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The Heat is On: Climate Change & Heatwaves in the Midwest

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PEW CENTER ON Global CLIMATE CHANGE

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Excerpted from the full report,
Regional Impacts of Climate Change: Four Case Studies in the United States
Prepared for the Pew Center on Global Climate Change

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Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

In 2007, the science of climate change achieved an unfortunate milestone: the Intergovernmental Panel on Climate Change reached a consensus position that human-induced global warming is already causing physical and biological impacts worldwide. The most recent scientific work demonstrates that changes in the climate system are occurring in the patterns that scientists had predicted, but the observed changes are happening earlier and faster than expected—again, unfortunate. Although serious reductions in manmade greenhouse gas emissions must be undertaken to reduce the extent of future impacts, climate change is already here and some impacts are clearly unavoidable. It is imperative, therefore, that we take stock of current and projected impacts so that we may begin to prepare for a future unlike the past we have known.

The Pew Center has published a dozen previous reports on the environmental effects of climate change in various sectors across the United States. However, because climate impacts occur locally and can take many different forms in different places, *Regional Impacts of Climate Change: Four Case Studies in the United States* examines impacts of particular interest to different regions of the country. This paper is an excerpt from the full report. Although sections of the full report examine different aspects of current and projected impacts, a look across the sections reveals common issues that decision makers and planners are likely to face in learning to cope with climate change.

Kristie Ebi and Gerald Meehl find that Midwestern cities are very likely to experience more frequent, longer, and hotter heatwaves. According to Dominique Bachelet and her coauthors, wildfires are likely to increase in the West, continuing a dramatic trend already in progress. Robert Twilley explains that Gulf Coast wetlands provide critical ecosystems services to humanity, but sustaining these already fragile ecosystems will be increasingly difficult in the face of climate change. Finally, Donald Boesch and his colleagues warn that the Chesapeake Bay may respond to climate change with more frequent and larger low-oxygen “dead zone” events that damage fisheries and diminish tourist appeal. These authors are leading thinkers and practitioners in their respective fields and provide authoritative views on what must be done to adapt to climate change and diminish the threats to our environmental support systems.

A key theme emerges from these four case studies: pre-existing problems caused by human activities are exacerbated by climate change, itself mostly a human-induced phenomenon. Fortunately, manmade problems are amenable to manmade solutions. Climate change cannot be stopped entirely, but it can be limited significantly through national and international action to reduce the amount of greenhouse gases emitted to the atmosphere over the next several decades and thereafter, thus limiting climate change impacts. Managing those impacts requires that we adapt other human activities so that crucial resources, such as Gulf Coast wetlands or public emergency systems, continue to function effectively. The papers in this volume offer insights into how we can adapt to a variety of major impacts that we can expect to face now and in decades to come.

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The Heat is On: Climate Change & Heatwaves in the Midwest

A. Introduction

Heatwaves affect human health through heat stress and exacerbate underlying conditions that can lead to an increase in mortality. Over the period 1979–1999, 8,015 deaths in the United States were recorded as being heat-related, 3,829 of which were attributed to weather conditions (Donoghue et al., 2003). Populations in the Midwest are particularly at increased risk for illness and death during heatwaves, as evidenced during events occurring in the 1980s and 1990s. A heatwave in July 1980 caused a 57 percent increase in mortality in St. Louis and a 64 percent increase in Kansas City (Jones et al., 1982). The 1995 Chicago heatwave is perhaps the most widely known; it caused an estimated 696 excess deaths (Whitman et al., 1997; Semenza et al., 1999). A heatwave of similar magnitude in 1999 resulted in 119 deaths in Chicago (Palecki et al., 2001).

B. Heat-Related Illnesses

Illnesses caused by exposure to high temperatures include heat cramps, fainting, heat exhaustion, heatstroke, and death (Kilbourne, 1997). Heat exhaustion is the most common response to prolonged exposure to high outdoor temperature; it is characterized by intense thirst, heavy sweating, dizziness, fatigue, fainting, nausea or vomiting, and headache. If unrecognized and untreated, heat exhaustion can progress to heatstroke, a severe illness with a rapid onset that can result in delirium, convulsions, coma, and death (Lugo-Amador et al., 2004). Heatstroke has a high fatality rate. Non-fatal heatstroke can lead to long-term illness. For example, about one-third of the patients admitted with heatstroke during the 1995 Chicago heatwave exhibited severe impairment and those who survived showed no improvement after one year (Dematte et al., 1998). In addition to heatstroke, many causes of death increase during heatwaves, particularly cardiovascular and respiratory disease (Kilbourne, 1997).

