Modelling the climate of Budapest with the SURFEX land surface model
-
validation and projection results of temperature and urban heat island

Gabriella Allaga-Zsebeházi (zsebehazi.g@met.hu)
Regional Climate Modelling Group, Modelling Unit
Hungarian Meteorological Service

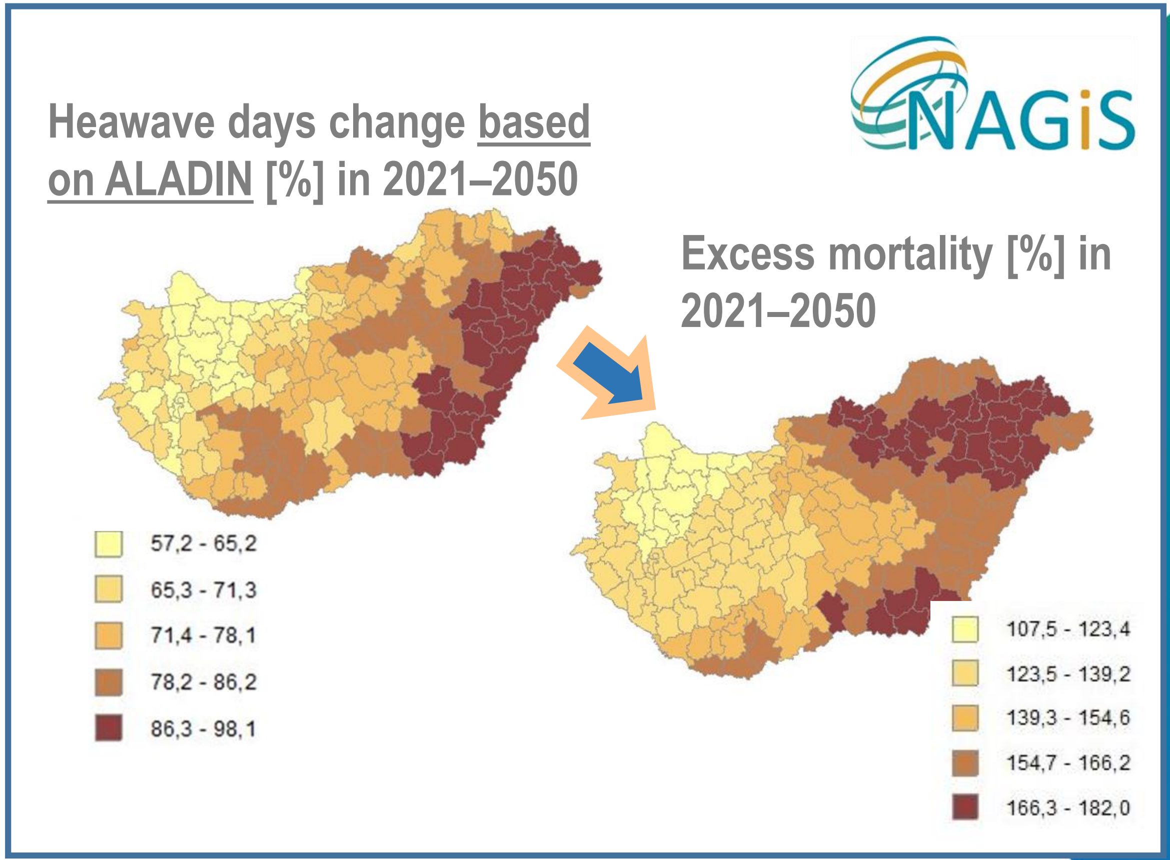
HUNGARIAN METEOROLOGICAL SERVICE

2021 AWARD CEREMONY OF DÉVÉNYI DEZSŐ MEDAL
8 DECEMBER 2021

Table of contents

Motivation

- Several aspects of climate change can affect cities more seriously (e.g. excess mortality due to heatwaves)
- At OMSZ future climate projections are achieved with 10 km resolution regional climate models (RCMs; without explicit urban parameterization scheme) → no detailed information about urban climate
- SURFEX land surface model (LSM) is applied to refine the RCM projections

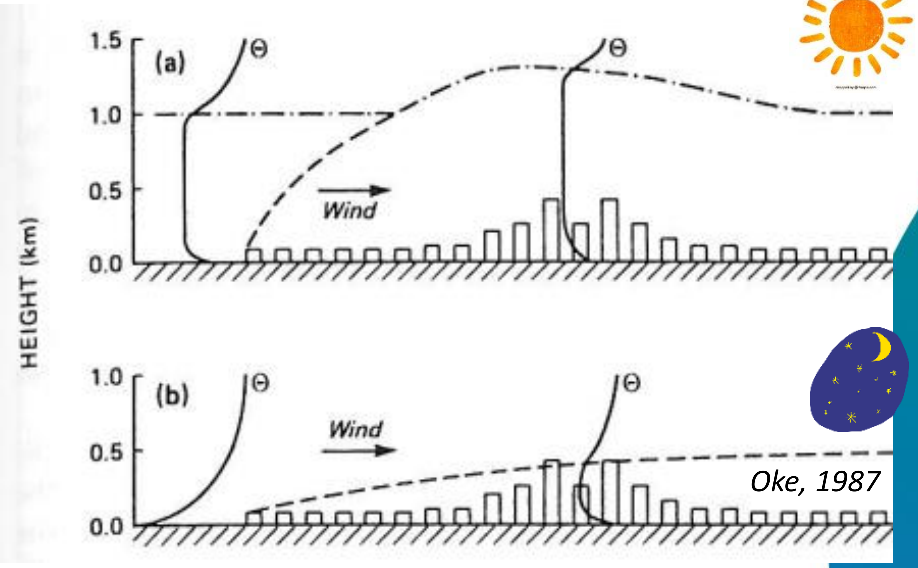


The urban boundary layer

Energy budget and the structure of boundary layer are modified due to artificial land cover in the cities:

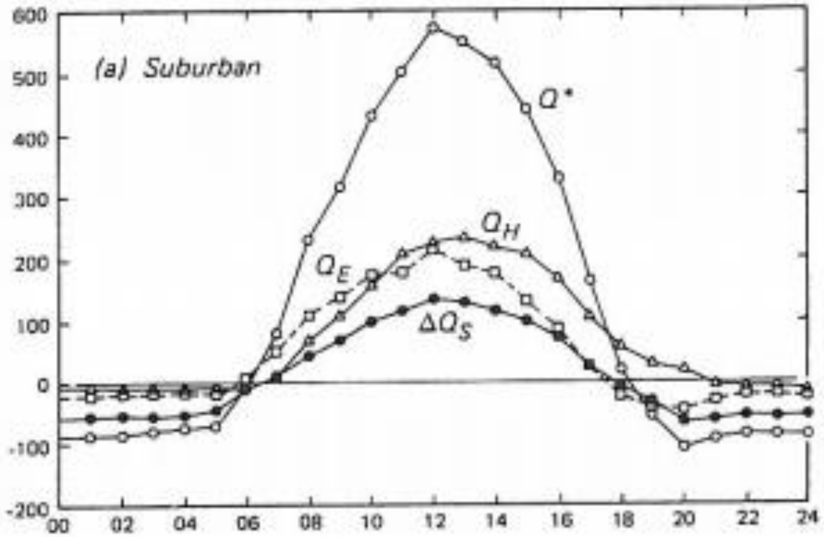
- Large heat capacity, good heat conduction of buildings
- During the day sensible heat is dominant over latent heat
- Dense built-up → radiation trapping
- Antropogenic heat source (e.g., heating)

