Urban scenarios in Brussels

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Introduction

Two types of model experiments were performed using the land-surface model SURFEX over Brussels: one vegetation and one albedo experiment. Their aim is to investigate how adaptation measures for Brussels could impact the urban climate in the future. In practice a change of albedo in urban areas can be established by a change the building colors. The vegetation scenario, on the other hand is implemented by the widespread introduction of new parks and plantation of trees. Since urban areas suffer from a wide range of impacts during warm and especially heat wave periods, we focus mostly on the summer period and perform a separate investigation for the impact during heat waves. Our experiments are very simple in nature since they involve spatially homogeneous changes in land-use characteristics to values that may be unrealistic to obtain in practice. Therefore, the experiments presented here should rather be interpreted as sensitivity experiments i.e. we estimate the sensitivity of the UHI with respect to changes in the land-use characteristics.

Methodology

Climate data generation

In order to obtain the 1-km climate simulations over Brussels, the SURFEX model was run in off-line mode using model output of the ALARO-0 model as atmospheric forcing data (Termonia et al, 2018a). More specifically, the output of the 4-km simulations over Brussels was used that follows the IPCC scenario RCP8.5 for greenhouse concentrations until 2100 (Termonia et al., 2018b). This simulation was obtained by dynamically downscaling the ALARO-0 simulations over the European (EURO-CORDEX) domain, as validated in Giot et al (2016). Comparable downscaling efforts for Brussels were performed and validated in Hamdi et al. (2015) with the difference that no daily restarts of the ALARO model are used and SURFEX was not (inline) coupled to the (4-km) ALARO model in the configuration at hand. As shown in Hamdi et al. (2014) the lack of this coupling results in a underestimation of the UHI effect.

The climate simulations span the time period 1976-2100 but for the analysis only the period 2010-2100 will be used to compare the impact of the different land-use scenarios. The area covered is a region of 30 km by 30 km over Brussels with a resolution of 1km and the land-use characteristics taken from the ECOCLIMAP (see Figure 1).

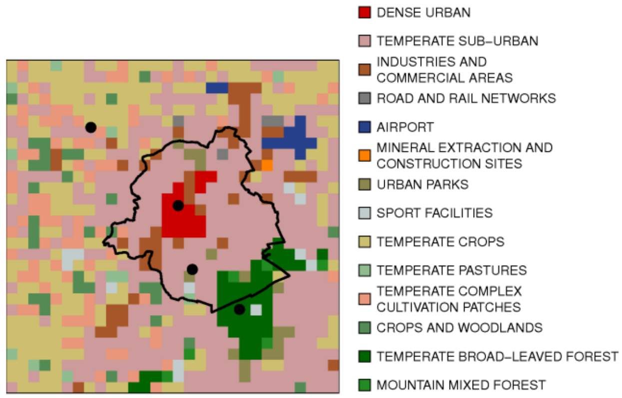


Figure 1: Land use characteristics at 1-km scale as used for the climate runs within SURFEX in the urban scenarios.

Land-use scenarios

Prior to introducing the land-use scenarios it is useful to discuss the land use characteristics over Brussels as shown in Figure 1. Whereas d different land-use types are used within the SURFEX model, we introduce here only three major categories: dense urban, sub-urban and rural tiles. The first two correspond to the 17 dark-red ("dense urban") and 250 light-pink ("temperate sub-urban") tiles in Figure 1, respectively. The rural tiles comprise the last six tile types in the caption of Figure 1.

The scenarios presented further only target the urban and sub-urban tiles while all results are averages over the concerned tiles. Their main characteristics (impermeable fraction, vegetation fraction and building heights) are tabulated in Table 1. The first experiment involves a change in albedo in the urban and suburban regions while the second vegetation scenario introduces a modified fraction of vegetation in the dense urban environment only. Finally, note that these change are introduced in the land-use characteristics of the (last) downscaling step using SURFEX only.

Table 1: Land-use characteristics of the dense urban and sub-urban tiles.