Except for heat cramps, heat-related illnesses are the result of varying degrees of the body's failure to regulate its internal temperature. To keep its internal temperature within healthy limits, the body's responses to hot weather include an increase in blood circulation (to move heat to the body surface) and an increase in perspiration. Heat loss is reduced when air temperature and/or humidity increase. To compensate, the body further increases circulation, but may be limited by its ability to increase heart rate and blood volume (because of loss of body fluids). For less fit subjects, heat illness can occur at low levels of activity, or even in the absence of exercise (Havenith et al., 1995).

C. Populations at Increased Risk

Although the risk of heat illness exists for the entire population, some factors increase the risk:

- ***Older and younger age.*** Older adults are more vulnerable to heatwaves because a natural part of the aging process is a decrease in the body's ability to control its internal temperature. Also, age correlates strongly with reduced fitness and increased illness, disability, and medication use. Most studies have found that heat-related mortality is highest in those over 65 years of age (Kovats and Koppe, 2005).

  Babies and infants also are at increased risk during a heatwave because they are at higher risk of dehydration, due to the relatively higher volume of fluid in their bodies compared with an adult (King et al., 1981). During 1979–2002 in the United States, 6 percent of the 4,780 deaths classified as heat-related occurred in children (LoVecchio et al., 2005).

- ***Use of certain drugs.*** Certain drugs interfere with the body's ability to cope with high temperatures (such as stimulants, beta-blockers, anticholinergics, digitalis, and barbiturates) (Koppe et al., 2004). For many individuals, a side effect of these drugs is that they may not be aware that high outdoor temperatures are making them ill and therefore may not take appropriate actions.

- ***Dehydration.*** Sufficient nonalcoholic fluid intake during a heatwave is a critical factor in reducing illness and death, particularly in those who are more vulnerable (Kilbourne, 1997).

Chronic dehydration, which is common among older adults, can increase susceptibility to heatwaves. The presence of multiple diseases and/or drug treatments also increases the risk of dehydration (Hodgkinson et al., 2003).

- ***Low fitness.*** A low level of fitness, due to reduced physical activity, increases vulnerability due to a reduction in the ability of the body to adjust to high outdoor temperatures (Havenith, 2001). Reduction in fitness can result in a vicious circle, as the increased strain experienced with activity may in itself result in further activity reduction, which may further decrease fitness.

- ***Excessive exertion.*** Excessive exertion during a heatwave is dangerous for everyone, regardless of age or fitness. Outdoor workers and those who maintain a vigorous exercise regimen during a heatwave are particularly at risk.

- ***Overweight.*** Being overweight increases the risk of heat-related illness and death. Fatty tissues are poorer conductors of heat than are other tissues in the body, thus providing an insulative barrier to heat flow (Koppe et al., 2004). Because a higher heart rate is needed to dissipate heat for an obese person, reduced fitness increases their risk further.

- ***Reduced adjustment to high outdoor temperatures.*** Although people physically adjust to the weather in the region in which they live, living in areas with relatively high daily temperature variability increases risk partly because adjustment is more difficult (Chestnut et al., 1998). Short-term adjustment to a change in outdoor temperature usually takes 3–12 days, but complete adjustment may take several years (Babayev, 1986; Frisancho, 1991). Short-term adjustment gradually disappears over a period of several weeks after a heatwave ends. Avoiding heat exposure leads to a reduction in the body's adjustment to higher temperatures, placing individuals at increased risk during a heatwave. This factor may add risk for people living in the Midwest where summer temperatures are highly variable and extreme heat occurs rarely.

- ***Urban populations.*** A number of studies suggest that urban populations suffer more illness and death during heatwaves (e.g., Smoyer et al., 2000; Sheridan, 2003). Urban populations may be more vulnerable because of higher underlying rates of cardio-respiratory disease. Also, a heatwave causes higher daytime and nighttime temperatures in cities than in rural areas because buildings and asphalt absorb more heat than do trees and plants. While rural areas cool after the sun goes down, this additional urban heat keeps temperatures high around the clock. Exposure to heat stress is higher in housing that is not designed to effectively insulate occupants from high outdoor temperatures.

