SENSITIVITY STUDY FOR SZEGED, HUNGARY USING THE SURFEX/TEB SCHEME COUPLED TO ALARO

Report from the Flat-Rate Stay at the Royal Meteorological Institute, Brussels, Belgium

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Gabriella Zsebeházi
Hungarian Meteorological Service
Budapest, Hungary

Supervisor:

Rafiq Hamdi
Royal Meteorological Institute
Brussels, Belgium

Introduction and purpose of the Flat-Rate Stay

In October 2014, for the first time I spent three weeks at the Royal Meteorological Institute (RMI), in Brussels, Belgium where in collaboration with Rafiq Hamdi we started to work on the sensitivity analysis of SURFEX land surface model focusing on its capability for simulating urban heat island in Szeged (Hungary) on a heat wave day in 2010. SURFEX is applied for urban climate impact studies at the RMI and also at the Hungarian Meteorological Service (HMS). At HMS the atmospheric forcings are derived from the hydrostatic, 10 km resolution ALADIN-Climate regional climate model. At the RMI SURFEX is driven with the fine resolution (4 km) ALARO numerical weather prediction model (operating in the grey-zone) applied also for climate simulations. The main objective of the first Flat-Rate Stay was to investigate different model set-up of SURFEX driven by ALARO. Moreover we intended to get an insight into how SURFEX coupled to ALARO (with very fine resolution and detailed physical parameterizations) performs over a Hungarian city in a summer day. For that purpose, we carried out short, 1-day simulations with the following features:

1. Atmospheric forcing at 4 km and 10 km resolutions;
2. Atmospheric forcing prepared with and without the TEB urban scheme;
3. Coupling of forcings on 3 hour and 1 hour temporal frequencies;
4. Different forcing levels on 50 m, 40 m, 30 m, 20 m, 10 m;
5. Different computation method of 2-m temperature using CANOPY, Paulson, and Geleyn schemes (CANOPY scheme calculates 2-meter temperature from prognostic equation on this level, while Paulson and Geleyn methods apply a formula based on the temperature of the lowest model level and the surface fluxes, surface temperature, respectively. These two diagnostic schemes are incorporated in the ISBA module, while in TEB the diagnostic CANYON scheme assumes uniform air temperature within the canyon and computes canyon air temperature from temperature of the lowest model level and of wall and road and takes into account the anthropogenic heat flux as well).

From these investigations we concluded that

- Stronger UHI intensity was obtained with the diagnostic (Geleyn, Paulson) schemes for calculating 2-m temperature compared with the CANOPY scheme (and this more intensive UHI is closer to the observations)
- The more frequent forcing update caused amelioration in the strength of UHI intensity after sunset
- Using the TEB scheme in ALARO resulted in slightly higher and more realistic UHI intensities in the end of the day
- Changing the resolution of atmospheric forcings and the forcing level heights affected the SURFEX results only little.

On the following stay we intended to continue the sensitivity analysis with SURFEX coupled to ALARO. First, we tried to answer some questions that arose previously. Then in the majority of our time we focused mostly on the uncertainties coming from the physiographic information.

1. Impact of different initialisation methods in SURFEX offline run

At the RMI climate simulations are performed with 36-hour ALARO integration reinitialised each day (and neglecting outputs from the first 12 hours), however soil temperature and moisture are let freely evolve. Consequently, SURFEX is applied with the daily reinitialisation method as well, with provision of initial values for prognostic equations and temperature profiles. We extended our interest to a 5-day long heatwave event (13–17 July 2010); choice of the period was motivated by the fact that heat waves are not accompanied by precipitation events making temperature investigations more simply. SURFEX simulations were coupled to the 10 km resolution ALARO run without TEB, over the same domain as previous (Szeged, Hungary; Fig. 1). Six simulations with different computation methods for 2-m temperature and different running methods – namely: (1) SURFEX reinitialised each day at 00 UTC, and (2) SURFEX initialised only at 00 UTC on the first day and run continuously with concatenated ALARO forcings – were achieved.

