meteoblue City Climate Model (mCCM): High-resolution Modeling for Urban Heatwave Management

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Introduction

- More than half of World's population live in urban areas.
- As urban areas continue to expand, they become increasingly vulnerable to the impacts of anthropogenic climate change.
- Variations in surface structure lead to differences in the surface energy budget.
- Weather models face challenges in accurately resolving urban air temperatures because:
  1. The model resolution is often too coarse.
  2. Measurement stations for statistical post-processing are typically located in peripheral areas.
- The meteoblue City Climate Model (mCCM) integrates surface-describing remote sensing data and numerical weather prediction (NWP) model data to resolve urban air temperature variability.
- By combining the mCCM with climate projections, Global Climate Models (GCMs) can be downscaled to the building level for enhanced precision.

Methods and Data

meteoblue City Climate Model (mCCM)

- The mCCM is a dynamic statistical downscaling model that utilizes Model Output Statistics (MOS) techniques.
- Trained on globally distributed urban measurement networks to capture and resolve the complex variability of air temperatures.
- The model relies on a multivariate regression approach, incorporating satellite-derived and land-use properties.
- Dynamics are accounted through model parameterizations, integrating key properties derived from Numerical Weather Prediction (NWP) models, such as wind and radiation.

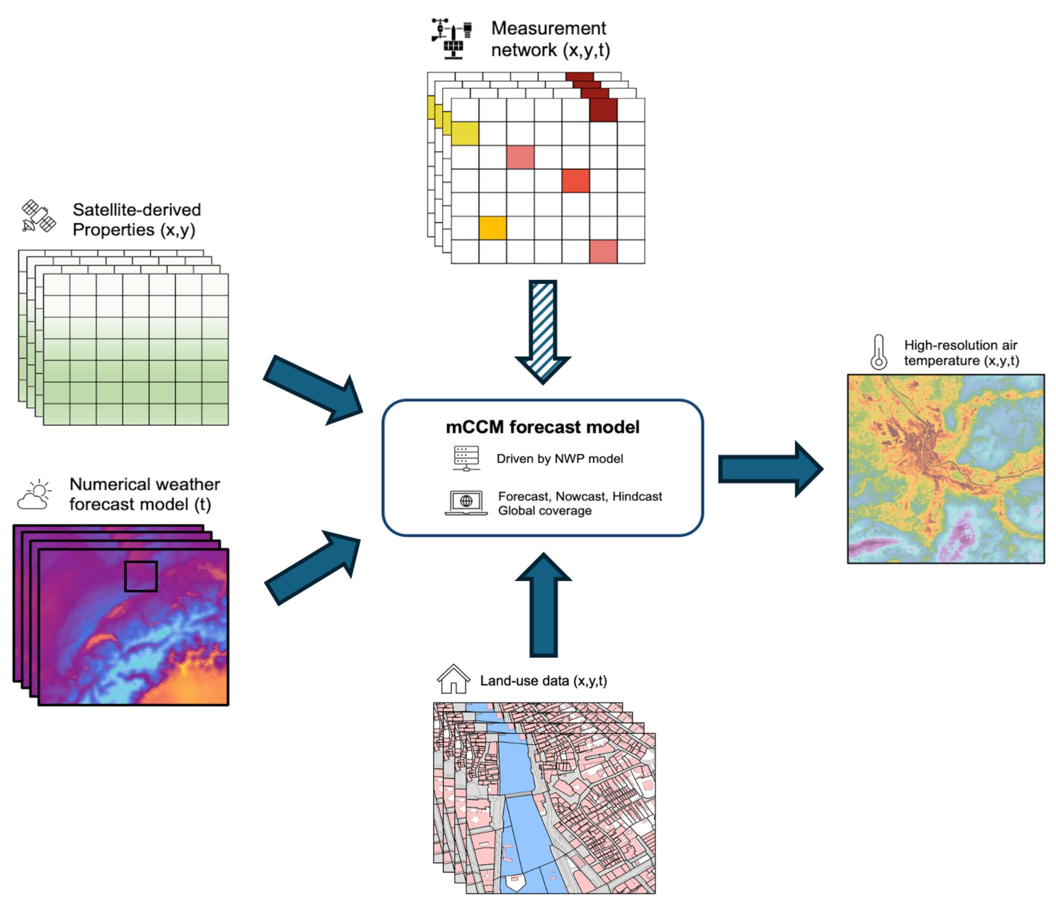


Figure 1: Structure of the mCCM to process high-resolution air temperature data. The model utilizes inputs such as satellite-derived and land-use properties, numerical weather prediction (NWP) model data, and, when available, observational measurement data.

