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Connecting people and place: a new framework for reducing urban vulnerability to extreme heat

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Abstract
Climate change is predicted to increase the intensity and negative impacts of urban heat events, prompting the need to develop preparedness and adaptation strategies that reduce societal vulnerability to extreme heat. Analysis of societal vulnerability to extreme heat events requires an interdisciplinary approach that includes information about weather and climate, the natural and built environment, social processes and characteristics, interactions with stakeholders, and an assessment of community vulnerability at a local level. In this letter, we explore the relationships between people and places, in the context of urban heat stress, and present a new research framework for a multi-faceted, top-down and bottom-up analysis of local-level vulnerability to extreme heat. This framework aims to better represent societal vulnerability through the integration of quantitative and qualitative data that go beyond aggregate demographic information. We discuss how different elements of the framework help to focus attention and resources on more targeted health interventions, heat hazard mitigation and climate adaptation strategies.

Keywords: vulnerability, extreme heat, adaptive capacity, urban, human health

1. Introduction

More than half of the world's population lives in cities, where the combined effect of urban heat islands and summer time extreme heat events, produce a myriad of negative health outcomes. Despite advances in meteorological forecasting capabilities and the widespread prevalence of air conditioning systems in American cities, extreme heat persists as a threat to human health. Extreme heat is a leading cause of weather-related human mortality in the United States and in many countries world-wide (Kalkstein and Greene 1997, CDC 2006, Pengelly *et al* 2007). Societal vulnerability to extreme heat has been highlighted during major heat events in Chicago (Semenza *et al* 1996), Philadelphia (Voelker 1995), Phoenix (Yip *et al* 2008) and across Europe (McGregor *et al* 2007). Increasing numbers of residents of expanding urban areas (UN Habitat Agency 2009), especially such vulnerable groups as the elderly and children, and projected increases in the severity, frequency and duration of extreme heat events (Meehl and Tebaldi 2004, IPCC 2007) may couple to further increase societal vulnerability to extreme heat.

Previous studies on extreme heat and human health helped to establish heat–health associations and estimate threshold temperatures beyond which there are negative health outcomes (Hajat *et al* 2006, McGregor *et al* 2007), provide epidemiological information about heat-related morbidity and mortality (Yip *et al* 2008), develop heat preparedness plans (EPA 2006), and identify vulnerable groups within the population (Semenza *et al* 1996, McGeehin and Mirabelli 2001, O'Neill *et al* 2003, Uejio *et al* 2010). Geographic analysis of social vulnerability to extreme heat has been commonly conducted using aggregate Census-based demographic and socio-economic information (Smoyer 1998, Vescovi *et al* 2005, Reid *et al* 2009, Johnson *et al* 2009).

While these approaches offer useful information about the geographic distribution of potentially vulnerable 'hot spots' in a study region, they are limited in delineating differential vulnerabilities to extreme heat within neighborhoods and social groups, due to disproportionate adaptive capacity of urban residents.

In this letter, we explore the relationships between people and place, in the context of urban heat stress, and present a research framework for a multi-faceted, top-down and bottom-up analysis of local-level vulnerability to extreme heat. This top-down, bottom-up approach strives to assess critical community participation in the development of adaptation strategies and subsequent ownership of these strategies (bottom-up) while concurrently engaging government officials (top-down) in the process to ensure program sustainability. The importance of the role of government in coordinating efforts cannot be underestimated; because extreme heat is only one among many health problems faced by residents, government support is essential if coordination of response efforts and stimulus to participate in adaptation and mitigation is to be maintained. For example, visible concern on the part of government affirms the serious nature of the threat and validates the need for adaptation efforts at the local level (Spiegel *et al* 2005). The likelihood of success is further enhanced if a wide range of local and regional partners are engaged in the effort, and government is in an excellent position to facilitate and broadly extend this process. This interpretation of a top-down, bottom-up approach incorporates and enhances the concept of interacting spatial scales of vulnerability indicators and their external drivers as denoted by O'Brien *et al* (2004). In this letter, we discuss how different elements of the framework help to focus attention and resources on more targeted health interventions, heat hazard mitigation and climate adaptation strategies.