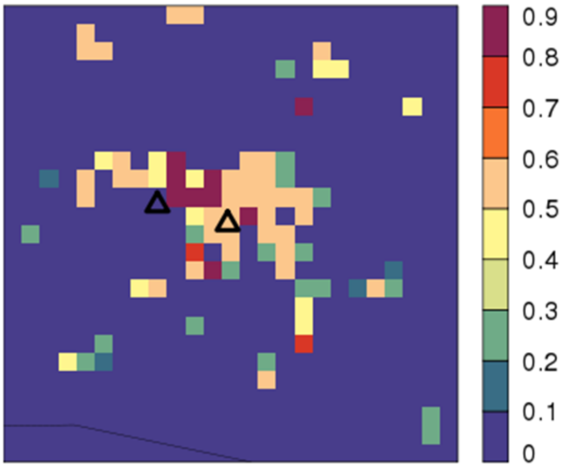


Fig. 1. Fraction of urbanized areas in gridpoints according to the ECOCLIMAP over the SURFEX domain consisting of 25x25 gridpoints (northeastern co-ordinates: lon=20.30, lat=46.35; southwestern co-ordinates: lon=19.98, lat=46.14). The triangles mark the closest gridpoints to the urban and rural observational stations.

Figure 2 shows the evolution of urban heat island between two gridpoints (dedicated to represent urban and rural conditions; see Fig. 1) according to the different model simulations. If TEB is activated in ALARO, the initial conditions for offline TEB (roof, wall and road surface temperature, internal road and building temperature, soil water interception for road and roof reservoir) are provided by ALARO outputs, hence variables of TEB are physically consistent with the forcings already in the beginning of the run. However in the other case, when ALARO runs without TEB (as in our case), the initial values have to be prescribed manually. It causes some imbalances between the forcings and TEB variables, and results fake UHI values in the beginning of the run. It turned out that TEB – especially if 2-m temperature is computed with the diagnostic CANYON scheme – needs approximately six hours to reach its balance. Since we started our model simulations at 00 UTC, the first six hours' "garbage information" is a big loss regarding urban heat island (since UHI is the most intensive during night). In our 5-day experiment we concluded that if the forcing for SURFEX is derived from a daily reinitialised atmospheric model which does not include TEB, SURFEX should be run continuously with initialisation at the beginning of the simulation only. If TEB is activated also in the atmospheric model, daily reinitialisation does not cause problems in the results.

