Feedbacks between vegetation, carbon, energy, and water cycles in the urban environment: Recent advancements from the **UrbaNature** project

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Contents

- Introduction
- Project objectives
- Progress and achievements
  - *In-situ* observations
  - Remote sensing
  - Modelling
- Future plans – Open questions
- Relevant progress, gaps and challenges

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Cities and climate change

- Health and security
  - Heatwaves & urban heat islands
  - Air pollution
  - Vulnerability to disasters (e.g. flooding)

- Greenhouse gas emissions
  - Cities are responsible for 70% of the global GHG emissions
  - Net-zero targets

Many climate change **mitigation and adaptation** actions focus on cities to enhance sustainability and resilience


Credit: P. Lopez Luz
Adapted from Oke et al., 2017

Transforming cities: role of vegetation

Increasing urban vegetation is suggested as an effective measure to (among others):

- lower air and surface **temperatures** (shading and transpiration)
- enhance **carbon sequestration** (wood and soils)
- reduce building **energy demand** (insulation, cooler temperatures)

Expected services rely on complex processes with potentially **opposing feedbacks** on urban climate:

- Plant stomatal control
- Soil/plant respiration
- Wind flow blocking
- Long-wave radiation trapping

Adapted from: GCA report, 2019

Lack of appropriate **observations and modelling tools** to quantify, observe, predict and evaluate the impacts of the implemented measures.

UrbaNature aims

- **Interdisciplinary**, silo-overcoming, innovative observing, understanding, modelling and/or predicting parts of the Earth System
- Closing critical observational gaps, combining **in-situ and remote sensing observations, as well as integrating them in modelling** frameworks and reanalyses
- Constraining **individual and overall fluxes** and processes, especially at **regional and local scales**
- **Developing and delivering added-value climate and air-quality services**

Focus on carbon, energy and water cycles in the **urban environment** across **multiple scales**

Advance current **understanding, observational** and **modelling** methodologies

Interdisciplinary approach, combining in-situ, remote sensing and modelling

Develop methods/tools for urban **planners**, climate **scientists** and **weather forecast** service providers

UrbaNature aims

Basel and **Zurich** as case studies

WP1: *In-situ* observations
Meteorology, ecophysiology, fluxes

WP2: Geospatial data and remote sensing
Basemaps, vegetation monitoring

WP3: Urban ecophysiology modelling
3D multi-layer energy, water, CO_2

WP4: Urban climate & CO_2 modelling
Integrated urban climate simulations

WP5: Project Management, Data and Communication

Specific objectives

ETH zürich — *In-situ* observations to identify plant **hydraulic strategies**

University of Zurich — Develop **remote sensing methods** for key urban abiotic & biotic parameter monitoring at appropriate resolution

University of Basel — Develop a high-resolution **ecophysiology model** for urban environments

Empa — Develop a **mesoscale urban climate model** integrating building-vegetation interactions

In-situ observations (WP1)

1) How does urban density constrain the hydraulic strategy of different tree species?

Experimental Design

- **6 intensive sampling campaigns** 2024 & 2025
- **32 trees** across Zurich urban density gradient
- **Target species**: *Acer platanoides* and *Prunus* species (P. avium, P. 'Umineko')

Isotopic Fingerprints

- **Sampling:** Isotope data of tree xylem and soil water profiles
- **Source Mapping:** Bayesian modeling of δ^2H and $\delta^{18}O$ to track water uptake

Results

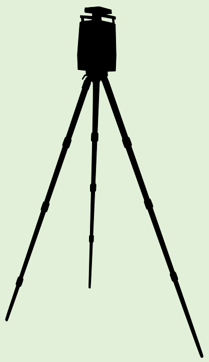
- **Deep-Water Access:** All sampled trees accessed deep water at least once; nearly one-third exhibited periods of deep water dominance
- **The Urban Density Effect:** Icreasing urban density significantly shifts the water balance away from deep water across all species

Find out more tomorrow on Poster 8

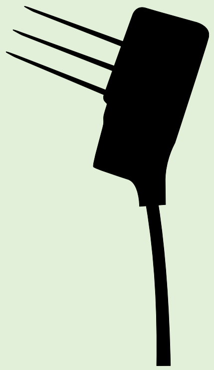
In-situ observations (WP1)

2) How does a tree's canopy architecture regulate the canopy microclimate and maintain cooling performance in urban environments?

