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Spatial and temporal air temperature variability in Berlin, Germany, during the years 2001–2010

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A B S T R A C T

Long-term data (2001–2010) were studied to analyse the spatial and temporal variability of air temperatures (T) in Berlin, Germany. Five sites were used to investigate spatial air temperature differences (ΔT). The sites were classified according to the Local Climate Zone concept. Temporal anomalies, being the differences between hourly values and the decadal average at that time, were investigated for air temperatures (T') and air temperature differences ($\Delta T'$). Decadal ΔT was strongly positive during night-time inside the city compared to the reference site (“scattered trees” – LCZ B) during summer. During winter ΔT was slightly positive throughout the whole day. Comparing two sites with LCZ “dense trees” inside and outside the city revealed a temperature excess of 0.3 K. T' inside the city compared to T' outside the built-up structures was damped by at least 10%. The urban canopy responded similar to a forest canopy in damping T'. Hot weather conditions lead to negative $\Delta T'$ during daytime and positive $\Delta T'$ at night. The nocturnal values were related to spatial mean vegetation fractions and sky view factors (SVF) including vegetation. SVF without vegetation did not show this relationship, highlighting the importance of including trees in spatially averaged SVF computation.

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1. Introduction

Urban–rural air temperature differences (ΔT_{u-r}) have been studied intensively and numerously during the past decades. Since Howard (1833) published the first scientific works on the topic of urban climate in 1818 and 1833, the urban heat island (UHI) effect is now one of the most studied phenomena of urban climatology (Arnfield, 2003; Souch and Grimmond, 2006; Stewart, 2010). Studies from all over the world have been carried out (Wienert and Kuttler, 2005; Chow and Roth, 2006; Fortuniak et al., 2006; Kłysik and Fortuniak, 1999; Schlünzen et al., 2010; Yow and Carbone, 2006) using a variety of methods to address the spatial and temporal aspects of ΔT_{u-r}. Other studies have related the intensity of the urban heat island (UHII) to factors such as population, city size, cloud cover or wind speed (Hinkel et al., 2003; Morris et al., 2001; Oke, 1973).

In recent years researchers have investigated how extreme weather events such as heat waves change the regular pattern of the UHII (Cheval et al., 2009; Zhou and Shepherd, 2010) or how the UHI can cause a rise in the frequency and duration of extreme heat events (EHE) Tan et al., 2010. Addressing not only meteorological or climatological questions, some studies investigated how heat waves contribute to intensified heat stress and mortality among the urban population (Changnon et al., 1996; Gabriel and Endlicher, 2011). However, only little is known and understood about the urban response to regional-scale temporal air temperature deviations, especially in view of the characterization of the response in the diurnal and annual cycle. Since many studies look only at a very limited number of EHE per city (sometimes just one EHE) the question arises: how are the results representative? Long-term observational data are needed and we therefore used air temperature data from one decade for this study.

Addressing the issue that the terms "urban" and "rural" are ambiguous for describing measurement sites, Stewart and Oke (2012) introduced the concept of "Local Climate Zones" (LCZs). The aim of the concept is to enhance the understanding and interpretation of air temperature differences within the urban context and to allow the communication and comparison of results between cities. It is a systematic approach to characterize the local surroundings of a measurement site. We adopted this system and characterized our sites accordingly. Henceforth, we do not use the term "urban heat island" when discussing air temperature differences between two sites but refer to their respective LCZ classification. Our purpose here is not to evaluate the LCZ scheme but to use it to describe the observation sites and help to understand the differences that arise.

Our chief objective is to examine the spatial and temporal characteristics of the urban effect on air temperatures (T) in Berlin, Germany. We base our analysis on data acquired from an urban climate network in Berlin over a ten year period (2001–2010) from five meteorological stations located in different urban landscapes. One station, located in an open grassland with scattered trees in south-western Berlin is designated as a reference station. Specifically, our analysis focuses on three aspects of the urban effect, namely,

(1) the long-term dynamics of air temperature variability (both spatial and temporal) based on the average annual and diurnal cycles,
(2) the short-term temporal anomalies, defined as the difference between hourly averages of air temperatures and its corresponding decadal mean, examined for diurnal and seasonal patterns and
(3) the nature of the urban effect during high temperature conditions. Here we investigate the correspondence of the temporal and spatial anomalies and link these to the nature of surface cover and sky view factor (SVF) at each site.

2. Materials and methods

2.1. Study area and Local Climate Zone classification

The study was carried out in the city of Berlin, Germany, which is located in eastern Germany (52.52 N, 13.40 E) with a population of around 3.4 million people in 2012. The city spans over an area