URBAN CLIMATOLOGY

IX. Urban climate modelling

Paper to read

Int J Biometeorol (2017) 61:527–539
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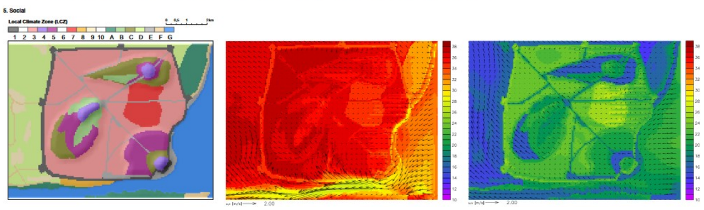
ORIGINAL PAPER

Enhancement of urban heat load through social inequalities on an example of a fictional city King's Landing

M Žuvela-Aloise[1]



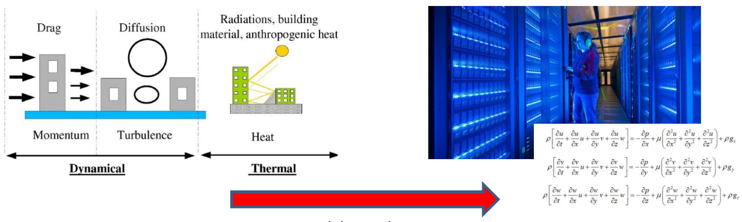
Simulation of the urban climate of an imaginary city as an illustrative example to demonstrate that the residential areas with deprived **socio-economic conditions** can exhibit an enhanced **heat load** at night, and thus more disadvantageous environmental conditions, compared with the areas of higher socio-economic status.

https://is.muni.cz/auth/el/sci/podzim2024/ZA311/um/67875456/09_modelling_s00484-016-1230-z.pdf?lang=en

9.1 Modeling urban climate

- Our knowledge on urban climates based on **empirical studies** is rather restricted

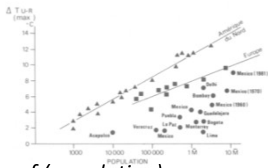
- (Urban) climatologists need some „laboratory“ to experiment
- **Models** of various **types** and **complexity** may be such a lab



model complexity

Urban Climate model types

Statistical models – simple to apply, restricted transferability, limited possibility of climate projections



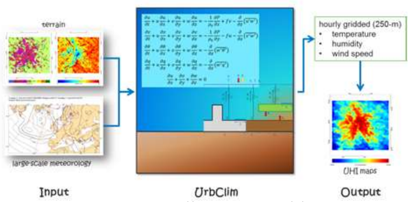
$\Delta T_{U\text{-}R} = f$ *(population)*

Physical models – requires careful design, provides experimental control, allows detailed study of selected features (wind tunnel), need of special facilities (expensive)

Oke *et al.*, 2017, *Urban Climates*

Numerical models – account for different scales of urban climate, physically correct, however quite complex, provide controlled experiments and climate predictions

The *UrbClim* model



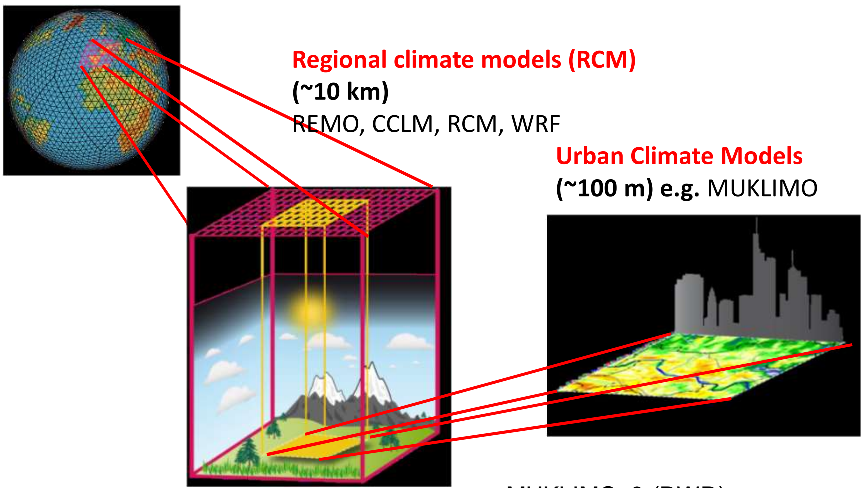
https://urban-climate.be/c/urbclimDescription/