2. Extreme heat and urban health

Management of urban health and quality of life is a continuing challenge because of urban growth. Heat-related mortality and morbidity result from a combination of stressors from both natural and human systems. While atmospheric conditions can create exposure to a heat hazard (Harlan *et al* 2006, Smoyer 1998), the features of the human system such as socio-economic inequality, characteristics of individuals and communities, building structure and housing density, access to material resources, and social networks, impact the ability of human populations to respond to and cope with these exposures (Harlan *et al* 2006, Klinenberg 2002, McMichael 2000, Wilhelmi *et al* 2004). The climate assessment community has defined vulnerability as 'the degree to which a system is susceptible to injury, damage, or harm' (Smit *et al* 2001). Vulnerability science has evolved over the past few decades from a concept primarily based on the severity of the natural hazard itself to a much more comprehensive notion involving social capital, poverty levels, and access to resources among other factors (Bankhoff *et al* 2003, Eakin and Luers 2006). Research on heat stress and human health has expanded rapidly since the early 1990s in various academic disciplines (see Kinney *et al* 2008, Gosling *et al* 2009). But, only relatively recently, have researchers started to explicitly incorporate information about social vulnerability in their studies (Smoyer 1998, Guest *et al* 1999, Chan *et al* 2001, Harlan *et al* 2006, Johnson *et al* 2009, Reid *et al* 2009).

Recent advances in geospatial research methods and analysis tools allow for spatially explicit characterization of extreme heat vulnerability in urban environments (Wilhelmi *et al* 2004). In large sprawling cities, with a highly variable socio-economic fabric, uneven infrastructure and multiple housing types, vulnerability is expected to be complex. The relative importance of the population's heat health risk factors has been investigated in several US cities (e.g., Smoyer 1998, Johnson *et al* 2009, Uejio *et al* 2010). These integrated neighborhood-level studies relied on remotely sensed land surface data and self-reported, aggregate information from the US Census (US Census 2000). These case studies showed that surface temperature, socio-economic vulnerability and neighborhood stability information can retrospectively be associated with extreme heat morbidity or mortality cases to identify first order risk factors and produce spatially variable zones of elevated heat risk within urban areas (Uejio *et al* 2010).

Recent and ongoing research on household-level extreme heat vulnerability, conducted in Phoenix, Arizona (Harlan *et al* 2006, Wilhelmi and Hayden 2009), illustrated that while Census data can summarize important demographic, socio-economic and housing characteristics on a neighborhood scale, they cannot fully capture the population's coping ability, perceptions, or people- and place-based community resources. Therefore, in order to have a more complete understanding of urban vulnerability, the aggregate analysis of demographic characteristics needs to be supplemented by quantitative and qualitative analyses of societal adaptive capacity in the context of heat health outcomes. Here, we present a research framework that addresses this critical research gap through explicit characterization of population adaptive capacity and integration of quantitative and qualitative physical and social science data at the local level. This is especially relevant in the context of climate change because previous research has shown that high adaptive capacity at the national or regional level may not automatically translate into successful adaptations to climate change at the local level (O'Brien *et al* 2006). Adaptive capacity at the local level is critical to understanding the vulnerability of urban population, and this argues for social science field research (e.g., household interviews) in order to validate researchers' hypotheses about vulnerability as perceived through aggregate demographic information.

