Gabriella Zsebeházi

Investigating the urban climate characteristics of two Hungarian cities with SURFEX/TEB land surface model

Gabriella Zsebeházi and Gabriella Szépszó
Hungarian Meteorological Service, Budapest, Kitaibel Pál street 1, Hungary, zsebehazi.g@met.hu

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Abstract

Regional climate models are successfully applied to estimate future climate change over a region or country in detail, although they cannot represent the urban climate characteristics in lack of sufficient spatial resolution and a specific parameterization scheme over cities. At the Hungarian Meteorological Service (HMS) the externalised SURFEX land surface scheme including the TEB urban canopy model is used to describe the interactions between the urban surface and atmosphere on few km spatial scale. In our study, the atmospheric condition is provided by the ALADIN-Climate regional climate model adapted at the HMS. SURFEX is applied in standalone (offline) mode, thus the urban surface processes do not produce feedback for the atmospheric model. In the first step of our research, a detailed validation is achieved to understand how the urban scheme modifies the forcing fields, and what the sensitivity of the SURFEX is to the ALADIN biases. Model experiments are conducted for 1991–2000 over two Hungarian cities: Budapest is the capital with 2 millions inhabitants and the smaller Szeged is located at the flat southern part of the country. In this study, temperature results of SURFEX and ALADIN are investigated and compared with measurements.

1. Introduction

Surface characteristics of urban areas substantially differ from the natural surfaces, hence different physical processes are dominant over these surfaces (*Oke*, 1987). For example longwave outgoing radiation is trapped in densely built-in city cores, energy is stored in buildings with high effectiveness, latent heat is reduced for the benefit of sensible heat due to the extended impervious surfaces, etc. These urban climate features result that inhabitants in the cities tend to be exposed to the climate change with higher degree.

Regional climate models are sufficient tools for estimating future climate change of a region or a country. Although due to their typical resolution (in general 10–50 km) and their simplified methods for describing the atmosphere – urban surface interactions, these models alone are not suitable for urban climate impact study applications.

SURFEX scheme (*Le Moigne*, 2009) is a state-of-the-art land surface model, which can be used for investigating mesoscale climate change impacts in cities thanks to its sub-model, Town Energy Balance physical parameterization scheme (*Masson*, 2000) operating over urban areas.

At the Hungarian Meteorological Service, studies over urbanized areas have been started using the SURFEX/TEB (hereafter referred to as SURFEX) model coupled to the ALADIN-Climate (hereafter referred to as ALADIN) regional climate model (*Csima and Horányi*, 2008). The main aim is to downscale the future climate projection results of ALADIN over some Hungarian cities to help decision making in urban adaptation based on scientifically reasoned climate data. As a first step, simulations are performed over 10-year past periods in order to assess the model's behavior, performance and added value to its driving model. The objective of the recent work is to show validation results focusing on temperature and urban heat island (UHI) results of the ALADIN and SURFEX models over two Hungarian cities, the capital, Budapest and a town in South-Eastern Hungary, Szeged.

2. Models and methods

SURFEX (Surface Externalisée) is an externalised (i.e. it can be applied in a stand-alone mode with different couplings) land surface model, that was developed in the Météo France. It simulates surface-atmoshere interactions over four different surface types, namely natural land surface, inland water, sea and town. Over urban surfaces the TEB (Town Energy Balance) scheme operates, which follows canyon approach, thus cities are simplified as roads with buildings on their two sides and any direction of streets has the same probability. TEB distinguishes roofs, walls and roads with separate energy and moisture budget. The anthropogenic heat and moisture fluxes derived from traffic, industry and domestic heating are also taken into account. SURFEX follows tiling approach, meaning that turbulent fluxes over different surfaces are computed by different schemes and their results are aggregated over each grid-cell.

In our experiment the physiographic information is obtained from the 1 km resolution ECOCLIMAP global database (*Masson et al.*, 2003), that was created from land cover maps, climate maps, Advanced Very High Resolution Radiometer (AVHRR) satellite data, and lookup tables. The atmospheric conditions (short-wave and long-wave radiation, surface pressure, temperature, humidity, horizontal wind components and precipitation) at 30 m above ground level are derived from the 10 km resolution ALADIN-Climate v5.2 results driven by ERA-40 reanalyses for 1991–2000 covering the Carpathian Basin (Fig. 1). We apply the 5.1 version of SURFEX in offline mode on 1 km resolution over two smaller domains (Fig. 1, covering Budapest and Szeged (with 61x61 and 25x25 gridpoints, respectively). Over natural surfaces the ISBA (*Noilhan and Planton*, 1989) scheme operates and the boundary layer processes are calculated explicitly with the Surface Boundary Layer Scheme (also known as CANOPY model; *Hamdi and Masson*, 2008).