- ***Lower socio-economic status.*** Studies have indicated that lower socio-economic status is a risk factor for heat-related mortality (Kovats and Koppe, 2005). For example, heatwave deaths in St. Louis in 1966 were the highest in inner city areas where population density was higher, open spaces were fewer, and where socio-economic status was lower than in surrounding areas (Henschel et al., 1969; Schuman, 1972). However, it is not clear whether the increased risk is due to differences in housing, neighborhood, access to air conditioning, or the underlying prevalence of chronic disease.

- ***Living alone.*** Studies designed to investigate why some people died during the 1995 and 1999 heatwaves in Chicago found that the strongest risk factor was living alone, particularly for those who did not leave home daily (Semenza et al., 1996 ; Naughton et al., 2002). O'Neill et al. (2003) found a nearly ten-fold increase in heat-related deaths for deaths occurring outside of a hospital compared with those in hospital, suggesting that people living alone without someone to check on them regularly are at particular risk. Similar risks were found in the 2003 heatwave in Paris and other regions of Europe, with many deaths of elderly adults occurring outside of a hospital (Kosatsky, 2005).

D. Projected Changes in the Frequency and Intensity of Heatwaves

There are a number of ways to define an extreme heatwave, most related to some kind of impact. We analyzed results from a global coupled climate model using two definitions of a heatwave.

The first definition comes from analysis of the Chicago heatwave of 1995. Mortality increased dramatically after three consecutive nights of very hot temperatures; in total, nearly 700 more people died than expected (Karl and Knight, 1997). Therefore, one definition of a heatwave is the warmest average minimum temperatures over three consecutive nights in a given year. This definition was used to quantify heatwave intensity for comparing observations and model results to determine how well the model simulates present-day events.

The National Center for Atmospheric Research/Department of Energy Parallel Climate Model (PCM) was used for the analysis. It is a global coupled climate model incorporating atmosphere, ocean, land surface, and sea ice components. Simulations of 20th century climate start in 1870, then run forward with time-evolving factors that affect the climate system, including natural (solar and volcanoes) and anthropogenic (greenhouse gases, sulfate aerosols, and tropospheric and stratospheric ozone) climate drivers (Meehl et al., 2004). The model was run four times from slightly different initial conditions, providing simulations for present-day heatwaves. Observations of past climate were analyzed in a similar fashion and compared to the model results (Figure 1a,b). The model did a good job of simulating the amplitude and the geographic pattern of observed heatwave intensity over North America. Both the model results and the observations show that heatwaves are most severe over the Eastern Seaboard, the southern and upper Midwest, and the southwestern United States. This model simulation of heatwave intensity is similar to a number of other models, as depicted by Tebaldi et al. (2006).