3. Extreme heat vulnerability framework

The extreme heat vulnerability framework was developed in response to the growing threat of urban heat to human health; it underscores the urgent need to better understand underlying societal vulnerability to this hazard. The proposed analytical framework adopts and expands upon concepts and definitions from previously proposed more generalized frameworks (Turner *et al* 2003, Wilhelmi *et al* 2004, Adger

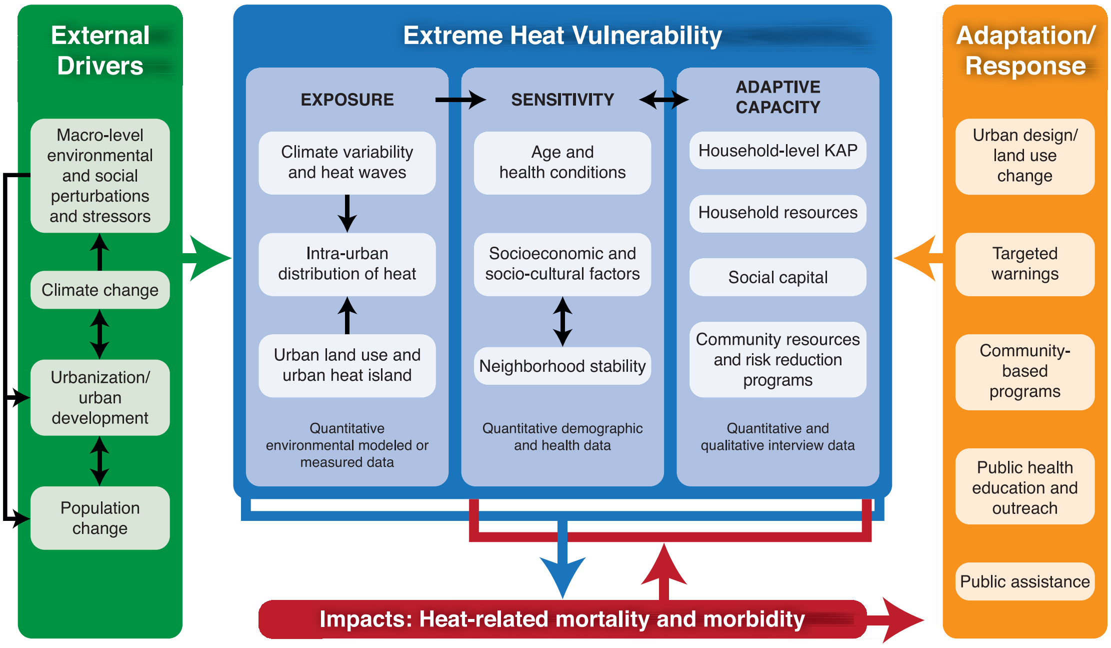

Figure 1. Extreme heat vulnerability analysis framework.

et al 2004, Adger 2006, Cutter *et al* 2008, Leichenko and O'Brien 2008, Acosta-Michlik and Rounsevell 2008) and focuses on societal vulnerability in the context of heat hazard and human health at the neighborhood scale or the US Census block group (~1/4 mi^2, or 65 hectares). The framework (figure 1) incorporates many of the scientific concepts published in the natural hazards and climate change literature and highlights a process of identifying and understanding the relevant components and indicators of vulnerability of human health to extreme heat as well as an evaluation of alternative strategies to manage negative health outcomes.

This framework adds to a growing body of literature on vulnerability assessments (Turner *et al* 2003, Eakin and Luers 2006, Patt *et al* 2008), indicating that societal vulnerability to urban heat needs to be studied at a local level using top-down and bottom-up spatial scales and scales of decision-making. The framework explores relationships of an urban system using GIS analysis tools, which are a commonly used by practitioners and the stakeholders. Mapping data to the local level facilitates ease of use by stakeholders while using human health as an outcome addresses priorities of public health officials. Previous heat–health research (Uejio *et al* 2010) highlighted the need to further delineate differential vulnerability of urban neighborhoods. Preliminary results from a case study conducted in Phoenix, Arizona (Wilhelmi and Hayden 2009) underscore the importance of acquiring and incorporating local-level, household data in the spatial analysis. Several recent studies (Johnson *et al* 2009, Uejio *et al* 2010) determined the relative importance of exposure and sensitivity factors for heat health outcomes, but do not include population's adaptive capacity. Research that is specific to extreme heat and human health (e.g., Klinenberg 2002) and more generalized approaches to assessing societal vulnerability (Leichenko and O'Brien 2008) illustrate that adaptive capacity is critical to an understanding of vulnerability.