Structure of PBL in the cities



Oke, 1987

Surface energy budget



Oke, 1987

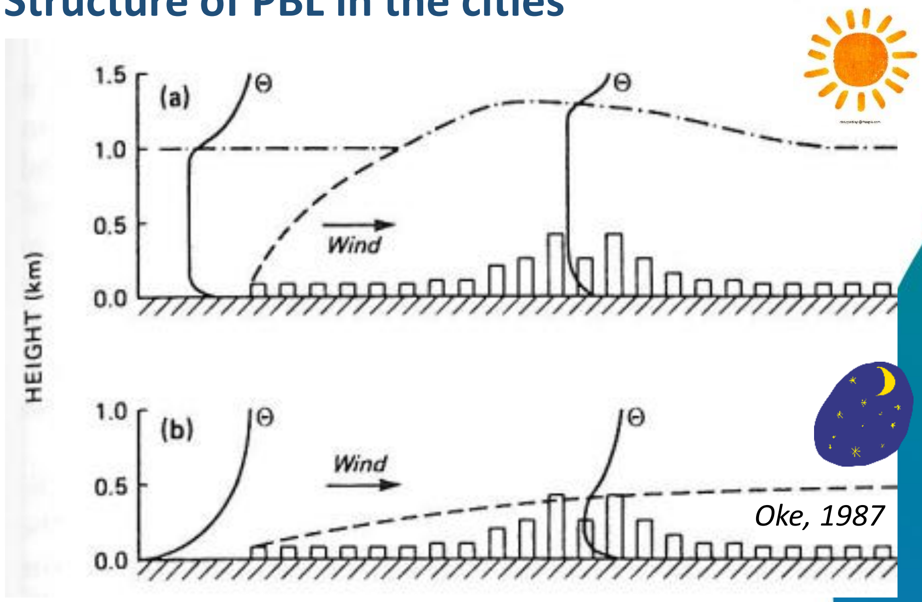
The urban boundary layer

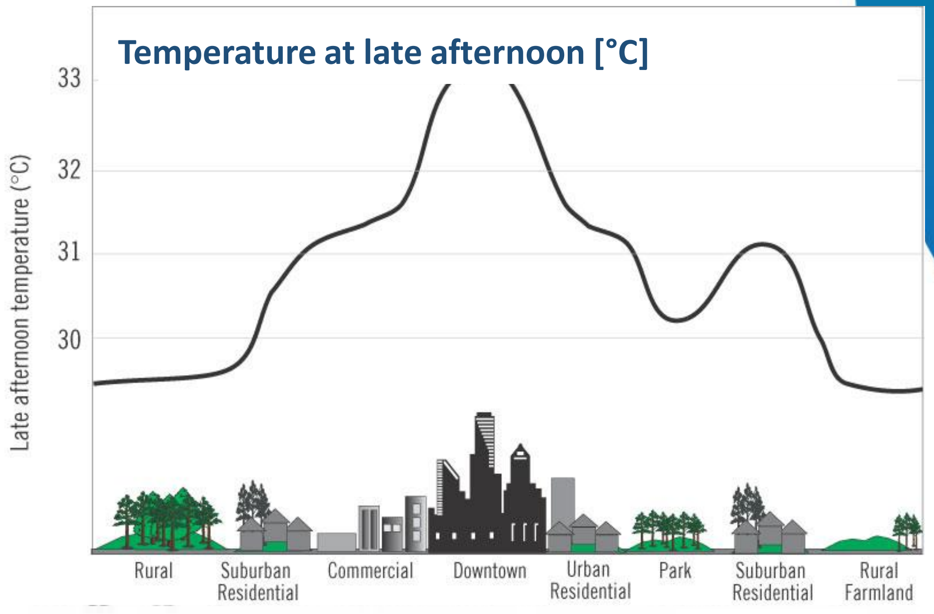
Energy budget and the structure of boundary layer are modified due to artificial land cover in the cities:

- Large heat capacity, good heat conduction of buildings
- During the day sensible heat is dominant over latent heat
- Dense built-up → radiation trapping
- Antropogenic heat source (e.g., heating)

Urban heat island

Structure of PBL in the cities

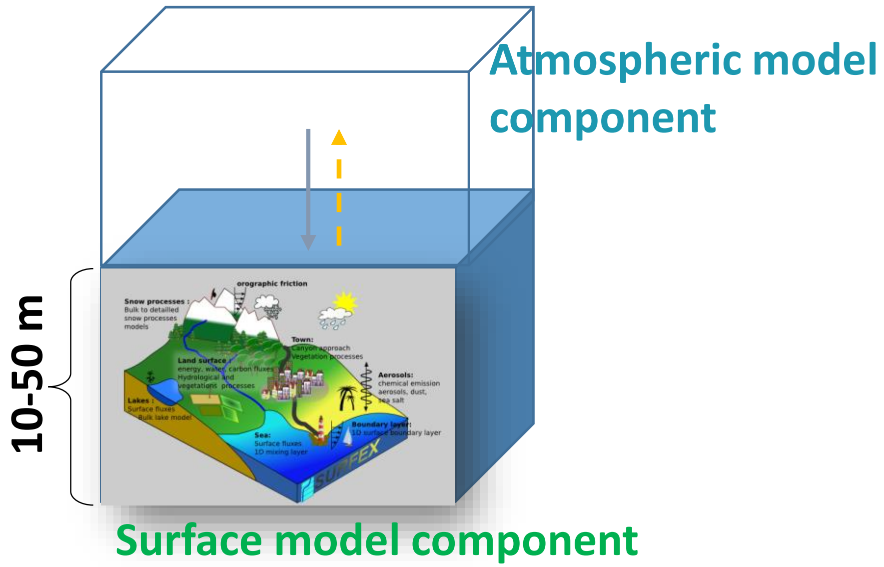


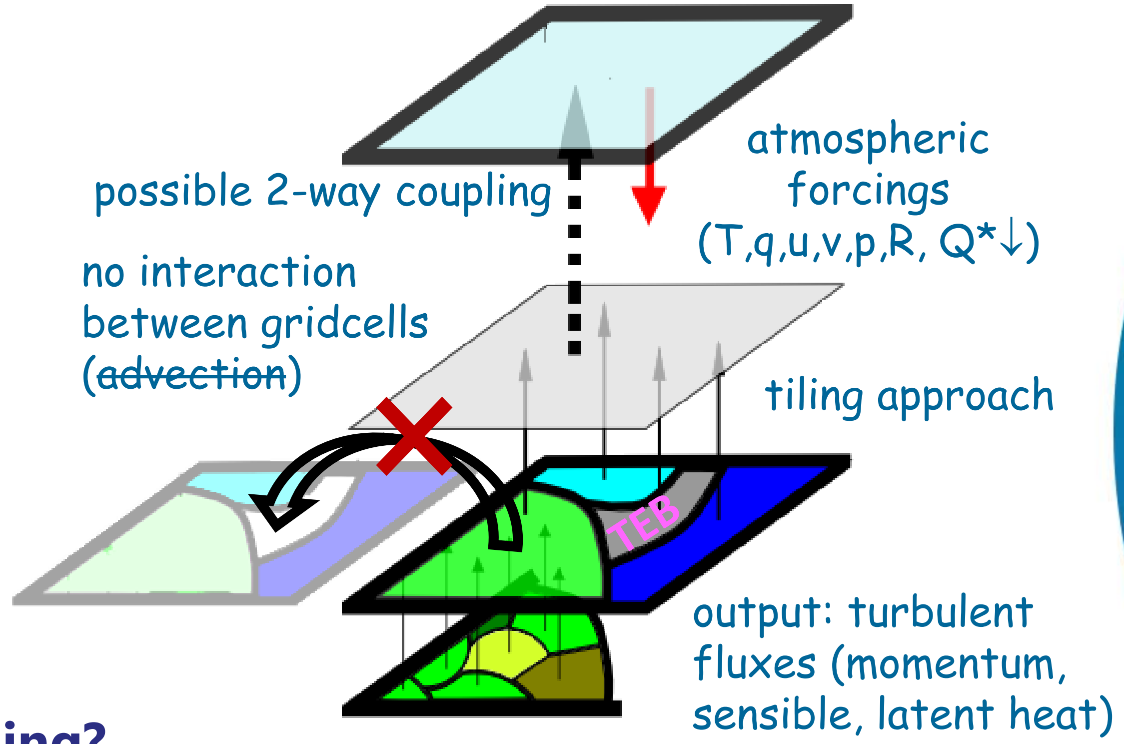


EPA, 2008

The SURFEX land surface model

SURFEX is the land surface model of the ALADIN, ALARO, AROME, HARMONIE





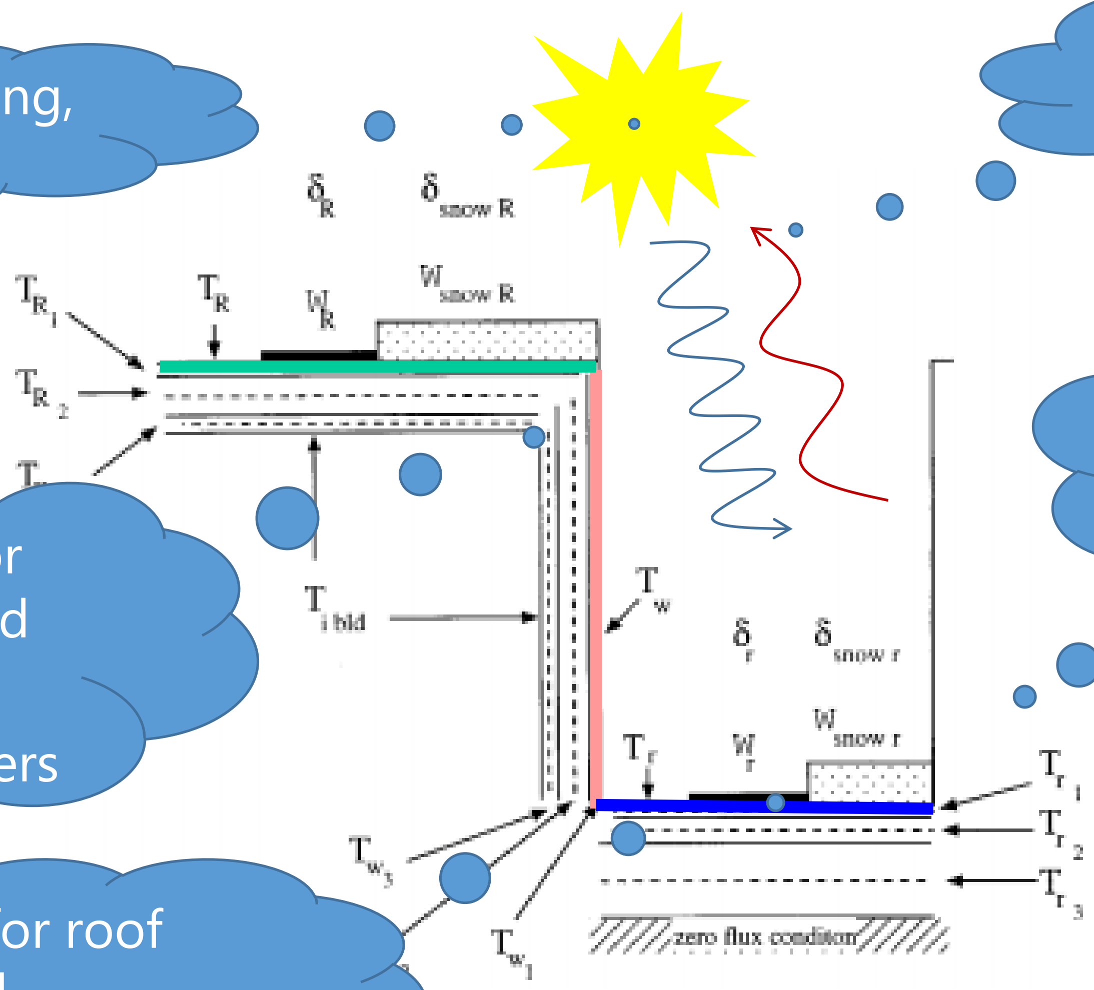
Why LSMs for urban climate modelling?