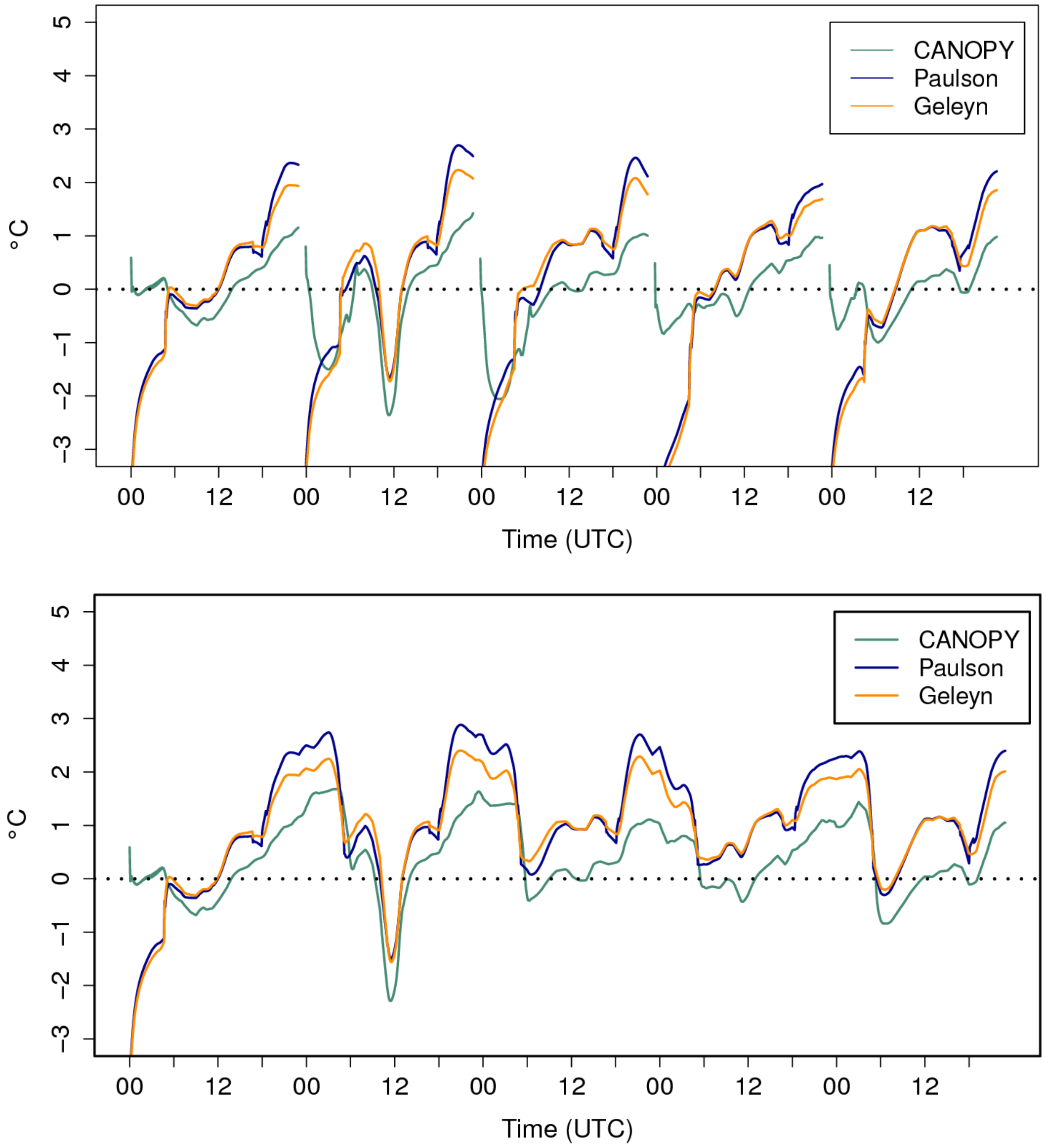


Fig. 2. UHI intensity (in °C) between two reference gridpoints (suburban and rural) simulated by SURFEX for 13–17 July 2010. 36-hour ALARO runs were reinitialised each day at 12 UTC; SURFEX was initialised each day at 00 UTC (top), only on the first day and was run continuously (bottom). Forcings were updated in every hour, TEB was not activated in ALARO. 2-m temperature was computed with the CANOPY scheme (green) and with two diagnostic schemes, Paulson (blue) and Geleyn (yellow).

In the next step we investigated the effect of initialisation timing on urban heat island. *De Ridder* (2009) suggests that spin up time of the land surface schemes highly depends on the initialisation time. To reach equilibrium at the fastest rate, the initialisation time should coincide with the time of maximum heat flux, which is around noon. To test this hypothesis, we achieved two 12-hour offline SURFEX simulations, initialised at 12 UTC, using diagnostic and prognostic calculation methods for 2-m temperature. TEB was not activated in ALARO. It can be pointed out that due to the initialisation at 12 UTC, the spin-up time reduced from six hours to one hour with both schemes. (Fig. 3).

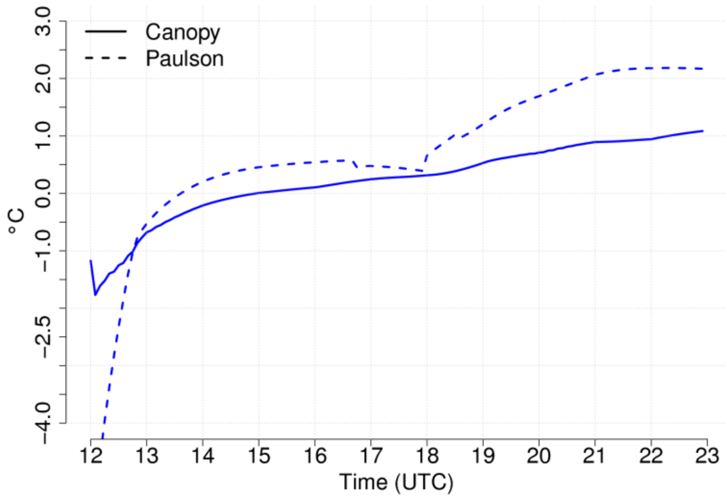


FIg. 3. UHI intensity (in °C) between two reference gridpoints (suburban and rural) simulated by SURFEX for 12 hours on 13 July 2010. SURFEX was initialised at 12 UTC. Forcings were updated in every hour, TEB was not activated in ALARO. 2-m temperature was computed with the CANOPY scheme (solid line) and with Paulson diagnostic schemes (dashed line).