Land-use feature	Dense Urban tiles	Suburbain tiles
Impermeable surfaces	90 %	50 %
Vegetation	10 %	50 %
Building height	30 m	10 m

Albedo scenario

The albedo scenario involves a change in albedo of streets, walls and roofs, that are used in the impermeable surfaces for both the urban and suburban regions. The default or "*initial*" albedo values are 8%, 25% and 15% for streets, walls and roofs, respectively. In Table 2 we tabulate the values used for the three scenarios: Albedo min, Albedo av and Albedo max. In practice, the maximal values (around 80%) are almost impossible to obtain for a large urban area but, as aforementioned, these extreme values are chosen to probe the sensitivity of the UHI with respect to changes in the land-use characteristics.

Note that, although an increase in the albedo of the urban environment will generally reduce the urban heat effect, it may have detrimental effects on human comfort during day-time. Indeed upon increase of the albedo a person walking outside will be subject to increased shortwave radiation that strongly affects his/her comfort level. The investigation of such effects is beyond the scope of this sensitivity study.

Table 2: The albedo in the SURFEX model for the street, walls and roofs for the different albedo scenarios.

Albedo experiment	streets	walls	Roofs
Initial	8 %	25 %	15 %
Albedo min	20 %	40 %	25 %
Albedo av	50 %	62 %	55 %
Albedo max	80 %	85 %	85 %

Vegetation scenario

While the vegetation fraction of the dense urban tiles is by default 10%, two vegetation scenarios are proposed here that increase this. More specifically the FractVeg 0.3 and FractVeg 0.5 scenarios increase the fraction to 30% and 50%, respectively as tabulated in Table 3. Apart from the expected reduction of the UHI upon increase of the vegetation fraction, one can expect the improvement of human comfort due to shading. Again, this will not be investigated here.

Table 3: The vegetation fraction of the dense urban tiles for the default configuration and two vegetation scenarios.

Vegetation experiment	Vegetation fraction dense urban tiles
Inital	10 %
FractVeg 0.3	30 %
FractVeg 0.5	50 %

Results

Results of the reference runs

Figure 2 shows increase in the average yearly temperature for the urban, sur-urban and rural parts of Brussels for the years 2010-2100 following the RCP 8.5 scenario. Temperatures in the dense urban environment are systematically higher than those in the sub-urban areas which, in turn, systematically exceed those in the rural areas. This clearly shows the existence in the model of the observed urban heat island effect over Brussels (Hamdi et al., 2014).

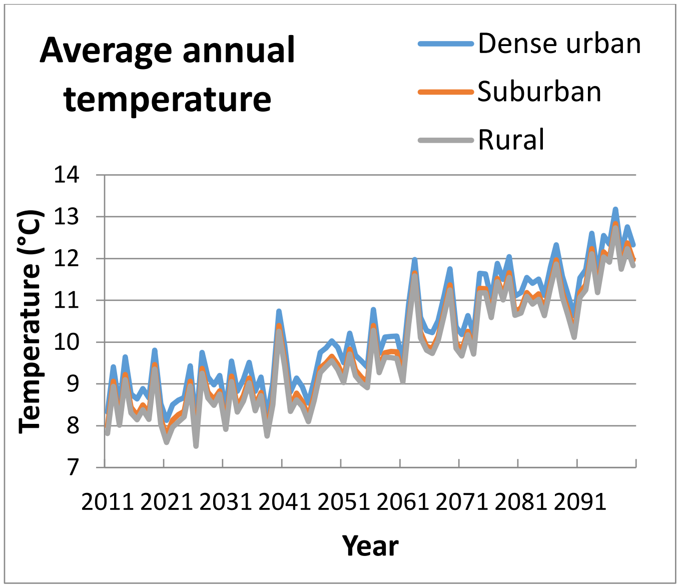


Figure 2: Average yearly temperature for rural (grey), suburban (orange) and dense urban (blue) locations over Brussels for the years 2010-2100 following the greenhouse gas scenario RCP8.5.