- ✓ RCM output fields as atmospheric forcings + physical description of urban processes (→←statistical methods)
- ✓ meso-scale modelling → can be applied on decadal time-scale over the entire city (cost efficiently)
  (→← microscale models)

The Town Energy Balance scheme

Radiation: shading, trapping

Cities are approximated as urban canyons



Average building height, width and road width is given in a gridcell

Energy budget for roof, wall and road separately

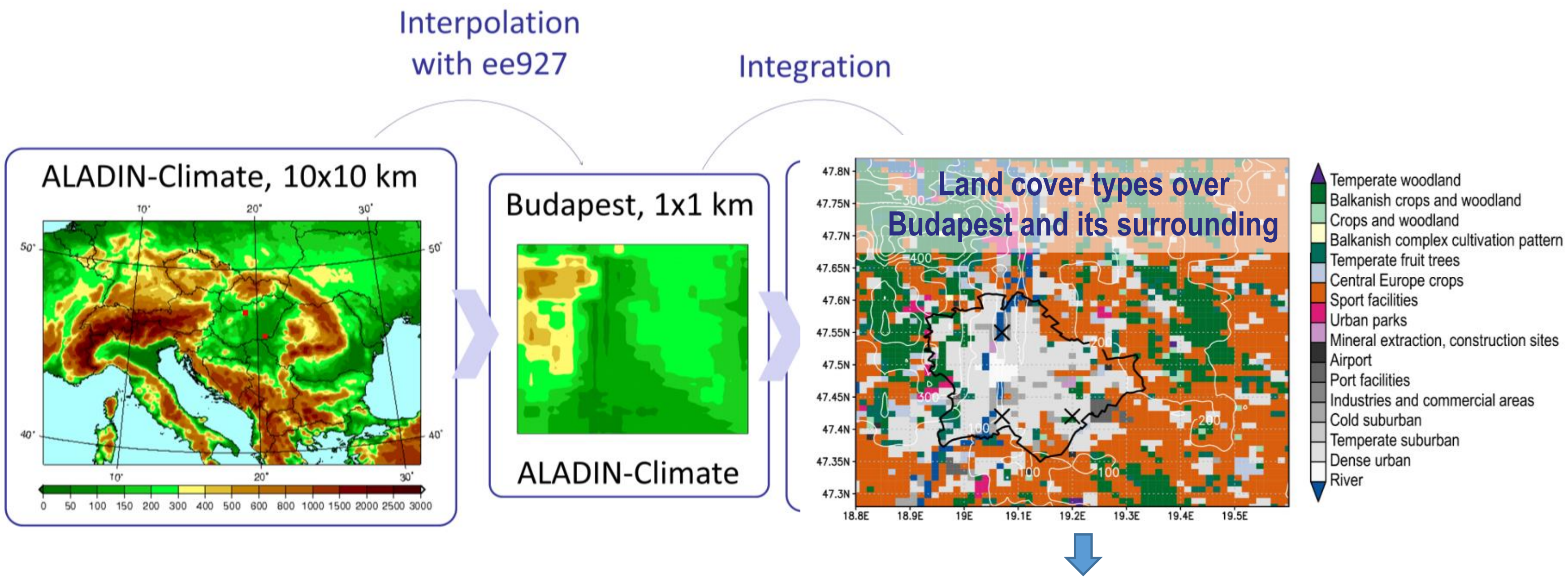
Several surface layers

Water budget for roof and road

Drainage in urban drains

Antropogenic heat source: domestic heating

Simulation set-up



- Based on previous land cover datasets, climate atlases, satellite observations
- 1 km resolution global dataset
- ECOCLIMAP-I is used: 215 land cover types

Validation studies

atmosphere

MDPI

Article

Assessment of the Urban Impact on Surface and Screen-Level Temperature in the ALADIN-Climate Driven SURFEX Land Surface Model for Budapest

Gabriella Zsebeházi [1,*] and Sándor István Mahó [2]

[1] Hungarian Meteorological Service, 1024 Budapest, Hungary
[2] Department of Physics, University of Helsinki, 00014 Helsinki, Finnland; sandor.maho@helsinki.fi
* Correspondence: zsebehazi.g@met.hu; Tel.: +36-1346-4851

Abstract: Land surface models with detailed urban parameterization schemes provide adequate tools to estimate the impact of climate change in cities, because they rely on the results of the regional climate model, while operating on km scale at low cost. In this paper, the SURFEX land surface model driven by the evaluation and control runs of ALADIN-Climate regional climate model is validated over Budapest from the aspect of urban impact on temperature. First, surface temperature of SURFEX with forcings from ERA-Interim driven ALADIN-Climate was compared against the MODIS land surface temperature for a 3-year period. Second, the impact of the ARPEGE global climate model driven ALADIN-Climate was assessed on the 2 m temperature of SURFEX and was validated against measurements of a suburban station for 30 years. The spatial extent of surface urban heat island (SUHI) is exaggerated in SURFEX from spring to autumn, because the urbanized gridcells are generally warmer than their rural vicinity, while the observed SUHI extent is more variable. The model reasonably simulates the seasonal means and diurnal cycle of the 2 m temperature in the suburban gridpoint, except summer when strong positive bias occurs. However, comparing the two experiments from the aspect of nocturnal UHI, only minor differences arose. The thorough validation underpins the applicability of SURFEX driven by ALADIN-Climate for future urban climate projections.

Keywords: urban climate modelling; land surface modelling; urban heat island; surface urban heat island; model validation

check for updates

Citation: Zsebeházi, G.; Mahó, S.I. Assessment of the Urban Impact on Surface and Screen-Level Temperature in the ALADIN-Climate Driven SURFEX Land Surface Model for Budapest. *Atmosphere* 2021, *12*, 709. https://doi.org/10.3390/atmos12060709

Academic Editors: Adina-Eliza Croitoru and

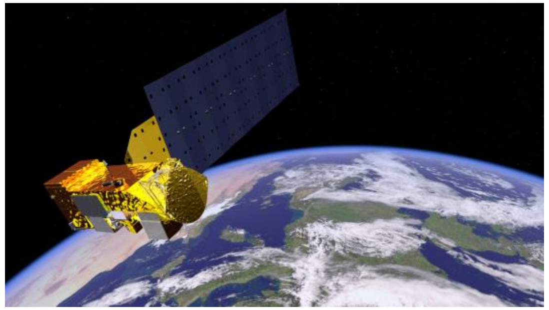
Methods

Methodology applied for regional climate models is followed:

Name of simulation	Driving global model	Regional Climate model	Land surface model	Horizontal resolution	Period
SURFEX-EI	ERA-Interim	ALADIN-Climate	SURFEX	1 km	1996-2005
SURFEX-ARP	CNRM-CM5	ALADIN-Climate	SURFEX	1 km	1961-2005

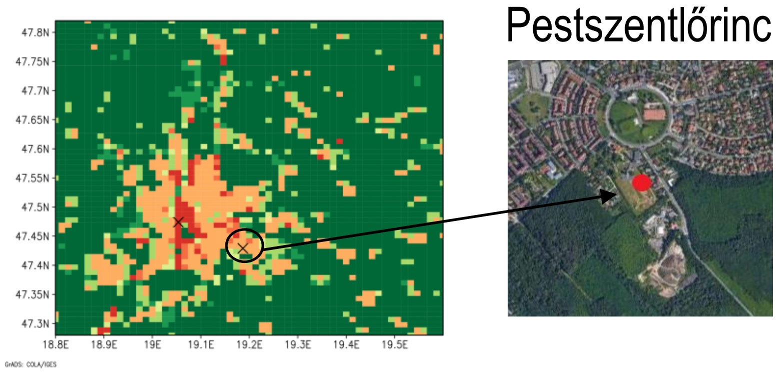
Reference?
For RCMs gridded observation dataset (e.g., E-OBS, CarpatClim) → 10 km resolution, urban stations are usually missing

Measurements used:

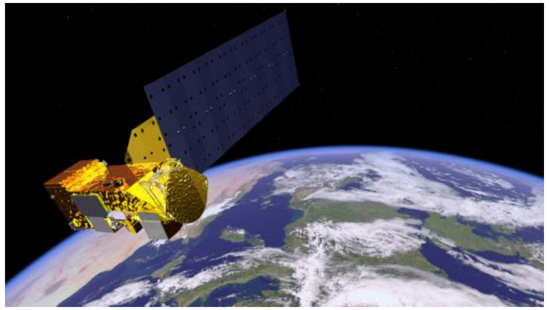


Satellite and station measurements

Station measurement



Satellite measurement



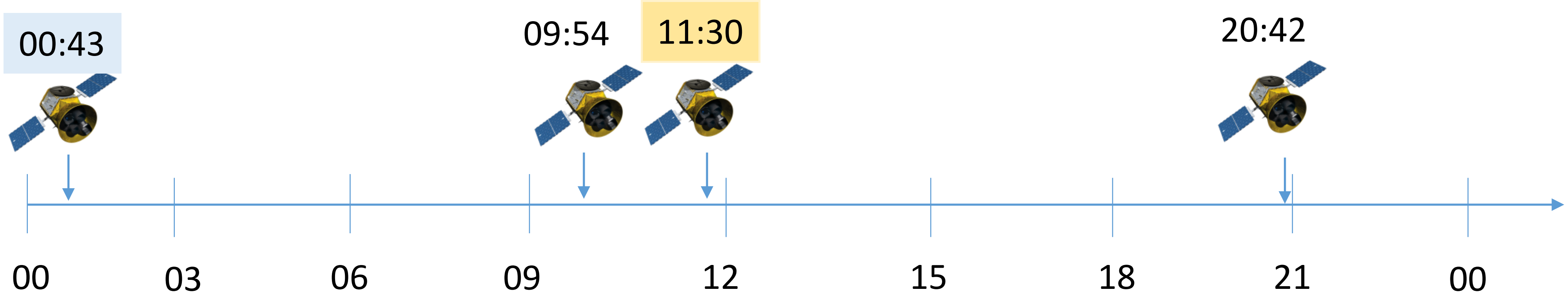
- 2-m temperature measurements from Pestszentlőrinc synoptic station (suburban)
- Advantages:
  - High temporal frequency
  - High accuracy
- Disadvantages:
  - No information from spatial distribution of the variables

- Land surface temperature (LST) measurements from Aqua and Terra satellites:
- Advantages:
  - Information from spatial distribution of the variable (1 km horizontal resolution)
- Disadvantages
  - 4 measurements per day (from end of 2002), does not match exactly with model data saving times
  - Only clear sky conditions
  - Indirect measurement, several uncertainty factors

Results

Validation of ALADIN-ERAI driven SURFEX' LST against satellite measurements for 2003-2005

Methodology



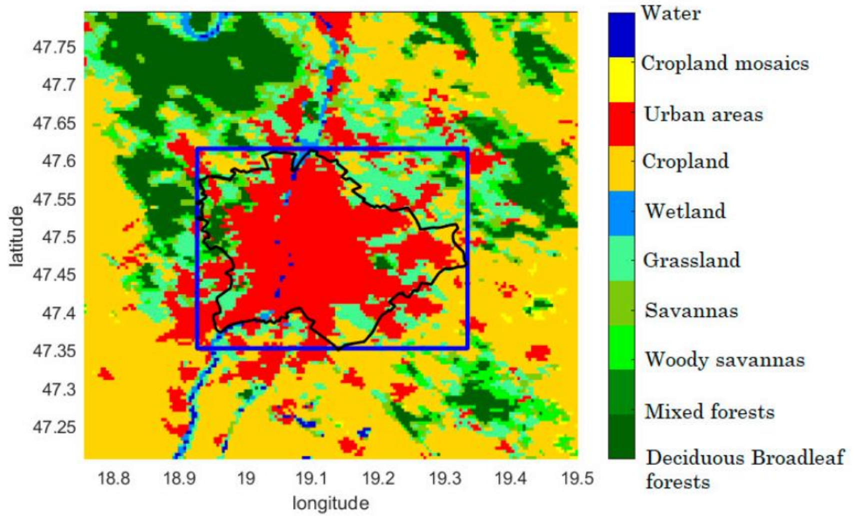
SURFEX data is saved 3-hourly

Land surface temperature in SURFEX: $$LST_{SURFEX} = x_{urban}\sqrt[4]{\frac{\overline{LW_{TEB}}}{\sigma\bar{\varepsilon}_{TEB}}} + (1 - x_{urban})\sqrt[4]{\frac{LW_{ISBA}}{\sigma\varepsilon_{ISBA}}}$$

Removal of cloud contaminated grid cells:

MODIS: information about the ratio of cloud cover in the gridcells

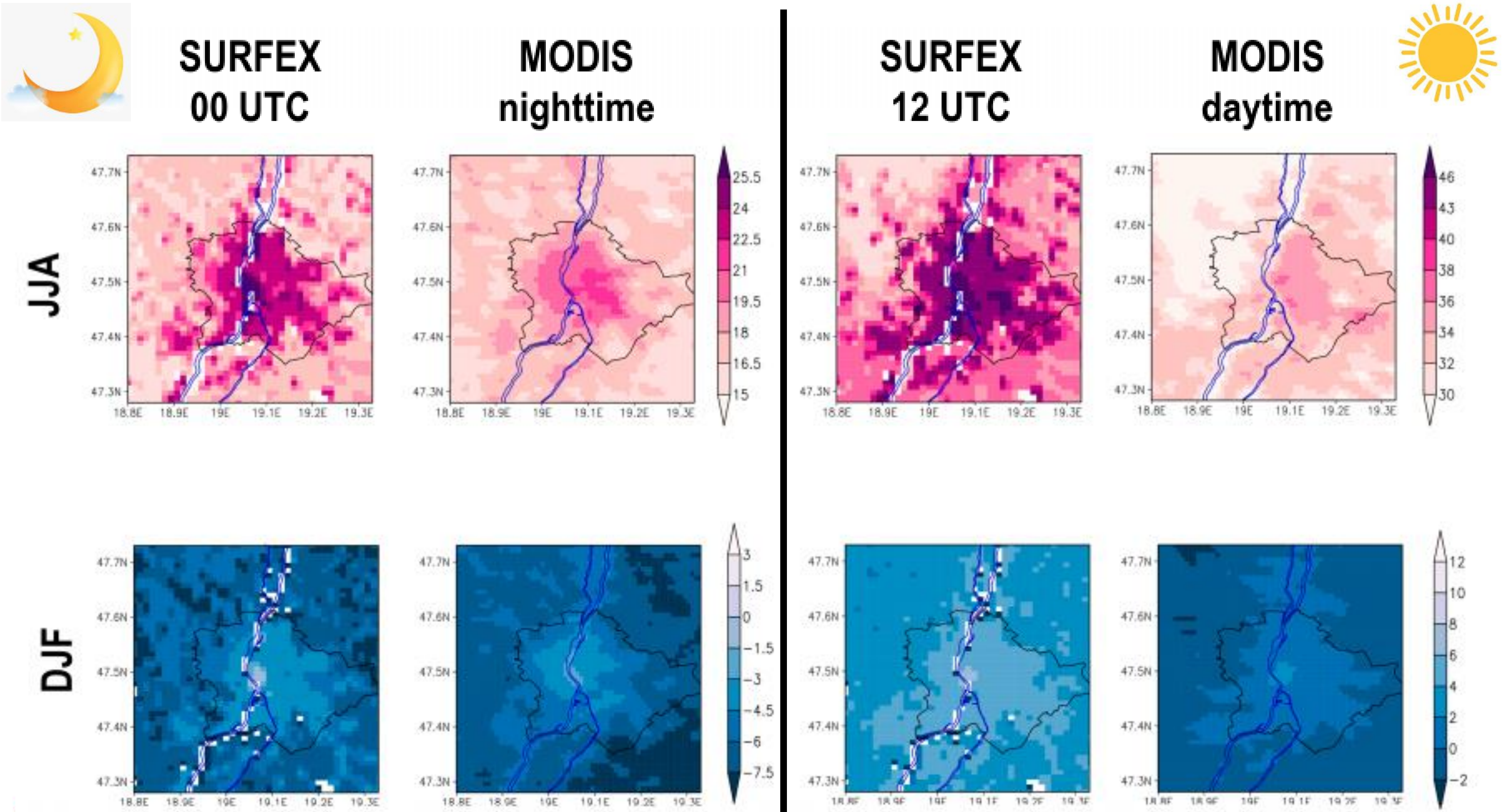
SURFEX: based on ALADIN cloud cover



Cloudy times: cloud fraction over the domain >25%

→ exclude from analysis

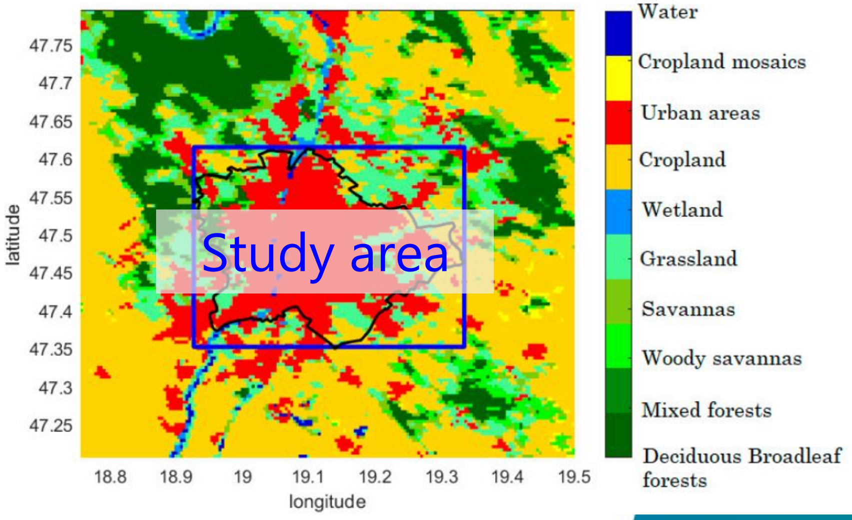
Observed and modelled spatial pattern of LST