In this study we focus on the spatial characteristics and temporal evolution of 2-m temperature and urban heat island effect (i.e., temperature difference between an urban and rural points) described by SURFEX. Moreover, we assess the added value of the detailed physical scheme to the driving atmospheric model. Validation is achieved with long-term station measurements over two-two selected gridpoints (Fig. 2), representing the urban and rural conditions for both case study areas. In Budapest the drawback of the selected points is that both are described as temperate suburban (composed of 60% town and 40% nature) by the ECOCLIMAP, and the inner point locates close to the Buda Hills. Szeged is situated in the Southern Great Plain Region, where higher elevated orographic objects (hills or mountains) cannot be found in the vicinity of the town. The surroundings of its inner observational site are also categorized as temperate suburban, but the outer point is a true rural point without urban contamination.

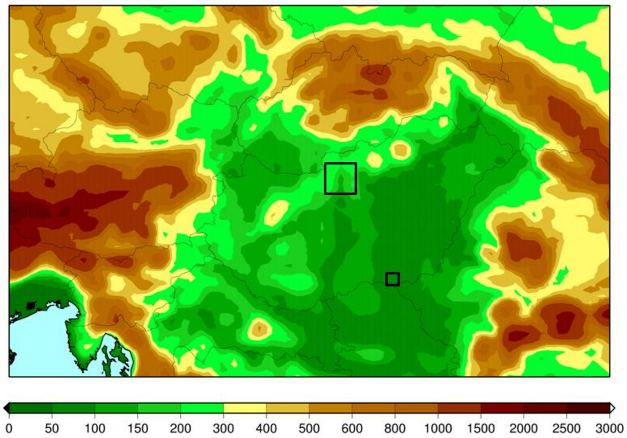

Fig. 1. Integration domain of ALADIN. Squares indicate the domain of SURFEX offline run over Budapest (Central Hungary) and Szeged (South Eastern Hungary).

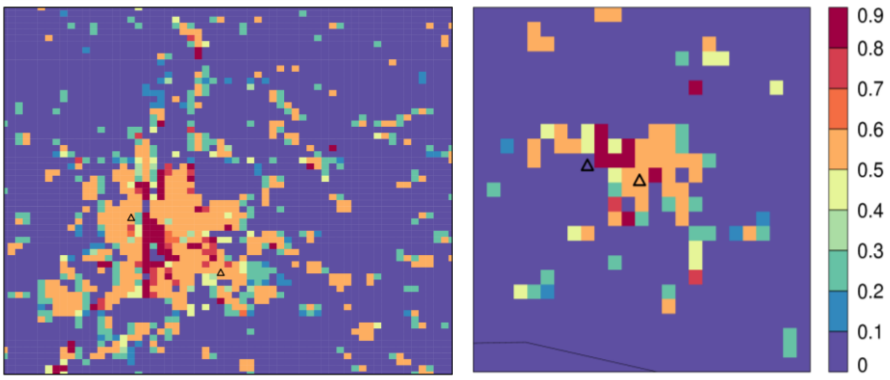

Fig. 2. Fraction of town category in gridcells according to ECOCLIMAP in Budapest (left) and Szeged (right). The triangles represent the validation points.

3. Results

3.1 Added value of SURFEX to ALADIN-Climate

The finer resolution and the detailed physical parameterization scheme used over the urban tiles in SURFEX simulations lead to more realistic results in the 2-m temperature fields (for Budapest see Fig. 3). One may notice that the city centre is warmer with approximately 2 °C in summer 1991–2000 compared to the rural areas, while the northwestern part of the city is characterized by lower temperature values due to elevated orography. The diurnal and annual characteristics of UHI (the most robust UHI occurs in the summer months at night time; in winter the daily cycle of UHI is more flat) are also reflected in the results (not shown).

