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Air temperature characteristics of local climate zones in the Augsburg urban area (Bavaria, southern Germany) under varying synoptic conditions

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ABSTRACT

In this contribution air temperature differences among Local Climate Zone (LCZ) categories are analysed with special consideration of varying synoptic conditions. Analyses are based upon an LCZ mapping for the urban area of Augsburg (Bavaria, Southern Germany) and hourly air temperature data from a comprehensive logger network. Quality checked air temperature measurements have been stratified according to season, hour of the day and weather situation. For resulting subsamples thermal differences among LCZs have been determined and appropriate statistical tests have been applied. Results confirm that built up LCZs feature higher temperatures than natural LCZs and that most distinct differences among LCZs appear under undisturbed synoptic conditions. With increasing cloudiness and in particular with increasing wind speed differences among LCZs diminish. But, even for strongly disturbed synoptic conditions statistical significance of the influence of LCZs on thermal characteristics could be assured. Thus, our findings provide clear evidence that detectable thermal differences among LCZs are not restricted to „ideal "synoptic conditions but occur as well under disturbed conditions. However, to assure not only the statistical but also the climatological and in particular the bioclimatological and human health related relevance of the documented differences among LCZs further studies incorporating appropriate metrics are intended.

1. Introduction

The climate characteristics of urbanized areas differ distinctly from those observed in their rural and natural surroundings. These urban climate modifications comprise urban-rural differences in various climate parameters, with the so called urban heat island (UHI) being the most prominent phenomenon illustrating the warming effect of urban structures on air temperature (Oke, 1987). Beside climatic differences between urban areas and their surroundings distinct differences also exist within the urban environment. Both effects –urban-rural and intra-urban climatic differences – are due to the spatial distribution of specific features (e.g. natural surfaces, sealed surfaces, buildings) that impact atmospheric processes and thus lead to distinct local scale climate modifications.

A recent approach to objectively categorize urban and rural structures with respect to their specific influences on local climate

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characteristics is the so called “local climate zone” (LCZ) concept that has been introduced by Stewart and Oke (2012). Primarily the LCZ concept intends to support the comparable and consistent selection and documentation of representative measurement sites and thus to enable the standardized determination of urban-rural and intra-urban climatic differences (as differences between pairs of specific LCZ categories) that are comparable among different urban regions (Stewart et al., 2014).

However, beside these main applications the LCZ concept has been applied to determine spatial patterns of climate relevant urban and rural structures for cities and their surroundings worldwide. Mainly in the framework of the World Urban Database and Access Portal Tools (WUDAPT) project (Mills et al. 2015) LCZ classifications and maps have been produced for numerous cities around the world following a standardized workflow (Bechtel et al., 2015). Based on these standardized informations on surface structure and surface cover it is possible to assess spatial patterns of potential local scale climate characteristics for individual urban areas and moreover to compare urban areas on the basis of consistent and objective criteria.

Accompanying the LCZ mappings the thermal characteristics of the LCZ categories have been analysed for different cities and utilizing different observational air temperature data sets.

Siu and Hart (2013) analysed thermal LCZ characteristics in the urban area of Hong Kong (SAR, China) on the basis of 17 meteorological measurement sites. Lehnert et al. (2015) compared temperature characteristics of LCZ categories in Olomouc (Czech Republic) using air temperature data from 14 measurement sites. Alexander and Mills (2014) utilized data from 6 fixed stations and from additional mobile measurements to examine LCZ specific air temperatures in Dublin (Ireland). Stewart et al. (2014) investigated LCZ climates – mainly on the basis of mobile measurements – in Nagano (Japan), Vancouver (Canada) and Uppsala (Sweden). For Nancy (France) Leconte et al. (2015) also performed mobile air temperature measurements to evaluate air temperature characteristics of LCZ types. For Berlin (Germany) Fenner et al. (2014, 2017) analysed LCZ specific temperature characteristics on the basis of up to 19 fixed meteorological stations and additional around 400 citizen weather stations. Several investigations of the air temperature characteristics of LCZ categories have been conducted in Szeged (Hungary) by Gál et al. (2016) using data from 24 fixed measuring stations, by Skarbit et al. (2017) analysing data from a subset of 20 selected stations and by Unger et al. (2017) performing analyses focusing on human bioclimatological aspects using data from six selected stations.

In general, results from these studies confirm the thermal relevance of the LCZ categories and thus the climatological validity of the LCZ concept for urban areas of varying size, with different urban structural settings and exhibiting different macro- and meso-climatic boundary conditions. In particular, distinct thermal differences have been ascertained between structurally diverse LCZ types – e.g. densely built-up surfaces versus open-space configurations – and for ideal - calm and clear - synoptic conditions. To the authors’ best knowledge, no studies so far have explicitly investigated in how far thermal characteristics of LCZ types behave under varying synoptic boundary conditions. Investigations in this direction are important in order to determine the order of urban-rural and intra-urban temperature differences that are related to different magnitudes of synoptic perturbations of the ideal i.e. calm and clear conditions. Although less pronounced than during ideal conditions spatial temperature variations accompanying disturbed conditions may nevertheless be significant and may have relevance considering human health related aspects.

Against the scientific background as briefly outlined above, the objectives of the analyses presented in this contribution are defined as follows:

- Based on automatically derived local climate zones for the urban area of Augsburg meteorological measurement sites are assigned to LCZ categories.
- Utilizing hourly mean air temperature data from suitable stations thermal characteristics of the LCZ types are determined and expressed as deviations from a reference station.
- LCZ specific air temperatures are investigated considering inter- and intra-zone variations and taking into account temporal (season, time of the day) differences and as well variations related to varying synoptic boundary conditions (i.e. categories of wind speed and cloud cover at a reference station), thus contributing to the climatological evaluation of the LCZ scheme.

Accordingly, the paper is structured as follows: Section 2 introduces the data sets underlying our analyses and explains the different methodological approaches that have been applied. In Section 3 the main results are presented and illustrated. Finally, Section 4 discusses our findings and provides some essential conclusions and a brief outlook.

2. Data and methods

2.1. Study area

Our study area is the urban area of Augsburg in Bavaria, Southern Germany. The area comprises the city of Augsburg (288.631 inhabitants, 146.86 km^2; Stadt Augsburg, 2017) and the surrounding municipalities of Stadtbergen, Gersthofen, Friedberg and Königsbrunn (Fig. 1). The long-term (1981–2010) mean annual air temperature in Augsburg is 8.5 °C, the warmest month is July (18.1 °C), the coldest month is January (−0.8 °C), the mean annual rainfall is 767 mm (Fig. 2; DWD, 2018a). The main wind direction is southwest and the mean wind speed is 2.9 m/s (DWD, 2018b).

2.2. Local climate zone classification for the urban area of Augsburg

The LCZ concept as introduced by Stewart and Oke (2012) discriminates ten built-up LCZ types and seven natural LCZ types (see Stewart and Oke, 2012 for a comprehensive description). Each of these LCZ types is characterized by a particular combination of