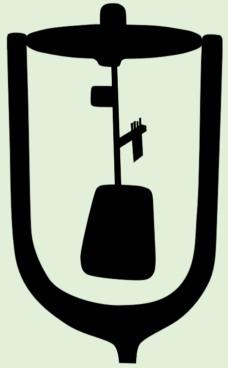
Current Activities & Methodology



Terrestrial Laser Scanning



Sap Flow Sensors



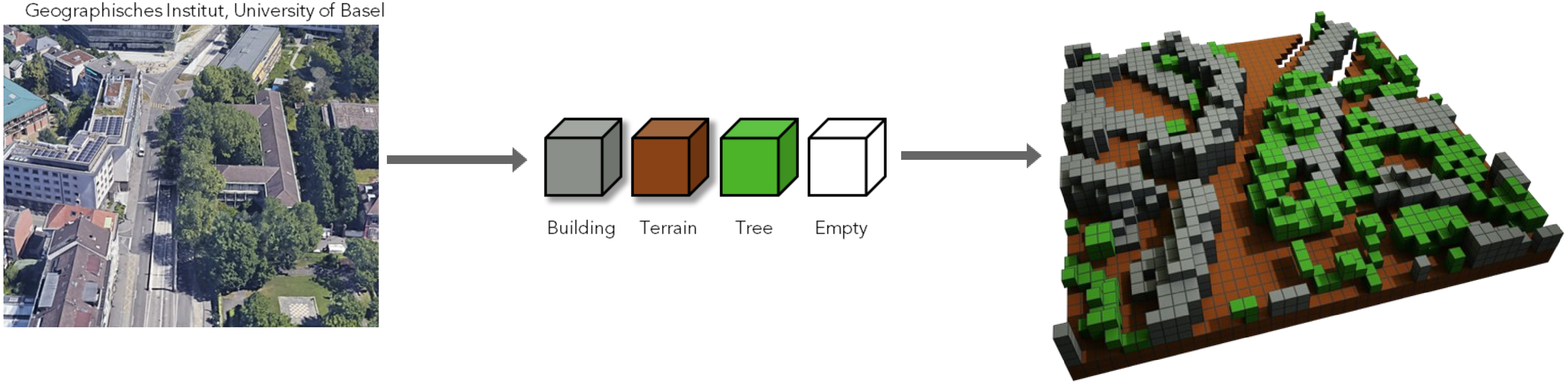
Within-canopy microclimate

Key Objectives: (1) Characterize the tree canopy structure, (2) link water transport to the actual temperature drop in the crown, and (3) determine how architectural traits affect a tree's cooling performance.

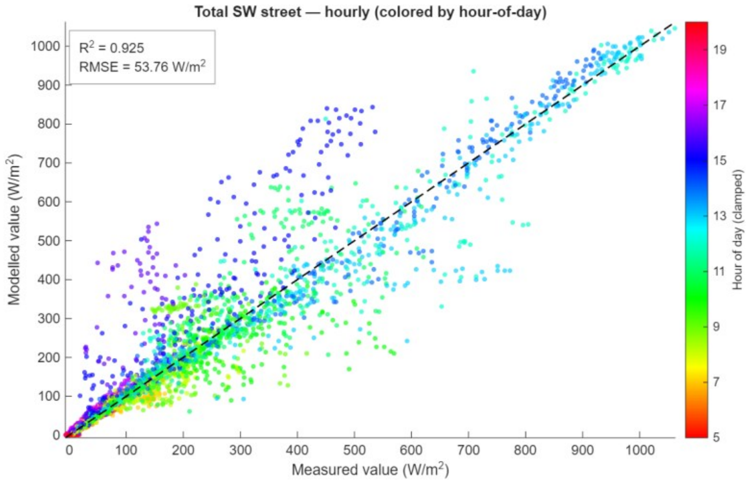
3D radiation model (WP3)

