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# 4. Health impacts of heat: present realities and potential impacts of a climate change

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## INTRODUCTION

In many mid-latitude locations it is recognized that heat is the most important weather-related killer – outpacing hurricanes, tornadoes, snow and ice, and lightning. In the US, about 1500 people are killed by heat during an average summer (Harvard Medical School 2005). During extreme heat events, such as the one that occurred in Europe in 2003, excess deaths were in the tens of thousands (Valleron and Mendil 2004). The scope of the problem is immense and large population centers around the world, from Shanghai to New Delhi to London to Toronto, are not immune (Tan et al. 2003).

The impact of a climate change could make matters worse. Several studies show that, if the climate changes as forecast by a number of climate models, the frequency of extreme heat events may double, or even triple, in many cities over the remainder of this century (Hayhoe et al. 2004b). This could lead to a dramatic increase in deaths from heat-related causes. It should be noted, however, that heat intensity is not the only major factor contributing to increased negative health responses. Probably more important is the variability of the weather. Clearly more people die from heat-related causes in cities like Philadelphia, Toronto and Chicago, than they do in Phoenix and Miami, where summer conditions are considerably warmer. This is due to the unexpected nature of extreme heat events at many mid-latitude locations, where benign weather is punctuated by heat events of great magnitude (WHO et al. 1996). Thus, if climate change brings about an increase in temperatures but a lower variability in summer weather (for example, if Philadelphia's summer climate approaches Miami's), heat-related mortality may not rise in a warmer world. However, if variability stays high, as many climate models indicate, heat-related problems will likely increase in a warmer world.

## How Does the Body Respond to Heat?

Human beings respond dramatically to the atmospheric environment because of the need to balance their heat budget. This involves all the complex conditions of heat exchange between the human body and the thermal environment (Parsons 2003). Accordingly, thermal stress can have adverse effects on human health. This issue has been addressed in numerous epidemiological studies in which the thermal environment was related to heat- and cold-related mortality (for example, Basu and Samet 2002; Hajat et al. 2002; Kunst et al. 1993; Kyselý and Huth 2004). In these studies different methods are used to assess the thermal environment. The methods range from simple one-parameter indices (for example, mean, minimum, maximum temperature), to indices that consist of more than one parameter (for example, temperature and humidity), to more complex indices such as the synoptic approach or assessment procedures based on thermo-physiological modeling of the human body.

Since humans adapt physiologically (acclimatization) to meteorological situations, there is a change in the physiological response we as humans have to thermal stress (Fanger 1972). This response reduces the effective heat load, or cold stress, a human has to bear by increasing the effectiveness of the thermoregulatory system. Additionally, the thermal load is reduced due to short-term behavioral adaptation. Many epidemiological studies show that humans, to a certain extent, adapt and acclimatize to their local climate. This fact can be seen in the regional and temporal variability of the thermal thresholds beyond which human health declines. Generally speaking, the more severe or unusual the thermal condition the greater the human mortality. In many studies, a so-called U- or V-shaped relationship between mortality and the thermal environment is established.

In addition to the absolute level of the parameter used to assess the thermal environment, the persistence of a thermal stress situation is important. Heat-related health impacts are in general greater the longer a heat situation persists (Smoyer et al. 2000). Some of the heat-related mortality is caused by the so-called ‘harvesting effect’, where a number of susceptible individuals die from the heat early in the summer season, leaving fewer susceptible individuals to die later in the season. Harvesting can account for 20–40 percent of the total deaths during an excessive heat event (Kalkstein 1998).

Of great interest is a study of different European time series of mortality and meteorological parameters using a physiologically based method that includes short-term behavioral adaptation and short-term acclimatization. This study showed that all of the analyzed time series had the highest mortality with values between 13 percent and 34 percent above the baseline during a 'strong heat load' situation (Koppe 2005). Smaller thermal loads were associated with average to slightly above average mortality; this clearly demonstrates the notion of a 'threshold' level of heat load beyond which mortality rises rapidly. In this study, the harvesting phenomenon was more pronounced in the warmer sections of Europe.

