water restriction on architectural processes affect the leaf area**

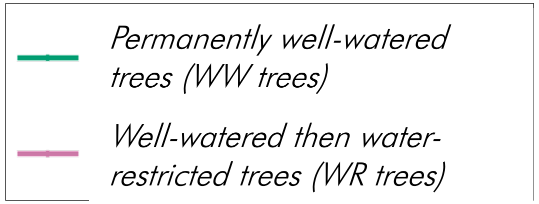


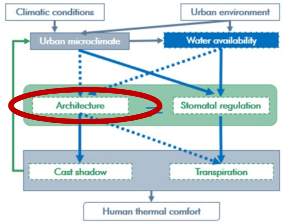




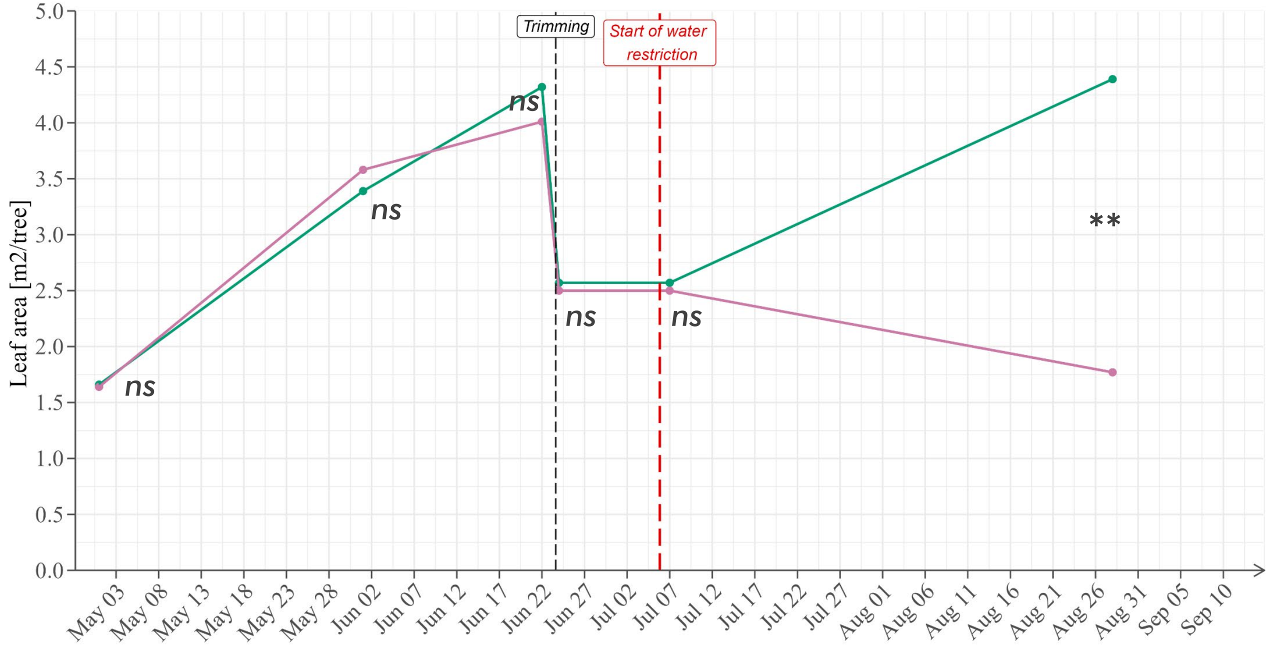


Crown geometry variables such as LAI are reduced after 7 weeks of water restriction due to reduction in leaf area