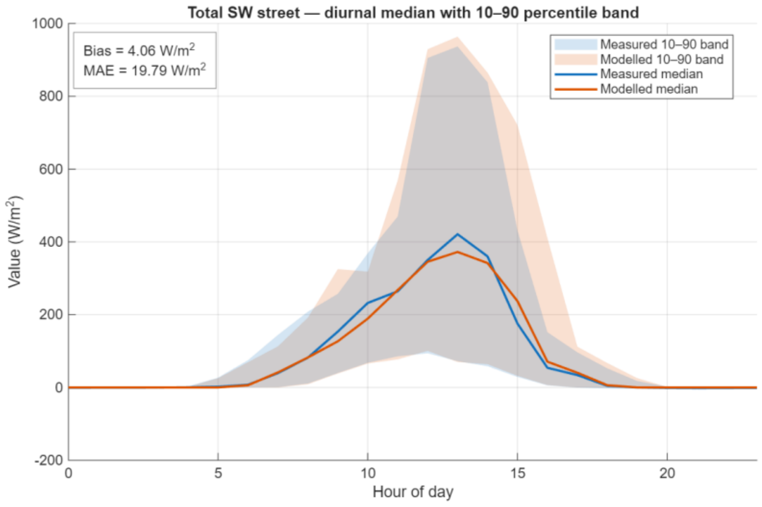
- The complexity of the **radiation interactions** between trees and built environment increases with urban heterogeneity
- A 3D model can simulate these interactions in **all directions** and reproduce realistically the environment experienced by an urban tree

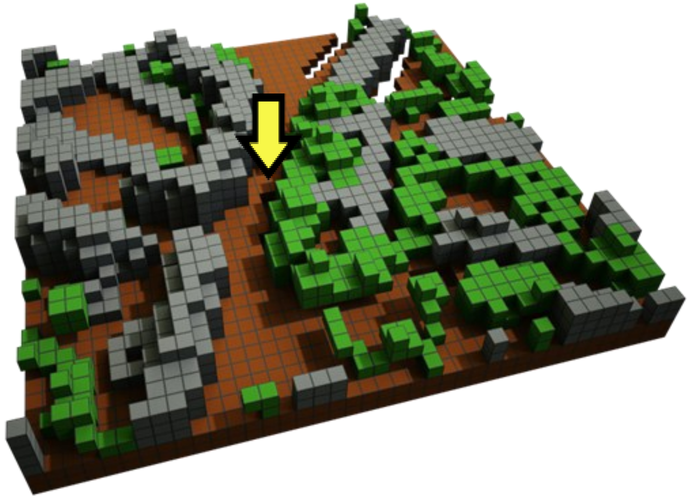
Geographisches Institut, University of Basel

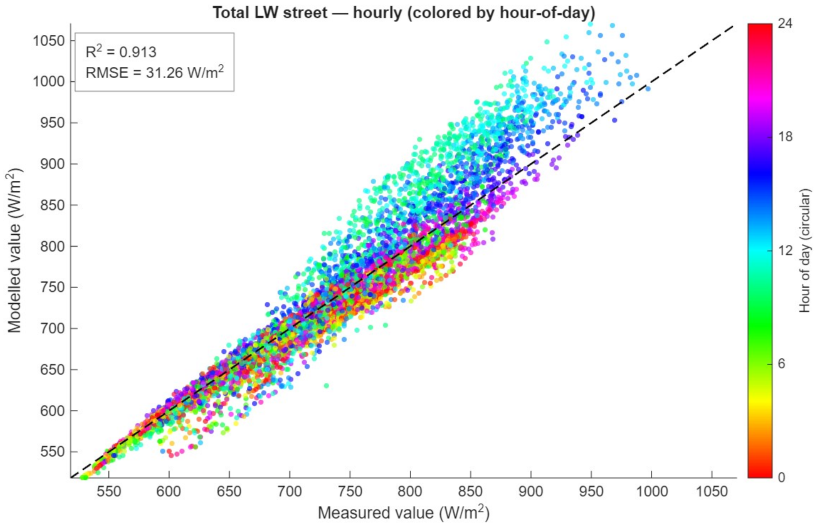


3D radiation model (WP3)