- Surface temperature is heavily overestimated over the city in summer (8.3 °C at daytime)
- Cooling effect of Buda-hills and forest on Buda is not captured by SURFEX at summer daytime
- Best seasonal aggreement in winter (< 1 °C difference)

…let's examine the surface UHI's spatial pattern more quantitatively

Surface UHI affected area



__Surface UHI affected area__ (*__Zhang and Whang__*__, 2008)__: size of the investigated area, where temperature significantly differs from the average temperature of the considered area

Methodology:

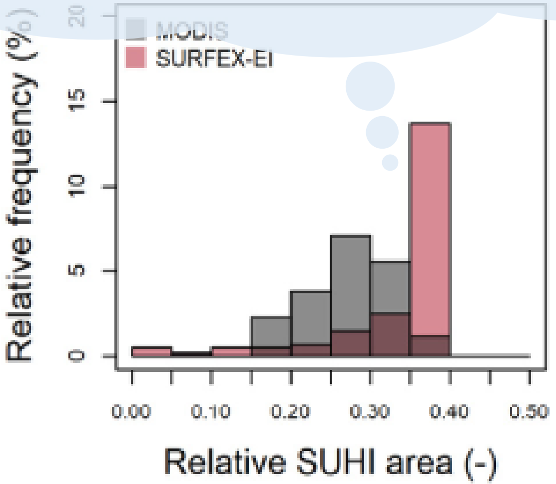
1. Compute spatial mean and standard deviation of temperature for each timestep

2. For each gridcell and timestep the following criterium was applied:

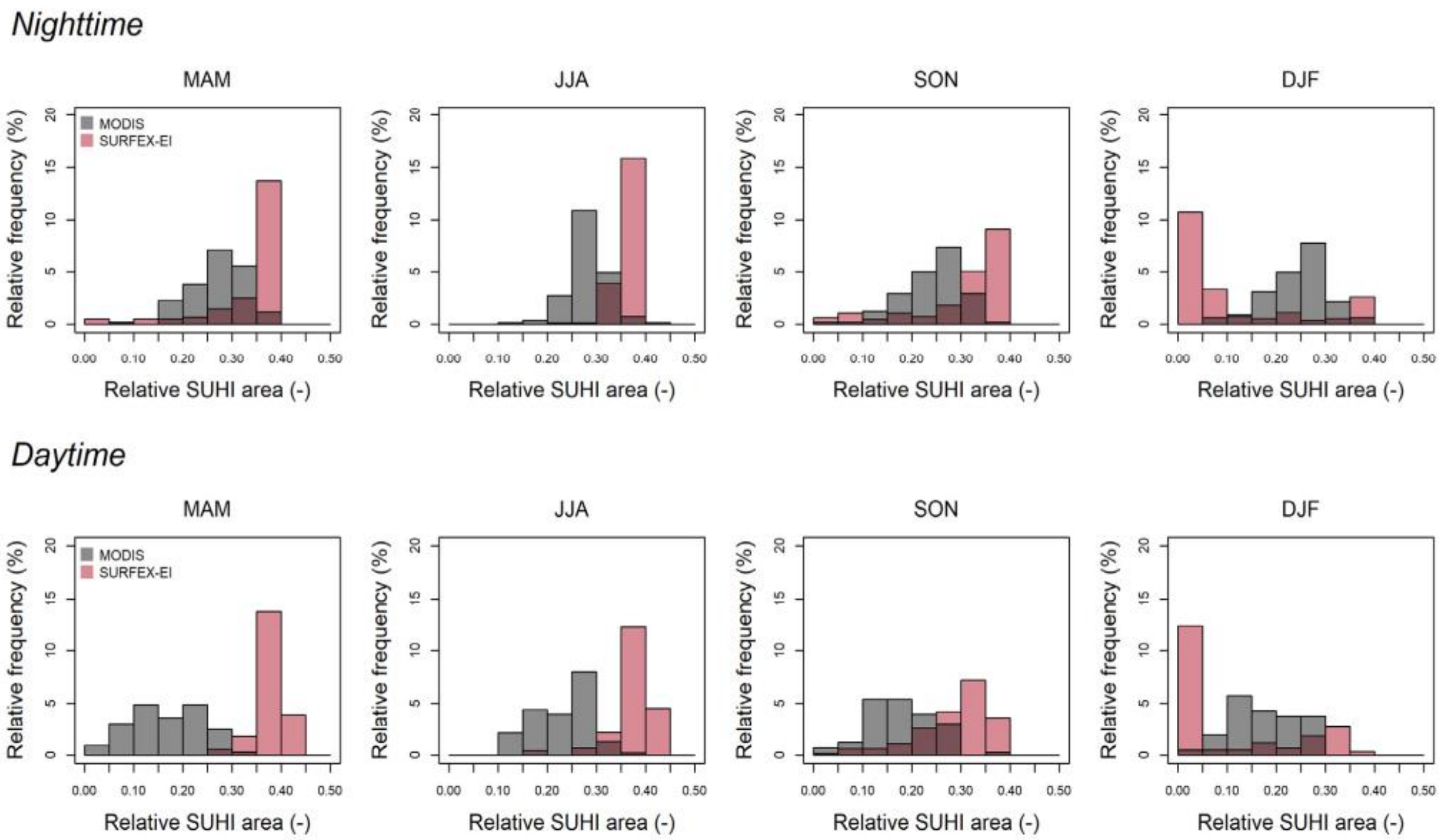
$$\begin{cases} T \geq \overline{T} + \sigma, & SUHI\ affected\ gridpoint \\ T < \overline{T} + \sigma, & omitted\ gridpoint \end{cases}$$

3. Take the spatial sum of the SUHI affected gridpoints (SUHI affected area) and plot the temporal distribution of relative SUHI affected area on histogram

In SURFEX in spring most often the SUHI affected area is 35-40% of the examined area



Seasonal surface UHI affected area



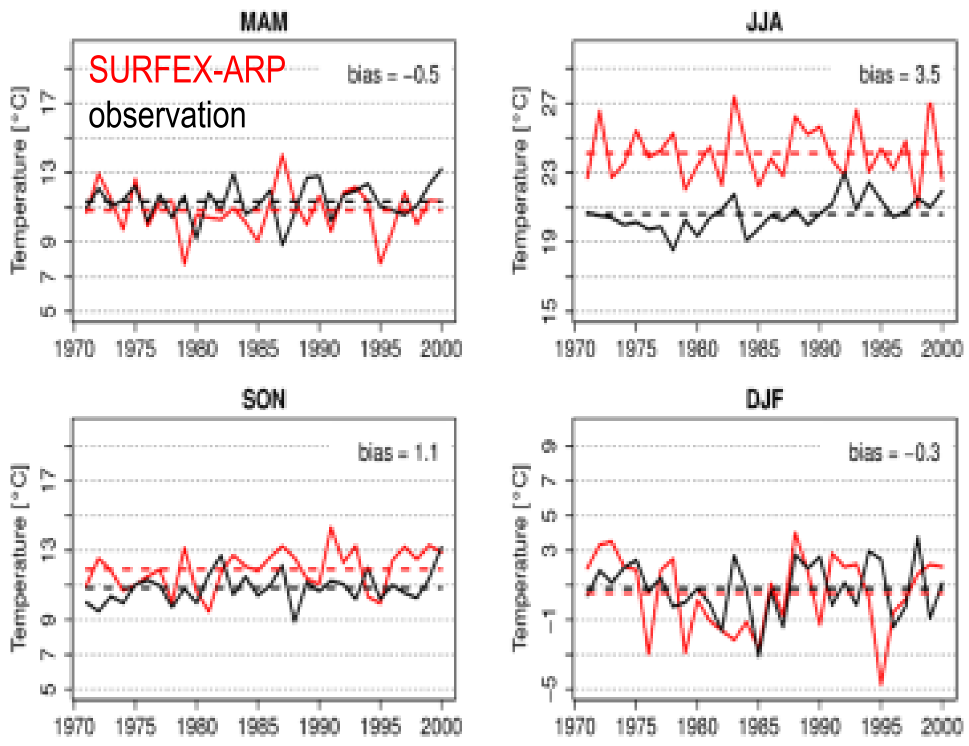
- Winter is fairly different from the rest of the seasons
- Spring – Autumn: most frequently SUHI affected area is 35-40% in SURFEX → overestimated at night and day
- In winter the SUHI affected area is underestimated by SURFEX
- Variance of SUHI affected area is generally smaller in SURFEX than observed