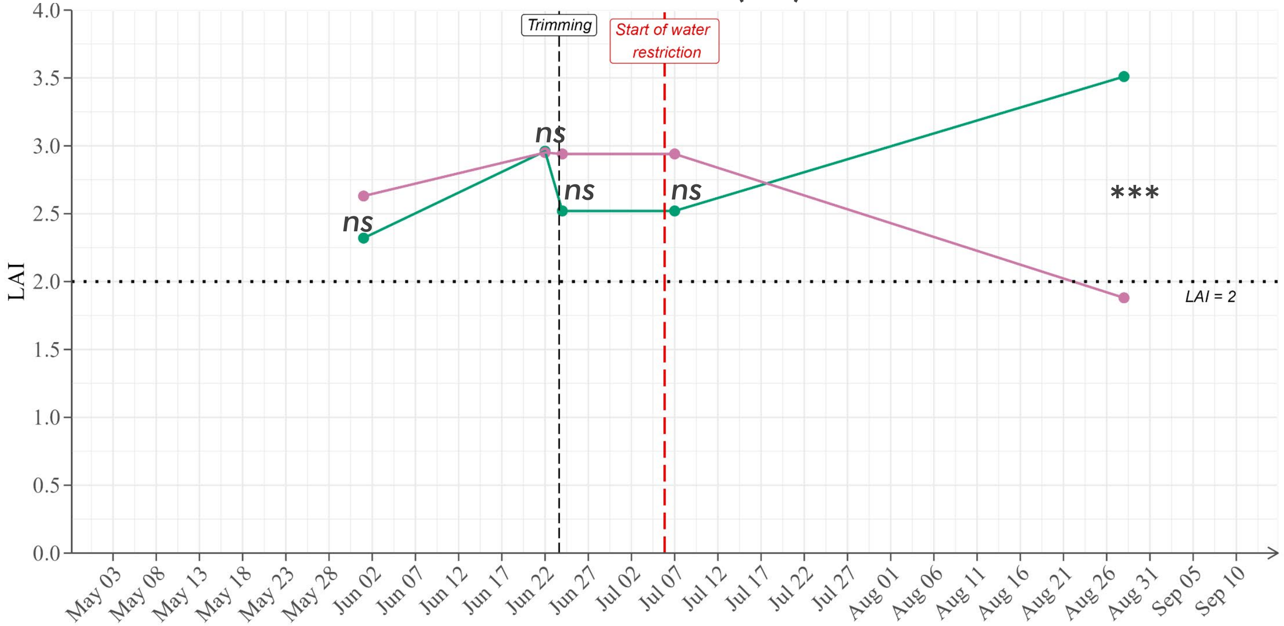


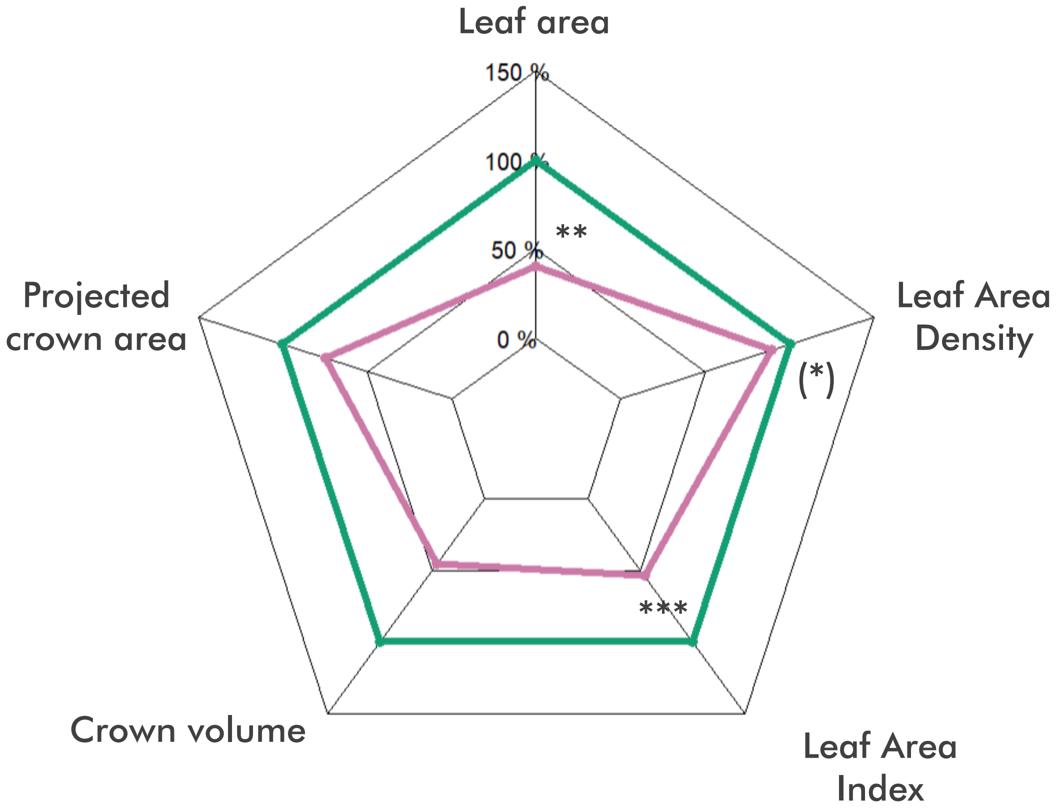


Evolution of leaf area of the trees

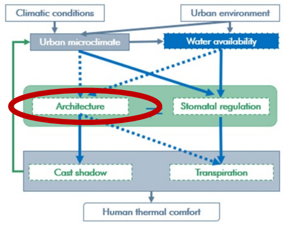


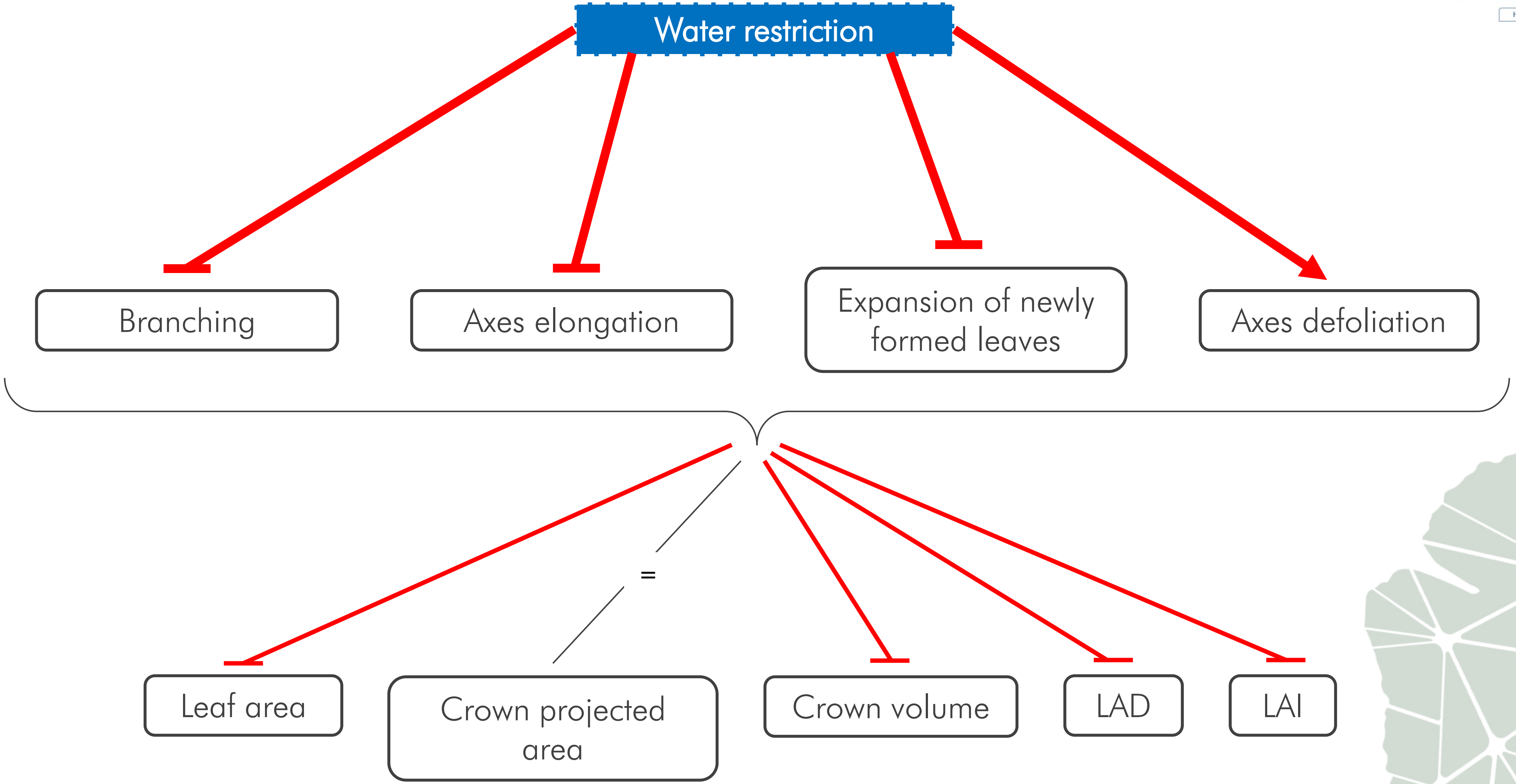
Evolution of leaf area index (LAI) of the trees





LAI values are **higher than or close to 2 during the whole season**, even after the water-restricted period for WR trees (=1.88)


Climatic conditions
Urban environment
Urban microclimate
Water availability
Architecture
Stomatal regulation
Cast shadow
Transpiration
Human thermal comfort


Water restriction
Branching
Axes elongation
Expansion of newly formed leaves
Axes defoliation
=
Leaf area
Crown projected area
Crown volume
LAD
LAI

Results

Impact of tree architectural modifications on associated climate services

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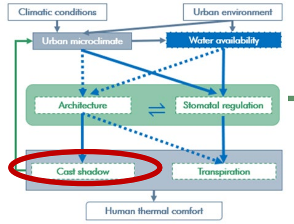
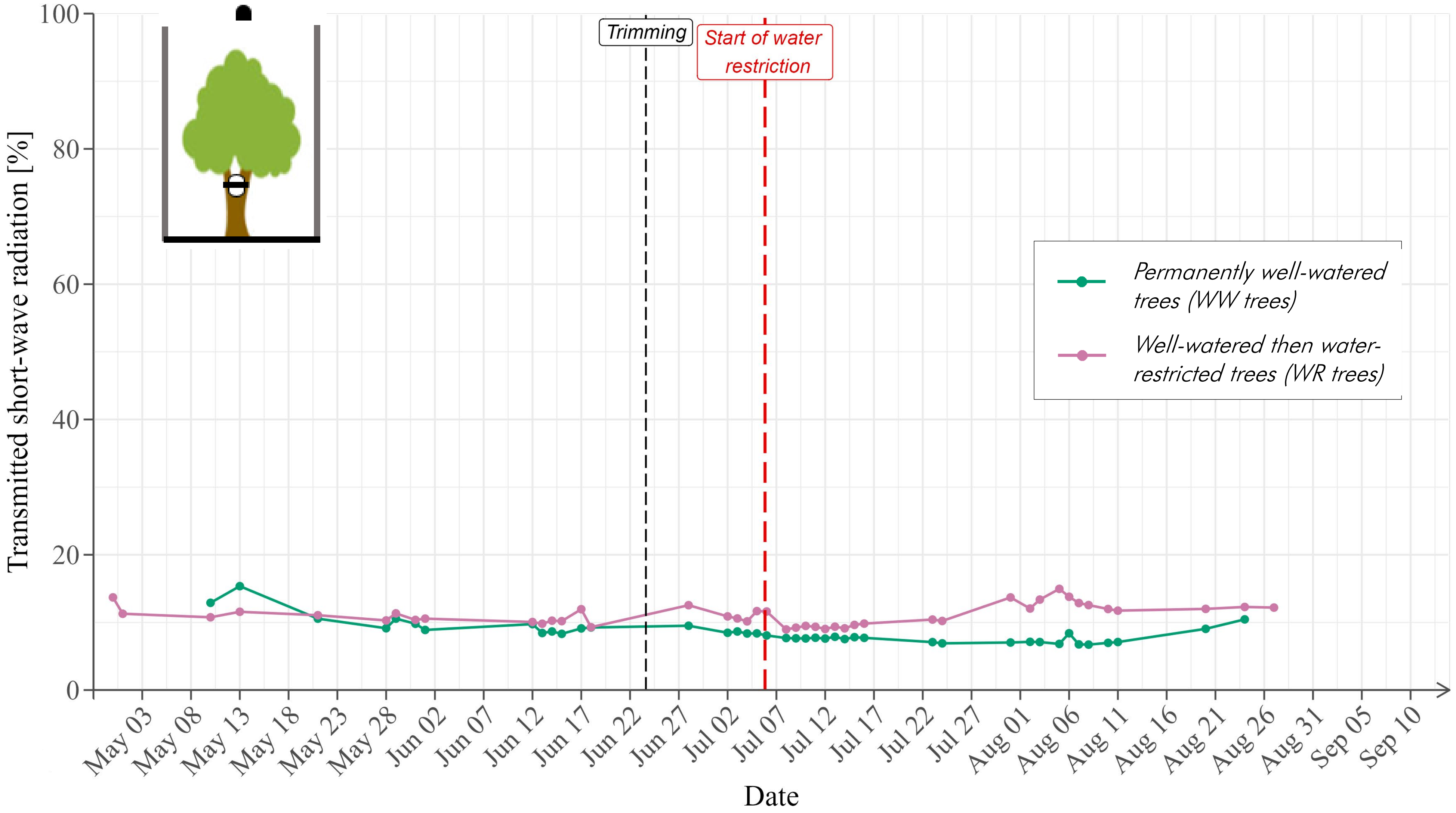
45 sunny days = studied days

Average between 11 am & 1 pm



Evolution of the percentage of short wavelength transmitted radiation measured under the crown (at 0.78 m above street ground level at reduced scale)