2. Sensitivity study on physiographic information in SURFEX

Method

In the majority of our work we focused on the physiographic component of SURFEX. We intended to estimate the level of uncertainty coming from the imperfection of land surface cover data. The dominant urban cover type over Szeged is suburban (ID=153), thus we focused on it during the investigations. We supposed the following sources of errors:

1. According to the ECOCLIMAP physiographic database the fraction of town and nature in the suburban cover type is town : nature = 0.6 : 0.4. We performed several simulations with different town fractions from 0.1 to 0.9 by 0.1. The fraction values can be changed with the modification of mode_cover.f90 file in the surfex/pgd library and recompilation of SURFEX offline source code.

2. Another source of bias may arise during the interpolation of ECOCLIMAP data on the targeted domain. After interpolation, “mixed” gridcells are resulted, where two or more cover types are partially represented. Typically this occurs at city borders. We changed the fraction of suburban and crop (ID=172; Central European Crops) from 0.1 to 0.9 by 0.1 in a gridcell. Note that even if we set the fraction of suburban to 0.9, town covers approximately half of the gridcell, because the fraction of town in the suburban cover type is 0.6 (thus the fraction of town in the whole gridcell is 0.54). This task was achieved with the modification of the pgd.txt file created in the PGD step (getting the physiographic data for the targeted domain) of SURFEX running. The pgd.txt file contains physiographic information, amongst others longitude, latitude and fraction of cover types in each gridcell. We changed manually the fraction of suburban and crop covers in the chosen gridcell and rerun PREP (initialisation of SURFEX) and OFFLINE (SURFEX offline) steps. The same

investigations were performed over a suburban–forest (ID=205; Balkanish broad-leaf forest) mixed gridcell as well.

3. We supposed that uncertainty may arise from the wrong definition of urban cover type as well. Over Szeged altogether six urban cover types (dense urban, suburban, industrial and commercial areas, road and railway networks, urban park, sport facilities) are represented according to the ECOCLIMAP. We performed a sensitivity analysis by substituting the suburban cover type with each of the five covers in a gridcell. This can be achieved with the modification of pgd.txt file as well.

In all cases forcings were updated one hourly from the 4 km resolution ALARO simulations run with TEB, height of forcing level was set to 30 m. Since from our previous analysis we found that degree of different sensitivities largely depend on the calculation method applied for 2-m temperature, we doubled the number of simulations and performed two runs with CANOPY (prognostic) and CANYON (diagnostic) schemes. In all cases we estimated daily urban heat island intensity between two gridpoints. In the 1st and 3rd tasks we selected the reference suburban (co-ordinate: x=13, y=14) and rural (co-ordinate: x=9, y=15) gridpoints that are closest to the observational sites (see Fig. 1). In the 2nd task we chose a suburban-crop mixed gridpoint (co-ordinate: x=11, y=13) which is close to the abovementioned inner point, in order to provide the same (or very similar) forcing in each tasks. The investigated gridpoints of the suburban-forest case however are rather far from the reference points; their location is x=11, y=8 of the inner, and x=22, y=2 of the rural point. With the abovementioned precautions we are able to compare the uncertainties of urban heat islands derived from each tasks.

Results

Figure 4 presents the spread of UHIs if different fraction of town and nature within a suburban gridpoint is applied; the curves show the UHIs with the highest and lowest suburban fraction. We can conclude that the diagnostic scheme for 2-m temperature is more sensitive to the change of town fraction than the prognostic CANOPY scheme. Although increasing the town fraction results higher nocturnal urban heat island (approximately 1 and 2 °C at 23 UTC with prognostic and diagnostic schemes, respectively; Table 1), its impact on the urban point is different during the day: using CANYON method warmer urban point is obtained, while with CANOPY the opposite, correct behaviour is observed at midday. The daily UHI is negative according to the measurements.

