Aspen Global Change Institute Energy Project

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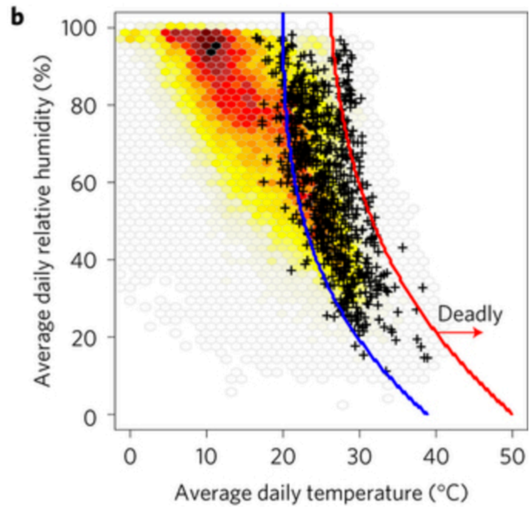
Mortality in a Changing Climate

Historically, heat waves leading to distress, and in some cases death, for human populations were considered extreme events due to natural variability in the climate system. More recently, heat waves have received attention not only for the magnitude of their impact, but also as a new area of research in the context of climate change science (e.g. Chicago 1995, Europe 2003, Western Russia/Eastern Europe 2010). It is well understood that a shift in the average climate to a warmer world will produce a greater likelihood of extreme heat events, thus exposing greater populations of people to extreme heat. Understanding frequency, intensity, and duration of extreme heat events in the present and future climate is an active area of research, as is the expected impact of these events on human wellbeing. As the century unfolds, mitigation to limit greenhouse gas emissions combined with adaptive measures will save lives. There is an "adaptation gap" to climate change impacts where those with the means to build adaptive capacity don't fully utilize their ability, as well as a gap for those of the most vulnerable populations such as the poor with inadequate access to suitable shelter, outdoor workers, and those with compromised health conditions including the elderly. Public health preparedness combined with early warning systems of heat wave events are key societal responses; however, the fundamental need is to stabilize the climate system by reducing greenhouse gas emissions to near zero this century.

Determining a Deadly Threshold

New work by Mora and colleagues reviewed studies on heat waves, heat stress, and mortality that were published between 1980 and 2014. The team confronted the

difficulty in overcoming different ways heat events are defined[1], how heat related mortality is sorted out from confounding factors such as air pollution, and how to attribute mortality to climatic conditions. They devised a climatic threshold by analyzing 16 climate variables combined with a statistical method to separate climatic conditions that are lethal from non-lethal events. They identified two key variables related to the "deadly threshold"— average daily temperature and relative humidity (See Figure 1). For example the figure shows that daily averages over 30°C and greater than 80 percent relative humidity become deadly.



The study concludes that about 30 percent of the world population is already exposed to the potential lethal threshold for at least 20 days per year. Low vs. high projections of future warming (IPCC scenarios Representative Concentration Pathways (RCP) 2.6 and 8.5) increases the percentage of people exposed to the deadly threshold by ~48 percent and ~74 percent, respectively, by the end of the century. Succinctly put by Mora et al. (2017), "the boundary at which temperature becomes deadly decreases with increasing humidity..."

Earlier work by Sherwood and Huber (2010) on the theoretical limit or "peak heat stress" for human exposure also focused on temperature and relative humidity using a wet-bulb (T_w) metric. The paper explores the limits to adaptability in a changing climate from heat stress. Based on thermodynamics and human physiology, this study concluded that a T_w of 35°C for six hours defines a survivability limit. For heat to dissipate from a body core temperature of 37°C in humans, the surface skin temperature needs to be cooler, about 35°C. Without the ability to dissipate heat, the core temperature climbs and hyperthermia ensues, leading to death. The ability to lose heat to the environment can occur by conduction, net infrared radiative cooling, or via sweat and the resulting evaporative cooling. Conduction and evaporative cooling from the skin to the environment require the ambient wet-bulb conditions to be cooler. Heat transfer to cool the body is dramatically reduced when the ambient conditions are hot and humid.

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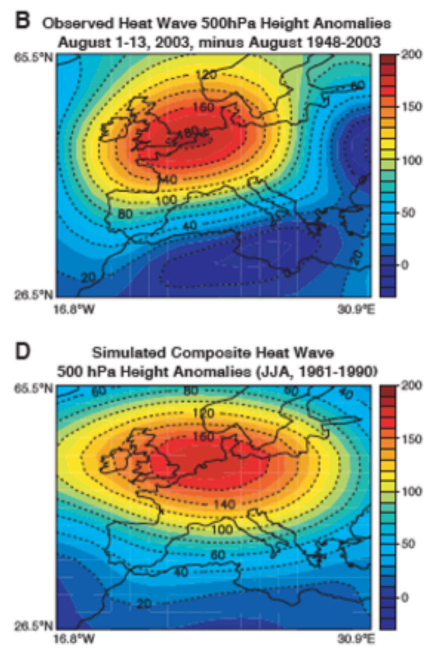
[1] In this study, the definition of lethal and deadly: "…'lethal' as referring to climatic conditions during documented cases of excess mortality and 'deadly' when referring to climatic conditions that are projected to cause death."