## HEAT RESPONSE, SOCIAL IMPLICATIONS, AND POTENTIAL CLIMATE CHANGE IMPACTS

Not all populations are equally vulnerable to extreme heat. Risk factors are physiological, demographic and social. Physiological risk factors include a wide range of underlying health conditions and the use of certain medications that impede the body's ability to maintain homeostasis (for example, in the case of extreme heat or cold, core body temperature). The very young (especially infants), the chronically ill and elderly have less of an ability to maintain thermal equilibrium. Accordingly, socio-economic risk factors for these groups are more complex.

The greatest social risk factor for extreme heat is poverty. Access to sufficient financial resources is essential for securing adequate housing and equipment. For example, air conditioning and the means to pay for its operation and maintenance are generally necessary to protect from extreme heat. Similarly, insulated housing, heating equipment and the funds for fueling it are needed for protection against extreme cold. Nations with more distributive economic systems may provide high-quality housing for impoverished households, while other nations may provide only basic housing with insufficient heating and cooling equipment, leaving residents at risk of extreme temperatures.

Access to health care is essential in maintaining good health and in lessening a group's susceptibility to extreme heat. Although universal health care is available in most industrialized nations, disparities in quality of care exist by socio-economic status. In the US, the wealthy can afford high-quality health care, many employers offer affordable health insurance, and the very poor may qualify for government-provided health care. The working poor, as well as some moderate-income families, may have insufficient or unaffordable health insurance and thus lack access to adequate health care. This, in turn, increases their vulnerability to extreme heat; a problem likely to be exacerbated if the climate changes in the future in accordance with the forecast of recent models.

With poverty comes a host of other conditions that are added risk factors to adverse health outcomes of extreme heat. For example, in Table 4.1, in perceived high crime areas people without air conditioning may not open their windows. This failure exposes them to dangerous indoor temperatures. Low-income individuals who suffer from mental illness, substance abuse or senior dementia are particularly at risk from social isolation – a known risk factor in heat-related mortality (Klinenberg 2002). These individuals are also more likely to inhabit substandard housing. In addition, low socio-economic status groups often have higher exposure to environmental toxins and air pollution. In addition they are more likely to live in socially marginalized, deprived areas with less access to health-promoting amenities ranging from healthy food retail outlets to physical activity centers. Thus the combined impacts of limited financial resources, stressful neighborhood environment conditions and limited health-promoting amenities all underlie their vulnerability to extreme temperatures, and impede resilience. The web of poverty, and the conditions that accompany it, set the stage for increased risk to extreme heat.

Climate change is expected to increase occurrences of high summer temperatures in many mid-latitude areas. While warmer winter conditions are expected to occur in many of these regions, research has shown that this does not necessarily decrease cold-related mortality (Kalkstein 2007). The societal implications of extreme heat and cold vulnerability under climate change are complex because accompanying climate change are several complex factors, all of which vary within and among countries. These factors include global changes in urban morphology, socio-economic characteristics and demographic structure. For example, increased standard of living in many countries leads to urban sprawl and the loss of green space, exacerbating urban heat islands and requiring more energy resources for heating, cooling, lighting larger dwellings and transportation. Impoverished populations are also extending into the suburbs, thus reducing access to social services and requiring more funds for transportation. The higher energy demands of these societal changes also increase emissions of greenhouse gases. Demographically, the populations of most nations are aging, while experiencing a reduction in family size and fragmentation of extended family networks. While the high-risk group of the very young may decrease in size, elderly populations (and with them, the chronically ill) are growing. Compounding the vulnerability of aging populations are changes in family structure and care-giving norms. This results in an increasing number of elderly without family support. Increasingly, public resources will be needed to provide health care and social services to this growing vulnerable population, regardless of the impacts of climate change.