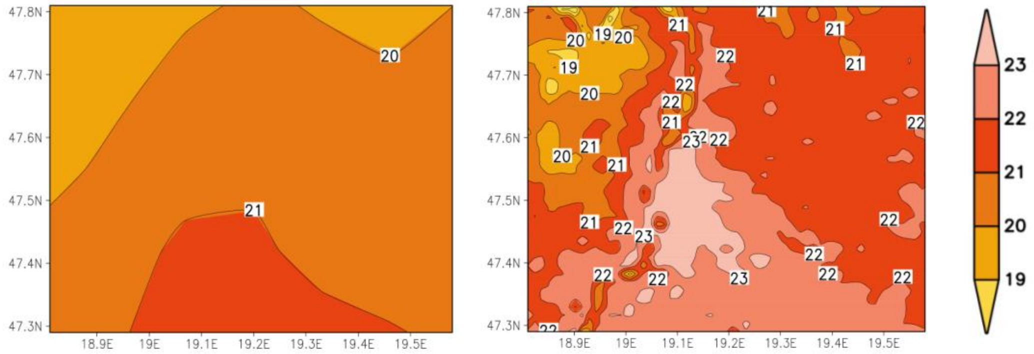

Fig. 3. Summer mean 2-m temperature (in °C) in Budapest simulated by the ALADIN on 10 km resolution (on the left) and the SURFEX on 1 km resolution (on the right) in 1991–2000.

3.2 Temperature and UHI in Budapest

Left panel of Fig. 4 shows the monthly mean 2-m temperature bias for the two reference points from the ALADIN results interpolated to the 1 km resolution grid and SURFEX. ALADIN underestimates the temperature in every month over both gridpoints, with the largest bias (reaching 3-5 °C) over the inner point in January, April and October. SURFEX adds extra heating to the ALADIN fields in every month, however the amount of this temperature surplus is approximately the same in the two locations. The reason for that is that ECOCLIMAP identifies both gridpoints with the same (temperature suburban) cover type. Consequently, SURFEX cannot change the relation of the bias in the two points, which results in negative urban heat island effect throughout the whole year (right panel). The classification of the two reference points is not appropriate in ECOCLIMAP, since according to the measurements the inner point is warmer than the outer point with 0.5-1 °C on average.

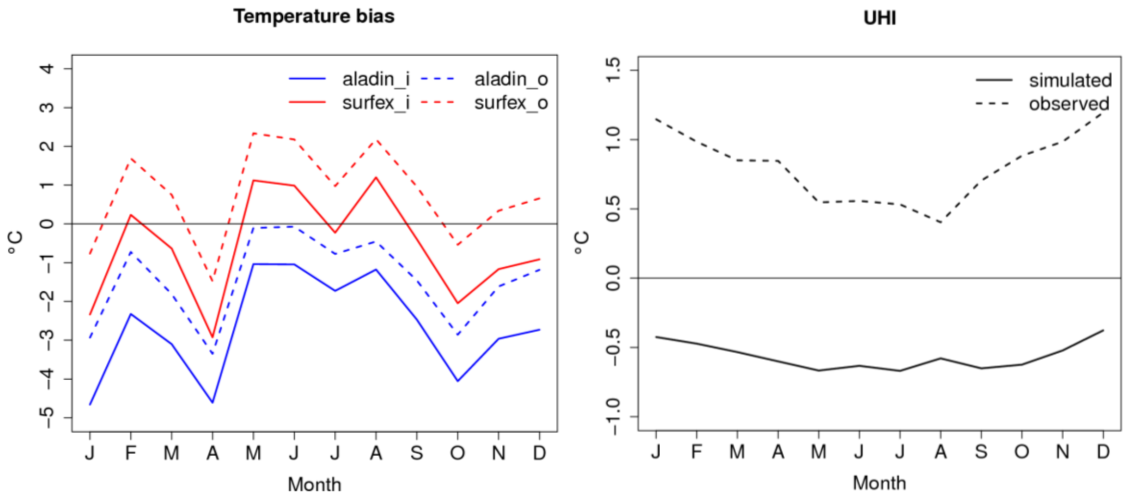

Fig. 4. On the left: monthly mean 2-m temperature bias (in °C) of the ALADIN (blue) and SURFEX (red) in 1991–2000 with reference to homogenized station measurements in the inner (solid line) and outer (dashed line) points. On the right: monthly mean urban heat island intensity (in °C) according to the measurements (dashed line) and SURFEX simulation (solid line) in 1991–2000.

3.3 Urban Heat Island in Szeged

Although Szeged is a much smaller town than Budapest (its total area is approximately half of Budapest), investigating its UHI characteristics is especially engaging, due to its favourable location (on flat area), which eventuates that the evolution of UHI is solely resulted by the town characteristics. Mean spatial UHI intensities were computed as the mean difference between the temperature of each gridpoint and of a reference gridpoint closest to the rural observational site. According to the SURFEX simulations, the city centre is warmer up to 1 °C in summer 1991–2000 (Fig. 5), that is the highest surplus amongst each season.