Urban Heat Island Effect

- 30-year reference period 1991 – 2020

$$\Delta T_{UHI}(x,y,t) = T_a(x,y,t) - \overline{T_{rural}}(t)$$

- Aggregation in time (days, years)
- Keep hourly and monthly variation of UHI effect

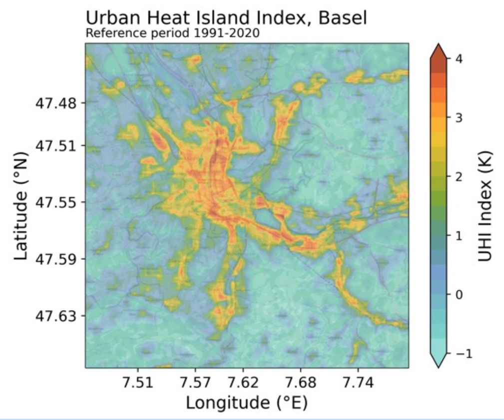


Figure 2: Urban Heat Island Index for Basel for the reference period 1991-2020.

Global Climate Model (GCM)

- SSP climate change scenarios in CMIP6 (IPCC, 2023)
- Statistical downscaling
  - Assess the change over time for each grid cell
    $\Delta T_{GCM} = T_{proj} - T_{base}$
  - Climate Signal (ΔT_{GCM}) is applied to the corresponding ERA5 grid cells
    $T_{proj\_30km} = T_{ERA5} + \Delta T_{GCM}$

→ Projection on ~30 km with higher spatio-temporal resolution

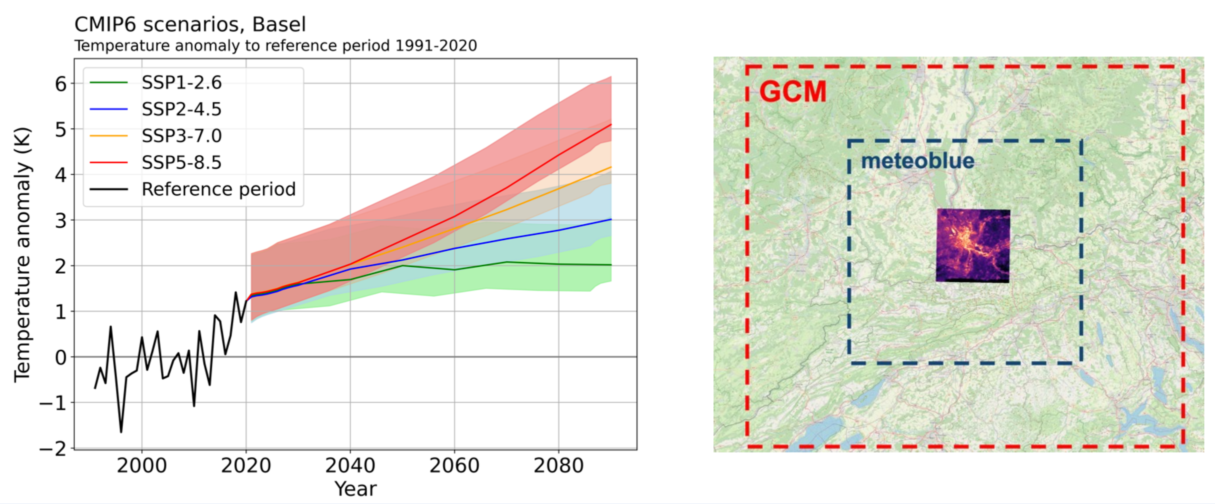


Figure 3: Projected air temperature trends through the end of the century under various SSP scenarios (left), alongside a comparison of resolution scales for GCM, meteoblue, and urban-level models.

GCM downscaling to building-level

- ERA5 time series (T_{ERA5}) for reference period
- Add climate signal (ΔT_{GCM}) to time series depending on scenario and decade
- Urban heat island (ΔT_{UHI}) effect is applied to represent urban scale variations

$$T_{proj\_urban} = T_{ERA5} + \Delta T_{GCM} + \Delta T_{UHI}$$

→ Resolve diurnal and intra-annual UHI variation

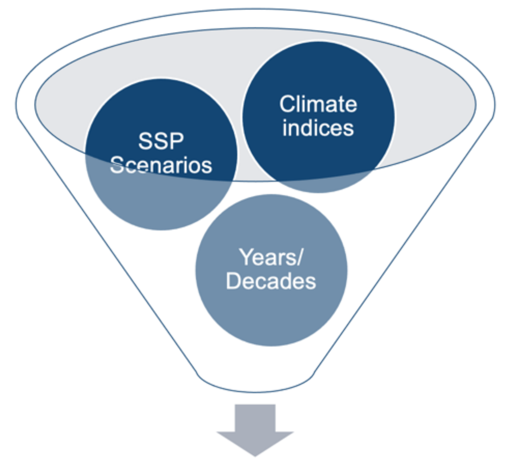
→ Get urban projections on ~ 10 m with hourly time series for statistical analyses