Recent vulnerability research (Leichenko and O'Brien 2008, Harlan *et al* 2006) demonstrated that interview- and stakeholder-based data help contextualize societal vulnerability and validate the mapping and modeling results. Few studies (e.g., Acosta-Michlik and Rounsevell 2008) have used interview-based data as *input* into spatio-temporal models. We explore these methodological concepts in the context of human health and heat hazards. The framework suggests that interview-based household-level data on adaptive capacity are explicitly incorporated into spatial analysis of vulnerability.

Similar to more generalized frameworks (Turner *et al* 2003, Patt *et al* 2008), we define *vulnerability* of the system as a function of three interactive components: *exposure* (i.e., climate and synoptic weather conditions which are exacerbated by the reflective, storage, and transportation characteristics of urban materials and vegetation), *sensitivity* (i.e., the extent to which a system or population can absorb impacts without suffering long-term harm), and *adaptive capacity* (the potential of a system or population to modify its features and behavior so as to better cope with existing and anticipated stresses). Each component consists of a set of dynamic, spatially variable indicators, which in turn are affected by external drivers, such as climate change, macro-scale socio-economic and environmental stressors and urbanization trajectories. For example, the pathway of urban development (e.g., large-scale urban agglomerations) can influence urban land use and consequently, the urban heat island, which affects human exposure to excessive heat during the day and night. Macro-scale socio-economic stressors, such as economic downturn, affect sensitivity of the socio-ecological system, through their impacts on housing, employment (i.e., decreased neighborhood stability, increased socio-economic disadvantage, limited household resources for cooling) and health conditions of individuals (i.e., limited access to healthcare).

3.1. Exposure

Intra-urban distribution of heat largely depends on local climatology and urban meteorology, combined with urban land use patterns. The term 'urban heat island' was introduced by Manley (1958) and has been extensively used in climate research primarily to describe warmer temperatures in urban areas compared to rural surroundings. A temperature gradient between an urban area and nearby rural land can often reach up to 10 °C (Oke 1997, Bornstein *et al* 2006). This phenomenon is largely attributed to excess heat absorbed and released from urban non-vegetated surfaces. Within cities, urban core and commercial districts generally have higher temperatures, especially during the night, compared to residential and suburban areas (Brazel *et al* 2007). As global warming patterns continue, researchers anticipate increases in the severity, frequency and duration of extreme heat events (Meehl and Tebaldi 2004, IPCC 2007). Recent studies on climate impacts demonstrate that climate change will have differential consequences in the US at the regional and local scales (IPCC 2007). Meehl and Tebaldi (2004) estimated that areas that experience the most severe heat events in the present climate, such as the western and southern US, will have the greatest increase in heat-wave severity in the second half of the twenty-first century. They also demonstrated that other areas, such as the northwest, which currently experiences few heat waves and is ill prepared to cope with extreme heat, will become more vulnerable to such events. A combination of existing urban heat islands and extreme temperatures, either due to local climate variability (e.g., Phoenix) or due to a heat wave (e.g., Chicago) produces a differential distribution of heat in urban neighborhoods and contributes to the *exposure* component of the extreme heat vulnerability framework. Exposure indicators are represented by quantitative environmental modeled or measured data that often exist in gridded (e.g., remotely sensed images or mesoscale weather model outputs) or point (e.g., station-based observations) formats.