Hierarchy of numerical climate models

Global circulation models (GCM)
Earth System Models (ESM)
(~100 km), GCM + IPCC scenarios

Regional climate models (RCM)
(~10 km)
REMO, CCLM, RCM, WRF

Urban Climate Models
(~100 m) e.g. MUKLIMO



- MUKLIMO_3 (DWD)
- ENVI-Met (http://www.envi-met.com/)

Urban climate numerical modeling

Allows us to examine and test our understanding how cities affect climate and *vice versa.*

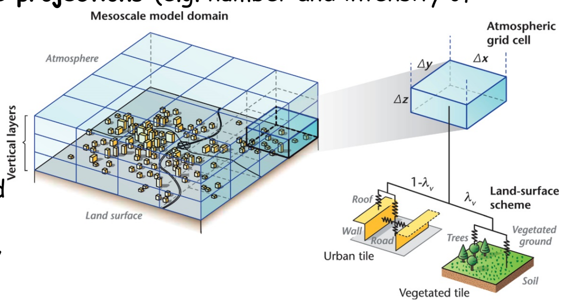
Models of varying complexity:

1. Allows **controlled experiments** by isolating certain processes (effect of buildings on wind field modification, role of sky view factor on radiation budget etc.
2. Provides future **climate projections** (e.g. number and intensity of heat waves

Governing equations – core set of equations that ensures the **conservation of momentum, mass and energy**

Small scale processes are solved through **parametrization**

Boundary conditions defined by higher order models

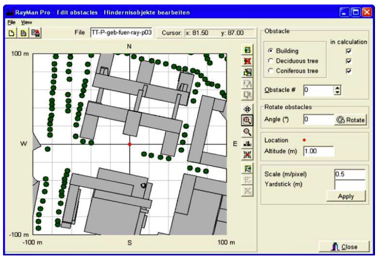


- Micro and local scale models – UCL, RSL
- Mesoscale urban models - UBL

Oke *et al.*, 2017, *Urban Climates*

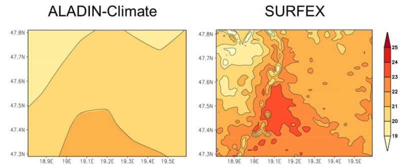
Model examples

- Rayman
  http://www.urbanclimate.net/rayman/
- ENVI-Met
  http://www.envi-met.com/



- The Urban Multi-scale Environmental Predictor (**UMEP**)
  http://www.urban-climate.net/umep/UMEP

- SURFEX
  http://www.umr-cnrm.fr/surfex/

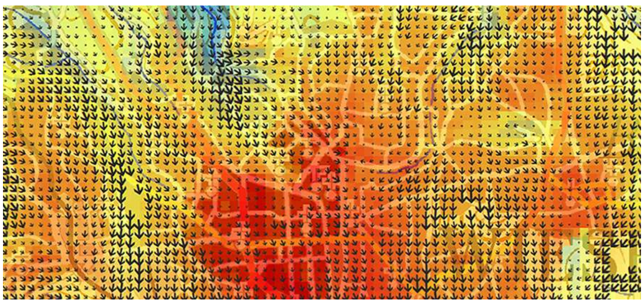


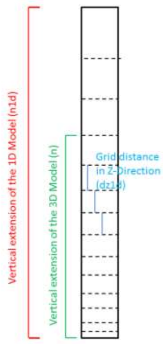
Summer mean 2-m temperature (°C) for 1991–2000 over Budapest according to the 10 km resolution ALADIN-Climate RCM and 1 km resolution SURFEX results

- MUKLIMO_3 (DWD)
- Comprehensive list of sources https://www.urbanclimate.net/E_1tools.htm