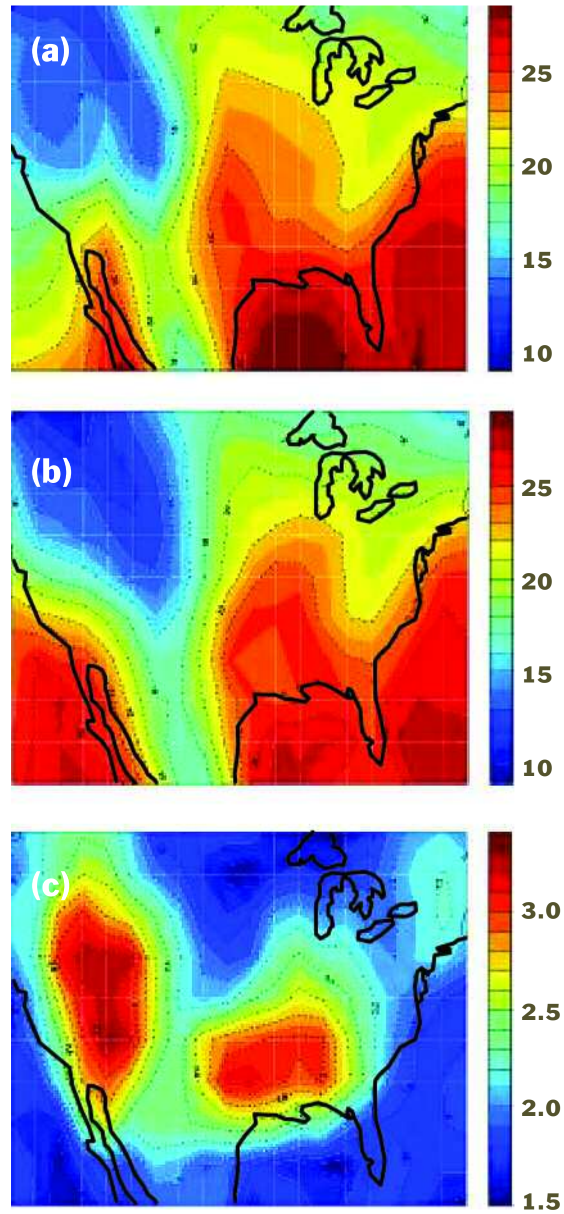
To project changes in future heatwaves, we used a "business as usual" future climate change scenario that assumed little policy intervention to mitigate greenhouse gas emissions in the 21st century (Dai et al., 2001). The model was run five times with slightly different initial conditions. We defined the "present-day" reference period as 1961–1990, and "future" as the time period from 2080–2099, and computed differences between these two periods. Future changes in heatwave intensity show a distinct geographical pattern (Figure 1c). Although differences were projected to be positive in all areas—indicative of the general increase in nighttime minimum temperatures—heatwave severity shows a greater increase in the western, upper midwestern, northeastern, and southern United States. Throughout much of the Midwest, the model projects future increases in nighttime temperatures of more than 2 °C (3.6 °F) during the worst heatwaves (Figure 1c).

Many of the areas most susceptible to heatwaves today (greatest heatwave severity in Figures 1a and 1b) are projected to experience the greatest increase in heatwave intensity in the future. But the model projects that other areas not currently as susceptible, such as northwestern North America, also could experience increased heatwave severity in the 21st century. These patterns of projected future heatwaves suggest different types of impacts. Regions already adapted to heat extremes (e.g., the southern, eastern, and southwestern parts of the United States) could experience negative effects related to increased power generation to run the greater use of air conditioning. In areas such as the northwestern United States, where heatwaves are not severe at present and where use of air conditioning is less common, future increases in heatwave intensity could result in more heat-related illnesses and deaths. As more people install air conditioning, the health impacts could lessen, but the region may then face an increased strain on power generation. The pattern of projected future changes is therefore important for assessment of vulnerability and adaptation.

Heatwaves also can be defined to occur when weather conditions exceed a particular threshold; this definition identifies changes in heatwave frequency and duration. We examined model outputs for grid cells near three Midwestern cities (Chicago, Cincinnati, and St. Louis), to illustrate future projections of heatwave characteristics using three criteria to define heatwaves: (1) maximum temperature exceeding the 97.5th percentile (i.e., an event happening one out of 25 times) for at least three days, (2) average minimum temperature above the 97.5th percentile for at least three days, and (3) maximum temperature above the 81st percentile for the entire period (Huth et al., 2000).

Figure 1

Heatwave **Severity**



Using the definition of heatwave severity as the average annual 3-day warmest nighttime minimum temperatures (ºC) from Karl and Knight (1997): a) observations for the "present-day" (1961–1990) from NCEP/NCAR reanalysis data for the United States; b) model simulation for the same period; c) model simulation for the "future" (2080–2099) minus model simulation for the "present-day" (1961–1990) for North America. Results in (c) indicate how much hotter on average heatwaves are projected to become by the end of the 21st century. (After Meehl and Tebaldi, 2004).

All model scenarios projected future increases in the average frequency and duration of heatwaves (Figure 2). For all three cities, the observed frequency fell within the range of the present-day (1961–1990) frequency simulated by the model, indicating that the model mimics the observed climate effectively. In contrast, all of the observed values for heatwave frequency fell outside of and below the frequency range simulated by the model for the future (2080–2099), thus projecting future increases in heatwave frequency for all three cities. The model results were similar for average heatwave duration, with the exception that the observed value for Cincinnati fell slightly below the range of the model-simulated present-day values. This one inconsistency suggests the model may overestimate the absolute duration of heatwaves near Cincinnati, but it does not challenge the relative increase in duration projected for the future.