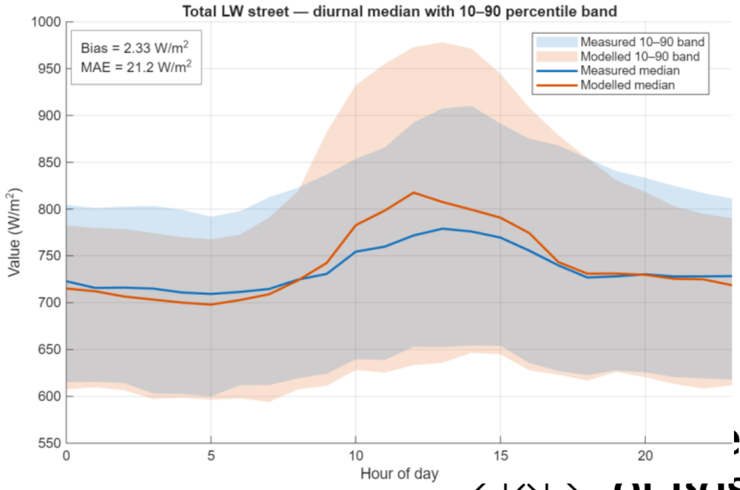








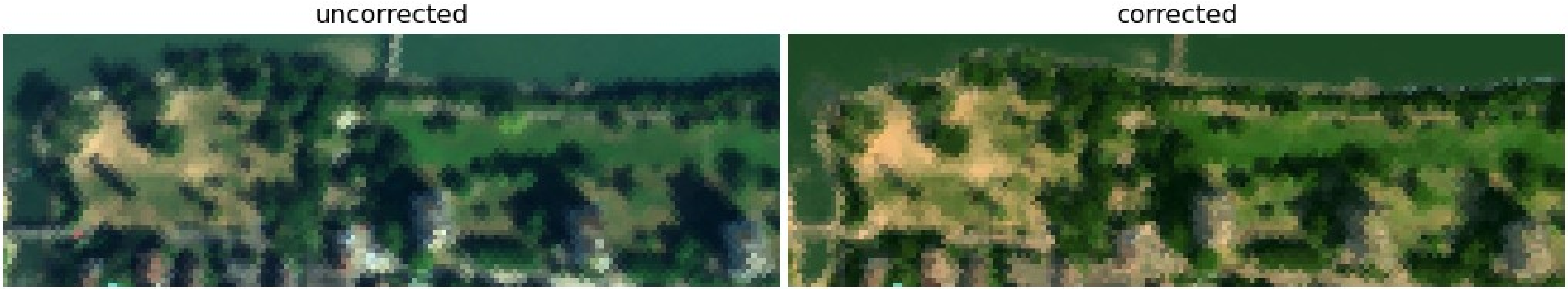
Find out more tomorrow on Poster 3



Remote sensing (WP2)

- Urban environments are challenging for remote sensing
  - High spatial **heterogeneity**
  - Complex 3D structure —> **shadows**
- We develop a **physically based framework** to reduce effects of shadows in image spectroscopy
  - Improved vegetation monitoring