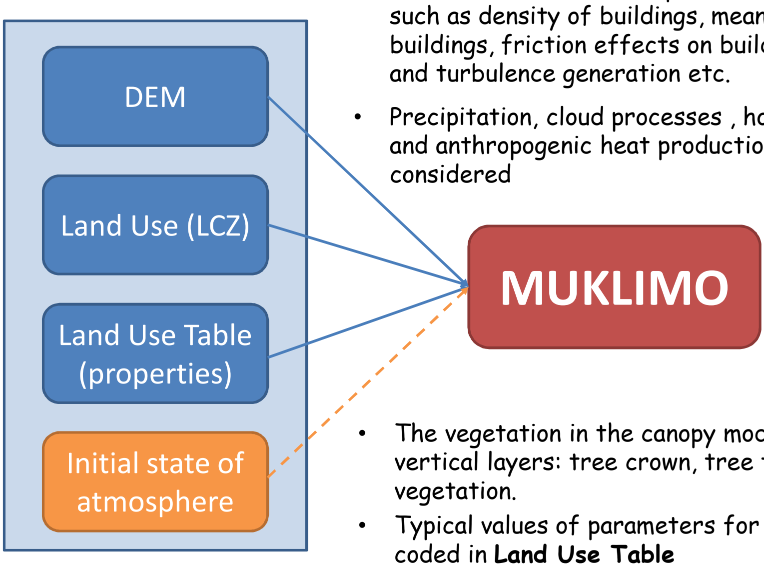
9.2 Model MUKLIMO_3

- Mikroskaliges Urbanes Klima-Modell, 3-dim
- Developed in DWD (Deutscher Wetterdienst), intensively used in Austria weather service (ZAMG)
- Model simulates atmospheric flow fields in the presence of buildings (air temperature field, relative humidity and 3D field of wind speed an direction)
- Horizontal resolution: 100 m, variable vertical resolution 10-100 m





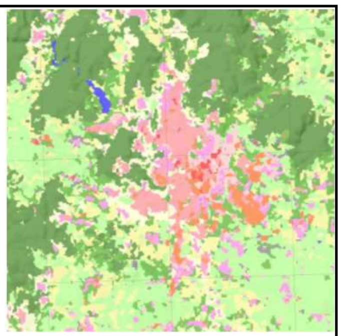
Model MUKLIMO_3 – input parameters

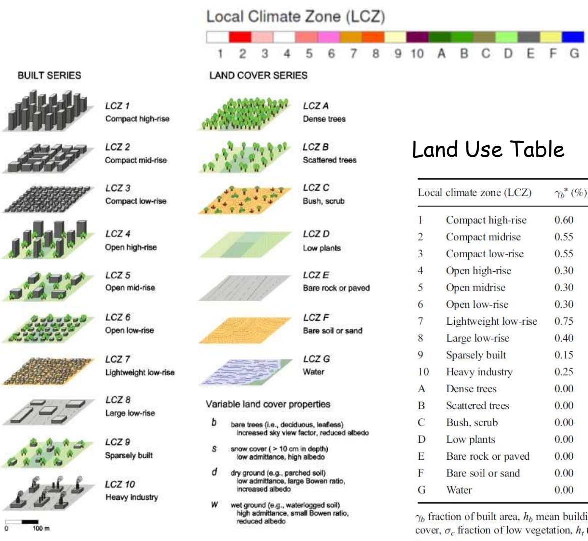


- Model considers several parameters of buildings such as density of buildings, mean height of buildings, friction effects on building surfaces and turbulence generation etc.
- Precipitation, cloud processes , horizontal runoff and anthropogenic heat production are not considered

- The vegetation in the canopy model has three vertical layers: tree crown, tree trunk and low vegetation.
- Typical values of parameters for each LCZ are coded in **Land Use Table**