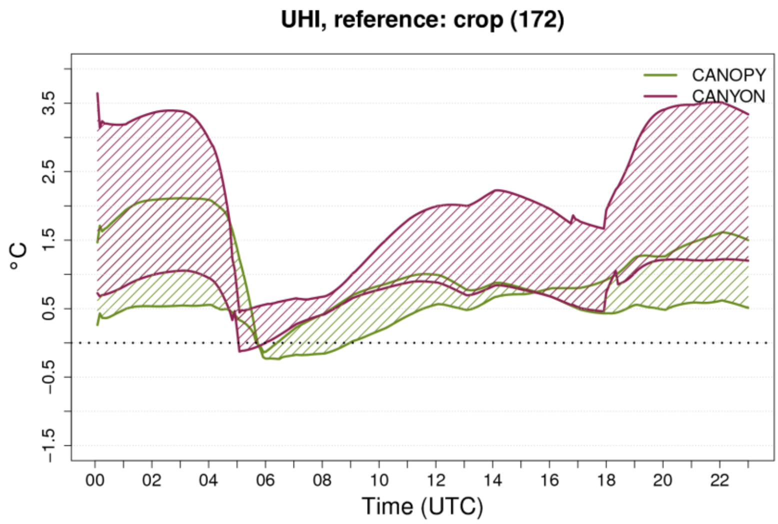
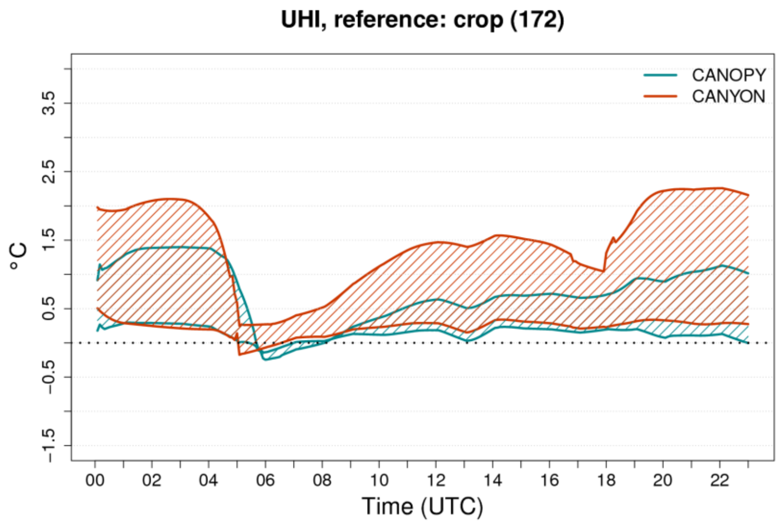


Fig. 4. Spread of urban heat island intensity (in °C) between two reference gridpoints on 15 July 2010, simulated by SURFEX with different fraction of town from 0.1 to 0.9 (same colour). 2-m temperature was computed with the CANOPY scheme (green) and diagnostically with the CANYON scheme in TEB (purple).

Level of uncertainty coming from the change of suburban and crop fractions and suburban and forest fractions can be seen on Fig. 5; the curves show the UHIs in case of the highest and lowest fraction of suburban. The UHI values and the spread are much smaller in these studies than in the former (as well as the next) experiments, especially when the focus was on suburban and forest fractions (at 23 UTC both the spread and UHI remain below 1^{o}C; Table 1). One may notice that the daily UHI evolution is substantially different in the crop and forest cases. Using CANOPY scheme, and increasing the town fraction while reducing the forest fraction in a gridcell, we succeeded to simulate the theoretical daily UHI evolution (that is positive during night, negative during day), but this feature is not caught by CANYON scheme. Explaining this behaviour is very ambiguous. The albedo of broadleaf trees is lower than of crop, which may results higher temperature in the forest-covered rural point compared to the inner point. However it is known that the evaporation of trees has significant cooling effect. We must say that more detailed analysis and probably longer run are needed in order to obtain reliable results and understand the different UHI evolution with crop and forest.