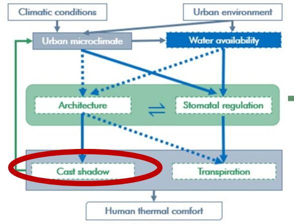


- **Before & after WR starts:**

  Both WW trees and WR trees afford strong cast shadow

45 sunny days = studied days

Average between 11 am & 1 pm



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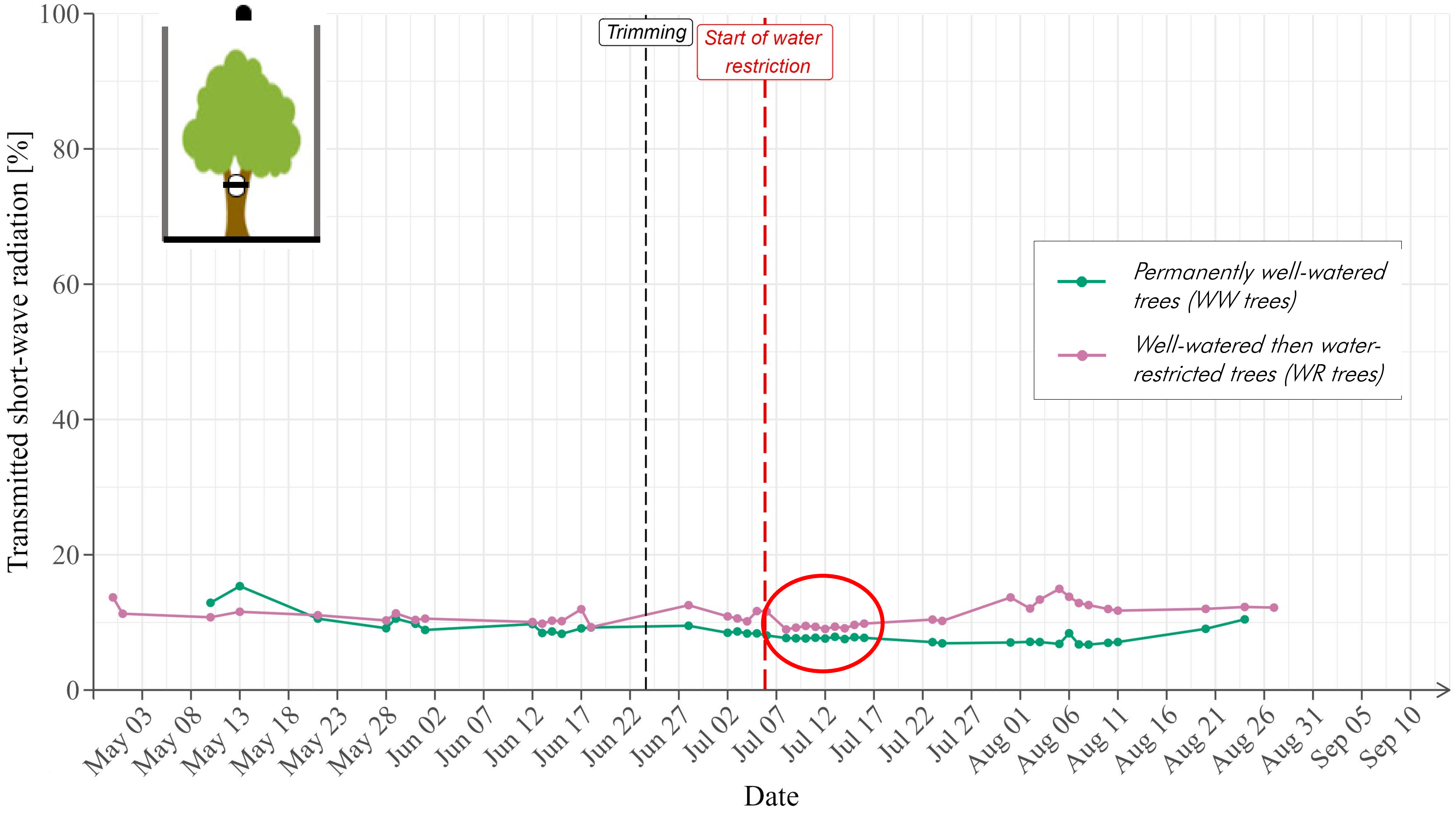

- **Before & after WR starts:**

  Both WW trees and WR trees afford strong cast shadow

- **After WR starts:**

  1) Cast shadow provided by WW trees ≈ WR trees

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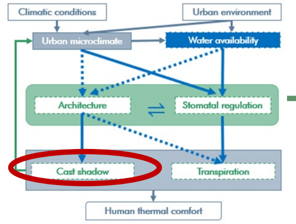
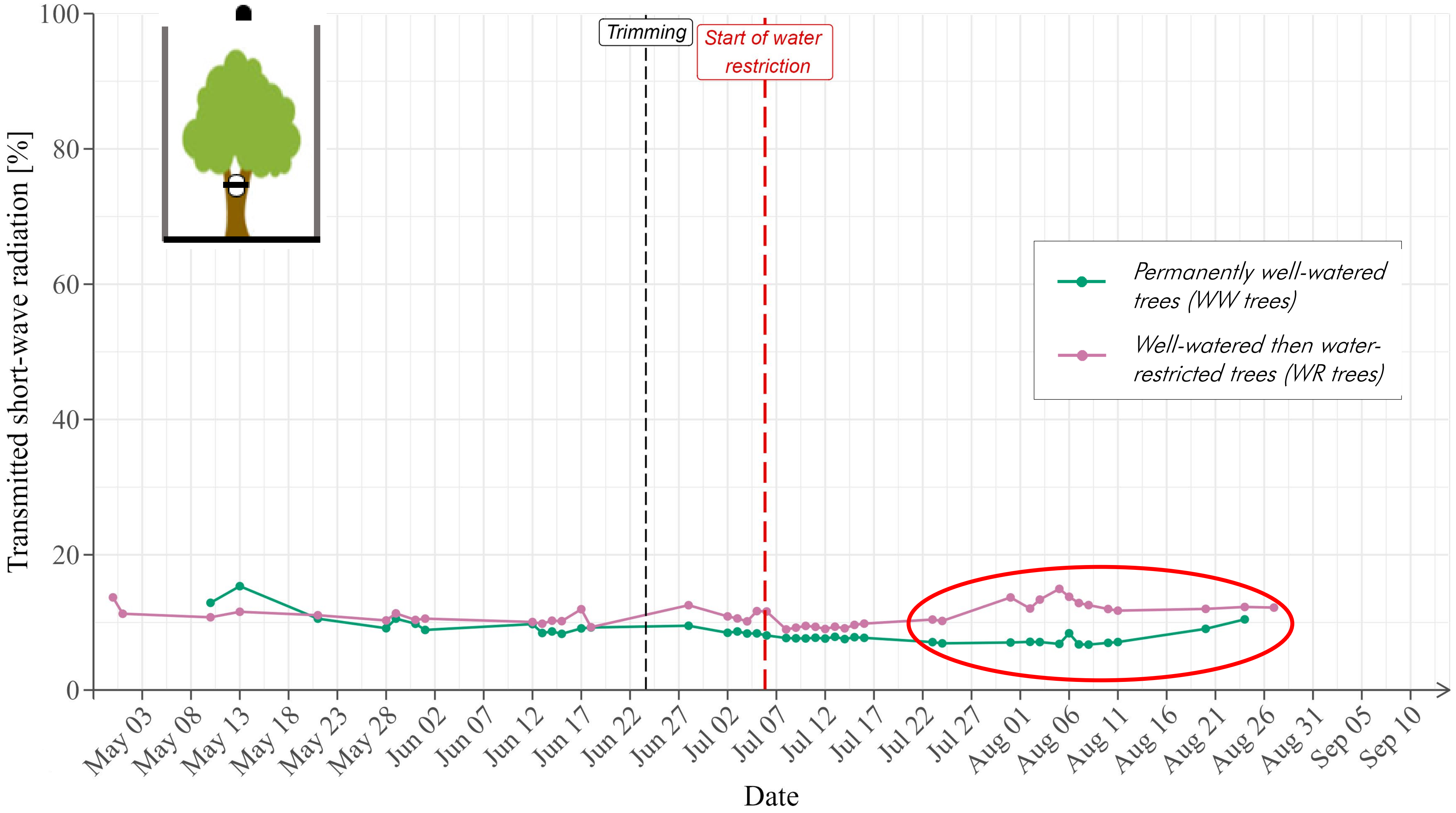
45 sunny days = studied days

Average between 11 am & 1 pm



Evolution of the percentage of short wavelength transmitted radiation measured under the crown (at 0.78 m above street ground level at reduced scale)