Brno – Local Climate Zones





Land Use Table

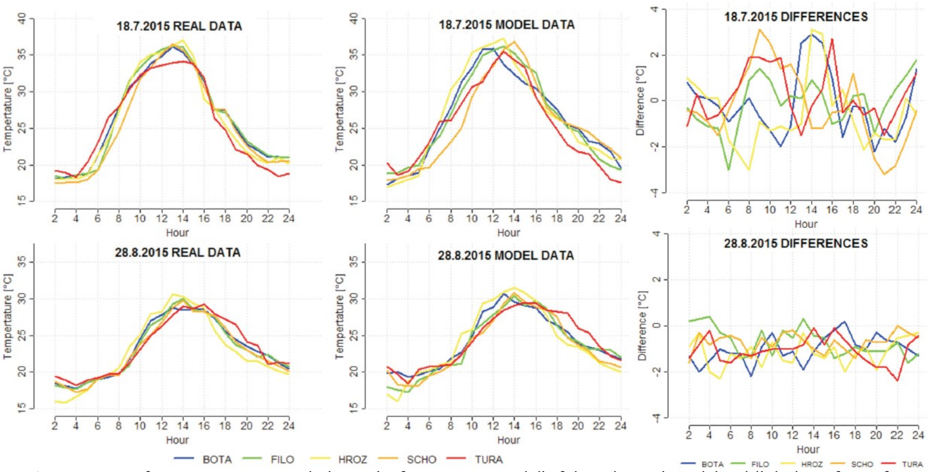
Local climate zone (LCZ)		γ_b[a] (%)	h_b[a] (m)	w_b	v[a] (%)	σ_t[a] (%)	σ_c[a] (%)	h_t (m)	h_c (m)
1	Compact high-rise	0.60	25	6.67	0.40	0.0	0.01	0	0.3
2	Compact midrise	0.55	15	4.50	0.30	0.0	0.08	0	0.3
3	Compact low-rise	0.55	7	2.33	0.20	0.0	0.13	0	0.3
4	Open high-rise	0.30	25	7.00	0.35	0.0	0.25	0	0.3
5	Open midrise	0.30	15	4.50	0.35	0.0	0.21	0	0.3
6	Open low-rise	0.30	7	2.33	0.35	0.0	0.25	0	0.3
7	Lightweight low-rise	0.75	3	1.80	0.15	0.0	0.03	0	0.3
8	Large low-rise	0.40	7	1.40	0.45	0.0	0.08	0	0.3
9	Sparsely built	0.15	7	2.80	0.10	0.0	0.60	0	0.3
10	Heavy industry	0.25	10	3.00	0.30	0.0	0.14	0	0.3
A	Dense trees	0.00	0	0.00	0.00	0.8	0.18	17	0.5
B	Scattered trees	0.00	0	0.00	0.00	0.4	0.54	9	0.5
C	Bush, scrub	0.00	0	0.00	0.00	0.0	1.00	0	1.5
D	Low plants	0.00	0	0.00	0.00	0.0	1.00	0	0.5
E	Bare rock or paved	0.00	0	0.00	0.95	0.0	0.01	0	0.3
F	Bare soil or sand	0.00	0	0.00	0.00	0.0	0.01	0	0.3
G	Water	0.00	0	0.00	−1.00	0.0	0.01	0	0.3

γ_b fraction of built area, h_b mean building height, w_b wall area index, v fraction of pavement, σ_t fraction of tree cover, σ_c fraction of low vegetation, h_t tree height, h_c height of the low vegetation

[a] Relative to total grid cell area

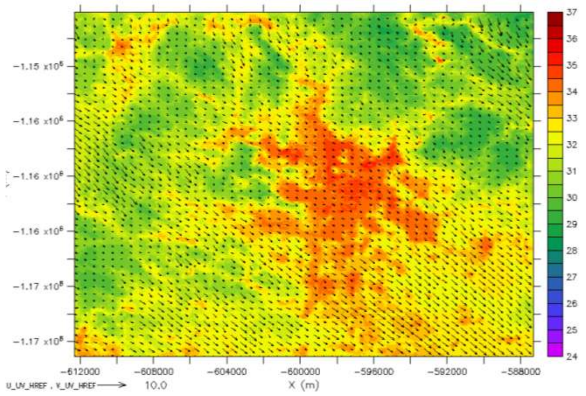
Model MUKLIMO_3

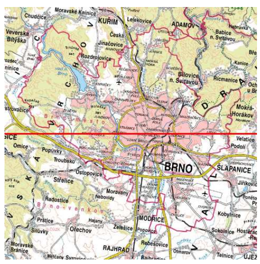
- **The 1D model** calculates **the daily cycle** of temperature, relative humidity and wind for the reference station located outside of the urban area