Results of the sensitivity study on different urban cover types can be seen on Fig. 6. The daily UHI evolution is found to be similar with all cover types, however, we obtained the largest uncertainty (2.43 °C with diagnostic scheme at 23 UTC; Table 1) in the results in this study. Focusing on the nocturnal values, the highest UHI intensities are resulted with the *dense urban*, *industrial and commercial areas* and *road and railway networks* cover types. The town fraction in these cover types are the highest (0.9) of all. However the daily UHI with *road and railway networks* are also the highest, which can be explained with its canyon geometry (small buildings, wide streets). The smallest nocturnal UHI and daily variability is found over the *urban park* and *sport facilities* cover types, which have smaller fraction of town (0.1 and 0.2, respectively).



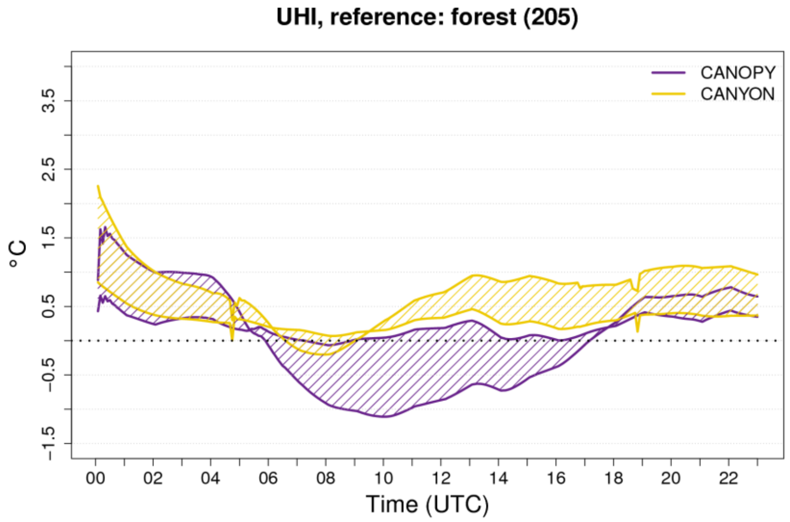
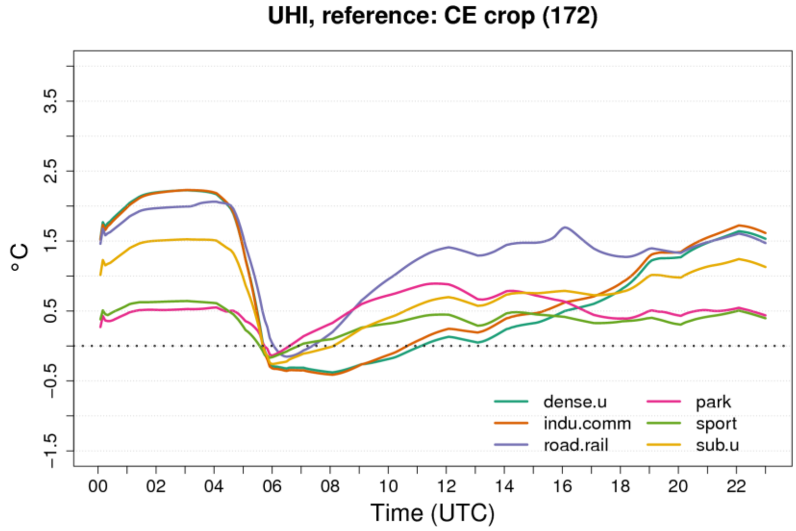


Fig. 5. Top: spread of urban heat island intensity (in °C) on 15 July 2010, simulated by SURFEX with different fraction of suburban and crop in a gridcell (co-ordinate: x=13, y=14), reference was a crop covered gridcell (co-ordinate: x=9, y=15). Bottom: the same as top, but with different fraction of suburban and forest in a gridcell (co-ordinate: x=11, y=8), reference was a forest covered gridcell (co-ordinate: x=22, y=2). 2-m temperature was computed with the CANOPY scheme and diagnostically with the CANYON scheme in TEB.