The impacts of climate change are not experienced equally. Financial

*Table 4.1 Heat-related mortality projections for the 1990s, 2050s and 2090s for five California cities, as calculated by Hayhoe et al. (2004a)*

| | 1990s | 2050s | | 2090s | |
|---|---|---|---|---|---|
| | Acc | UnAcc | Acc | UnAcc | Acc |
| Los Angeles | | | | | |
| Actual | 165 | | | | |
| PCM B1 | 158 | 357 | 304 | 394 | 319 |
| PCM A1 | 158 | 818 | 719 | 948 | 790 |
| Had B1 | 153 | 351 | 275 | 667 | 551 |
| Had A1 | 153 | 432 | 339 | 1429 | 1182 |
| San Francisco | | | | | |
| Actual | 41 | | | | |
| PCM B1 | 35 | 84 | 84 | 134 | 134 |
| PCM A1 | 35 | 146 | 146 | 447 | 447 |
| Had B1 | 39 | 92 | 92 | 153 | 153 |
| Had A1 | 38 | 75 | 75 | 271 | 271 |
| San Bernardino / Riverside | | | | | |
| Actual | 32 | | | | |
| PCM B1 | 28 | 50 | 50 | 83 | 83 |
| PCM A1 | 28 | 57 | 57 | 104 | 104 |
| Had B1 | 28 | 60 | 60 | 82 | 82 |
| Had A1 | 33 | 73 | 73 | 135 | 129 |
| Sacramento | | | | | |
| Actual | 10 | | | | |
| PCM B1 | 14 | 18 | 11 | 29 | 17 |
| PCM A1 | 14 | 25 | 15 | 86 | 52 |
| Had B1 | 15 | 43 | 26 | 51 | 31 |
| Had A1 | 25 | 42 | 25 | 148 | 89 |
| Fresno | | | | | |
| Actual | 13 | | | | |
| PCM B1 | 10 | 19 | 5 | 30 | 7 |
| PCM A1 | 10 | 26 | 6 | 72 | 17 |
| Had B1 | 12 | 14 | 4 | 18 | 5 |
| Had A1 | 14 | 42 | 10 | 74 | 18 |

*Note:* UnAcc refers to unacclimatized values; Acc are acclimatized values.

resources facilitate adaptation to extreme heat, and impoverished groups will need to allocate more of their already limited resources to stay cool during increasingly hot summers. In some areas, winter temperatures are expected to rise, thus reducing the financial burden of heating costs. However, the economic and health implications of added financial demands for basic heating and cooling are likely to be both pervasive and hard to predict.

### A Quantitative Evaluation of Climate Change-Induced Heat Mortality: the California Example

Summer temperatures in California under scenarios of future climate change are projected to increase by two degrees, to 7°C, depending on the emission scenario used and the sensitivity of the climate model. Increases will be accompanied by longer, more frequent and more severe extreme heat conditions (Hayhoe et al. 2004b). Estimates of increases in heat-related mortality for these scenarios were developed for five California urban areas (Table 4.1), and indicate that mortality totals are likely to rise dramatically, even if the population acclimatizes somewhat to the warmer conditions. The models used, the PCM and Hadley models, were run assuming business as usual (A1, higher emissions in the future) and reduced emissions (B1). In virtually all cases, even if emissions are reduced, the number of deaths is expected to increase markedly.

In another study that attempted to determine the potential impacts of a climate change, the very hot summer in Europe of 2003 was used as an analog for five US cities (New York, Philadelphia, Detroit, St Louis and Washington). This study attempted to determine how mortality might increase in these cities if such a heatwave occurred here (Kalkstein et al. 2008). The premise was that heatwaves similar to the European 2003 event are more likely to occur in a warmer world. Results indicate that excess heat-related mortality for the analog summer is two to over seven times the long-term average in US cities – with New York showing the greatest increases. In all cities, calculated excess heat-related mortality for the analog summer exceeds the hottest recorded summer in the past 35 years. These numbers should be treated with care, since they do not consider potential changes in urban structure, demographics and intervention strategies within the cities.

## MITIGATING THE PROBLEM

Because of the recent recognition that heat is a major killer, and due to the possibility of a warmer world in the future, an increasing number of cities are implementing hot weather health warning systems (HHWSs). These systems are designed to inform the public and important stakeholders about hazardous heat. Although they are an important part of adaptation to extreme heat, they cannot solve the problem of vulnerability to extreme heat on their own. Potential solutions for decreasing the impact of heat for all income groups include planning solutions like those already underway in cities as diverse as Chicago, Toronto and Shanghai. These include 'cool city' initiatives to reduce the urban heat island, such as using lighter-colored building materials, increasing urban green spaces, tree planting programs and green roof projects (for example, replacing tar surfaces with gardens). Government-sponsored or public–private partnerships provide a member of these alternatives to increase product and housing efficiency (especially of heating and cooling equipment). These are other ways of offsetting the increased financial burden of reducing vulnerability to extreme heat and cold for low-income households, as well as for reducing greenhouse gas emissions.