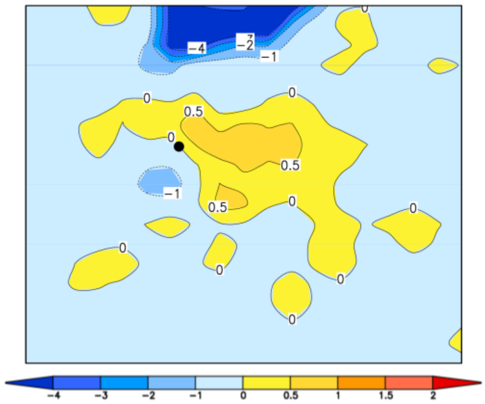

Fig. 5. Summer mean UHI (in °C) over Szeged simulated by SURFEX for the period of 1991–2000. Reference rural gridpoint is marked with a black point.

Climatological measurements in the city centre started in May 1998, which means that the validation of the model results can only be achieved for two complete years (1999–2000). Left panel of Fig. 6 presents the monthly mean 2-m temperature bias of ALADIN and SURFEX in the reference inner and outer gridpoints. The monthly variability of the bias is very similar to the one revealed over Budapest, however in summer ALADIN loaded with positive bias over Szeged. One very prosperous outcome of the location of the measurement sites is that since the outer point is a true rural site, SURFEX warms the temperature in urban point with larger amount. As a result the bias over the two gridpoints becomes very similar in the SURFEX results, which leads to a better estimation of UHI in Szeged (right panel).

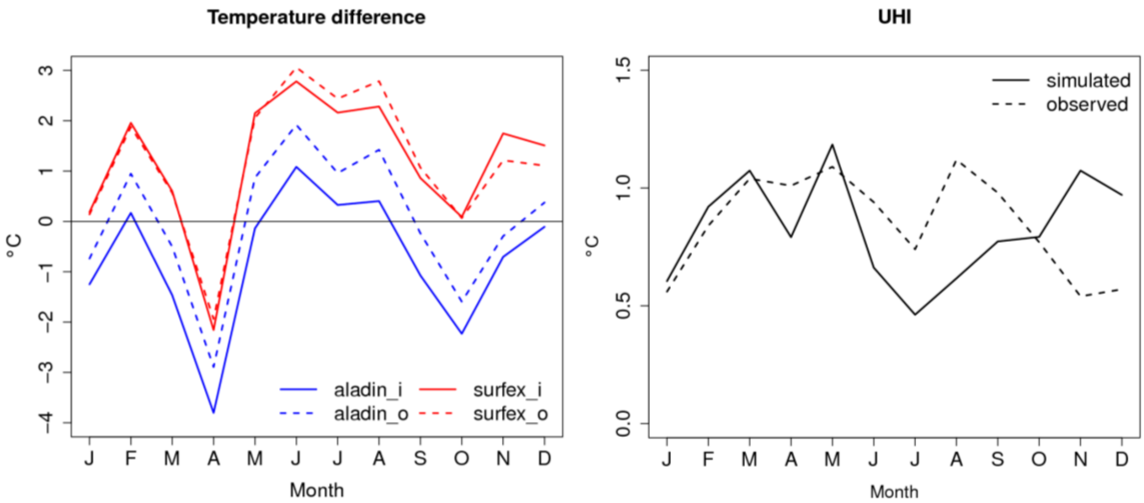

Fig. 6. On the left: *monthly mean temperature bias (in °C) of the ALADIN (blue) and SURFEX (red) 2-m temperature in 1999–2000 with reference to station measurements in the inner (solid line) and outer (dashed line) points. On the right: monthly mean urban heat island intensity (in °C) according to the measurements (dashed line) and SURFEX simulation (solid line) in 1999–2000.*

The simulated daily variability of the UHI between the inner and the outer point varying throughout the year in 1991–2000 is shown on Fig. 7. It can be stated that SURFEX is able to reproduce the theoretical daily evolution of UHI. The largest positive difference, that is 1.8-2.2 °C, between the two points occurs in the nocturnal hours from May to September (however in July it is slightly reduced). On the contrary, in the late mornings of summer and autumn the outer point can be warmer than the inner one, since the city is warming more slowly due to the larger heat capacity of urban surfaces and the urban canyons form obstacles for low sun-rays. In December and January UHI remains positive all day, however the maximum intensities are much lower than in summer.