Results

Climate predictions on building-level

- Temperature-related climate indices in high-resolution
- Different decades until the end of the century
- All available SSP scenarios

Climate indices	Scenarios	Decades
Hot Days	SSP1-2.6	2021-2030
Tropical Nights	SSP2-4.5	2031-2040
...	...	...

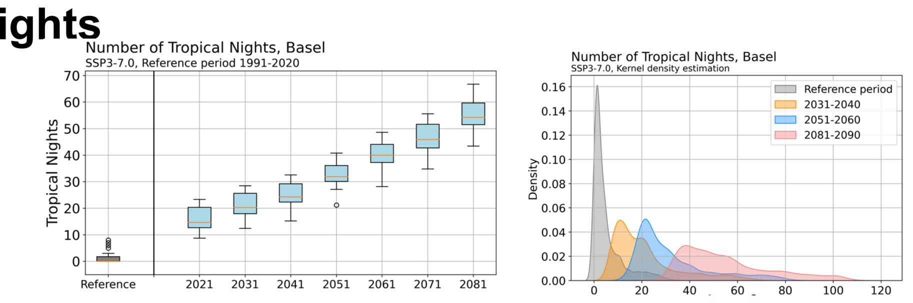


Example simulations – Basel, Switzerland

- Number of **Tropical Nights**

$T_{min,night} \geq 68\,°F$

SSP3-7.0



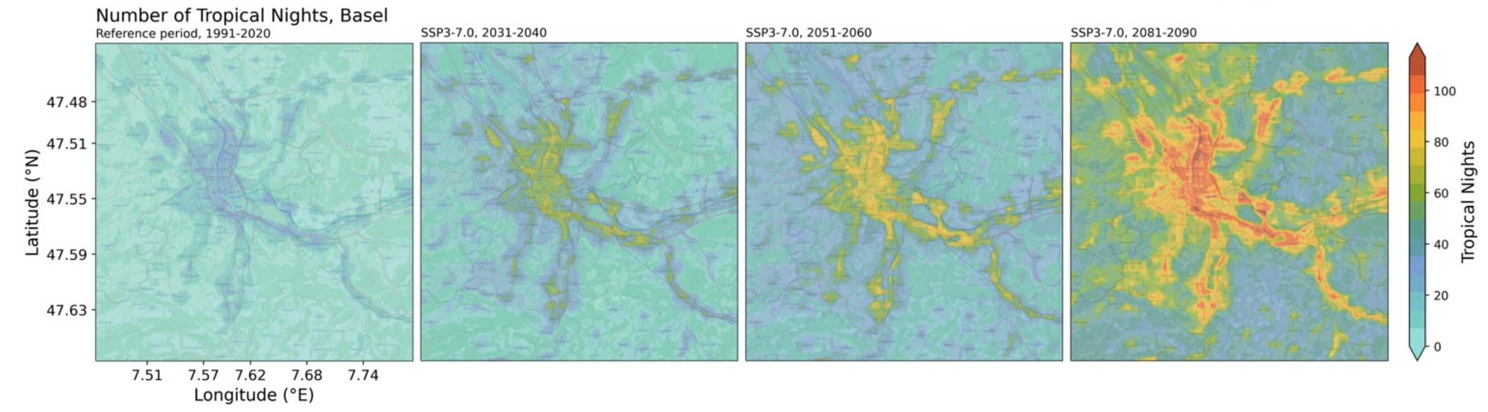
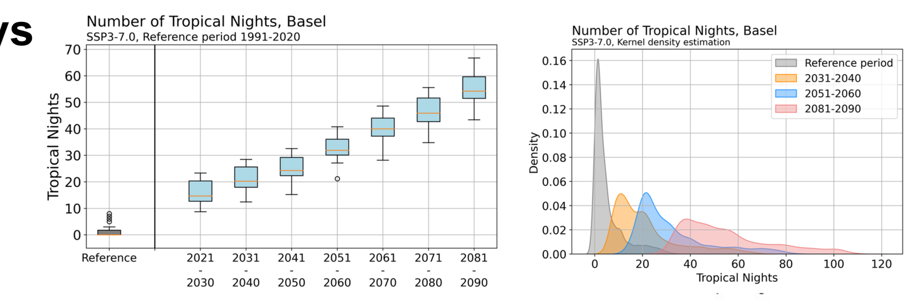


Figure 4: Number of Tropical Nights under the SSP3-7.0 scenario, spanning from the reference period (1991-2020) until 2090.