However, interest in the development of HHWSs has been quite recent. For example, before the intense event of 2003, very few systems existed in Europe (Koppe and Becker forthcoming). Like numerous other environmental forcing factors, a disaster must occur before decision-makers will begin to work to mitigate the problem.

An HHWS is designed to alert both decision-makers and the general public of impending dangerous hot weather, and to serve as a source of advice on how to avoid negative health outcomes associated with hot weather extremes (WHO et al. 1996). The development of a high-quality HHWS requires a number of steps and pathways to be completed, including accurate weather forecasting, dissemination of the watch or warning, identification of vulnerable population groups, interaction with stakeholders, implementation of a mitigation procedure and a check of effectiveness, among others.

An effective HHWS can employ a myriad of meteorological procedures and its physical nature may vary based on local population, political constructs of the area and available resources. Still there are several system aspects that must be universal. First, all systems must be custom-developed for each local area, and their construction should consider local meteorology, demographics and urban structure (Sheridan and Kalkstein 2004; Kalkstein et al. 2008). A common mistake often made by national weather service offices is to develop a one-size-fits-all set of systems, for a large number of urban areas, within different cultural and climate zones. For example, in the US a system was designed in the 1990s to call an excessive heat warning whenever the apparent temperature was forecast to exceed 41°C for three consecutive hours on two consecutive days, no matter where it occurred (NOAA 1996). Such a system does not take into account the relative, rather than absolute, nature of weather's impacts upon a particular area. Second, all systems should be based upon thresholds that are related to actual heat – health outcomes. HHWSs trigger mechanisms should be geared to the point when human health actually deteriorates, and this threshold varies greatly from place to place. It can also vary within one particular place. For example, a meteorological situation leading to excess morbidity or mortality could be different early in the summer season as opposed to later within the season, at the same place. For this reason, some new generation systems actually have changing thresholds within the same urban area as the summer season progresses. Third, the HHWS nomenclature should be clearly understood by the public, local stakeholders and decision-makers. Thus, on a national level, it is best to have the same names for warnings, alarms and alerts, and the same sort of understandable criteria. Fourth, all systems should be paired with a quality notification and response program. This involves interaction with the media, and messages to the public, as to how they should react to the extreme weather. Finally, all systems should be evaluated to determine their effectiveness. A good example of a detailed evaluation plan has been put forth by the Italian Department of Civil Defense (Protezione Civile Nazionale 2005), which determines the accuracy of the Italian systems in forecasting deadly heat events, and checks to see if the systems actually save lives.

The development of most HHWSs begins with the establishment of certain thresholds of human health tolerance to the extreme weather. If these thresholds are exceeded, this would trigger the issuance of a warning or alert. The benchmark for issuing a warning varies from place to place, based upon differential local responses to extreme weather. However, in most cases, prior to HHWS development, correlations between negative human health outcomes (morbidity, mortality, heat load on the body) and extreme weather are developed to permit an estimate of those health outcomes based on forecast data.

In most locales, it is the national weather service office (NWS) that is responsible for issuing advisories and warnings for heat. Forecasts issued by the NWS are then used as the primary input into the HHWS where, most frequently (but not always), algorithms based on the human heat–health responses attempt to estimate the degree of negative health impact of the weather. If the negative impact is significant, the responsible agency (whether it is the NWS or a local health department) issues a warning or alert.

If a good-quality HHWS is paired with proper intervention procedures, along with increasing public awareness and the ability of responsible agencies to respond rapidly, it is likely that such a system will provide quality adaptation measures, even if the climate warms as many expect.

### Asthma and Climate Change: Another Set of Challenges

Of course, many health issues are closely related to weather, and may be exacerbated if a climate change occurs. A number of reports on time trends in asthma prevalence have shown a substantial increase in cases since the early 1960s. However, accumulating evidence indicates that rising trends in prevalence of asthma among adults and older children may have plateaued, or even decreased, after increasing for decades. This is especially true in countries with existing high rates of occurrence (von Hertzen and Haahtela 2005). Younger childhood data are less reassuring, and show continued increases (Asher et al. 2006). Allergic rhinitis is an increasing global health problem, affecting between 10 and 25 percent of the population. It significantly alters the social life of patients and affects school learning performance as well as work productivity. Thus it results in a significant economic effect on society in terms of both direct and indirect costs.