Typically, wet-bulb maximum temperature $T_{w(max)}$ is 26-27°C with very few instantaneous readings on Earth reaching a $T_{w(max)}$ of 31°C; however these upper values are projected to increase with global warming. Sherwood and Huber conclude that present impact assessment models underestimate the human ability to survive in increasingly hotter environments. They also point out that the direct impact of a heat stress limit is not confined to humans, but also applies to both wild and domesticated mammals. As the world becomes more urbanized this century, an added concern is that the urban heat island effect will exacerbate the impact due to higher temperatures found in cities (See Cities on the Frontlines of Climate Impacts and Response, also in the June 2017 Quarterly Research Review).

Modeling Heat Waves in a Warming Climate



The year after the devastating 2003 heat wave that killed thousands in and around Paris, a study was published by researchers at the National Center for Atmospheric Research on projected heat waves in the 21st century. Utilizing a global climate model, they showed that a world altered by increasing greenhouse gases produces a unique pattern of heat waves like the one over Europe in 2003 and Chicago in 1995 (Meehl & Tebaldi 2004). They compared a high emissions scenario for the period 2080-2099 to the baseline reference period of 1961-1990. The study found modeling evidence for greater intensity, duration, and higher frequency of similar heat wave events in a climate forced by a century of continued buildup of greenhouse gases. The pattern of the 1995 and 2003 heat waves were similar to those of the model simulations. Figure 2 shows observed and modeled results for the air mass over central Europe. The authors concluded that areas subject to intense heat waves today will likely see continued intensification, and areas not known for heat waves today are potentially prone to greater impacts with global warming because these populations are not as well adapted to heat wave conditions from past experience. Twelve years after the Meehl and Tebaldi heat wave study, a new team led by Mitchell and colleagues utilized a high-resolution regional model to also examine the 2003 Paris event, explore attribution of the extreme event between human induced and natural causes, and explore the significance of attribution studies to estimates of loss and damages. They found that ~70 percent of the 2003 Paris heat wave event can be attributed to anthropogenic emissions rather than natural variability (Mitchell et al., 2016).

Tebaldi and Wehner (2016) compared emission scenarios RCP 4.5 and 8.5, and both to the reference period of 1996-2005, assessing one day and three day maximum and minimum temperatures. Minimum temperatures are important in providing nighttime relief from the daytime high temperatures. As the century unfolds in the model runs, both scenarios show an increase in the magnitude of extreme temperature events and greater land area affected; however deleterious changes under RCP 4.5 are much less than those in 8.5. Not surprisingly, this study shows that a great deal can be gained in the reduction of human health impacts by achieving a low emissions path. For example their study concluded that by 2075 under RCP 4.5 vs. 8.5, 95 percent of land areas would experience greater than a 1°C reduction in one-day heat extremes compared to a 1996-2005 reference period (Tebaldi and Wehner, 2016).

An Emergent Epidemic from Heat Stress

Complementing the more theoretical studies described above is an increasing body of literature on case studies in public health with linkages to climate change. One of the most vulnerable populations in the coupled human-climate system is the field worker. As with many climate related impacts, multiple stressors can be at play, creating an amplified effect not anticipated by factors considered in isolation. A combination of medical physicians, biochemical researchers, and climate experts have worked together in an interdisciplinary fashion to better understand the rise in the incidence of Chronic Kidney Disease (CKD) or heat stress-associated nephropathy among field workers. An important example of this new type of research focuses on how extreme heat events combined with worker conditions are related to CKD (explored in depth at the 2016 AGCI workshop 'Health Impacts from Climate Change: The Importance of Health Partnerships'). Inadequate shade, rest, and hydration are confounding factors combined with hot and humid conditions already present in today's climate, and are projected to worsen with global warming.

A study by Glaser and colleagues considered field worker populations in Central America and other locations around the world for a set of health conditions related to climate change. The heat exposure index used in the study, Wet Bulb Globe Temperature (WBGT) is used in establishing outdoor worker standards. As a point of reference, in the U.S., OSHA suggests 15-minute breaks per hour for WGBT of 26°C, and 45-minute breaks per hour for a WGBT of ≥30°C. The study focused on sugarcane field workers in parts of Central America where worker scheduled relief from high WGBT conditions is often not followed. Workers experience "heavy exertion, lack of shade, infrequent breaks, long work hours (in some regions), and lack of access to sufficient potable water during the workday." Even though workers begin their day in the early morning, by mid-morning WGBT values can exceed 28°C. Further exacerbating the problem is hydration with high sugar content drinks rather than water (Glaser et al. 2016). The CKD study illustrates

how improving worker conditions can make a significant difference; however, as shown by heat wave mortality studies, there are fundamental physiological limits.

Multiple Stressors and Impact Projections

Here we have discussed some recent research on the effects of heat waves on human health and mortality. But impacts in complex systems are not found in isolation. There has been an important evolution in the study of impacts on society more broadly due to climate change, as more observational data and better models are applied to the problem in a multidisciplinary manner. Moreover, these impacts are already having measurable impact. A study by Carleton and Hsiang (2017) explores how new data and analysis techniques are uncovering interrelated aspects of the human-climate system where "research has begun to illuminate key linkages in the coupling of these complex natural and human systems, uncovering notable effects of climate on health, agriculture, economics, conflict, migration, and demographics." Policies measured against incomplete assessment of impacts are likely to fall short of what is needed to guide mitigation and adaptation investments for an uncertain future. The existential threat of climate change is real and increasingly being explored by studies such as those outlined here. As the evidence mounts for the need to avoid the impacts of climate change, so too is the body of solutions being proposed and implemented, from the exponential growth of clean energy to community-based adaptive strategies.

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