- **Before & after WR starts:**

  Both WW trees and WR trees afford strong cast shadow

- **After WR starts:**

  1) Cast shadow provided by WW trees ≈ WR trees

  2) Cast shadow under WR trees is 5% less than under WW trees

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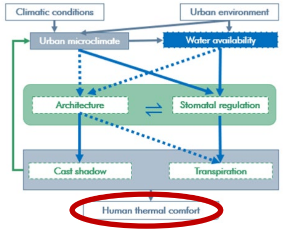
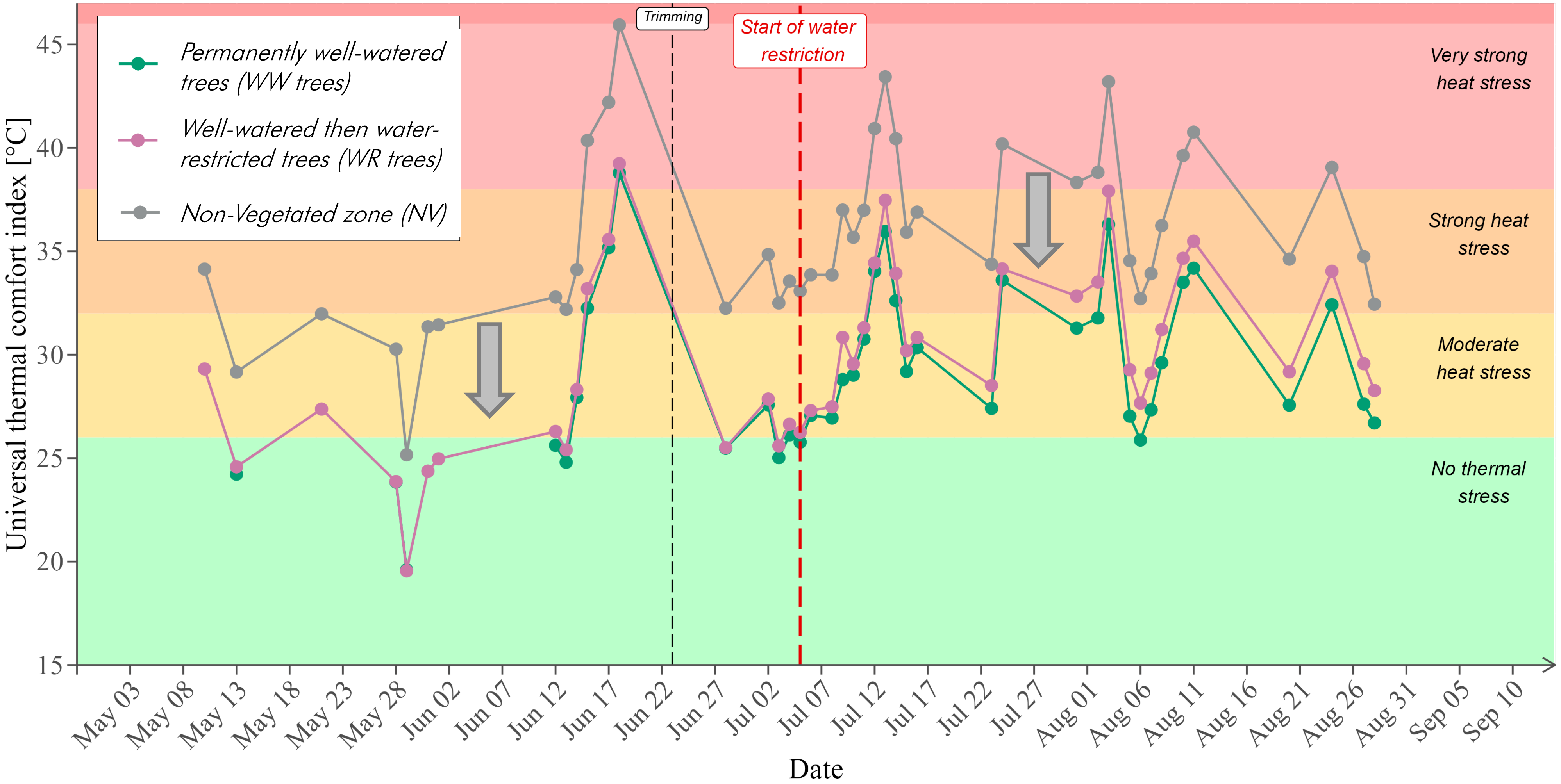
45 sunny days = studied days

Average between 11 am & 1 pm



Evolution of the UTCI at human height (at 0.40 m above street ground level at reduced scale)



- On the whole study period, i.e. **even when air temperature & hydric restriction ↗:**

  UTCI reduced under both WW trees and WR trees

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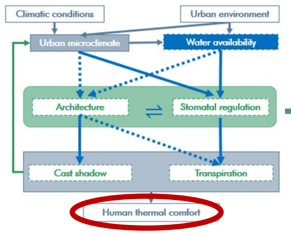
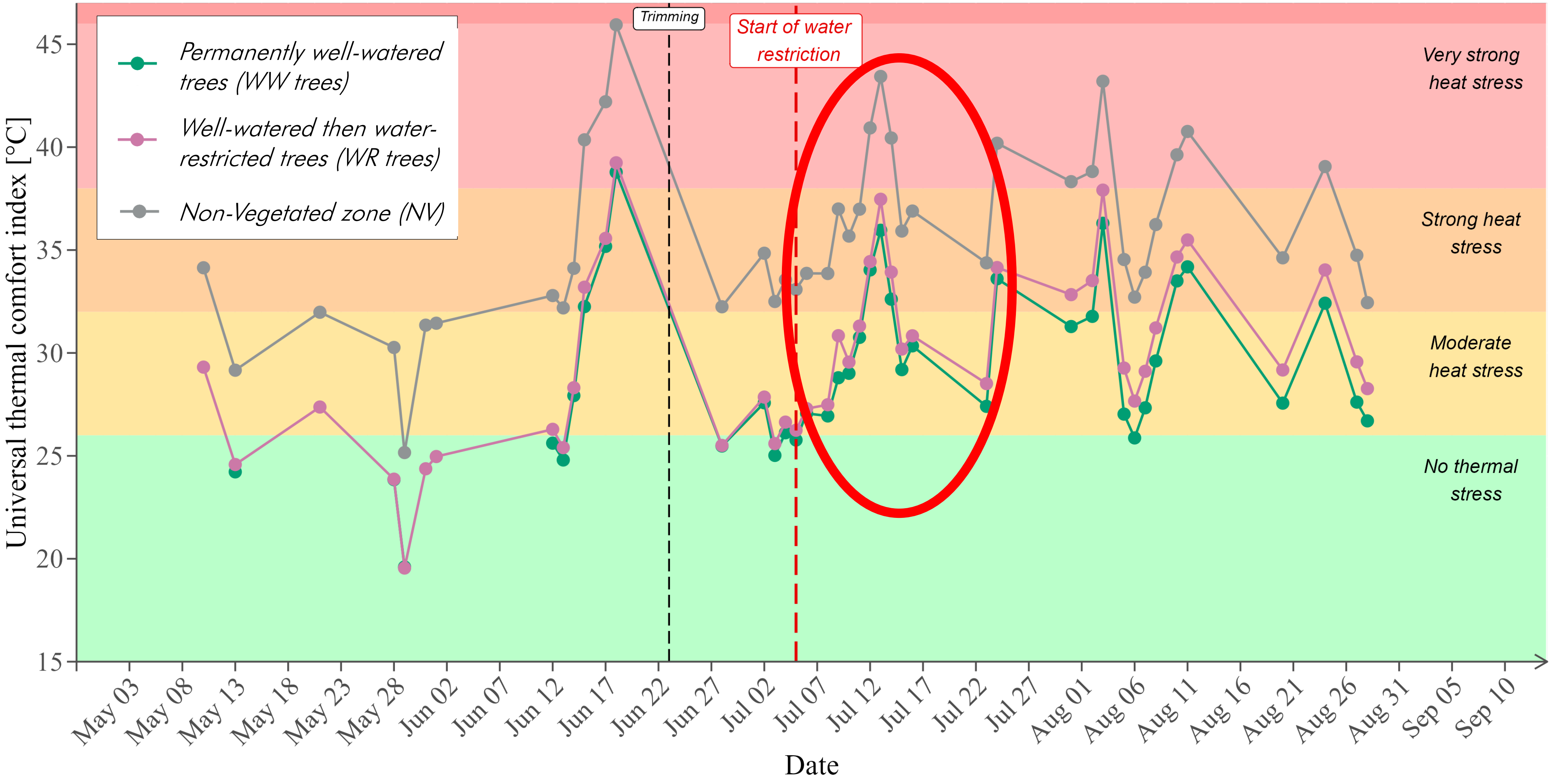
45 sunny days = studied days

Average between 11 am & 1 pm



Evolution of the UTCI at human height (at 0.40 m above street ground level at reduced scale)



- On the whole study period, i.e. **even when air temperature & hydric restriction ↗:**

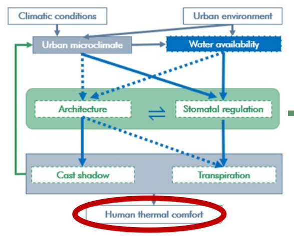
  UTCI reduced under both WW trees and WR trees

- After WR starts:

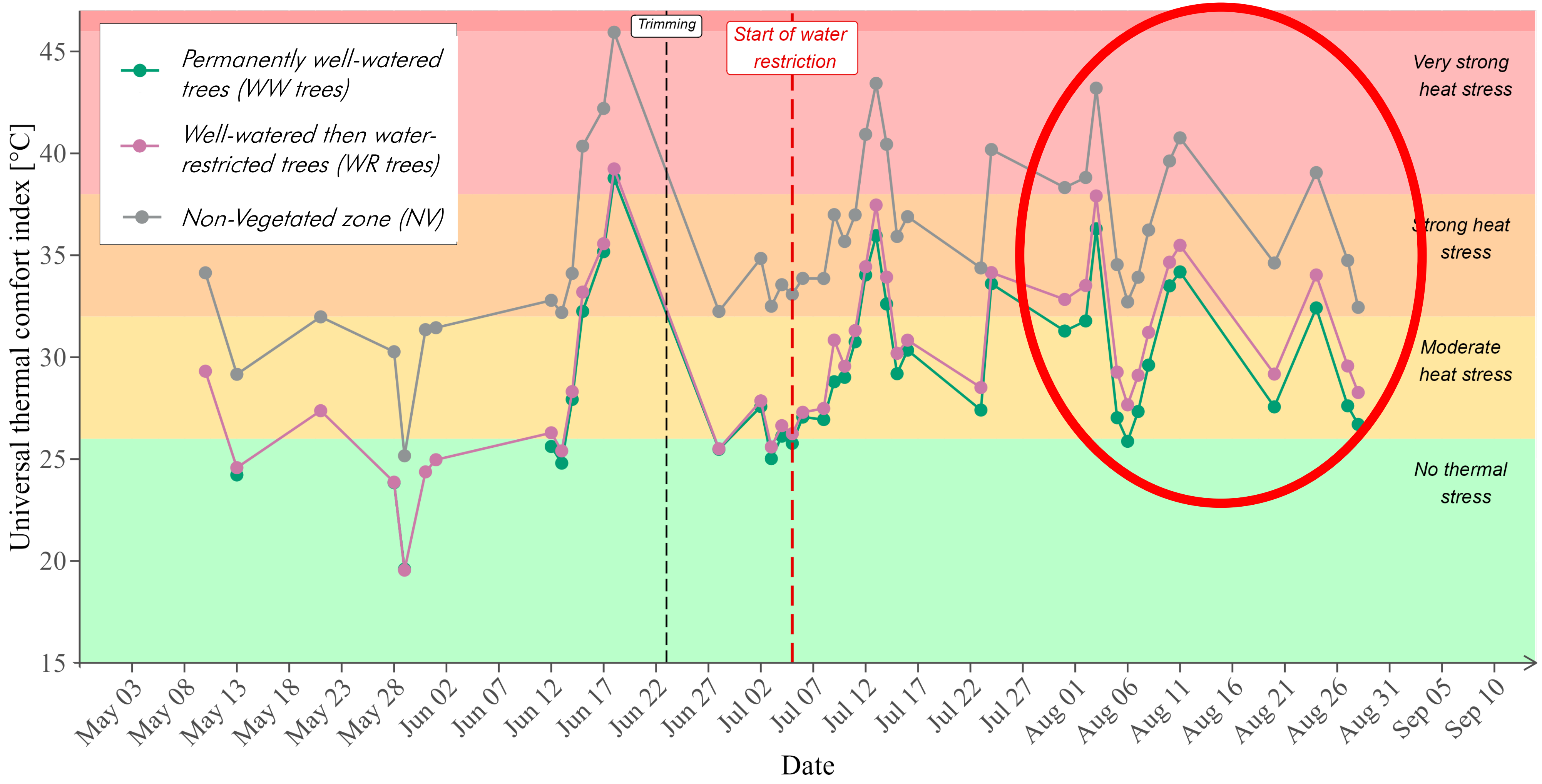
  1) UTCI provided by WW trees ≈ WR trees