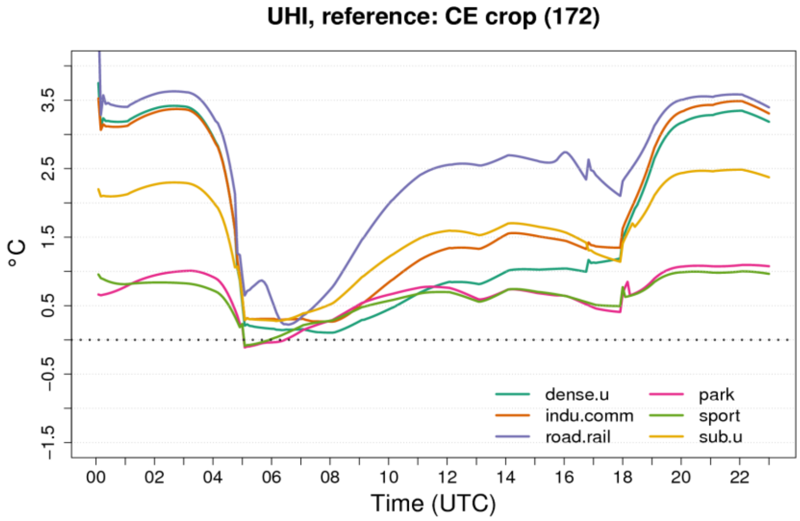


Fig. 6. Daily evolution of UHIs (in °C) on 15 July 2010 simulated by SURFEX with different urban cover types in one selected grid cell. UHI was computed with respect to a selected rural gridpoint. 2-m temperature was computed with the CANOPY scheme (top) and diagnostically (bottom).

Table 1. Spread (in °C; the upper values in the cells) and the highest and lowest UHIs (in °C; in the brackets) between the selected urban and rural gridpoints at 23 UTC on 15 July 2010 derived from the SURFEX simulations performed with two calculation methods for 2-m temperature (in rows) and different sensitivity test for physiographic information (in columns).

	Fraction of town	**Fraction of cover types**		**Different urban cover types**
		crop	forest	
CANOPY	1.0 (1.5–0.5)	1.0 (1.0–0)	0.3 (0.6–0.3)	1.1 (industry-sport: 1.5 – 0.4)
CANYON	2.2 (3.3–1.2)	1.9 (2.2–0.3)	0.6 (1.0–0.4)	2.4 (road-sport: 3.4–1.0)

3. Impact of TEB in the offline SURFEX run

Finally we investigated the impact of TEB in the offline SURFEX run. If TEB is not active in SURFEX, urban surfaces are considered as rocks, and the turbulent fluxes are computed by the ISBA scheme. This is a much simplified method, for example it does not take account the radiation trapping or shading effect of buildings. We performed two SURFEX offline simulations without TEB and with different 2-m temperature schemes (diagnostic and prognostic). The forcing was derived from the 4 km resolution ALARO results, which also run without TEB. We compare the UHIs resulted from these simulations, and the same ones but using TEB in the offline run (performed during my first stay). Figure 7 presents the difference between UHI intensities derived from the SURFEX simulations without and with TEB, 2-m temperature was computed with CANOPY. The results show that in the majority of the urban gridcells the impact of the detailed parameterization scheme is less than +0.2 °C. To investigate the UHIs' evolution temporally, we compared them over two gridpoints (for urban point we chose the gridpoint where the highest difference between simulations with and without TEB was observed; for rural point we chose the previously selected reference point; Fig. 8). Focusing on the last hours of day, TEB adds extra heating to the urban point, however it is clear that choice of 2-m temperature calculation schemes causes much larger departure in the results (around 1 °C) than activating TEB. During midday the prognostic and diagnostic schemes behave differently as it was observed previously as well. If CANOPY is activated, the TEB scheme lowers significantly the UHI during the day, hence reduces the biases. This behaviour cannot be identified in the diagnostically computed temperature results.