Want to know how? Tomorrow Poster 10



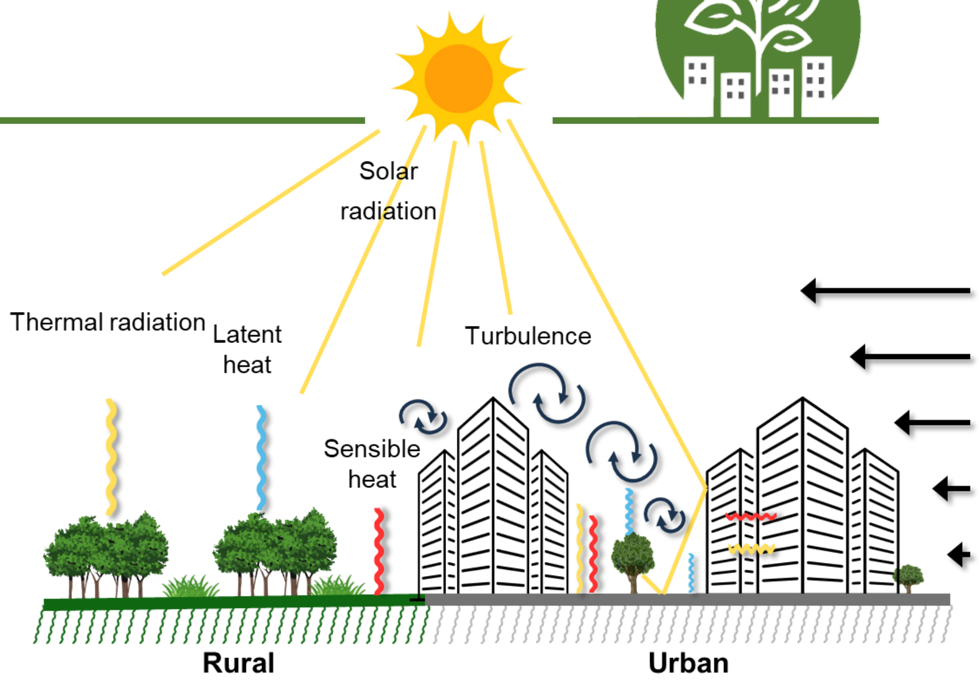
University of Zurich[UZH]

Urban climate model (WP4)

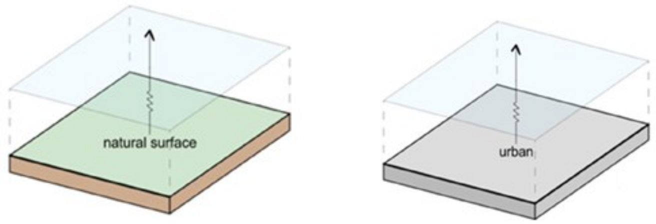
Integrate urban processes into weather prediction and climate model ICON

- **Step 1**: ICON + Terra-Urb (existing)
  - Improve representation of urban parameters
  - Apply and test for Zurich and Basel
- **Step 2**: ICON + BEP-Tree (new development)
  - Much better representation of physical processes
  - Accounts for street trees and green roofs
  - Couple BEP-Tree externally
- **Step 3**: Improve ecophysiology in BEP-Tree
- **Step 4**: Impact of different scenarios on urban climate / urban heat

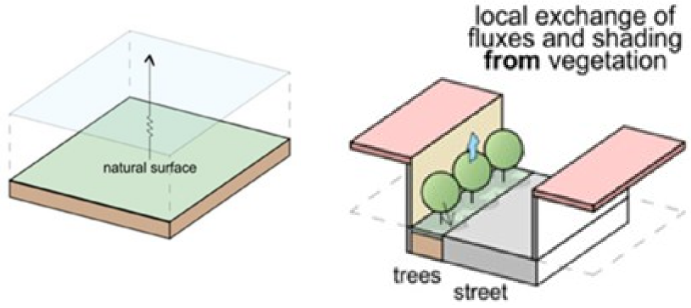
Real world



Terra-Urb (0D - bulk)



BEP-Tree (1D - vertical structure)