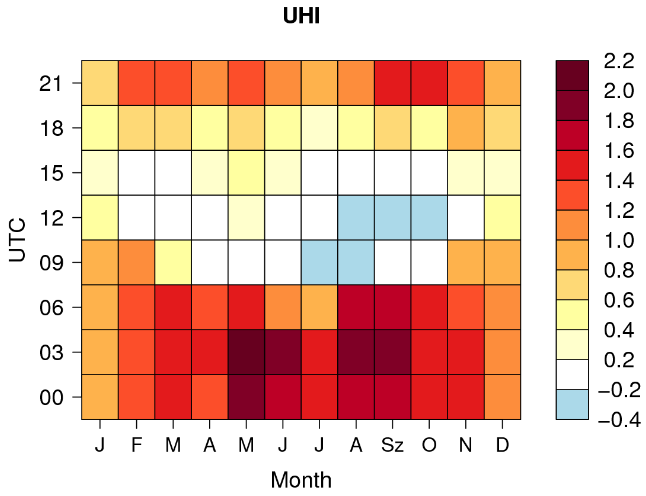

Fig. 7. Annual and daily cycle of UHI intensity (°C) between the two selected points in Szeged simulated by SURFEX in 1991–2000.

4. Summary and conclusions

At the Hungarian Meteorological Service dynamical urban climate research is conducted with the SURFEX land surface model that includes specific parameterization scheme (TEB) for describing interactions between urban surfaces and atmosphere. The atmospheric conditions are prescribed by the 10 km resolution ALADIN-Climate regional climate model, adapted at the HMS. As a preliminary study we performed 10-year simulations for 1991–2000 with SURFEX coupled to the ALADIN in a stand-alone (offline) mode over two Hungarian cities, Budapest and Szeged, and investigated the added value of SURFEX to the ALADIN through temporal and spatial characteristics of 2-m temperature and UHI. The validation of the models was achieved using homogenized timeseries of two-two measurement sites representing the urban and rural conditions as reference.

We concluded that SURFEX is able to simulate the characteristics of specific climatology typical over urban areas, especially for Szeged: e.g. the city core emerges from its surrounding area with higher temperature mostly at summer nights. Comparing the monthly mean temperature results with measurements, it was revealed that ALADIN is featured with considerable (and mostly negative) errors in certain months. Due to the identical cover type of the two selected gridpoints provided by ECOCLIMAP over Budapest, SURFEX warms both points equally, which leads to negative UHI values all year. In the last 15 years, more urban climate measurement sites have been settled in the city centre allowing to choose a more representative reference points; it may contribute to the better understanding of climate of Budapest and more complete validation of SURFEX. The location of the reference points in Szeged is much more favorable, where SURFEX provides more realistic UHI results for the investigated 2 years.

In the following steps we intend to perform a detailed sensitivity analysis regarding the model settings and surface parameters in order to better understand the behavior of SURFEX and its interaction with its forcings, and to find the most proper model set-up suitable for our purposes in the future climate change experiments.

References

Csima, G. and Horányi, A., 2008: Validation of the ALADIN-Climate regional climate model at the Hungarian Meteorological Service. *Időjárás,* **112**, 155–177.

Hamdi, R. and Masson, V., 2008: Inclusion of a Drag Approach in the Town Energy Balance (TEB) Scheme: Offline 1D Evaluation in a Street Canyon. *J. Appl. Meteor. Climatol.,* **47***,* 2627–2644*.*

Le Moigne, P., 2009: *SURFEX Scientific Documentation*. Note de centre (CNRM/GMME), Météo-France, Toulouse, France. 211p.

Masson, V., 2000: A Physically-based Scheme for the Urban Energy Budget in Atmospheric Models. *Bound.-Layer Meteor.*, **94**, 357–397.

Masson, V., Champeaux, J.-L., Chauvin, F., Meriguet, C. and Lacaze, R., 2003: A global database of land surface parameters at 1km resolution in meteorological and climate models. *J. Climate*, **16**, 1261–1282.

Noilhan, J. and Planton, S., 1989: A simple parameterization of land surface processes for meteorological models. *Mon. Wea. Rev.,* **117**, 536–549.

Oke, T. R., 1987: *Boundary Layer Climates*, chapter 8. Routledge, 2nd edition, 262–303.