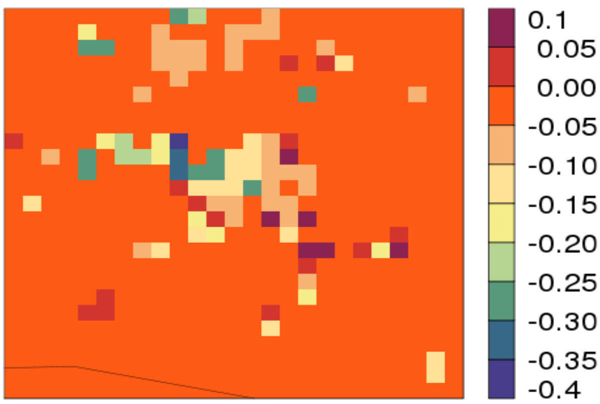


Fig. 7. Difference (in °C) between UHI at 23 UTC on 15 July 2010, according to SURFEX offline simulations where TEB was not and was activated. SURFEX was driven by the 4 km resolution ALARO run without TEB.

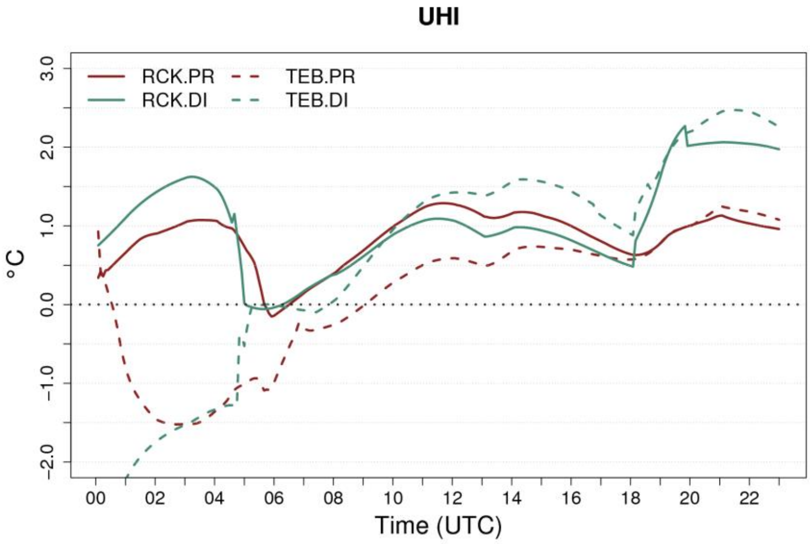


Fig. 8. UHI intensities (in °C) on 15 July 2010, according to SURFEX offline simulations where TEB was not (solid line) and was (dashed line) activated. 2-m temperature was computed diagnostically (green) and prognostically (red). SURFEX was driven by the 4 km resolution ALARO run without TEB.

Summary and conclusions

The main aim of the recent Flat Rate Stay at the RMI was to continue the sensitivity study with SURFEX coupled to ALARO that was started at my first visit. This time on the one hand we were interested in the initialisation method and its timing in SURFEX. However in the majority of our work we tried to assess the level of uncertainty coming from the physiographic information provided to SURFEX.

Regarding the initialisation method and its timing, we found that in case of the ALARO forcing run without TEB, SURFEX should be run continuously instead of daily reinitialisation. Moreover in order to reach the shortest spin up time, the initialisation time should be around the time of maximum heat flux, i.e. around noon.

In the following, we supposed three different sources of possible imperfections of physiographic information provided to SURFEX. These are (1) fraction of town in a certain urban cover type. We focused on the suburban cover, since it covers the majority of Szeged. (2) Fraction of two cover types in a mixed grid cell. We analysed the suburban and crop fractions and suburban and forest fractions. (3) Different urban cover types. In all cases we computed UHI between two gridpoints (as much as we could, we selected the same gridpoints, in order to obtain comparable results). Moreover to set the uncertainty coming from the physiographic information against the one coming from the model set-up, we performed the simulations with CANOPY and the diagnostic schemes for 2-m temperature, since previously we found that UHI results are the most sensitive for this setting. We can conclude that larger uncertainty was occurred in the different physiographic tasks if the diagnostic scheme was applied in SURFEX. Moreover the change of town fraction and the different urban cover types caused similar uncertainty and bigger than the fraction of cover types.

This preliminary sensitivity study is an important preceding step of long term climate simulations to achieve the most suitable model adjustments for our purpose and estimate the uncertainties to future land cover modifications. Our future plan is to perform a similar study on a longer period (e.g. one month) and in different seasons to get more reasoned conclusions.

Acknowledgement

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References

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