The summer temperature difference of the dense urban and sub-urban environment with the rural area is shown in Figure 3 for three periods: 2010-2040, 2040-2070 and 2070-2100. It is clear that the differences among the different periods are very small and similar findings recur when studying the scenarios. The invariance of UHI with respect to the time period might, however, not be realistic and most probably arises due to the absence of explicit urban-atmosphere coupling in the SURFEX forcing data (Hamdi et al., 2014).

There is, on the other hand a marked difference in the UHI between the dense urban and the sub-urban region, especially at night. This is in line with the expected behavior and confirms earlier findings for Brussels.

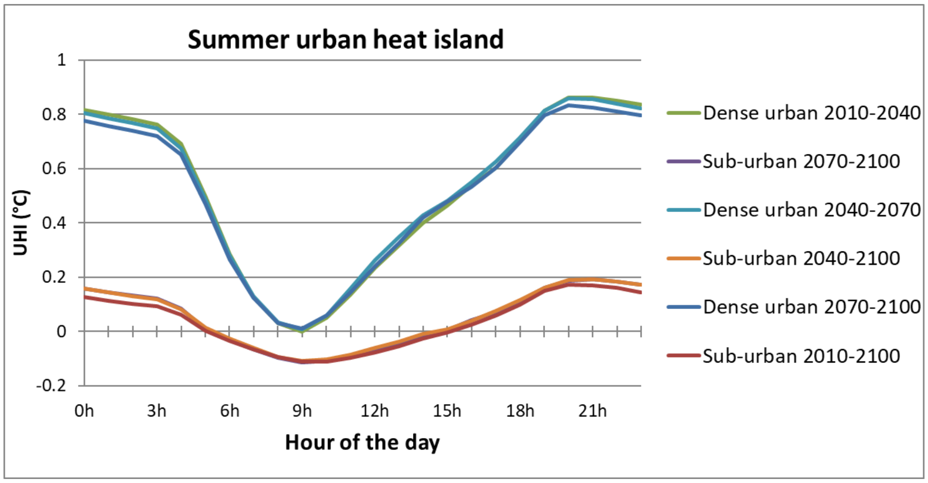


Figure 3: Diurnal cycle of the summer Urban Heat Island (UHI). The UHI is obtained by subtracting the temperature of the dense urban (blue line) or sub-urban (orange line) environment with the temperature of the rural environment.

For the heat wave in this work, we use the definition from the Belgian Public Health authorities. According to this definition, a heat wave is a period of at least three consecutive days, with an average daily minimum and maximum temperatures which exceed 18°C and 30°C, respectively. The constraint on the minimal temperature in this (health-related) definition stems from the fact that people suffer most from heat waves when there are high night-time temperatures.

In line with the overall increase in temperature until the end of the century as shown in Figure 2, there is also a stark increase in the number of heat waves, especially in the period 2070-2100. This is shown in Figure 4 for the dense urban, sub-urban and rural areas.

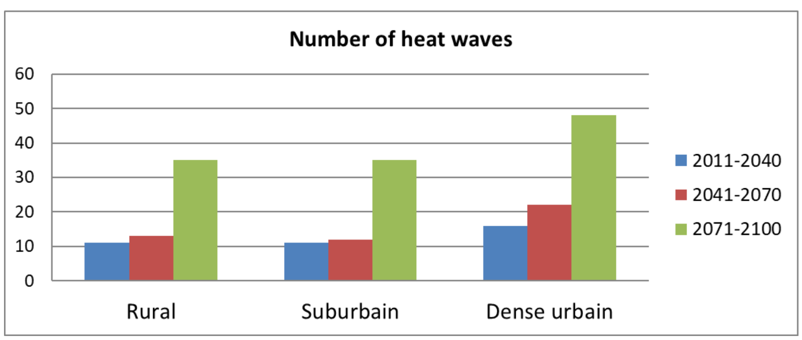


Figure 4: The number of heat waves for the three land-use types and for the periods 2010-2040, 2040-2070 and 2070-2100 following the RCP8.5 scenario.