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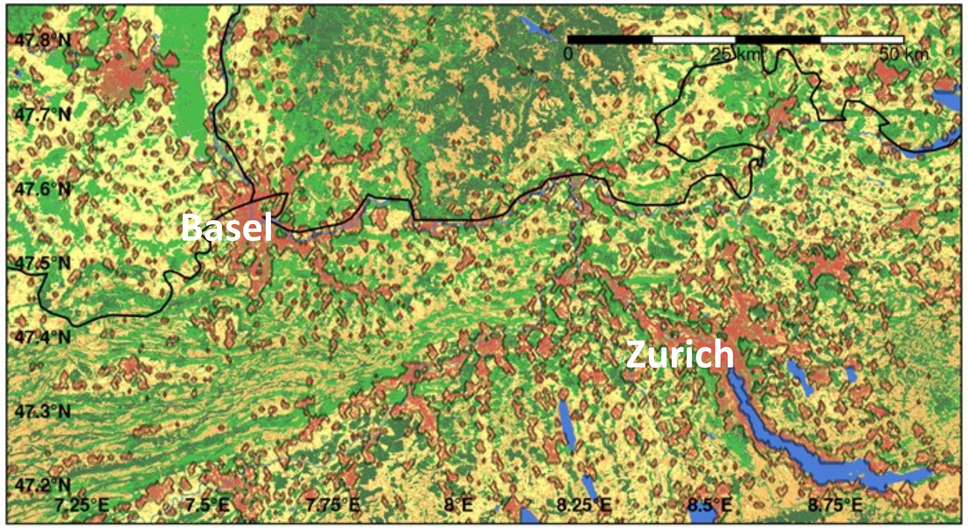
Urban climate model (WP4)

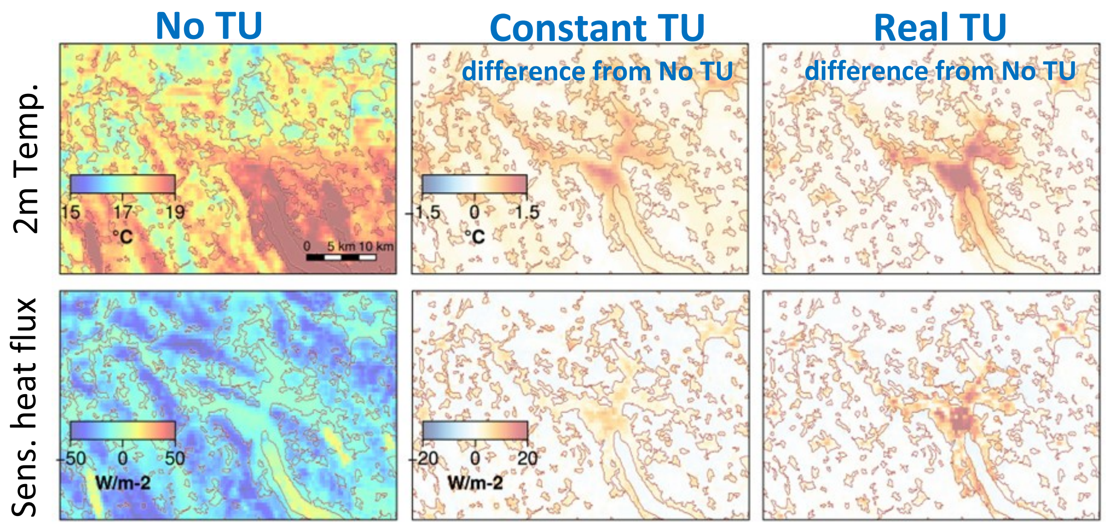
ICON-TERRA-URB simulation for Jul/Aug 2023 with spatially fixed (Constant TU) and variable (Real TU) morphological & radiative parameters

Model domain (500 m x 500 m resolution)