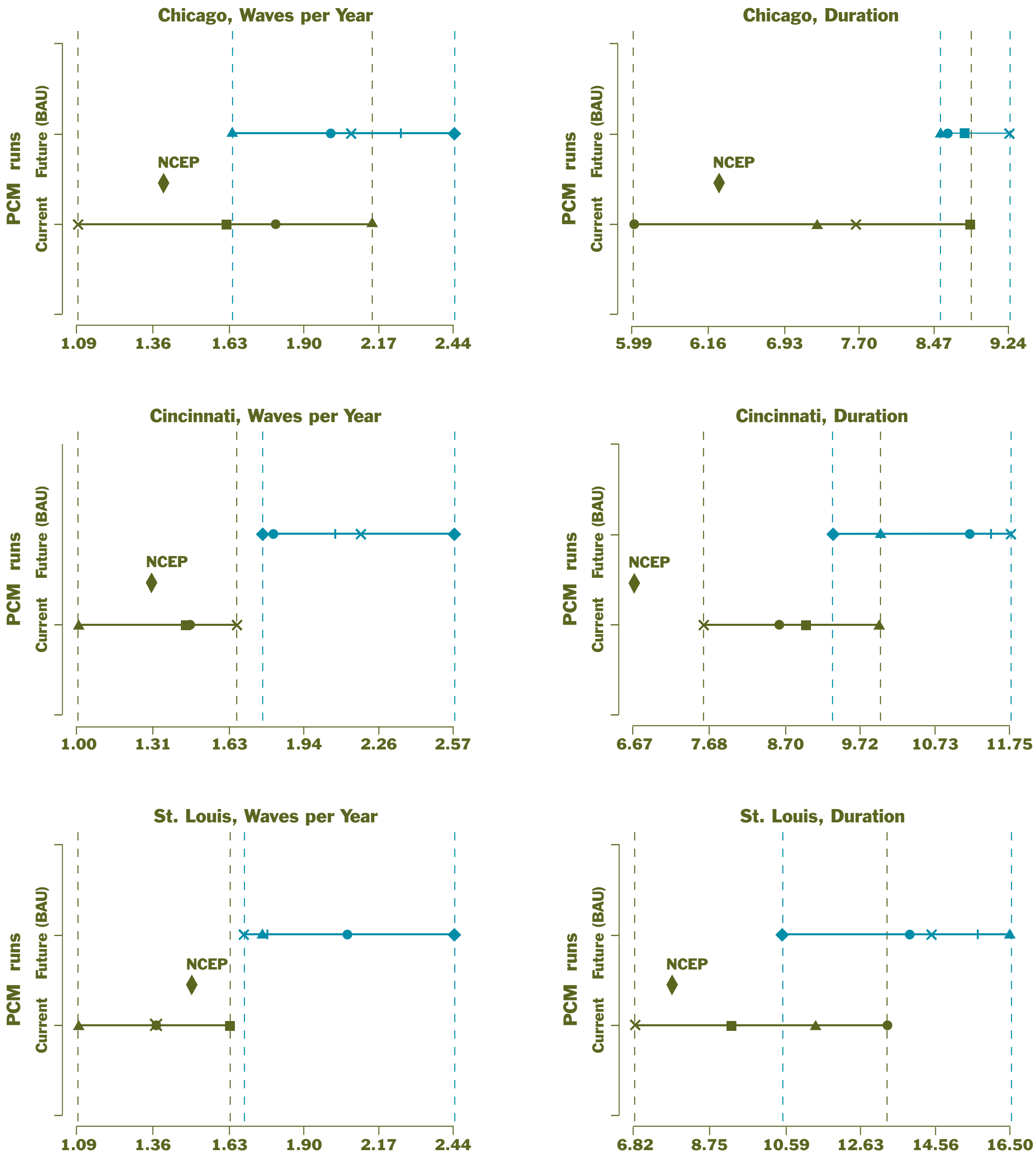
The model projected an increase in the average heatwave frequency of about 24 percent for Chicago—from 1.7 to 2.1 heatwaves per year; 50 percent for Cincinnati—from 1.4 to 2.1 heatwaves per year; and 36 percent for St. Louis—from 1.4 to 1.9 heatwaves per year. The average duration of heatwaves was projected to increase by 21 percent for Chicago—from 7.3 to 8.8 days; by 22 percent for Cincinnati—from 8.8 to 10.7 days; and by 38 percent for St. Louis—from 10.3 to 14.2 days.

