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Assessing the current and future urban heat island of Brussels

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ABSTRACT

This study examines the urban heat island (UHI) of Brussels, for both current (2000–2009) and projected future (2060–2069) climate conditions, by employing very high resolution (250 m) modelling experiments, using the urban boundary layer climate model UrbClim. Meteorological parameters that are related to the intensity of the UHI are identified and it is investigated how these parameters and the magnitude of the UHI evolve for two plausible trajectories for future climate conditions. UHI intensity is found to be strongly correlated to the inversion strength in the lowest 100 m of the atmosphere. The results for the future scenarios indicate that the magnitude of the UHI is expected to decrease slightly due to global warming. This can be attributed to the increased incoming longwave radiation, caused by higher air temperature and humidity values. The presence of the UHI also has a significant impact on the frequency of extreme temperature events in the city area, both in present and future climates, and exacerbates the impact of climate change on the urban population as the amount of heat wave days in the city increases twice as fast as in the rural surroundings.

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1. Introduction

The continuous growth of urban population has led to an increasing amount of interdisciplinary research focussing on urban climate and the effects of urbanization at different scales (Arnfield 2003). The most prominent phenomenon is the fact that urban areas are generally warmer than their rural surroundings, the so-called urban heat island (UHI). In particular, cities experience higher air temperatures than rural areas, with night-time temperature differences up to 10 °C under favourable conditions (Landsberg, 1981; Oke, 1997). The UHI is caused by the increased heat capacity of cities, anthropogenic heat sources and the imperviousness of urban surfaces which inhibit evaporative cooling (Oke et al., 1991; Masson, 2006; Lynn et al., 2009). Because of the UHI increment, cities are particularly vulnerable to heat waves, with higher heat-related excess mortalities (Gabriel and Endlicher, 2011; Dousset et al., 2010).

Several observational studies have indicated that the magnitude of the UHI is strongly influenced by meteorological conditions. Bornstein (1968) and Gedzelman et al. (2003) studied the UHI of New York City and found that it was most pronounced on calm, dry, clear nights during which a strong nocturnal inversion could form over the countryside. They found a strong correlation between the UHI and the cloud cover, wind speed, wind direction and surface temperature

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inversion. Similar results were obtained for the cities of Athens and Thessaloniki in Greece, which showed that the largest UHI values were reached during clear nights with low humidity and anticyclonic conditions (Kassomenos and Katsoulis, 2006; Giannaros and Melas, 2012). The development of a sea breeze had a negative effect on UHI values. Also in Seoul (South Korea), the magnitude of the UHI was found to relate to wind speed and cloud cover, with the weakest UHI development during precipitation days (Kim and Baik, 2005; Lee and Baik, 2010). There, the UHI was stronger during week days, due to extra anthropogenic heat releases.

During the last years, increasingly sophisticated urban parameterizations are used to improve the representation of urban surfaces in regional and global climate models, in order to understand urban climate and its interactions with climate change. This is highly relevant, since climate projections indicate that in the future, cities may become more often exposed to extreme heat stress (IPCC, 2012). A lot of these urban surface energy balance models are compared by Grimmond et al. (2010, 2011), who conclude that simple models can perform as well as complex ones, and parameter values need to be carefully chosen for each specific city.

Studies with global climate models coupled to urban surface schemes indicate that urban and rural areas respond similarly to climate change, hence keeping UHI values more or less constant, although the number of extreme hot nights increases stronger in the cities (Fischer et al., 2012; Oleson, 2012). However, because of the coarse resolution of global climate models, they may not capture mesoscale or local features and feedbacks, that are important for UHI development (Hamdi et al., 2013). It should also be mentioned that these results are for conditions where the urban areas are static, that is, urban extent and properties do not change in the future.

Therefore, regional climate models with increasingly high resolutions are used to downscale the global climate scenarios. McCarthy et al. (2012) applied a 25 km resolution to study the UHIs of several cities in the UK under an A1B scenario. They found that the UHIs remained constant but caused the number of heat waves to be twice as high in cities, and the number of extreme hot nights to be even five times higher. In a study on both urban expansion and climate change with a 2 km resolution mesoscale model, Argüeso et al. (2013) found a strong effect on nocturnal temperatures due to urbanisation, which enhanced the climate change signal at local scales in Sydney (Australia). In a model set-up that is more or less similar to the one in this study, Kusaka et al. (2012) used a model resolution of 3 km to simulate the summer month of August for 10 consecutive years in the present (2000–2009) and the future (2070–2079) in a study over the largest urban areas in Japan. They also reported constant UHI values under warmer future conditions.

But even a model resolution of a few km is not enough to resolve all urban-scale features, for which a horizontal spatial resolution of the order of a kilometre or even higher is required. At this resolution mesoscale models become exceedingly slow because of numerical stability constraints, i.e. shorter time steps are required, so long model integrations are difficult to achieve. A method is proposed by Lemonsu et al. (2013) that projects the global climate at the regional scale with dynamical and statistical techniques, and then simulates the local scale with an offline urban model with a resolution of 1 km. They reported a decrease of the UHI of Paris by the end of the century under A1B and A2 scenarios due to a stronger increase in rural temperatures caused by soil dryness in summer. The same effect is found by Hamdi et al. (2013) in their study of the Brussels UHI, in which they applied a more sophisticated method to achieve 1 km resolution results, involving an offline boundary layer scheme.

Our work builds on the research mentioned above by applying a horizontal model resolution of 250 m, that is unprecedented for this kind of study, in our dynamically downscaling experiment over Brussels (Belgium). This high resolution has an important added value when assessing the heat exposure of inhabitants of the city, or identifying areas where people are most at risk, for which a map with a resolution of several kilometres makes little sense. To achieve this, the urban boundary layer climate model UrbClim (De Ridder et al., 2015) is used, which takes into account advection and feedback processes regarding air temperatures and humidity between the urban surface and the atmosphere, that cannot be included in studies with offline surface schemes. The goal of this study is to assess the current UHI of Brussels, define the meteorological parameters that play a role in its formation, and to investigate how these parameters and the magnitude of the UHI evolve for two plausible trajectories for future climate conditions: Representative Concentration Pathways (RCPs) 4.5 and 8.5.

The remainder of this paper is organized as follows. In Section 2, both the urban boundary layer climate model and the regional climate model, which provides the large-scale meteorological boundary data, are described. This section further provides an overview of all the input datasets and the experiment setups. Section 3 presents the results and discussions of this research, while conclusions are drawn in Section 4.

2. Numerical models and experiment setup

2.1. The UrbClim model

The model simulations in this study are performed with the urban boundary layer climate model UrbClim, designed to cover individual cities and their nearby surroundings at a very high spatial resolution (De Ridder et al., 2015). UrbClim consists of a land surface scheme containing simplified urban physics, coupled to a 3-D atmospheric boundary layer module. The latter is tied to synoptic-scale meteorological fields through the lateral and top boundary conditions, to ensure that the synoptic forcing is properly taken into account. The land surface scheme is based on the soil–vegetation–atmosphere transfer scheme of De Ridder and Schayes (1997), but is extended to account for urban surface physics. This urbanisation is

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