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Reconstructing urban climate of Vienna based on historical maps dating to the early instrumental period

Maja Žuvela-Aloise [a,*], Roland Koch [a], Anton Neureiter [a], Reinhard Böhm [a], Saskia Buchholz [b]

[a] ZAMG – Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria
[b] DWD – Deutscher Wetterdienst, Offenbach, Germany

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ABSTRACT

The relationship between urbanization and long-term modification of the urban climate of Vienna is investigated by modeling the present-day spatial distribution of the urban heat load and comparing it with the one based on the historical land use characteristics. Geographical maps of the First Military Mapping Survey of the Austrian Empire from the period 1764–1787 are used to assess the historical land use distribution. The simulations are performed with the urban climate model MUKLIMO_3 using the high resolution orography, land use and climatological data for the time period 1981–2010. The modeling results indicate that the intensity of the urban heat load in the historical center of Vienna might have been similar to today's values. The magnitude of the urban climate signal and its long-term alteration are comparable with findings based on the meteorological observations dating to the early instrumental period. The spatial patterns derived from the modeling experiments show complex response to the exerted land use change and reveal expansion of areas with excessive heat load which can be attributed to the city growth solely. These results illustrate long-term consequences of the urbanization and set base for investigation of future trends in urban climate related to the urban development.

* Corresponding author. Address: Hohe Warte 38, 1190 Vienna, Austria. Tel.: +43 1 36026 2236.
E-mail address: maja.zuvela-aloise@zamg.ac.at (M. Žuvela-Aloise).

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1. Introduction

The urban heat load in Vienna has been increasing over the past decades. Based on the homogenized temperature data the mean annual number of summer days (days with maximum air temperature (T_{max}) greater than or equal to 25 °C) at the station Vienna Hohe Warte increased from an average value of 49.4 for the climatic period 1961–1990 to 62.8 summer days per year in the recent climatic period 1981–2010. In exceptionally warm years, such as in summer 2003, more than 100 summer days were registered. The positive trend could be assigned both to the warming of the regional climate (Auer et al., 2007) and changes in the urban environment (Böhm, 1979; Böhm, 1998). The mean annual temperature excess in the center of Vienna against the rural surroundings for the period 1951–1980 amounts to 1–1.5 °C (Auer et al., 1989) and a positive trend in urban heat excess of up to 0.6 °C in 45 years (1951 to 1995) was observed at individual stations in Vienna (Böhm, 1998).

One of the early attempts to quantify the intensity and trends in the urban bias was to correlate the city size with the urban-rural temperature difference (Oke, 1973; Landsberg, 1981), assuming that a growing city would have a proportional enlargement of the urbanized area and consequently amplify the UHI effect. This relationship has been questioned by investigating long-term temperature trends and historical urban development data from Vienna, Austria. The evaluation of the temperature trends showed that it is possible that the UHI effect of a city without extensive urban sprawl or growth in population can increase due to the changes in energy consumption and urban morphology (Böhm, 1998).

A particularity of the city of Vienna is its inherited shape and structure of a historical design and growth of the city around a medieval core. As an empire capital it reached the present population size (about 1.7 million) already at the end of the 19th century. Increase in density of the existing built-up area, further pavement and reduction of vegetation amplified the urban heat load in the last decades. Previous studies pointed out that the method of estimating the formation and development of the UHI on the basis of a few monitoring stations might be too simple (Böhm, 1998; Jones et al., 1990). The evaluation of temporal trends is crucially dependent on the location of the monitoring stations. Intensity of the UHI effect based on point measurements lacks the information of the spatial structure, allowing actual maxima in the urban heat load to remain unidentified. This problem has been generally recognized and several methods have been applied to assess the spatial patterns in urban heat load including densification of the urban monitoring station network, mobile measurements or analysis of thermal airborne and satellite imagery (e.g. for Vienna in Mursch-Radlgruber et al. (2009) and Pongracz et al. (2010)). However, these studies primarily captured the contemporary state of the urban climate and miss the information of the long-term urban development, leaving open questions on urban climate trends on a climatological time-scale (30 years or more). Few attempts have been made to evaluate warming trends related to the land use changes on centennial time-scales (Ichinose, 2003; Lenz, 1996; Giovannini et al., 2014). The study of Ichinose (2003) investigated regional warming trends in Japan using land use datasets for 4 historical periods, earliest dating back to ca. 1850. In the study of Lenz (1996), the historical maps from ca. 1700 were used to develop land use scenarios in the Upper Rhine Valley. Both studies simulated changes in daily temperature cycle for clear sky summer conditions using mesoscale models. The horizontal resolution (2 and 4 km, respectively) as well as representation of the surface processes was not appropriate to capture the effects of the urban canopy structure. Moreover, the evaluation of temperature modifications was limited to specific weather conditions and does not provide climatological analysis for different synoptic situations. The modelling study for the city of Trento (Giovannini et al., 2014) with historical (late 19th-early 20th century) and present land use suggests that the thermal field in the historical urban area did not change significantly from the past, whereas progressive urbanisation might have modified the temperature records in the surrounding area.

The homogenization of the early instrumental meteorological data (Auer et al., 2007), well documented state archive in Vienna (ÖSTA) and the new urban climate modeling approach developed by the German Weather Service (Früh et al., 2010) provided an opportunity to evaluate the changes in urban climate in Vienna on a climatological time-scale.