These analyses show that the model simulated the present-day number and duration of heatwaves within or near the range of the observations, and that the range of projections lies well beyond the present-day observations (i.e. more and longer-lived heatwaves). On average, the frequency of heatwaves for all three cities increased by 36 percent and the duration of individual heatwaves increased by 27 percent. Combining these two effects implies an overall increase of about 70 percent in the annual number of heatwave days for the Midwestern region by the late 21st century. Moreover, as shown in Figure 1, these extreme days will be hotter on average than at present.

Heatwaves generally are associated with semi-stationary "domes of high pressure" that produce clear skies, light winds, warm air, and prolonged hot conditions at the surface (Kunkel et al., 1996; Palecki et al., 2001). These conditions were present during the 1995 Chicago and 2003 Paris heatwaves (Meehl and Tebaldi, 2004), with significant domes of high pressure over Lake Michigan and over northern France for the duration of the heatwaves. The model projections simulated comparable patterns during heatwaves. One reason for the intensification of future heatwaves is that the high pressure associated with a given heatwave is projected to be amplified due to anthropogenic emissions

Figure 2

Present and Future **Frequency and Duration** of Heatwaves



Based on the threshold definition of heatwaves from Huth et al. (2000), this figure shows the observed and model-simulated average number of heatwaves per year and the average duration of heatwaves for the "present-day" (1961–1990) and the "future" (2080–2099) climate near Chicago, Cincinnati, and St. Louis. In each panel, the green diamond marked "NCEP" indicates the observed value for the "present-day" base period of 1961–1990, computed from NCEP/NCAR reanalysis data. The green segment shows the range of values obtained from the four model runs for the "present-day" (1961–1990) simulation and the blue segment shows the range of values obtained from the five model runs for the "future" (2080–2099) simulation. The values for individual model runs are marked by individual symbols along the green and blue segments. Dashed vertical lines mark the endpoints of the simulated ranges for the "present-day" (green) and "future" (blue) and facilitate comparisons of the simulated ranges and observed values. (Results for Chicago are from Meehl and Tebaldi, 2004; results for Cincinnati and St. Louis are unique to this study).

of greenhouse gases (Meehl and Tebaldi, 2004). The average future climate shows higher pressure over the upper Midwest, which is directly associated with more intense heatwaves.

This pattern of increased high-pressure events results in an increase in summer nighttime minimum and daytime maximum temperatures (Meehl and Tebaldi, 2004), consistent with increased variability of temperature extremes in addition to a shift in the average (Schar et al., 2004). Thus, such events as the 2003 Paris heatwave could become common in the future climate (Stott et al., 2004). A study by Tebaldi et al. (2006) shows that such results are typical, with all models indicating an increase in heatwave intensity in a future warmer climate.

E. Projected Health Impacts of Future Heatwaves

Projections of an increase in the frequency and intensity of heatwaves are insufficient to estimate future illness and death. Projections of the health impacts of future heatwaves need to incorporate a variety of factors, including the degree to which the population is acclimatized to higher temperatures, the characteristics of the vulnerable population, and the extent to which effective adaptation strategies and measures have been implemented. These factors need to be estimated for the geographic region and time scale of interest, acknowledging that estimates of these factors become more uncertain for longer time frames.

A few studies have projected that health impacts of heatwaves could increase under various climate change scenarios (Kalkstein and Greene, 1997; Keatinge et al., 2002; Dessai, 2003; McMichael et al., 2003; Hayhoe et al., 2004). When the model includes assumptions about adjustment to higher outdoor temperatures and adaptation measures, estimates of heat-related deaths attributable to climate change are reduced but not eliminated. Because of incomplete understanding of how future populations might respond to heatwaves, these studies could either over- or under-estimate possible health impacts. Also, studies have not included changes in the frequency or intensity of severe heatwaves, such as occurred in 2003 in Europe and as projected to occur in this study (Figures 1 and 2).