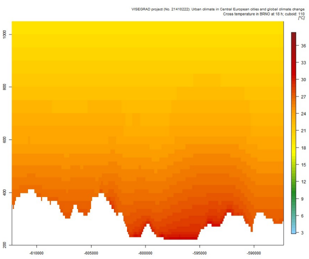


Comparison of air temperature daily cycle from measured (left) and simulated (middle) data from five stations in Brno (for 18. 7. and 28. 8. 2015). Figures on the right side show differences between measured and modelled air temperatures

Model simulation of air temerature and wind filed, an ideal case, 16 h GMT







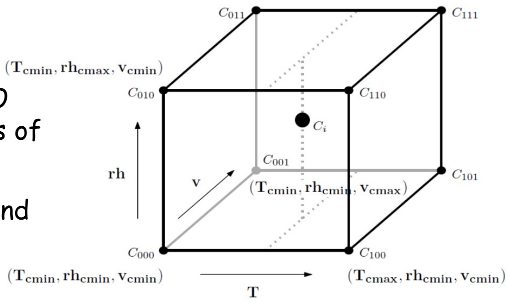
Cross-section of air temerature in Brno area

Model MUKLIMO_3

- The **1D simulation** is run for 24 h after which the values for air temperature, relative humidity and wind are used to initialize the 3D model taking into account terrain height and soil type.
- The meteorological fields given as the output of the **3D model** are used for the analysis of the UHI effect and the calculation of **climate indices**.
- Model is used to evaluate particularly the urban **heat load** in summer period.
- For that purpose, the climate indices, such as mean annual number of summer days (Tmax ≥ 25 °C), hot days (Tmax ≥ 30 °C) and tropical nights (Tmin ≥ 20 °C), are calculated.
- The climate indices are calculated with **the cuboid method**. The method enables the calculation of heat load on a longer temporal scale by using a limited number of urban climate model simulations.

CUBOID method

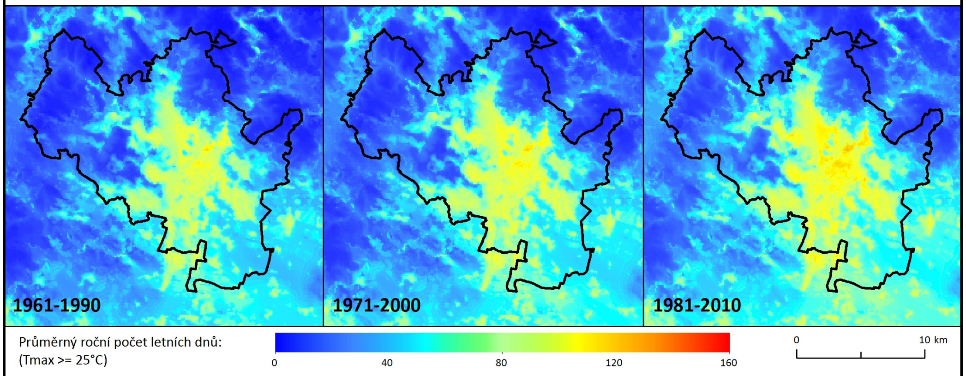
- Model simulations in MUKLIMO are done only for eight corners of a cuboid.
- These corners represent min and max values
- Method uses 3D interpolation.



Meteorological data from the reference station located behind the city determine the range of mean daily air temperature (T), relative humidity (rH) and wind speed (v)

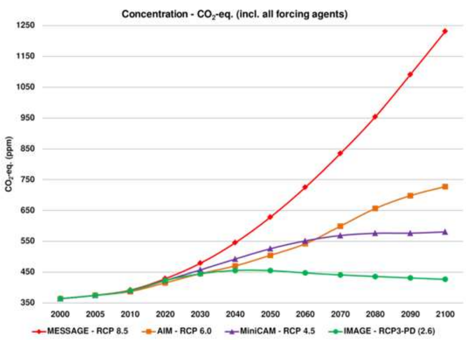
135	315	NE and SW
15,0	25,0	T
40,0	80,0	r_H
0,3	3,0	v