Results for the Albedo scenarios

Figure 5 shows the impact of the albedo increase of the dense urban and sub-urban environment on the diurnal cycle of the summer UHI for the urban and sub-urban environment for the period 2010-2040. Note that results for the periods 2040-2070 and 2070-2100 were practically identical. As expected, the largest impact of the albedo increase concerns the day-time UHI as a consequence of the increased incoming radiation. While the maximal UHI reduction in the dense urban environment is 0.46°C (dashed orange line), the reduction in the sub-urban areas is 0.55°C. The difference can be attributed to the dense urban environment where, compared with the sub-urban areas, 1) there is an enhanced heat trapping in the urban canopy and 2) there is more conversion to sensible as opposed to latent heat of the (remaining) incoming radiation.

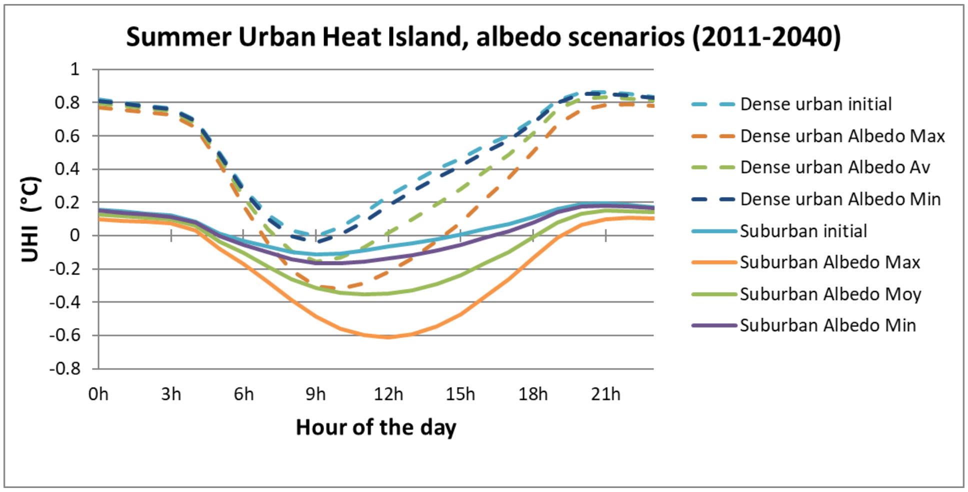


Figure 5: Diurnal cycle of the summer Urban Heat Island (UHI) for different albedo scenarios for the period 2010-2040. Note that the results obtained for the periods 2040-2070 and 2070-2100 are almost identical.

Results for the Vegetation scenario

While a change in albedo mostly affects the day-time UHI, the inverse is true for the increase in vegetation fraction. As seen in Figure 6, there is a strong reduction in the night-time UHI of 0.47°C following the VegFraction 0.5 scenario and only a slight UHI increase during day time.