Hayhoe et al. (2004) projected the implications of low and high greenhouse gas emission scenarios (Nakicenovic et al., 2000) for extreme heat and heat-related mortality in California. Taking some acclimatization into account (but no change in the prevalence of air conditioning), assuming a linear increase in heat-related mortality with increasing temperature, and assuming no change in the population, expected heat-related deaths in Los Angles were projected to increase (from a baseline of about 165 excess deaths annually) two- to three-fold under a low emission scenario and five- to seven-fold under a high emission scenario by 2070–2099.

Trends that are likely to increase vulnerability to heat-related morbidity (prevalence of disease) and mortality in the next few decades include an increased number of elderly people (Hobbs and Damon, 1996), increased urbanization, and increased frequency and intensity of heatwaves.

Overall, in the Midwest, the health burden of heatwaves is likely to be relatively small for moderate heatwaves, because most deaths will occur in persons who are already ill and because implementation of effective heatwave early warning systems has increased. Moreover, the prevalence of air conditioning in cities in the Midwest is high and can reasonably to be expected to increase further, which should further reduce population vulnerability. Extreme heatwaves present greater risk and are likely to become more frequent if manmade greenhouse gas emissions continue to rise unabated. Greater adaptation measures will be needed to manage these risks.

F. Adaptation Options

Short-term adaptation options include development of effective heatwave early warning and response plans, increasing appropriate use of air conditioning, and better education. Heatwave early warning systems can be an effective approach to reducing the illnesses and deaths associated with heatwaves (Palecki et al., 2001; Weisskopf et al., 2002; Ebi et al., 2004). Because heatstroke has a fast onset and a poor survival rate, prevention efforts must begin when oppressive weather is forecast, rather than when it arrives. The principal components of an early warning system include identification and forecasting of the event (including consistent, standardized weather criteria guiding the activation and deactivation of warnings), prediction of possible health outcomes that could occur, effective and timely response plans that target high-risk populations, and ongoing evaluation and revision of the system and its components (Ebi and Schmier, 2005; Bernard and McGeehin, 2004). Longer-term adaptation options focus on infrastructure changes, such as establishing building codes designed to reduce urban heat islands.

Considerably more education is needed of the public and of the responsible agencies about the dangers associated with heatwaves and about the appropriate responses. For example, in the review of heatwave response plans in the United States, five of the plans reported fan distribution programs, despite evidence that fans may increase heat stress if used improperly (Bernard and McGeehin, 2004). In addition to general messages detailing ways to lower body temperature to prevent the onset of heat stress (including drinking more fluids, going to an air-conditioned place, wearing light-colored and loose-fitting clothing, and limiting outdoor activity; CDC, 2007), messages should be targeted to vulnerable groups—such as those with low incomes, the elderly, the disabled, children, and ethnic minorities (Ebi and Schmier, 2005). A review of 18 U.S. heatwave response plans found that although people with mental or chronic illnesses and the homeless constitute a significant proportion of the victims in recent heatwaves, only one plan emphasized outreach to disabled persons, and only two addressed the shelter and water needs of the homeless (Bernard and McGeehin, 2004).

Air conditioning is frequently promoted as a key adaptation option to reduce heat-related illness and death. There is evidence that increased air conditioning coverage in the United States has reduced vulnerability (Davis et al., 2003). More than 80 percent of homes in the United States have air conditioning (U.S. Census Bureau, 2002). On the other hand, centralized cooling centers have not proved effective in reaching the most at-risk seniors (Naughton et al., 2002; Palecki et al., 2001). Hence, increased prevalence of air conditioning alone does not necessarily address the needs of those at greatest risk.

A key constraint to reducing the health impacts of heatwaves is that a normal part of the aging process is a reduction in the ability to thermoregulate. Many of the elderly at increased risk during a heatwave have underlying diseases that cause them to feel ill on most days. During a heatwave, feeling hot in addition to feeling ill is insufficient motivation for many of the elderly to take actions to reduce body temperature, such as visiting a cooling center, opening windows, drinking additional water, changing into more appropriate clothing, or turning on an air conditioner.

Better understanding of how to motivate appropriate behavior during a heatwave will reduce current and future vulnerability, no matter what the future climate brings.

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