Simulated number of summer days in Brno (recent climate)



Mean number of summer days (Tmax >= 25°C) for three different decades of recent climate in Brno area

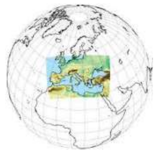
9.3 Future climate

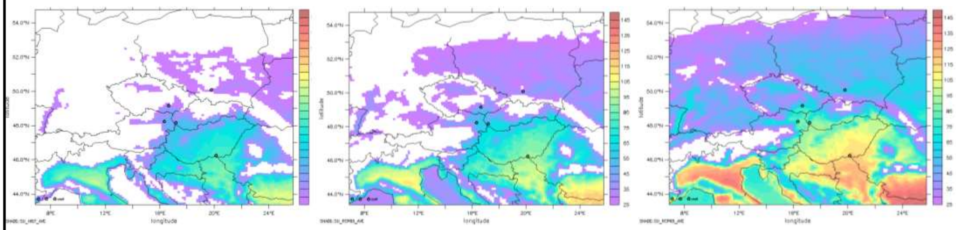


- Modelling of future climate is based on the use of different scenarios that estimate future level of green house gass concentrations
- Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014
- They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come
- The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively)

Future climate

- In model MUKLIMO outputs from Regional Climate Models instead of contemporary real measurements may be used
- RCP4.5 a RCP8.5 resulting from the project EURO-CORDEX (Coordinated Downscaling Experiment) - European Domain were used to model the climate of Brno in 21st Century

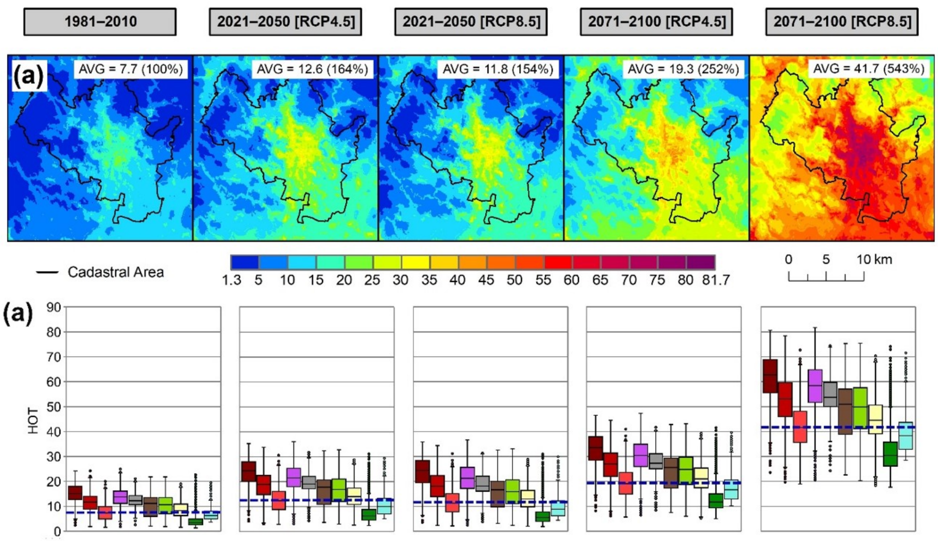




1971-2000 **2021-2050** **2071-2100**

Mean annual number of summer days (Tmax ≥ 25°C) simulated for RCP8.5 scenario; avearage from an ensemble of eleven regional climate models

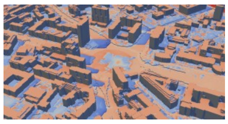
Brno – no. of hot days in future climate



