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Challenges associated with projecting urbanization-induced heat-related mortality

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HIGHLIGHTS

- Extreme heat is a public health hazard in metropolitan Maricopa County, Arizona.
- Urbanization is a key driver of future regional temperature changes.
- Projections of heat–health impacts for 2050 vary across urbanization scenarios.
- The sign and magnitude of projections are also sensitive to exposure variable choice.
- Consideration of urbanization effects is critical for heat–health policymaking.

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ABSTRACT

Maricopa County, Arizona, anchor to the fastest growing megapolitan area in the United States, is located in a hot desert climate where extreme temperatures are associated with elevated risk of mortality. Continued urbanization in the region will impact atmospheric temperatures and, as a result, potentially affect human health. We aimed to quantify the number of excess deaths attributable to heat in Maricopa County based on three future urbanization and adaptation scenarios and multiple exposure variables. Two scenarios (low and high growth projections) represent the maximum possible uncertainty range associated with urbanization in central Arizona, and a third represents the adaptation of high-albedo cool roof technology. Using a Poisson regression model, we related temperature to mortality using data spanning 1983–2007. Regional climate model simulations based on 2050-projected urbanization scenarios for Maricopa County generated distributions of temperature change, and from these predicted changes future excess heat-related mortality was estimated. Subject to urbanization scenario and exposure variable utilized, projections of heat-related mortality ranged from a decrease of 46 deaths per year (−95%) to an increase of 339 deaths per year (+359%). Projections based on minimum temperature showed the greatest increase for all expansion and adaptation scenarios and were substantially higher than those for daily mean temperature. Projections based on maximum temperature were largely associated with declining mortality. Low-growth and adaptation scenarios led to the smallest increase in predicted heat-related mortality based on mean temperature projections. Use of only one exposure variable to project future heat-related deaths may therefore be misrepresentative in terms of direction of change and magnitude of effects. Because urbanization-induced impacts can vary across the diurnal cycle, projections of heat-related health outcomes that do not consider place-based, time-varying urban heat island effects are neglecting essential elements for policy relevant decision-making.

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1. Introduction

Extreme heat is the leading weather-related cause of death in the United States (Luber et al., 2006), and urbanization, population aging, and global-scale climate change will likely conspire in future years to increase population vulnerability to heat. Despite a growing body of research advancing our understanding of spatial, temporal, environmental, social, and behavioral dimensions of heat-related health risks (e.g., Anderson and Bell, 2009; Harlan et al., 2013; Hondula et al., 2012), the institution of warning systems and other intervention measures (e.g., Hondula et al., 2013; Sheridan and Kalkstein, 2010), and the fact that relatively simple measures can prevent heat-related illnesses and

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deaths (e.g., Luber and McGeehin, 2008; O'Neill et al., 2009), heat persists as a public health burden. There has been an increase in research efforts to apply climate change projections to health outcomes, with the greatest emphasis on predicting future heat-related mortality. From a global perspective, increasingly frequent and severe hot days are expected to lead to an increase in corresponding negative health outcomes (McMichael et al., 2006). There is now interest in quantifying the related health burdens to inform planning and policy (Ebi et al., 2006; Gosling et al., 2009; Sheridan et al., 2012). The level of an investment a particular municipality would make in mitigation and adaptation programs aimed at reducing thermally stressful situations in the future would likely be influenced by the magnitude of the expected changes in undesirable heat-attributable health outcomes.

Populated cities in hot climates offer an interesting case for analysis of resident sensitivity to heat under current and future climatic conditions. The population of Maricopa County, Arizona, home of the Phoenix metropolitan area, the hottest major urban area in the United States, is not immune to the dangerous effects of heat (Chuang et al., 2013; Harlan et al., 2013). Unlike many other large metropolitan areas in the United States where episodic heat is associated with elevated risk of illness and death (Anderson and Bell, 2009, 2011; Barnett et al., 2010; Sheridan and Kalkstein, 2004), dangerously high temperatures persist in Maricopa County for much of the warm season. Whereas cities in the southeastern United States exhibit decreased (or no) sensitivity to heat compared with mid-Atlantic and northeastern cities (Curriero et al., 2002; Davis et al., 2003), the temperature extremes present for such an extended period of time result in high heat sensitivity among residents of Maricopa County.

A wide range of studies has documented a significant heat effect in Maricopa County and its associated cities (e.g., Phoenix, Tempe, Glendale, Scottsdale, Mesa, Chandler, Gilbert, and Peoria) (e.g., Harlan et al., 2013; Yip et al., 2008). Most recently, the Maricopa County Department of Public Health reported 106 heat-related deaths in the county in 2011 and at least 102 deaths in 2012 (with 13 cases pending review) (MCDPH, 2013). Heat-related mortality in the region occurs among young and elderly populations alike: a majority of indoor deaths during the period 2000–2005 occurred among the elderly while a majority of outdoor deaths occurred among those less than five years old (Yip et al., 2008). Analysis of a different time period (2002–2009) showed that men in agricultural and construction/extraction occupations were at particularly high risk (Petitti et al., 2013). National-scale studies have reached mixed conclusions regarding the sensitivity of the region's population to extreme heat compared to other cities, ranging from little to no effect of heat (Kalkstein and Greene, 1997; Sheridan and Kalkstein, 2010) to statistically significant effects equal or greater than those in other major U.S. cities (Anderson and Bell, 2009, 2011; Saha et al., 2014).