45 sunny days = studied days

Average between 11 am & 1 pm



Evolution of the UTCI at human height (at 0.40 m above street ground level at reduced scale)



- On the whole study period, i.e. **even when air temperature & hydric restriction ↗:**

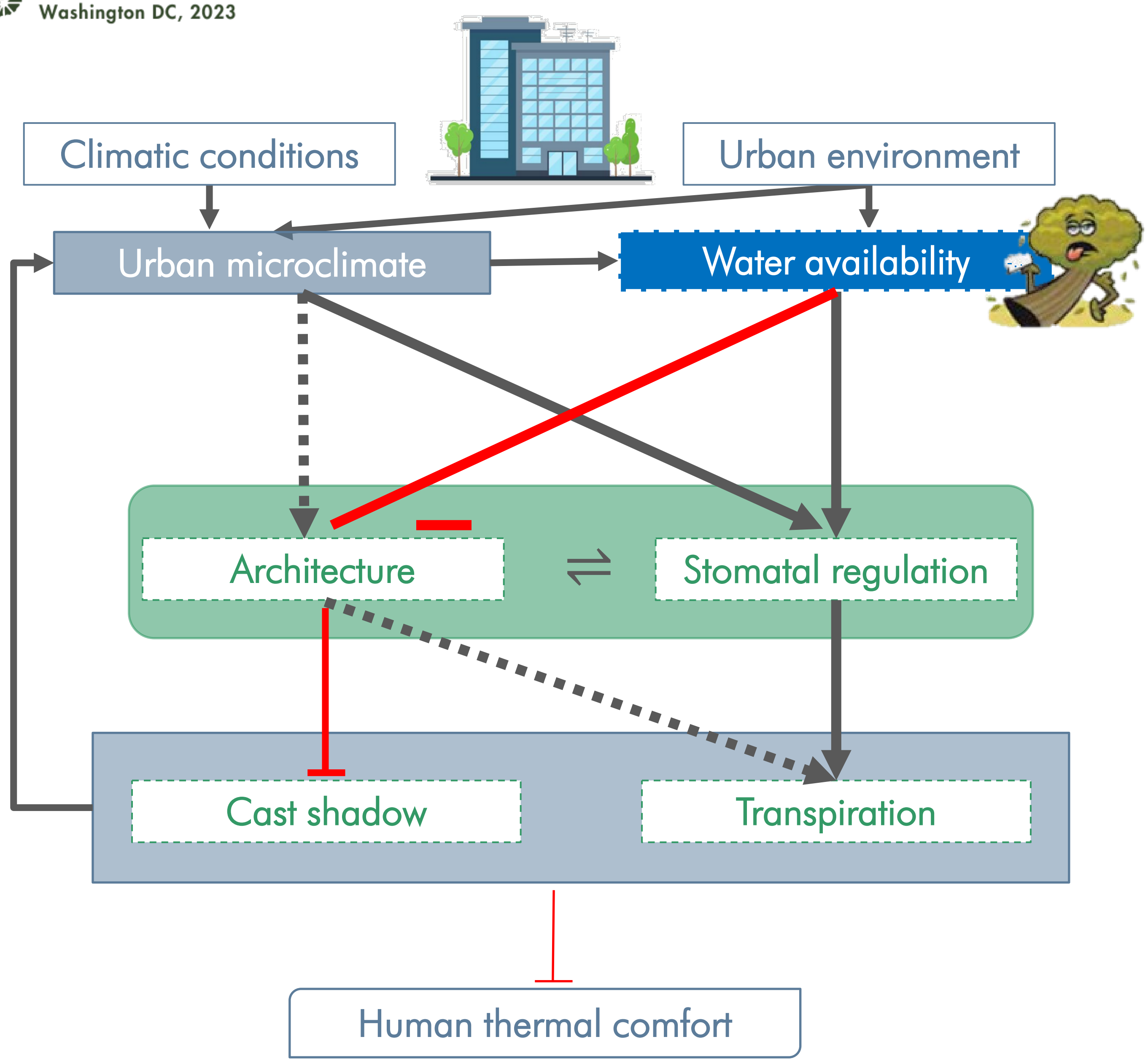
  UTCI reduced under both WW trees and WR trees

- <u>After</u> WR starts:

  1) UTCI provided by WW trees ≈ WR trees

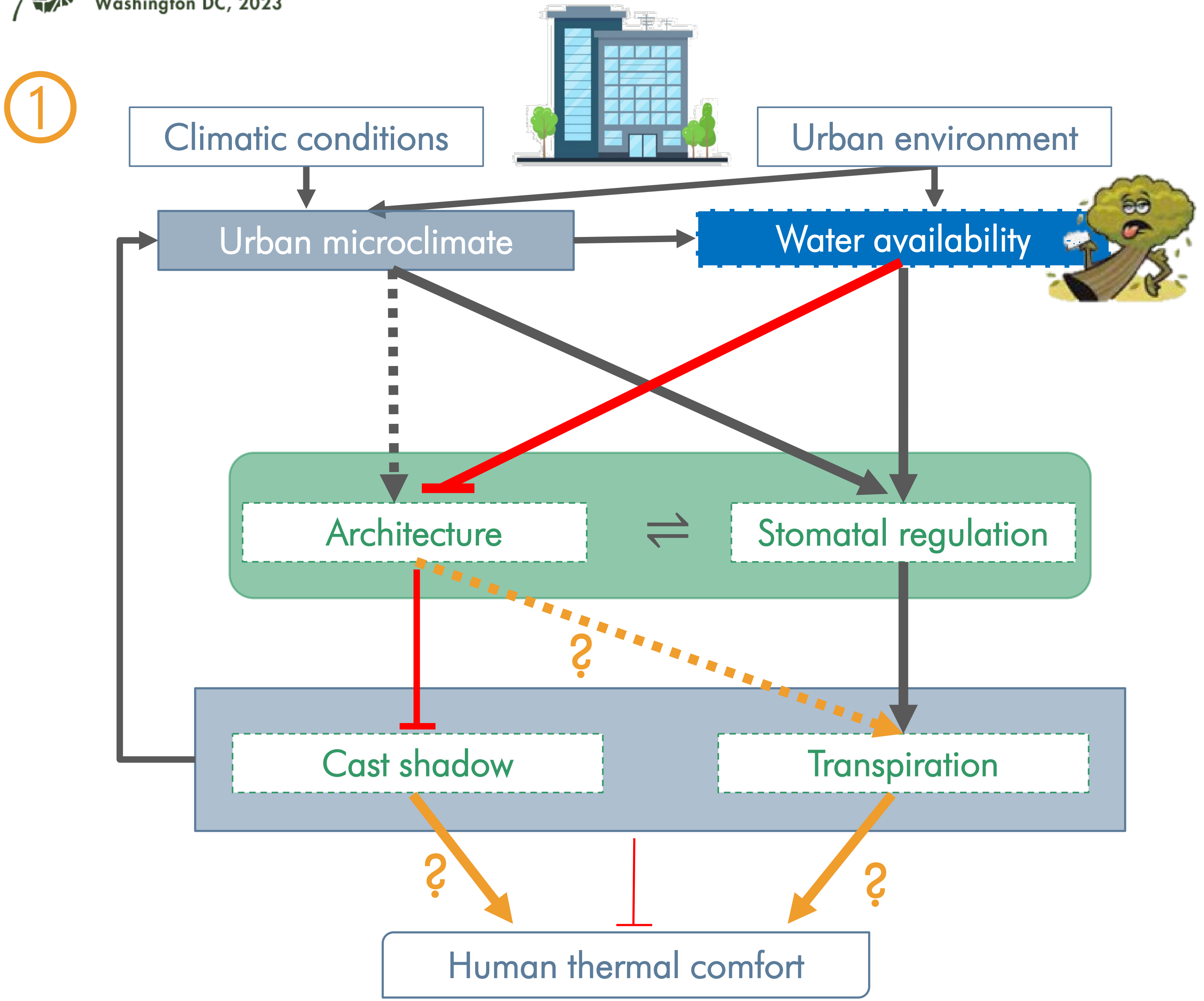
  2) UTCI provided by WW trees > UTCI provided by WR trees by 1.7°C