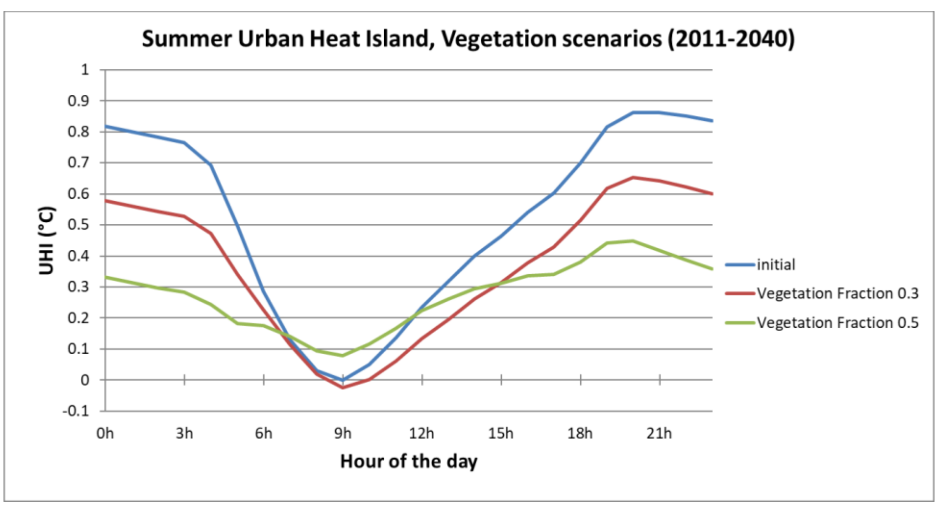
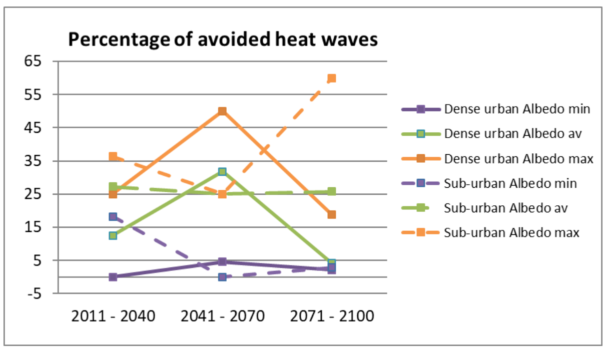


Figure 6: Diurnal cycle of the summer Urban Heat Island (UHI) in the dense urban environment for different Vegetation scenarios for the period 2010-2040. Note that the results obtained for the periods 2040-2070 and 2070-2100 are almost identical.

Scenario impacts on the heat waves

While, at least in the current model setup, the UHI is not affected by the time period considered, the background temperatures will be steadily increasing with time following the RCP8.5 scenario and reach 3°C to 4°C at the end of the century. Therefore, a local reduction of temperature with 0.5°C will become a minor contribution. This effect can be quantified by the use of the fraction of avoided heat waves upon implementation of a certain adaption measure. These are shown if Figure 7 for the Albedo scenarios (left) and the vegetation scenarios (right).

While the fraction of avoided heat waves can be up to 35% for the period 2010-2040 and even up to 45% for 2040-2070 (both upon following the Albedo max scenario), there seems to be a strong decline for the period 2070-2100, except for the Albedo max scenario in the sub-urban environment. The effect of the vegetation adaptation on the (fractional) heat wave reduction becomes negligible for the period 2070-2100.



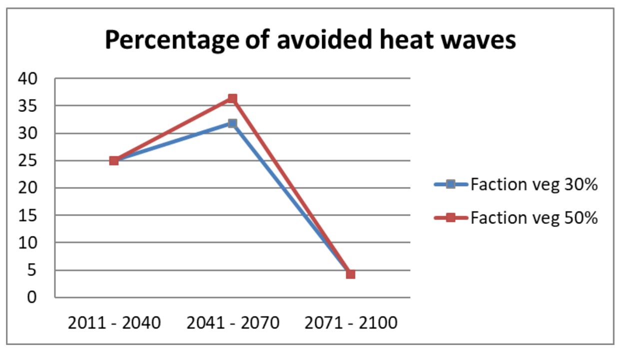


Figure 7: Fraction of avoided heat waves (%) different time periods and for different albedo scenarios (left) and vegetation scenarios (right), all following the RCP8.5.

Discussion

As expected, an albedo increase strongly reduces the day-time UHI while an increase of the vegetation fraction reduces the night-time UHI. Both scenarios had a maximal effect of reducing the UHI by 0.5°C. The vegetation scenario can therefore be considered to have the largest impact on health as it allows people in an urban environment to cool down at night. Moreover, the day-time outdoor human comfort is generally improved by shading when trees are introduced while it is deteriorated by the increase of albedo. These human comfort effects were not taken into account in this study.

References

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