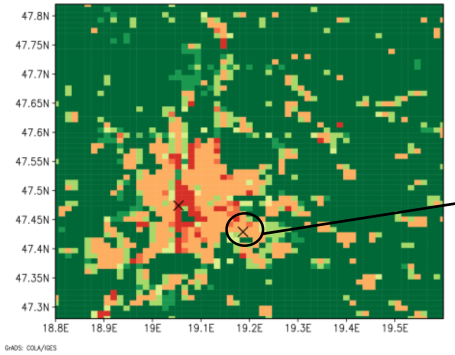
Results

Validation of 2-m temperature climatology of SURFEX-ARP for 1971-2000

Seasonal mean temperature

Seasonal 2-m temperature in 1971-2000





Pestszentlőrinc

- Large overestimation in summer, which is partly inherited from the driving ALADIN-Climate model
- Summer warming trend is not captured

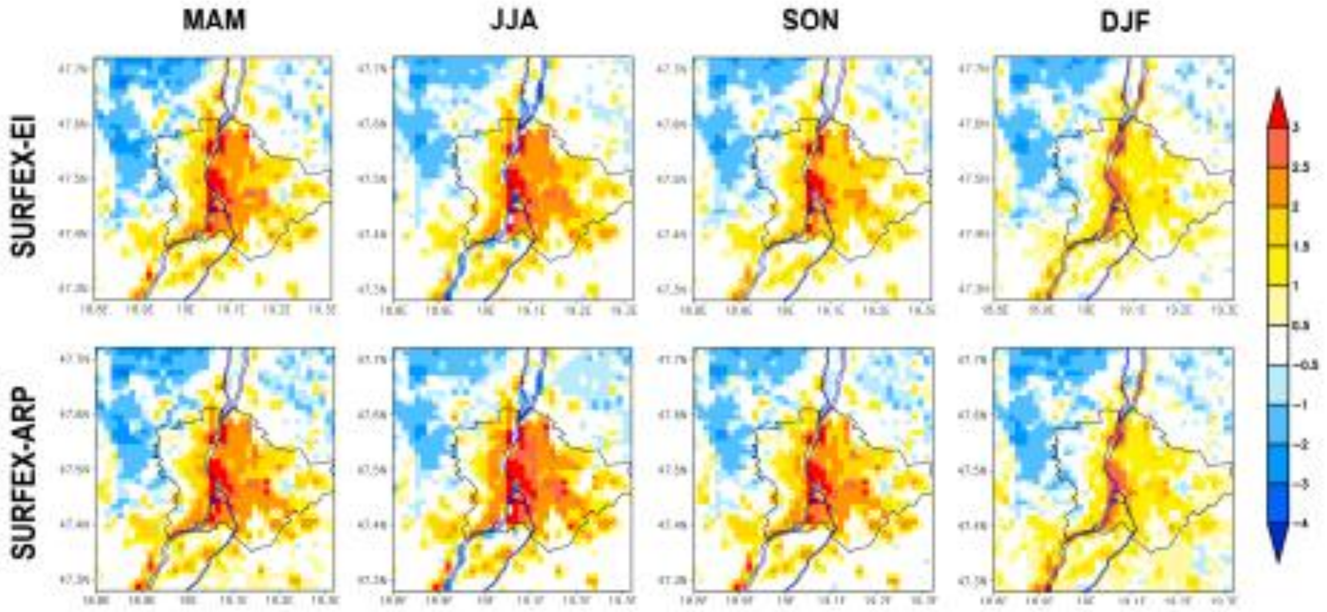
Seasonal mean bias (°C) of ALADIN and SURFEX with respect to CarpatClim-HU in 1971-2000 over the SURFEX domain

	MAM	JJA	SON	DJF
ALADIN-ARP	-2.0	2.9	-0.7	-2.0
SURFEX-ARP	-1.2	3.0	0.6	-0.7

Results

Comparison of SURFEX-ERAI and SURFEX-ARP for 1996-2005

Urban Heat Island at 0 UTC

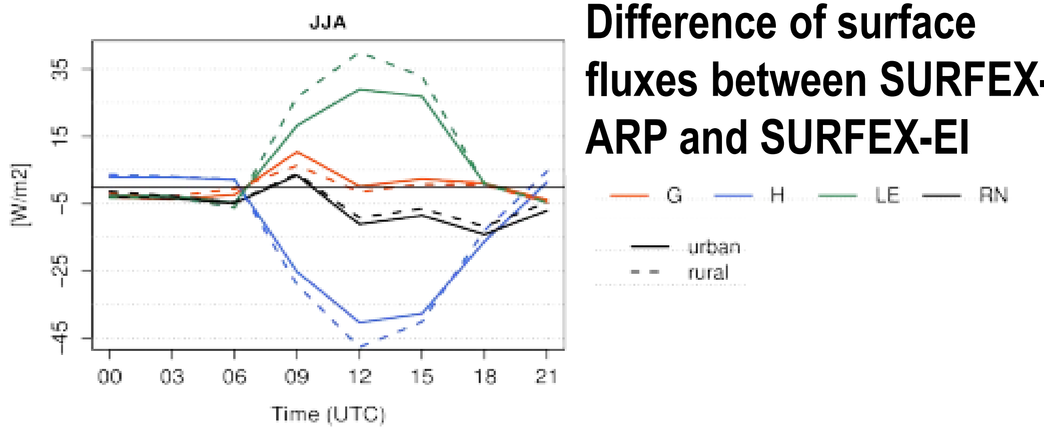


$UHI_i = (T_u)_i - (\overline{T_n})_i \quad i: gridpoints$

- UHI is slightly more intensitve in SURFEX-ARP from spring to summer
- Larger differences in 2-m temperature bias

Temperature bias with respect to CarpatClim-HU

	MAM	JJA	SON	DJF
SURFEX-EI	-0.9	1.0	0.5	0.4
SURFEX-ARP	-1.5	2.5	1.4	0.9



Difference of surface fluxes between SURFEX-ARP and SURFEX-EI

Possible reason of heavier UHI in SURFEX-ARP:

- More heat (G) is absorbed in the morning hours in SURFEX-ARP and more is emitted at night

Main conclusions from validation studies

- Spatial extention of surface UHI is heavily overestimated in SURFEX both day and night → *lack of modelling the full boundary layer, canyon concept for all urban gridpoint*

- At summer daytime surface temperature is less warm over Buda than Pest (hilly, green area) → *urban and natural areas are treated separately in the model (e.g. no shading effect)*

- 2-m temperature is better described by SURFEX than surface temperature → *lot of approximations and uncertainties in LST validation, but 2-m temperature was validated in one gridpoint*

- The driving regional climate model has a large impact on the behaviour of the land surface model, but the latter can eliminate the RCMs biases

- 2-m temperature bias is mainly eliminated when UHI is computed

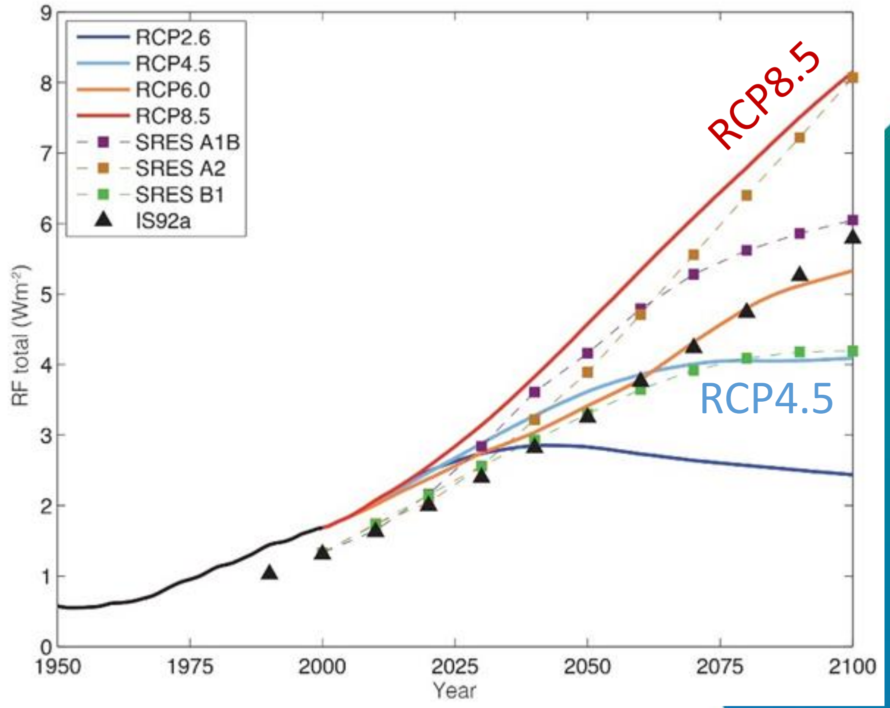
Future urban climate simulations

Urban climate projections

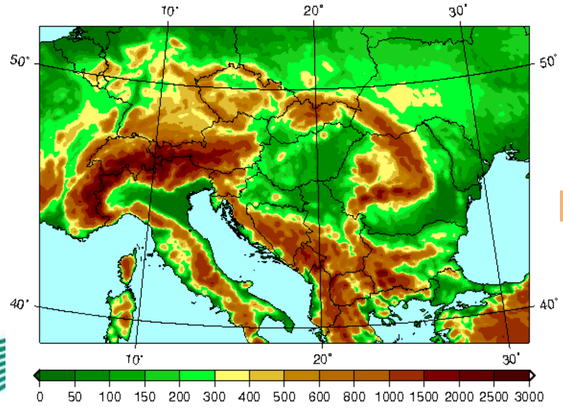
	Forcings	Period
PROJECTION	ALADIN5.2_CNRM-CM5_RCP8.5	2006-2100
	ALADIN5.2_CNRM-CM5_RCP4.5	2006-2100