Conclusion & Perspectives



<u>Take home messages:</u>

1. Water restriction had strong impacts on architectural processes.
2. These impacts induced major changes in leaf area and leaf area index (LAI) at crown scale …
3. … but tree climate services were only little reduced by water restriction.
4. This is probably because the water restriction began late, when a sufficient leaf area was already developped and for a species whose services mainly rely on shade (Mballo et al, 2021)



2

Objectives

1. Analyze the effects of a drought period on the **architectural development** and the transpiration of alignment trees in a canyon street

2. Characterize **their consequences on cooling services**

3. Identify the **architectural and ecophysiological variables that best explain** the variations in climate services over time

3

- Explore the **place of plant taxa** in the tree contribution to improve human thermal comfort

Special thanks to:

- Financial support: CPER (French ministry for agriculture and food & French Region Pays de la Loire), Regional program "Objectif Végétal, Research, Education and Innovation in Pays de la Loire" (French Region Pays de la Loire, Angers Loire Métropole and the European Regional Development Fund), City of Paris & French Ministry of Education, Research and Innovation through the ANRT (National Association for Research and Technology)
- Contribution in reflection, data acquisition and technical resources (BARRAUD-ROUSSEL Yvette (UR EPHor), BERTHELOOT Jessica (UMR IRHS), BOZONNET Emmanuel (UMR LaSIE), CANNAVO Patrice (UR EPHor), LEVI Rachel (UR EPHor), NGAO Jérôme (UMR Eco&Sol), SAKR Soulaiman (UMR IRHS), WALSER Pascal (UMR PIAF))
- Experimental maintenance: PHENOTIC platform (UMR IRHS)
- Tree supply: Nursery André Briant Jeunes Plants

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Thank you

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Washington DC, 2023

In the Cool of the Day

Tree Species Influence in Reducing Urban Heat Island Effects in Local Climate Zones of Nairobi

Presented by

Onyango Sharon Anyango

Landscape Planner and Urban Climate Scientist

Jomo Kenyatta University of Agriculture and Technology

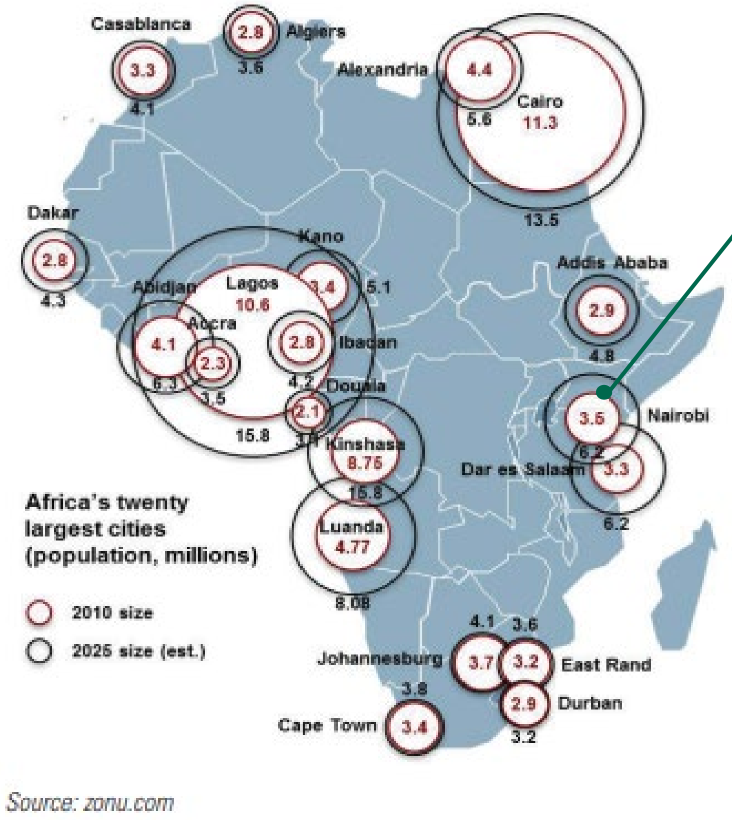
MSc. Landscape Planning and Conservation (Major: Urban Climate)

Introduction:

Kenya's Urbanization rate: 29% (Statista, 2021)

Nairobi City: 4.5million (6.2m - 2025)

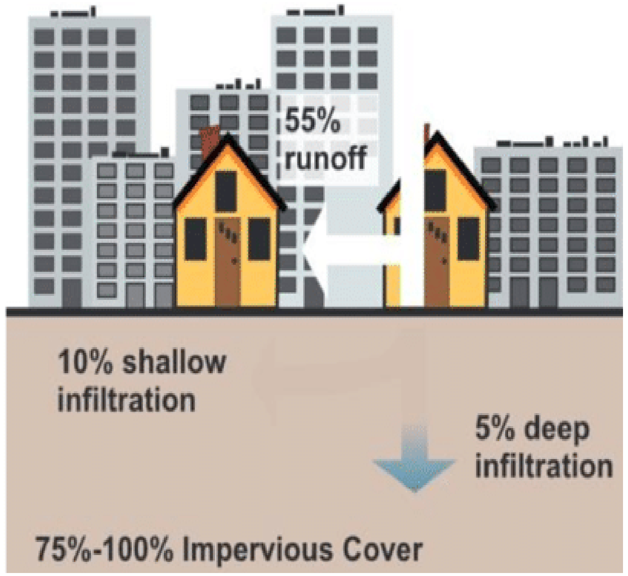
Africa (1 billion people) 15 - 40%



(UN-HABITAT, 2018).

- Nairobi; the "Green City in the Sun"
- Urban sprawl - loss of forests and other natural areas converted to built-up areas (Tibaijuka, 2007).
- Temperatures in Kenya could increase by about 2°C by 2050 (UNDP, 2017).

Vegetation (UGS) Loss



(UN-SEPA, 2013).

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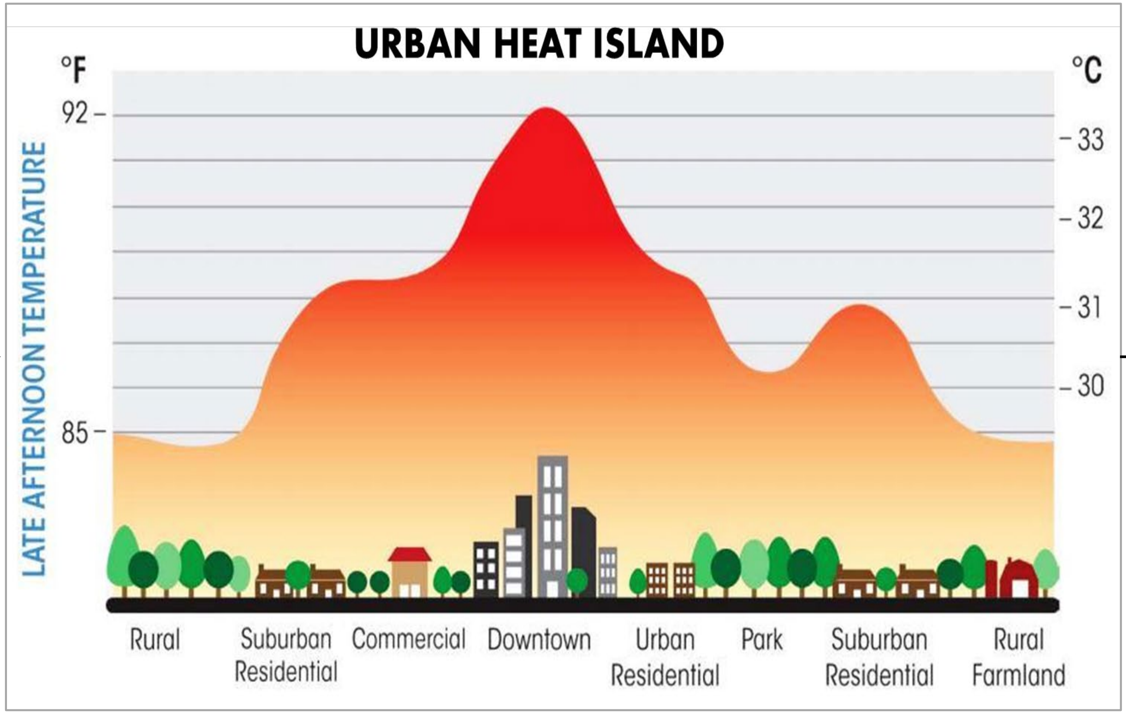
Problem Statement:

Increasing urban population; need for infrastructure

Natural & anthropogenic sources Changes in albedo

Changes in biophysical features from natural to built up areas



(Stewart & Oke, 2012)

Compromised outdoor thermal comfort

Increased energy costs
& air pollution levels

Increased heat-related illness & mortality

Rationale:

- Local Climate Zones (LCZs) approach, a universal climate-based classification, established by Stewart & Oke, (2012), considered effective in UHI and thermal environment studies.
- 17 Classes;10 (1-10) built-up and 7 (A-G) natural surface, considering the micro-scale details of the urban thermal observations.
- Using thermal indices like Physiologically Equivalent Temperature (PET) (Matzarakis & Amelung, 2008), is necessary in quantifying the thermal comfort rate within these LCZs.
- Dire scarcity of information regarding the effectiveness of diverse mature tree species in microclimate variation within heterogenous urban environments, particularly in tropical climate areas.