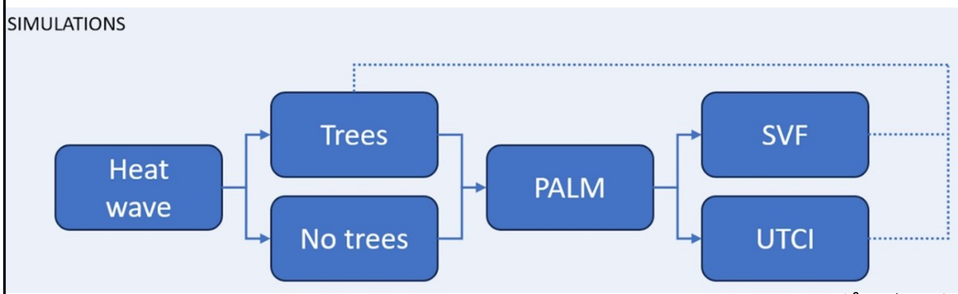
Contribution of different LCZs to the increase of no. hot days

Effect of trees on SVF and thermal comfort in Prague

The PALM model - able to solve turbulence, energy processes and thermal conditions at the street level resolving individual buildings.

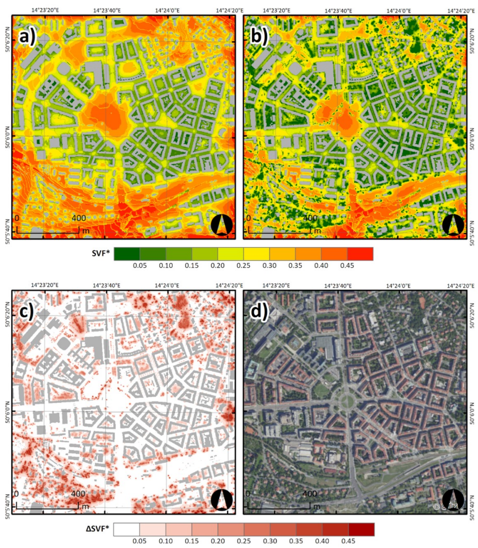


- The model experiment was carried out by two simulations with: (1) the complete structure of the study domain; (2) the domain without individual shrubs and trees.
- The differences in Universal thermal climate index (ΔUTCI) between these two simulations characterise the effect of trees on the thermal comfort of pedestrians.



Janků et al. 2024

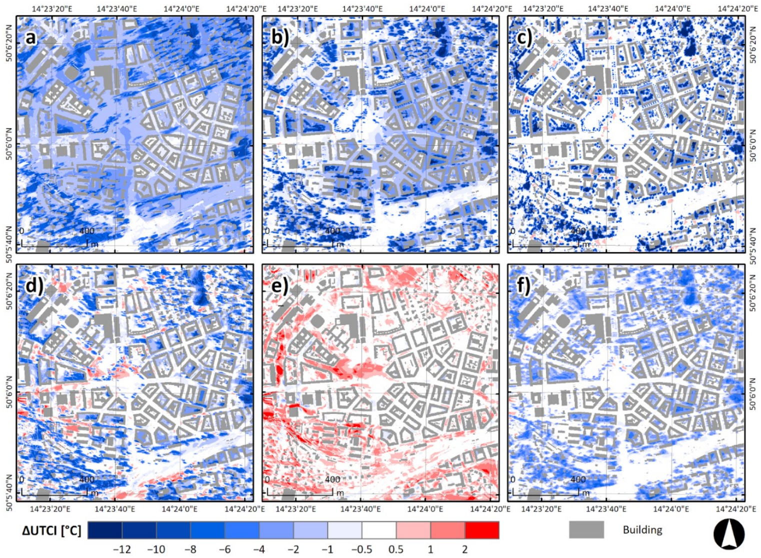
Effect of trees on SVF and thermal comfort in Prague



Calculated sky view factors (SVF*) for both simulations (a) without trees and (b) including trees, and (c) differences between both simulations (ΔSVF*), and (d) orthophoto of Prague-Dejvice district