Simulation method is the same that applied for validation:

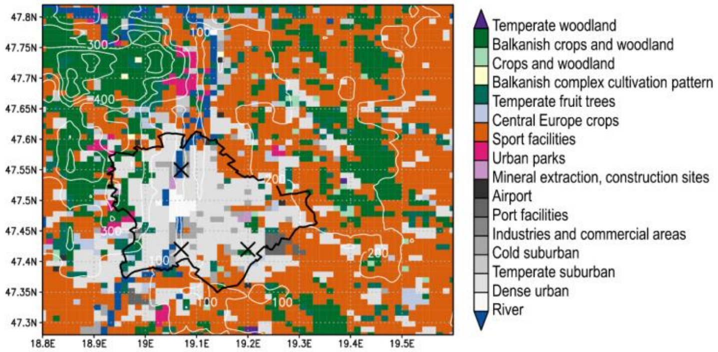
Anthropogenic scenarios



Domain of ALADIN

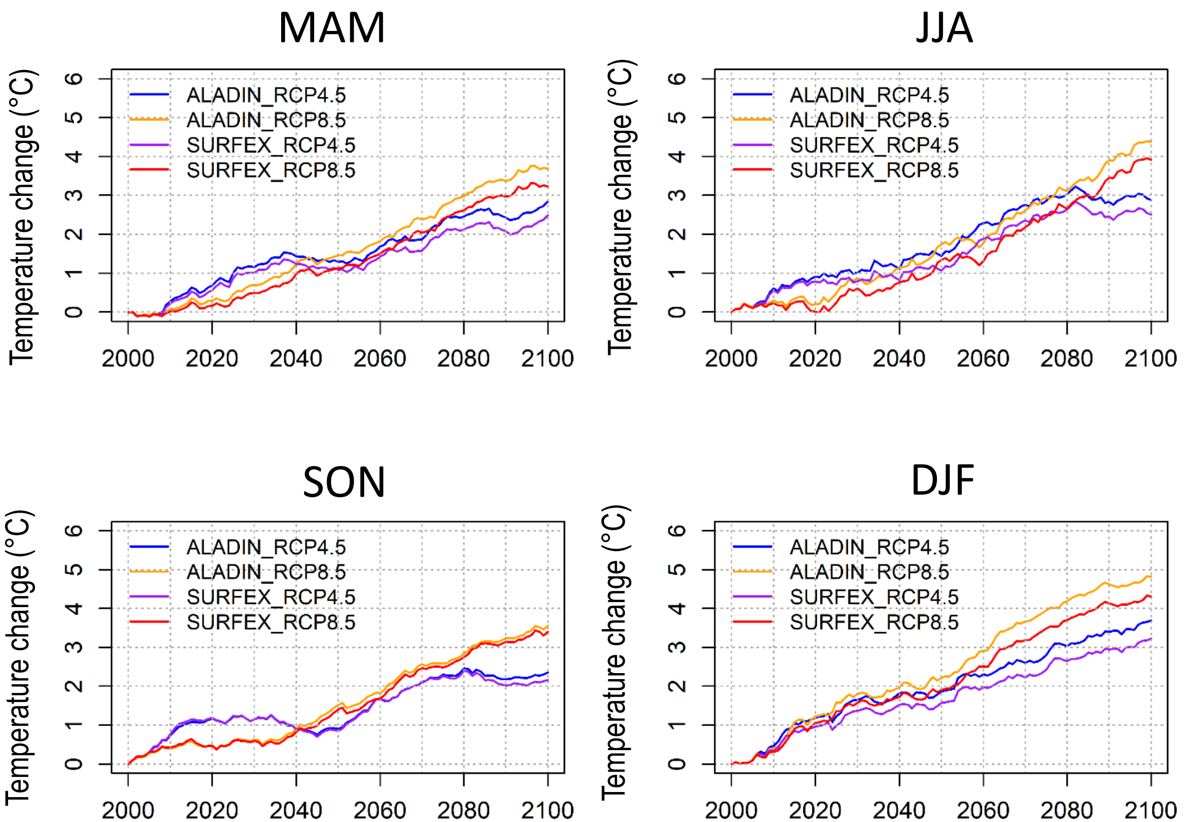


Domain of SURFEX



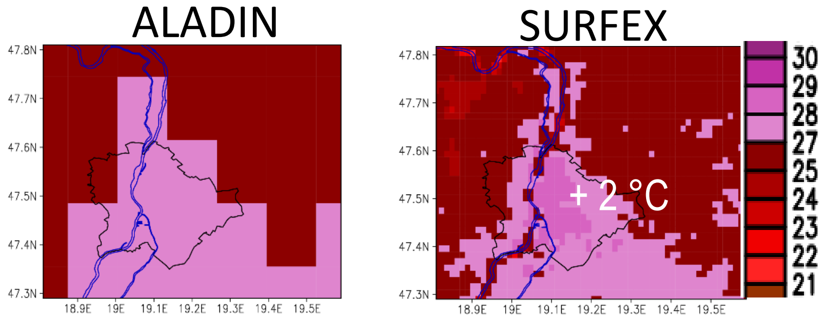
- Evaluation period: 2021-2050 and 2071-2100
- Reference: 1971-2000

Comparing SURFEX and ALADIN for temperature projections



- Largest warming is expected in winter (in 2071–2100 3.2-4.3 °C)
- Temporal evolution of warming is similar in the RCM and LSM, but SURFEX projects lower temperature increase compared to ALADIN → but the city remains warmer in the future as well

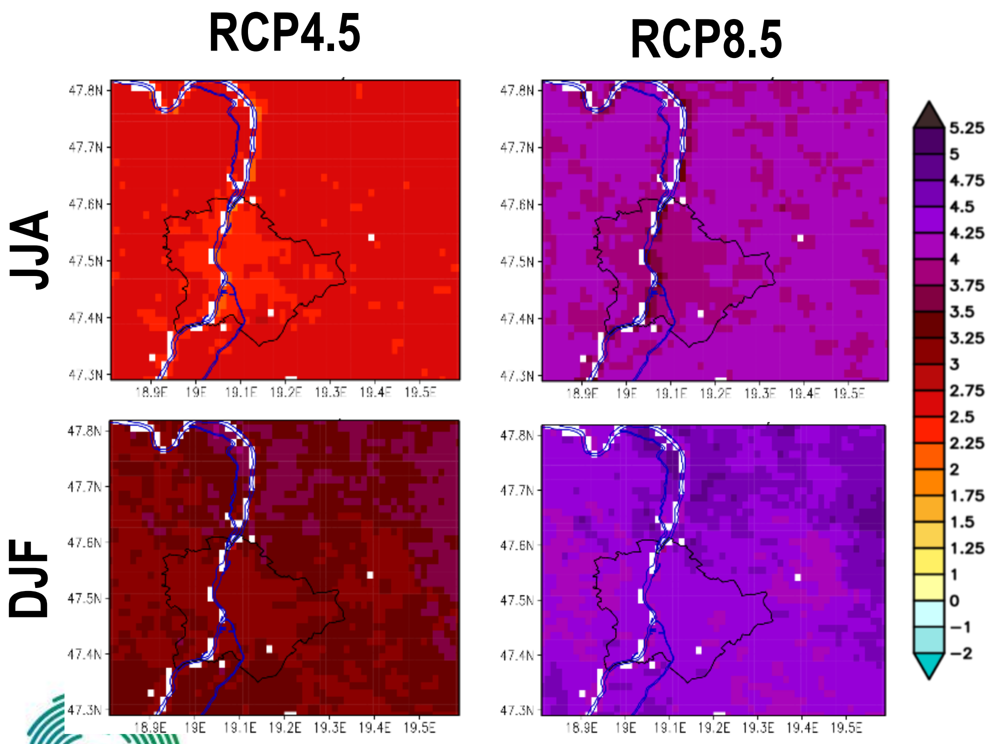
Mean temperature in 2071–2100 summer



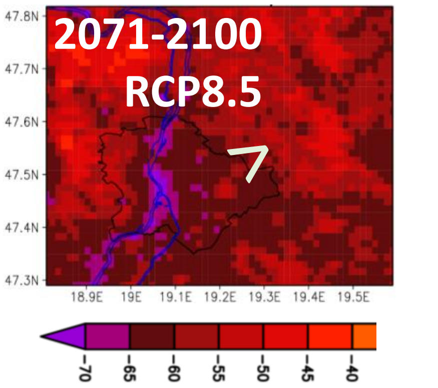
Allaga-Zsebeházi, 2021 (accepted)