Study Area:

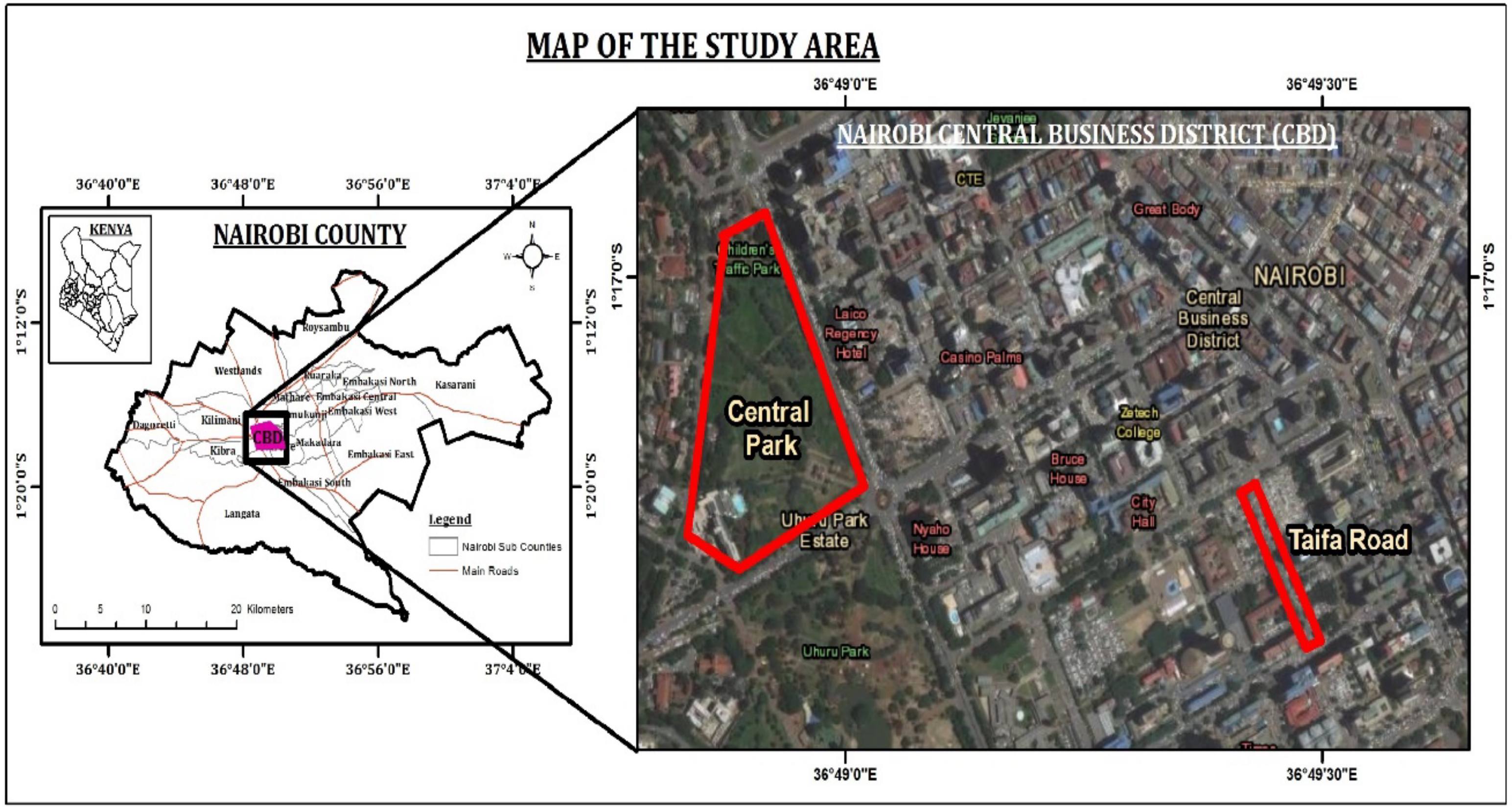


Fig. 3: The maps of Africa, East Africa, Kenya, Nairobi County and the Selected Study Sites: Central park (CP) and Taifa road (TR) within the central business district.

Objective

To evaluate tree species' influence in ameliorating urban heat island (UHI) effects and enhancing human thermal comfort (HTC) within local climate zones (LCZ) of Nairobi City

Selected sites: Local Climate Zones

- Two LCZs were selected represented by A Park and A street (**Fig 1.**)
- To compare similar plant species in two different LCZs within Nairobi CBD;
    - i. **LCZ B**: *Scattered trees*:- Central Park
    - ii. **LCZ 4**: *Open High-rise*:-Taifa Road.

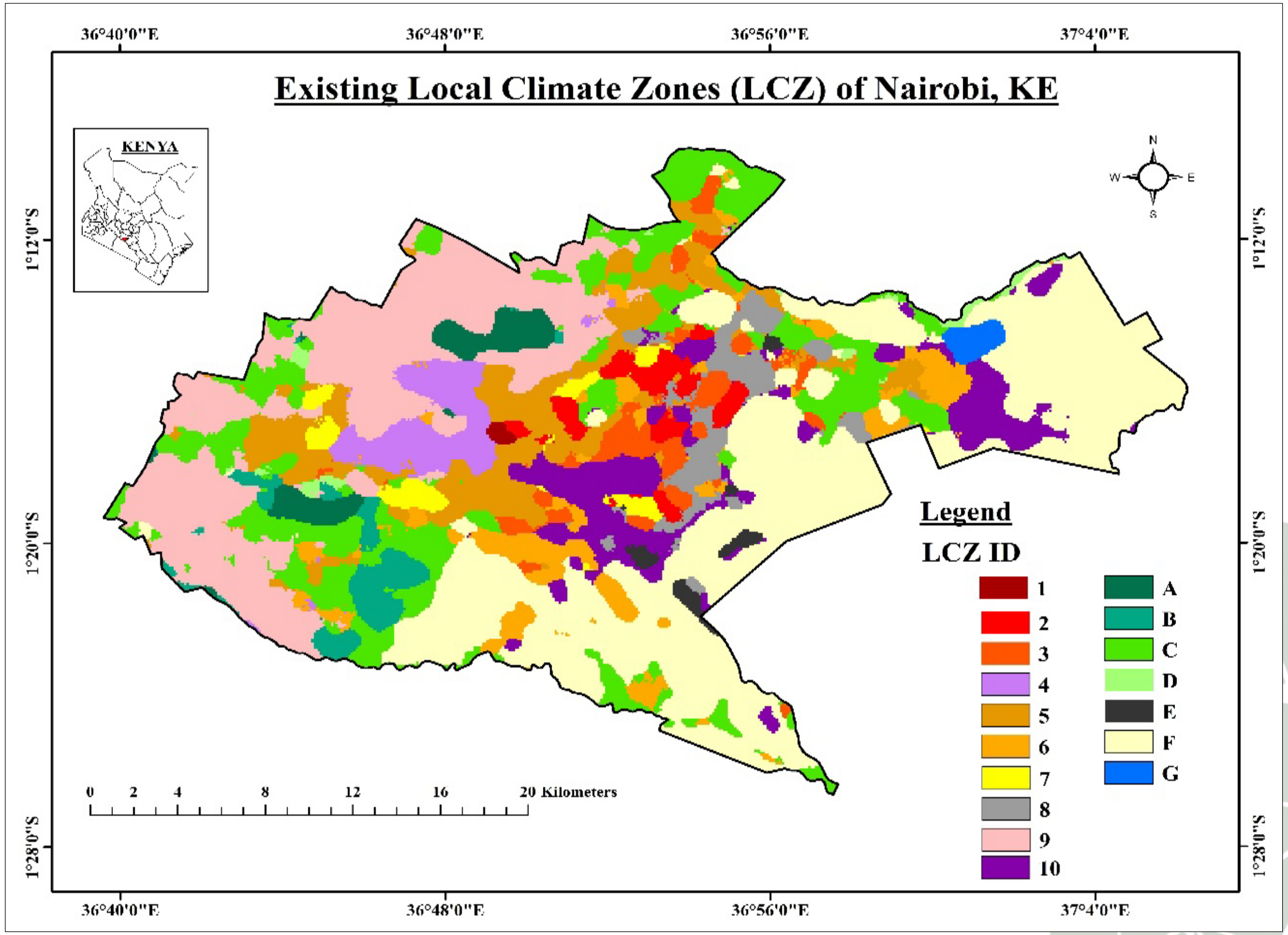
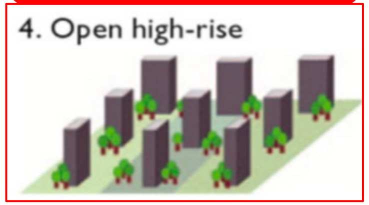


Fig 4: Spatial distribution of the existing LCZs in Nairobi (Source: WUDAPT)

Data Collection:

Site 1: Central Park
(LCZ B: Scattered

Site 2: Taifa Road
(LCZ 4: Open High-rise)



Screening of local *in-situ* plant.