Here, we compare projections of heat-related deaths for Maricopa County using regional urbanization scenarios associated with high growth, low growth, and adaptation-oriented growth (Georgescu et al., 2013). In Maricopa County, urbanization and urban heat island intensity have been linked to higher heat vulnerability (Chow et al., 2012; Golden et al., 2008; Harlan et al., 2006; Jenerette et al., 2011; Ruddell et al., 2009). There has been minimal research specifically examining the extent to which urbanization (versus greenhouse gas-forced climate change) may contribute to future increases or decreases in heat-related mortality, which is important to consider because urbanization rates can be managed at the local and regional levels. Urban development modifies regional climate primarily through reduced evening and nighttime longwave energy loss to the overlying atmosphere, relative to rural areas, based on the geometry and higher heat capacity of the built environment (Georgescu et al., 2011). We also explore the extent to which choice in exposure variable (e.g., maximum, mean, or minimum temperature) impacts the projection, which has been largely unaddressed to date (Huang et al., 2011). Exposure variable is especially important to consider in semiarid environments where urbanization-induced changes can lead to substantial differences in projected minimum and maximum temperatures.

2. Methods

2.1. Data sources

Maricopa County is located in central Arizona in the northern portion of the Sonoran Desert (see Fig. 1). The urbanized area is contained largely in a valley surrounded by mountains ranging from 300 m to 2000 m above the valley floor. Summer afternoon temperatures regularly exceed 40 °C, and occasionally approach 50 °C. The metropolitan area continues to be one of the fastest growing in the United States, growing from just over 3,000,000 residents in 2000 to over 4,000,000 in 2010, despite a downturn in the economy during that time period. The County is the anchor of the ever-growing Arizona Sun Corridor that extends from Tucson and Nogales to the south and Prescott to the north and west.

All-cause daily mortality data for residents of Maricopa County were obtained from the Office of Vital Records at the Arizona Department of Health Services for the time period 1983–2007. Over the 25-year period of record there were 472,327 deaths in the study region. The increasing daily mortality counts over the period of record are primarily reflective of the rapid population growth in Maricopa County (see Supplemental Material Fig. S1). Seasonal variability is also evident in the data with mortality peaking in January and at a minimum in August. We elected to use all-cause mortality as the variable of interest for this study because exposure to high ambient temperatures can exacerbate a range of health problems and lead to premature death (Sheridan and Kalkstein, 2004; Kovats and Hajat, 2008). The use of all-cause mortality also facilitates comparison with other studies projecting future heat-related health impacts (e.g., Greene et al., 2011; Petkova et al., 2013; Sheridan et al., 2012). The use of human subject data in this research is exempt from the IRB per Title 45 Part 46 Exemption Category 4. These data were preserved by public agencies for research purposes and personal identifiers were removed, eliminating the requirement for consent.

Daily minimum and maximum temperature data for the geographic centroid of Maricopa County were obtained from Daymet (Thornton et al., 2012). The Daymet model provides daily values for a suite of meteorological parameters over a 1 km by 1 km continuous surface spanning the United States and portions of Canada and Mexico based on meteorological observations and a digital elevation model (Thornton et al., 1997). We used Daymet data to facilitate the future extension of this work to other locations where ground-based monitors may not be available. Daily mean temperatures were calculated as the average of daily minimum and maximum temperatures.

Urbanization-induced climate change scenarios were based on Maricopa Association of Governments (MAG)-projected high- and low-development Sun Corridor expansion scenarios for 2050 (Georgescu et al., 2012, 2013). The expansion scenarios considered included a maximum (both geographical urban extent and density) and minimum (both geographical urban extent and density) expansion, hereafter referred to as SunCorrHi and SunCorrLo, respectively. These scenarios account for the largest degree of uncertainty associated with differing Sun Corridor urbanization paths, whose actual development trajectory remains unknown. Finally, widespread adoption of cool (i.e., highly reflective) roofs was utilized as an adaptation approach corresponding to the SunCorrHi expansion scenario (hereafter SunCorrAdapt). These scenarios were incorporated into and used as surface boundary conditions for the Weather Research and Forecasting (WRF) Model (Skamarock and Klemp, 2008; Georgescu et al., 2013). WRF simulation output was extracted for 0500 and 1700 local standard time (LST), consistent with observed average daily minimum and maximum temperatures (Georgescu et al., 2011). The average of the 0500 and 1700 LST data

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