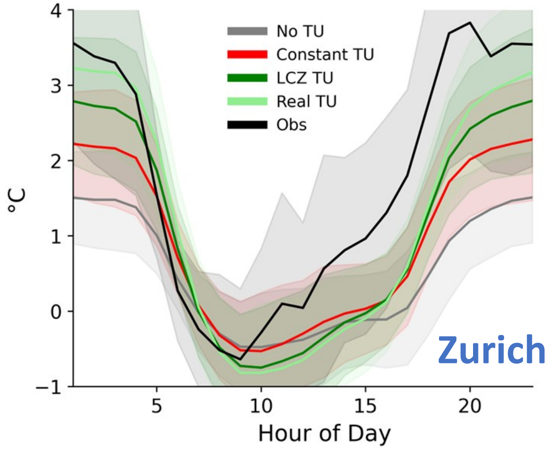


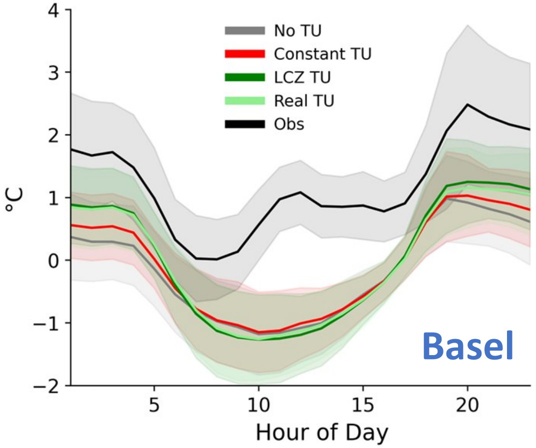
urban areas in red

Average nighttime (23-03 UTC) conditions



Urban heat island intensity (city - rural)





Empa

Future plans – open questions to address

Do urban trees maintain their cooling capacity/services across different seasons/conditions?

- Combined *in-situ* tree ecophysiological, micrometorological and terrestrial laser scanning campaigns during 2026
- Comprehensive analysis and publication of plant ecophysiological responses to the urban environment – focus on seasonal water uptake and species-specific hydraulic strategies

How well do satellite observations track vegetation state and processes in complex urban environments?

- Develop and assess the potential of a new physical-based shade correction method to improve estimates of Sentinel-2 reflectances and plant ecophysiological information time-series

What are the expected magnitudes of urban tree transpiration across different urban typologies?

- Link leaf-level process modeling with the 3D radiation model and estimate canopy transpiration according to different building surroundings and weather inputs – validate with *in-situ* observations

What is the impact of urban greening scenarios on street level temperatures and human comfort?

- Couple ICON with the multi-layer BEP-Tree model to simulate the effects of trees on city climate and run multiple street-tree scenarios for Zurich and Basel – evaluate real situation with *in-situ* observations

Relevant progress, gaps and challenges

Developments in urban climate-GHG monitoring

Urban ecophysiology
- Continuous *in-situ* and modeling studies on urban trees and lawns
- Tree sensor networks on carbon and water dynamics expanding to cities: radial growth, sap flow

Sensor networks
- Street-level weather sensor networks in Bern, Basel, Zurich
- Mid-cost rooftop CO_2 sensor network in Zurich

Flux towers
- Advancements in urban eddy covariance methodology and source partitioning (Basel, Zurich)
- Evaluation and optimisation of urban GHG emission inventories

Remote sensing and models
- Diversification of satellite missions and method improvements
- High-resolution biospheric CO_2 flux models for cities

Weather prediction and atmospheric transport modeling
- Micro and mesoscale atmospheric models for cities
- Assimilation of mid-cost CO_2 sensor data for GHG emissions

Gaps and challenges

- **Integrated & continuous approaches**: Combine observational and modeling approaches to assess both urban biosphere, climate and GHGs using common methodological frameworks
- **Bridging across scales**: from *micro* (sensor networks), through *local* (flux towers, satellites) to *meso* (ICON) scales; such integrated approaches can identify method-specific limitations and create synergies across approaches
- **Urban climate in a changing climate:** Assess how climate change will affect urban vegetation, urban climate and human comfort
- **Potential of ML in urban climate research**: Use knowledge-guided ML to create insights into highly complex, interacting processes

Thank you for your attention!

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