4 most common single isolated species selected

Climatic parameters;

Air Temp.
Surface Temp.
Relative Humidity
Wind Speed

0800hrs – 1800hrs
Every 20min
For 3days
Same time for all sites

Under tree shades
5m from the tree
Control; Open area
At 1.1m height.
Day 138-140 of May 2018

Plant characteristics;
LAI, DBH, Height, Crown Diameter

Fish-eye photographs; calc. sky view factor (SVF); det PET using Rayman

LCZ B: Scattered trees (Central Park)

P1

Cassia spectabilis
Cassia

Podocarpus falcatus
EA yellow wood

Terminalia mantaly
Umbrella tree

Control: Open area

Tipuana tipu; Tipu tree

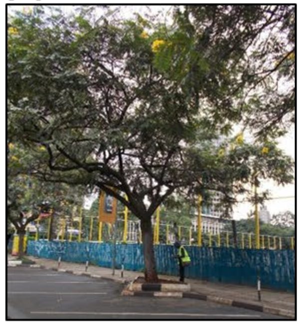
LCZ 4:Open-Highrise (Taifa road)

Terminalia mantaly
Umbrella tree

Control: Open area

Tipuana tipu; Tipu tree

P1



Cassia spectabilis
Cassia

Podocarpus falcatus
EA yellow wood

Source: Researcher, 2018

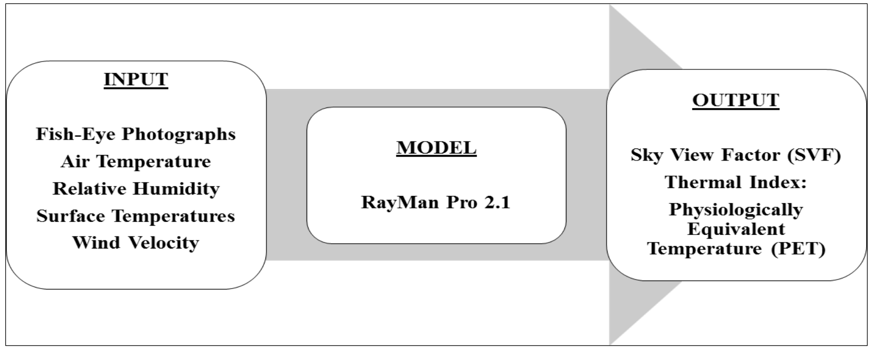
Data Analysis:

Tree Species effect on Microclimate

- Three specific hours used; 8am (chilled air), 1pm (air heated up) and 6pm (heat island effect is felt) (Matzarakis & Amelung, 2008; Van Hoof *et al*., 2010; Sodoudi *et al*., 2018).

- Statistical Package for Social Sciences (SPSS)
- Non parametric ANOVA
- Kruskal-Wallis Test; intra-site comparison
- Mann Whitney U Test; inter-site comparison
- $P < 0.05$ statistically significant

Human Thermal Comfort



PET Classification according to Martzarakis and Meyer (1997)

PET (°c)	Thermal Perception	Grade of physiological stress
<4.0	Very cold	Extreme cold stress
4.1 - 8.0	Cold	Strong cold stress
8.1 – 13.0	Cool	Moderate cold stress
13.1 – 18.0	Slightly cool	Slightly cold stress
18.1 – 23.0	Neutral (comfortable)	No thermal stress
23.1 – 29.0	Slightly warm	Slightly heat stress
29.1 – 35.0	Warm	Moderate heat stress
35.1 – 41.0	Hot	Strong heat stress
41>	Very hot	Extreme heat stress

Results:

a. Selected plant species' canopy densities & allometric properties

Table 1: Selected plants' allometric properties; *CP - Central Park, TR - Taifa Road*.

Plant Species	LAI		DBH (m)		Crown Diameter (m)		Tree Height (m)	
	C P	T R	C P	T R	C P	T R	C P	T R
P1: *Cassia spectabilis*	3.25	3.43	0.63	0.60	7.00	7.20	7.90	7.60
P2: *Podocarpus falcutus*	3.02	3.21	0.60	0.56	6.60	6.00	8.90	8.50
P3: *Terminalia mantally*	4.10	4.10	0.75	0.73	8.80	8.40	8.50	8.30
P4: *Tipuana tipu*	3.58	3.85	0.69	0.67	7.10	8.00	8.20	7.70

Results:

b. Inter-site/Inter-species effects on microclimate

- Mean (AT) in the Park were 1.0°C, 2.3°C and 1.3°C lower than the AT in the Street at 8am, 1pm and 6pm respectively. Lowest values at trunk, 5m and control.

- RH was 1.4°C, 8.2°C and 9.3°C higher in the Park compared to the Street at 8am, 6pm and 1pm respectively. Highest values at the trunk, 5m & control.

- ST in the Street were 3.5°C, 6.4°C and 5°C warmer compared to Park at 8am, 1pm and 6pm respectively. Cooler surfaces at 8am, slightly warmer at 6pm and warmer at 1pm.

- WV in the Street was 0.2m/s, 0.3m/s and 0.1m/s higher compared to the Park at 8am, 1pm and 6pm respectively. No general trend.

Results:

c. Human Thermal Comfort evaluation

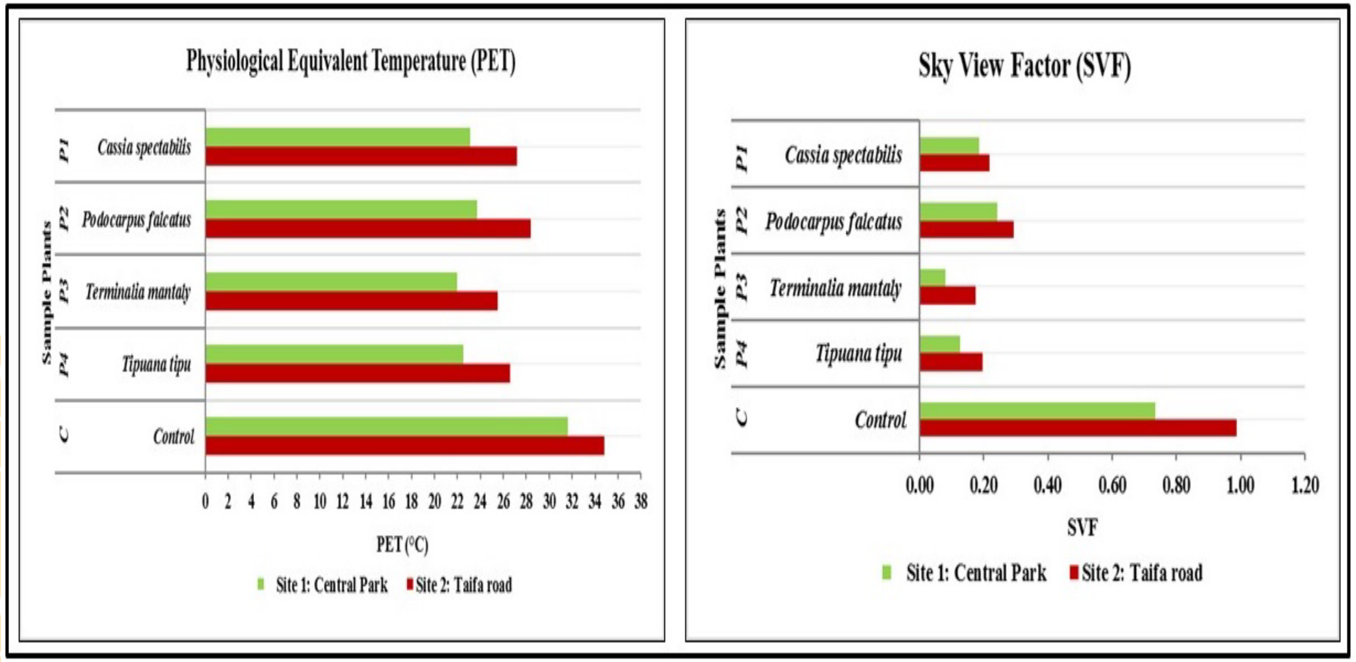


Figure 8: PET and SVF distribution for both sample sites

- *Terminalia mantaly* (P3); best cooling effect, PET reduction of 18% (9.6°C) and 15% (9.3°C) in the Park and Street respectively.
- *Tipuana tipu* (P4) was the second best with 17% (9.2°C) and 13% (8.2°C).
- *Cassia spectabilis* (P1) with 16% (8.5°C) and 12% (7.6°C).
- *Podocarpus falcatus* (P2) with 14% (7.9°C) and 10% (6.4°C).

A strong negative correlation between the LAI and PET was obtained from both sites (S1; *r* = -0.96, S2; *r* = -0.8).

Conclusion

- Nairobi city residents are more likely to suffer no thermal stress in parks to warm moderate heat stress in built areas during hot seasons

- Consider tree species with strong trunks, spreading canopies as well as rounded canopy forms, such as *Tipuana tipu* tree species. Evergreen trees with more foliar/canopy densities, similar to *Terminalia mantaly (some are deciduous) through seasons*

- Besides the aesthetics and functionality of the plants, considering the urban trees' architectural aspects and form are essential in regulating microclimate in Nairobi

- Frequent assessment of the vegetation alterations & Sustainable planning within Nairobi's LCZs, following set developmental standards, guarantees the vegetation cover improvement significantly

- Incorporating eco-friendly infrastructure in the city's spatial advancement plans is imperative, specifically the use of reflecting roofs and walls, UV-absorbent windows, and pavements with high albedo. Equal resource disbursement to counties to minimize rural-urban migration

- **Way forward:** Develop a Guide for Practitioners (collaborative)

Output:

- Onyango, S. A., Mukundi, J. B., Adimo, A. O., Wesonga, J. M., & Sodoudi, S. (2021). Variability of In-Situ Plant Species Effects on Microclimatic Modification in Urban Open Spaces of Nairobi, Kenya. Current Urban Studies Journal, 9, 126-143. https://doi.org/10.4236/cus.2021.91008

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Variability of *In-Situ* Plant Species Effects on Microclimatic Modification in Urban Open Spaces of Nairobi, Kenya

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"We simply must do everything we can in our power to slow down global warming before it is too late. The science is clear. The global warming debate is over."
~ Arnold Schwarzenegger

Thank you

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Session 1.4: In the Cool of the Day: The role of urban forests in improving microclimate and reducing the heat island effect

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