3.2. Sensitivity

There are myriad factors that can influence inequalities and differential ability to respond to extreme heat, including material and behavioral constraints and perception of risk. Perception is often regarded as a precursor to behavior (D'Andrade 1995), and, as such guides action (Glanz *et al* 1997). These issues influence sensitivity to extreme heat and differ spatially by socio-economic status and cultural context. Vulnerability is not solely dependent on physical proximity to the source of the hazard, but rather on the interconnectivity among multi-scale social, cultural, and economic influences and biophysical location. Neighborhood as well as household level influences which reflect structural and cultural aspects of social capital are critical to understanding vulnerability. For example, those living in urbanized locations may be exposed to a high environmental heat load, but may also have the resources to protect themselves against the effects of extreme heat; conversely, those living in an area with a slightly lower heat load, may not have the necessary safety nets to withstand high temperatures. A number of case studies have used epidemiological and statistical techniques to understand the relationship between heat waves, heat-related morbidity, and mortality and to identify vulnerable groups of people (Smoyer 1998, Chan *et al* 2001). These case studies demonstrated that certain groups in the population (e.g., elderly, very young, obese individuals, people using certain medications, socially isolated individuals, poor, the mentally ill, those without air conditioning, outdoor workers) are disproportionately affected by elevated temperatures (Curriero *et al* 2002, O'Neill *et al* 2003, Medina-Ramon *et al* 2006, O'Neill *et al* 2005, Kalkstein and Greene 2007). In the proposed framework, sensitivity indicators are represented by neighborhood-level quantitative aggregate demographic data (e.g., per cent of households living below poverty level) and health conditions (e.g., mental disability) data.

3.3. Adaptive capacity

Improving health outcomes related to exposure to extreme heat requires moving beyond the spatial analysis of quantitative aggregate demographic data toward understanding knowledge, attitudes and practices (KAP) regarding extreme heat. Because awareness of extreme heat does not necessarily translate into action to reduce vulnerability, household-level perceptions of risk to extreme heat based on home, workplace or recreational exposure as well as protective behaviors (i.e. avoidance of heat exposure during the hottest part of the day) need to be better understood. Documentation of coping mechanisms such as air conditioning and, in drier climates, evaporative coolers, air-conditioned transportation, and air-conditioned shelters in the event of power outages as well as barriers (i.e. economic constraints) to the use of existing coping mechanisms are important indicators of vulnerability, yet need to be collected at the household level. Understanding safety nets in the form of social networks that connect individuals to their community resources (people- and place-based) helps define coping mechanisms through contextualization of social capital. Smit and Wandel (2006) note that 'in the climate change field, adaptations can be considered as local or community-based adjustments to deal with changing conditions within the constraints of the broader economic–social–political arrangements'. This highlights the importance of scale as internal to the system indicating that what occurs at the household level also affects the community; this is in turn influenced by the large-scale forces (e.g., economic downturn) that shape the ability of individuals to adapt to extreme heat. In order to associate data on health disparities to a neighborhood level, it is critical to incorporate the influence of individual level socio-economic indicators as well as local-level adaptive capacity/adaptation as determinants of vulnerability to heat (Pickett and Pearl 2001). Local knowledge systems are integral to understanding local-level adaptation (IPCC 2007), and are an understudied dimension of climate change research. Field research data on individual and household level, both quantitative (e.g., survey) and qualitative (e.g., interviews) are necessary for a comprehensive analysis of a population's adaptive capacity.