Comparing temperature change over the urban and rural areas in SURFEX

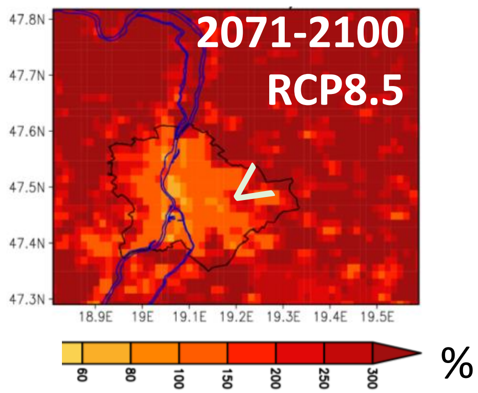
Temperature change (°C) in 2071–2100



Relative change of frost days (Tmin < 0 °C)



Relative change of tropical nights (Tmin > 20 °C)

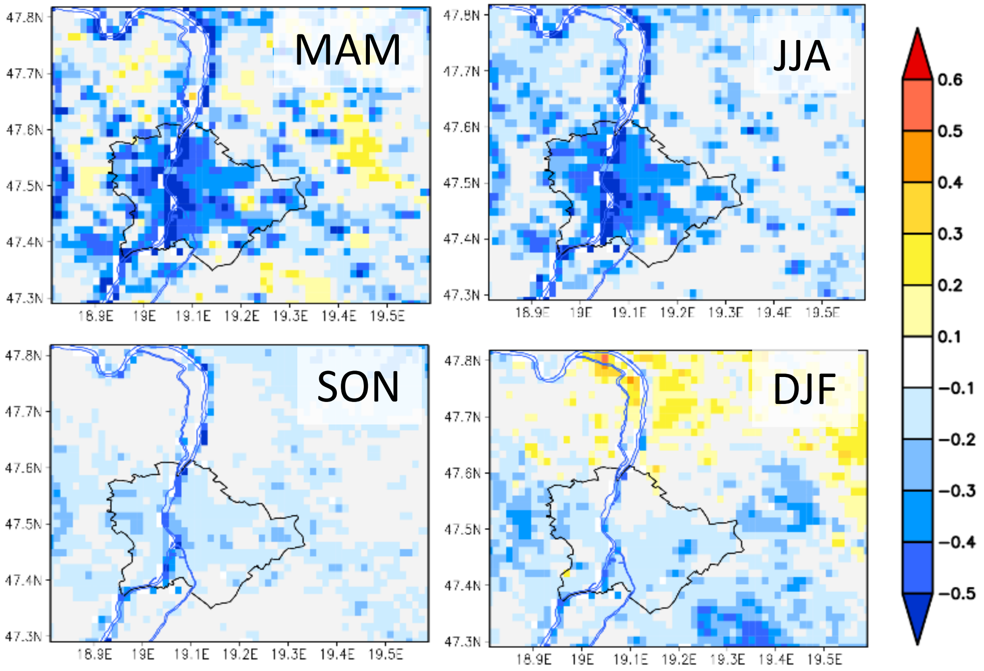


- More moderate warming over the city especially at summer (0.25 °C difference)
- Frost days relatively change more in the city center, while tropical nights change less compared to the outer parts of the city and the rural areas

Allaga-Zsebeházi, 2021 (accepted)

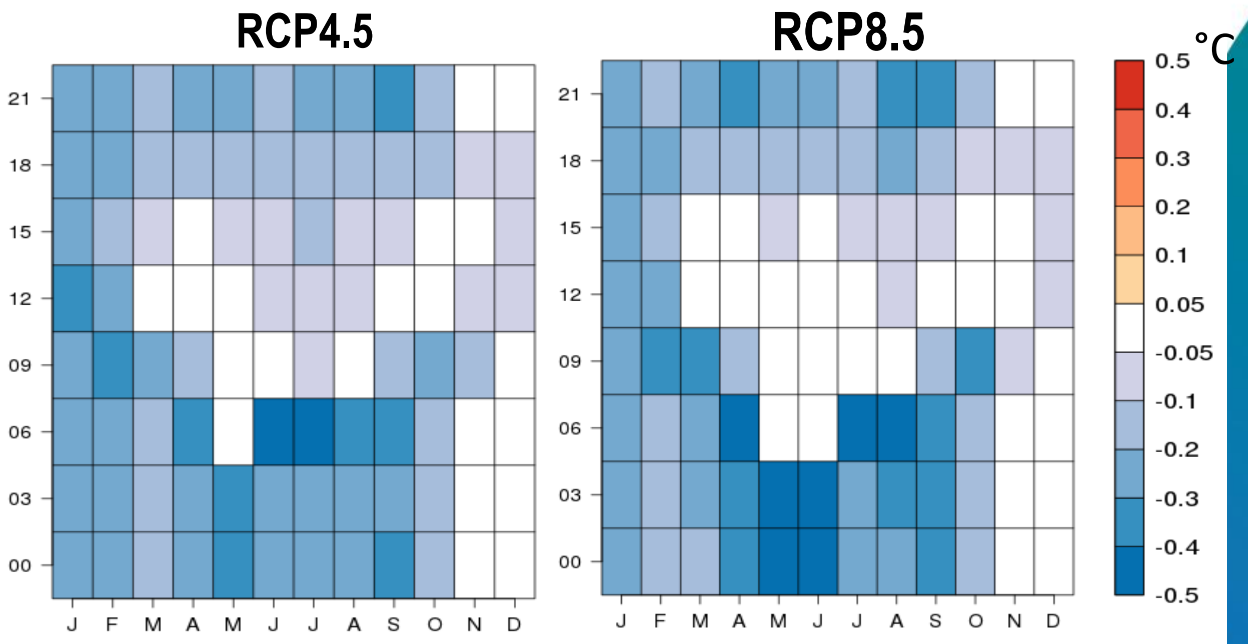
Future change of urban heat island

UHI change at 0 UTC
2071-2100 (RCP8.5)



$$UHI_i = (T_u)_i - (\overline{T_n})_i$$ *i : gridpoints*

Monthly mean change of 3-hourly UHI in 2071-2100



- Nocturnal UHI intensity will slightly decrease in the future, mostly in spring and summer
- In daytime the UHI remains invariant (except winter)

Allaga-Zsebeházi, 2021 (accepted)

Main conclusions from projection studies

- SURFEX projects smaller temperature change over the city compared to ALADIN
- More moderate warming in the city center, decreasing UHI intensity in the future
- Some climate indices change less in the city center than in the outer regions

How to present and communicate these results?

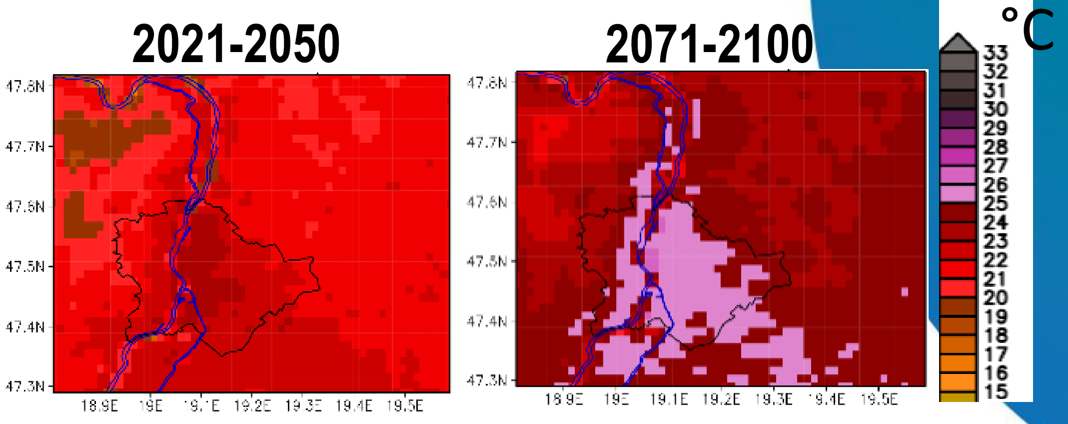
- Regional climate projection results are presented in the form of
  - Mean changes → urban projection: may not raise enough attention of decision makers
  - Bias adjusted values → high resolution observation that shows realistically urban climate is needed

Post processing of urban climate projections

- In order to the users properly interpret and use the SURFEX' results, they are subjected to post-processing (bias correction)
- In the lack of high resolution gridded urban observation dataset the following method is applied:
  - Mean ALADIN fields are corrected with the delta change method using CarpatClim-HU + SURFEX „urban sign" is added
  - E.g., for temperature:

$$\bar{T}_{corr} = \underbrace{(\bar{T}_{RCM,f} - \bar{T}_{RCM,p}) + \bar{T}_{obs,p}}_{\text{Bias adjustment of ALADIN}} + \underset{\substack{\downarrow \\ \text{SURFEX urban sign}}}{UHI_f}$$

Corrected summer mean temperature



Allaga-Zsebeházi, 2021 (accepted)

Other ongoing activities and future plans

- Corrected urban climate projections (temperature and temperature indices) are implemented in the KLIMADAT database
- (KLIMADAT: interactive web-based GIS platform that will contain climate projections and observations → dedicated for climate data users (planners, stake holders)
- Evaluate climate projections for Szeged in order to investigate the impact of climate change on different cities

- Use other RCM (REMO) to force SURFEX → taking into account the uncertainty source of regional climate models as well
- LIFE in RunOff project: provide SURFEX data for urban vulnerability studies and perform sensitivity studies for different urban adaptation options

Thank you very much for your attention

Special thanks to Sándor István Mahó, my co-author of the Atmosphere paper and Gabriella Szépszó, my PhD supervisor