Janků et al. 2024

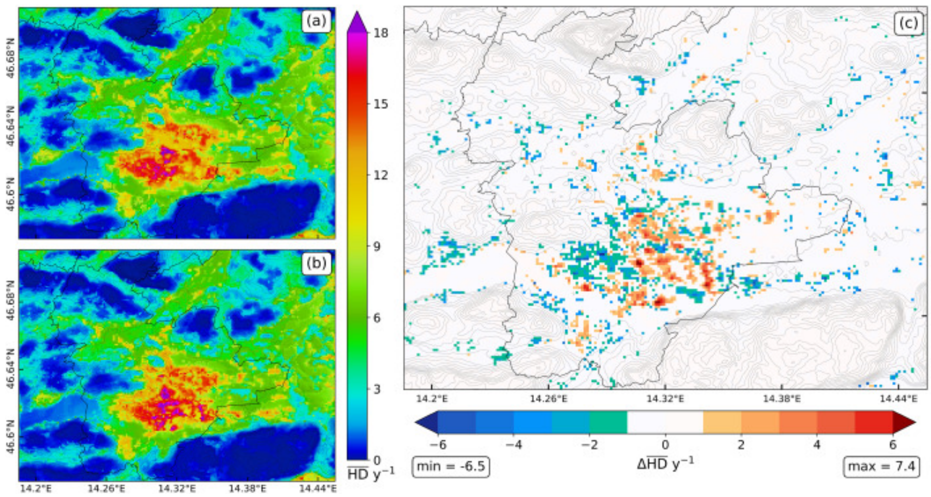
Effect of trees on SVF and thermal comfort in Prague



Spatial distribution of the UTCI differences caused by tree SVF* reduction (ΔUTCI) within the study domain as hourly means at (a) 06–07 CEST, (b) 08–09 CEST, (c) 13–14 CEST, (d) 18–19 CEST, (e) 22–23 CEST and (f) daily mean.

Janků et al. 2024

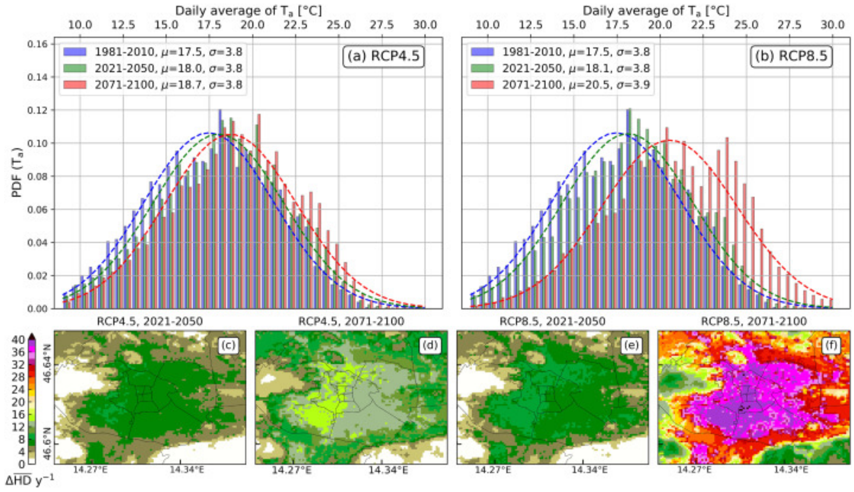
Modelling changes in LU/LC distribution and their thermal characteristics response



Average number of hot days per year in Klagenfurt (Austria) between 1981 and 2010 for simulations considering (a) the initial Urban Atlas map and (b) the proposed land use classification. Panel (c) provides the difference in the simulations in panels (a) and (b).

Oswald et al. (2020)

Modelling changes in LU/LC distribution and their thermal characteristics response



Future climate projections shown as a probability density function (PDF) of the air temperature (Ta) taken from the bias-corrected EURO-CORDEX data set for (a) RCP4.5 and (b) RCP8.5 for the extended summer season (MJJAS) in Klagenfurt (Austria)

Oswald et al. (2020)

9.4 Final remarks and questions

- Models is able to simulate main features of spatial distribution of several climate indices which characterize potential heat load in cities
- Parts of the city with the highest heat load correspond with the recent knowledge that is based on real measurements (model validation)
- In controlled experiments models are able to quantify the role of selected urban features to heat load
- Future climate simulations show significant increase of heat load especially for RCP8.5 at the end of the 21st century

Final remarks and questions

1. What is the main purpose of urban climate models?
2. What aspects of urban climate would be useful to simulate?
3. Is there any other method how to do projections of future climate?
4. What is a difference between “projection” and “prediction”?