3.4. Reducing vulnerability to extreme heat

Various combinations of the exposure, sensitivity and adaptive capacity indicators result in spatially differential negative impacts on human health. A causal analysis of heat-related mortality and morbidity allows tracing outward from each impact to the underlying indicators of vulnerability that contribute to the resulting impacts. By linking heat health impacts to possible causal mechanisms on a local level, the framework provides a mechanism to reduce vulnerability within a socio-ecological system and affect health impacts, since it is through responding to its causes that vulnerability can be effectively addressed (Ribot 1996, Hayes *et al* 2004). Spatial assessments, common in vulnerability research, often result in vulnerability index maps, where indices are constructed as cumulative composites of multiple factors. They highlight relative vulnerability within an urban boundary, but do not often provide sufficient information for communities and policy makers on specific intervention and vulnerability reduction actions. This framework suggests specific heat stress adaptation and response strategies to target specific corresponding indicators of vulnerability (i.e., causes of impacts, such as lack of resources, social networks or urban land use) and their relative importance in contributing to negative health outcomes. This approach requires the integration of diverse data, both quantitative and qualitative, as well as flexibility and continuing input from the stakeholders. Extreme heat mitigation measures and societal adaptation, which refers to the actual adjustments made to cope with the stressors, in turn can decrease societal vulnerability and lessen the negative health impacts from extreme heat. Current thinking in terms of adaptation and mitigation to heat stress emphasizes technological interventions such as improved infrastructure and access to air conditioning (Jones *et al* 1982, Semenza *et al* 1996, McMichael 2000, Klinenberg 2002). However, social and economic inequalities that exist on a local level (i.e. access to air conditioning, social isolation) create differential adaptive capacities (McMichael 2000, Klinenberg 2002, O'Brien *et al* 2004, Harlan *et al* 2006). The proposed framework emphasizes that the negative health outcomes from heat (with and without external drivers) can be reduced through the coping mechanisms of the individuals, hazard mitigation actions (e.g., land use planning, community-based programs, early warning systems) and adaptation to new conditions through both physical, infrastructure-based and social measures (Wilhelmi *et al* 2004, Bernard and Ebi 2001).

4. Connecting people and place

To this end, we propose to engage stakeholders from both the top-down and the bottom-up—this will allow the opportunity to better understand local-level vulnerability and existing adaptation toward a goal of targeting limited resources in order to positively affect health outcomes from extreme heat. Engagement of stakeholders is not limited to understanding local-level response to a hazard, but rather challenges the researcher and public health practitioner to engage the public at multiple levels, from the household to the state and national level to ensure the acceptance and validity of proposed adaptation and mitigation strategies. Community-based programs have often been viewed as an economical *alternative* to government programs. However, the role of government in coordinating interventions cannot be dismissed—without a corresponding effort from both the top-down and bottom-up, interventions are unlikely to be sustainable (Zielinski-Gutierrez and Hayden 2006). Contextualizing vulnerability can influence the process used to formulate successful approaches that are targeted locally using resources allocated according to decisions made at a state or national level. This process can help with strategies at differing timescales—whether they involve short-term technological adjustments or long-term adaptation to climate change.

Integration of quantitative and qualitative data on social vulnerability and adaptive capacity presents a methodological advancement in the assessment of vulnerable populations through geospatial (i.e., Geographic Information Systems, data mining), statistical and social science (i.e., survey, interviews) research methods (Wilhelmi and Hayden 2009). In addition, once typological (i.e., profiles of vulnerable groups) and spatial patterns of adaptive capacity and vulnerability are understood, these can be used to better interpret heat stress in other regions, not as broad homogeneous geographic units, but rather, as patchwork mosaics of neighborhoods and households within their regional context. Because urban systems are akin to living organisms and constantly evolving, this framework emphasizes an iterative process through integration and updating of existing knowledge related to social changes, vulnerabilities, adaptations, and the lessons learned from previous heat-wave events. Because of current climate variability and projected climate change, evolving socio-economic conditions and adaptation options, the process is, of necessity, iterative.

5. Conclusions

Social vulnerability to extreme heat can be viewed as a function of both natural and human systems, which can be affected by external drivers, (e.g., climate change, environmental and economic perturbations) coupled with drivers internal to the system. Negative health outcomes from heat (with and without external drivers) can be reduced through the coping mechanisms employed by individuals, hazard mitigation actions (e.g., land use planning, community-based programs, early warning systems) and adaptation to variable conditions through both physical, infrastructure-based and social measures (Wilhelmi *et al* 2004, Bernard and Ebi 2001). The extreme heat vulnerability framework presented in this paper is a step toward including drivers of vulnerability at multiple scales, connecting people- and place-based vulnerability assessment approaches and enhancing the ability of communities and stakeholders to develop proactive programs to mitigate risk and respond efficiently to heat emergencies.

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