- Probability of **Hot Days**

$T_{max} \geq 86\,°F$

SSP5-8.5



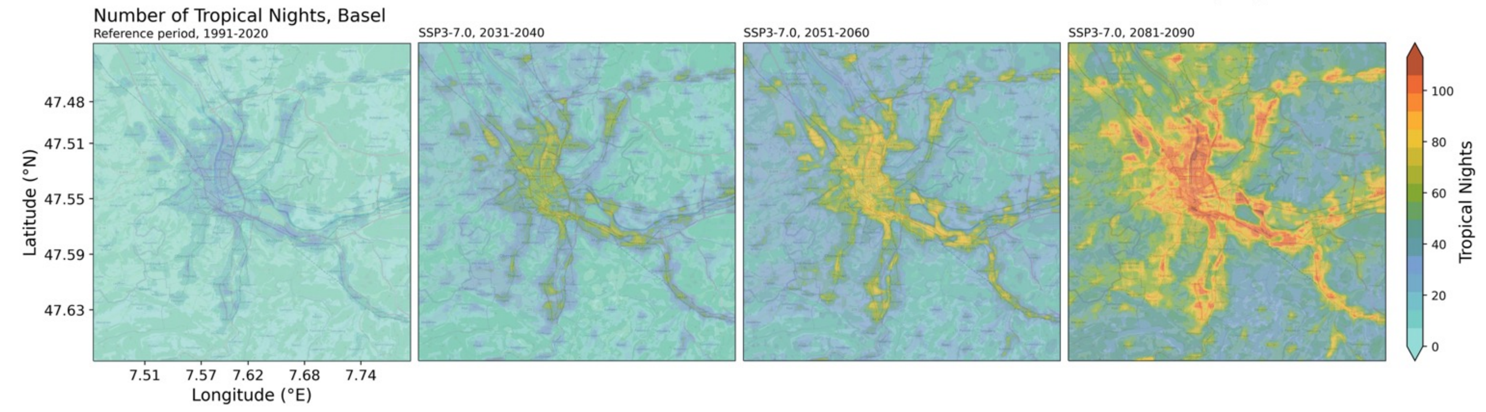


Figure 5: Probability of Hot Days under the SSP5-8.5 scenario, spanning from the reference period (1991-2020) until 2090.

- Change of **Hot Days**
  2081-2090 vs. Reference
  SSP5-8.5

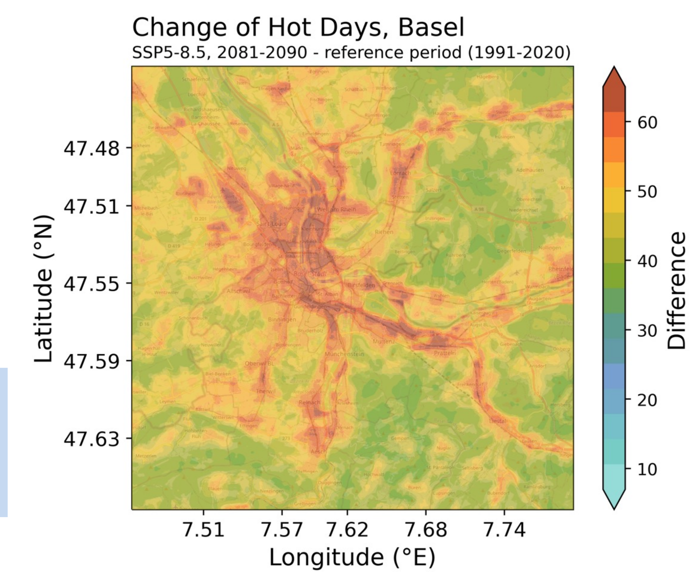


Figure 5: Absolute change of Hot Days for the decade 2081-2090, compared to the reference period 1991-2020.

Summary

- The meteoblue City Climate Model (mCCM) provides precise resolution of urban air temperature maps.
- It facilitates the downscaling of GCMs to the building level, offering enhanced accuracy for localized climate projections and urban planning.
- The model delivers high-resolution, location-specific data, enabling deeper insights into urban climate dynamics and localized environmental impacts.
- It supports advanced risk assessments, with the information needed to make well-informed, strategic decisions addressing future challenges.

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