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Methods to assess heat exposure: A comparison of fine-scale approaches within the German city of Karlsruhe

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ABSTRACT

Knowledge on the most exposed areas of a city constitutes an important basis for suitable short and long-term planning. We present and compare three different methods that allow us to assess the potential heat exposure for the smallest administrative spatial units, the quarters, in the German city of Karlsruhe which was repeatedly affected by heat waves in the past. The three methods are based on (1) meteorological station data from the city and its hinterland, (2) a city climate index and (3) remote sensing data. The aim is to answer the question whether different approaches provide different levels of heat exposure. By comparing the three methods we could identify regions by cross validation where the level of heat exposure is highly confident. Regions where one model result deviates from that of another, give interesting insights in the interrelation of features of the method and circumstances in the study area. Regions were all the three models showed different results remained very rare. The results may be relevant for decision-makers who want to implement small-scale measures for heat mitigation but only have limited resources available.

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1. Introduction

Extended periods of intense heat can have severe impacts on people and infrastructures. During the summer of 2003, large areas of Western Europe suffered from extraordinarily high temperatures. In Europe as a whole, 70,000 people (including 7000 in Germany) died due to the stresses and strains of this heat wave (Robine et al., 2007). Older people (Hondula et al., 2012; Medina-Ramon and Schwartz, 2006), infants (Loughnan et al., 2010; McGeehin and Mirabelli, 2001), those with a low socio-economic status (Harlan et

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al., 2006; Huang et al., 2011) or with pre-existing diseases (Vandentorren et al., 2006) are particularly susceptible to heat. However, not only individuals, but also the health sector is affected. Dolney and Sheridan (2006) have shown a significant correlation between periods of extreme heat and an increase of emergency calls. Parts of a city that are specially heat exposed also have a higher risk of damage to infrastructure (Rosenzweig et al., 2011).

Existing studies analyze the spatial distribution of heat exposure in urban regions using different input data and methods. For decision makers the question arises as to which method to use and which results to trust when it comes to implementing proper adaptation measures. This paper focuses on comparing the results of three methods. We are interested in answering the following question: Does using different methods to assess the relative heat exposure within a city necessarily lead to different results?

There are many studies that have examined the relationship between temperature and different influencing factors. The temperature distribution within a city is influenced by natural and anthropogenic factors. The natural factors include, for example, altitude which is negatively correlated to temperature (Alcoforado and Andrade, 2005) and vegetation which can provide cooling and fresh air for cities (Bowler et al., 2010; Hart and Sailor, 2009; Heinl et al., 2015; Peng et al., 2012; Radhi et al., 2013; Senanayake et al., 2013). Population density, which is positively correlated with temperature (Bottyán et al., 2005; Klysik and Fortuniak, 1999; Radhi et al., 2013), is often used as a proxy for anthropogenic factors like the compactness and heat-storing capacity of buildings (Goh and Chang, 1999; Pandey et al., 2014), the percentage share and type of sealed surfaces (Akbari et al., 2001) and heat emissions caused by industrial or residential activities (Hart and Sailor, 2009; Nkemdirim and Truch, 1978).

Following the IPCC definition, we define exposure as "the presence of people […] that could be adversely affected (IPCC, 2014)". Thus, a high exposure means circumstances of extraordinary heat with potentially stressful effects on human health and well-being. Vice versa, a low exposure is characterized by low or negligible risk of heat impacts.

Three kinds of data collection methods can be found concerning the assessment of spatial differences in exposure to temperature in cities. Firstly, there are studies that are based on measured temperature data from mobile sensors or meteorological stations (Alcoforado and Andrade, 2005; Bottyán et al., 2005; Hart and Sailor, 2009; Steeneveld et al., 2014). Secondly, there are analyses based on urban climate maps (Acero et al., 2013; Hebbert, 2014; Houet and Pigeon, 2011; Ren et al., 2010). Sismanidis et al. (2015) describe advances in a novel methodology of using geostationary satellite thermal infrared data for deriving land surface temperature data with a high spatial and temporal resolution. Thirdly, there are analyses that use remote sensing data (Effat and Abdel Kader Hassan, 2014; Heinl et al., 2015; Li et al., 2011; Senanayake et al., 2013; Zhou et al., 2013). Additionally, there are some studies that use a combination of measured near-surface data and remote sensing data (Kato and Yamaguchi, 2005; Radhi et al., 2013; Sodoudi et al., 2014). Studies that use two different methods only compare the temperature at different meteorological stations or at different times of the day, but do not compare the results from using data from different sources.

For Karlsruhe, which was one of the most affected cities in Germany during the heat wave of 2003, we critically review three methods to assess the relative heat exposure on a small scale. We choose the spatial level of quarters (in German: Stadtviertel), which is the smallest administrative unit in the city of Karlsruhe. Although quarters in Germany are administrative divisions with no regulatory power or jurisdictional autonomy, it is helpful and often even necessary for a decision maker to have small-scale information on heat exposure in order to focus adaptation measures on the most exposed parts of the city. Different quarters together form a district (in German: Stadtteil), which in many large cities worldwide is the only unit of subdivision. Some districts in Karlsruhe have committees that have to be consulted regarding important issues, but decisions cannot be taken at this administrative level.

As different parts of a city may not be evenly affected by extreme weather events, methods for the assessment of climate change impacts for quarters are required. Thus, we introduce three possibilities to determine exposure to heat waves, which are based on different data sources: meteorological stations, a city climate index, and remote sensing. These methods differ in terms of their data requirements, processing effort, necessary knowledge, and resources, and the accuracy of the results may also differ (see Discussion). Therefore, it is the aim of this study to compare the results of these three methods. We also describe the strengths and weaknesses of the three methods in terms of revealing the heat distribution in Karlsruhe.

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