Data about the influence of weather on asthma are poor and controversial. Weather affects asthma directly, acting on airways, or indirectly by influencing airborne allergens and the level of pollutants. The complexity of the aerosol reaching the airways and the several compounds that play a role in this relationship might explain the controversial results of studies conducted so far. Decreases in air temperature represent an aggravating factor of asthmatic symptoms, regardless of the geography or the climate of areas under study. Furthermore, studies based on a synoptic method support findings derived from analyses with only air temperature as the meteorological variable. While results about effects of cold air on asthma are consistent, the role of humidity, wind and rainfall is still debated and studies including these variables showed inconclusive and inconsistent results. This is believed to be due to the fact that their impact on the diffusion of allergens and pollution is greater than that of air temperature (Cecchi et al. 2006b).

Upper respiratory infections also play a key role in exacerbating the presence of chronic pulmonary diseases, producing the typical increase of hospitalizations and medical calls in cold months. The reasons for the seasonal pattern of infections are generally behavioral because people spend longer periods of time in confined and crowded places, allowing for wider diffusion and transmission of viruses. Recent findings, however, also suggest an impairment of natural immunity mechanisms of airways induced by cold air breathing (Beggs 2004).

While the impact of weather and climate change on the prevalence of allergic diseases is still speculative, the influence on aeroallergens is suggested based on recent studies showing impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution, and other plant attributes (Fitter and Fitter 2002). Analysis of data from the International Phenological Gardens in Europe (a network of sites covering 69–42° N and 10° W–27° E) shows that spring events, such as flowering, have advanced by six days, and that autumn events have been delayed by 4.8 days, compared with the early 1960s. On average the length of the growing season in Europe increased by 10–11 days during the last 30 years up to the year 2000. Trends in pollen amount over the latter decades of the twentieth century are increasing based on local rises in temperature (Menzel 2000). Substantial increases in pollen production resulted from exposure to increased $CO_2$ concentrations under experimental conditions (Rogers et al. 2006); this might provide a reliable model for evaluating the effects of global warming. Duration of the pollen season is also extended with warmer temperatures, especially in summer and in late-flowering species. In addition, there is evidence of significantly stronger allergenicity in pollen from trees grown at increased temperatures (Ahlholm et al. 1998). These associations with changes in temperature vary across plant species (annual more than perennial species, with insect-pollinated species advancing more than wind-pollinated ones).

Changes in climate appear to have altered the spatial distribution of pollens. New patterns of atmospheric circulation over Europe might contribute to episodes of long-distance transport of allergenic pollen, increasing the risk of new sensitizations among allergic population (Cecchi et al. 2006a). There is growing evidence that climate change might also facilitate the geographical spread of particular plant species to new areas which become climatically suitable. However, the effect of the expected rate of warming could be less pronounced than effects of land use change, sociocultural changes and international transport.

The socio-economic burden of allergic diseases is increasing worldwide, especially in developing countries. However, the influence of climate change on prevalence and symptoms of respiratory allergy is still unpredictable. Two opposite effects could be at work if the climate warms. On the one hand, global warming could increase the length and severity of the pollen season. On the other, it could reduce the effects of cold air on asthma and rhinitis, also making patients less susceptible to upper respiratory infections.

## CONCLUSIONS

Although the majority of research suggests that both heat-related illnesses and asthma prevalence may increase if the climate warms, there are still many uncertainties that cannot be accounted for in the models or the historical record. Demographic changes, the effectiveness of mitigation measures, urban structure changes and adaptation will all play roles in determining how humans respond to climate change. Thus, any 'predictions' must be viewed with caution. However, heat-related mortality is already the leading weather-related killer in the Western world and asthma prevalence is increasing among younger individuals. Thus, regardless of climate change impacts, it is important that we become more aware of the vagaries of weather upon the human body, and develop means to lessen the negative health outcomes.

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