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PROJECTIONS AND POTENTIAL IMPACTS

CHAPTER FOUR – HEALTH

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CHAPTER
Four

HEALTH

Warmer summer weather, while welcome to many, also brings with it the risk of increased heat-related impacts on human health. The most direct effect of warming temperatures is to increase the frequency and severity of extreme heat events, or heat waves. Extreme heat and oppressive heat events are known to produce elevated rates of both illness and death.[1,2,3,4] In addition to its direct impacts, sustained extreme heat events exacerbate pre-existing cardiovascular, respiratory, and other conditions.[5,6] Changes in climate can also affect our health indirectly, through shifts in the geographic range and/or population of animal hosts and arthropod (i.e., mosquito or tick) vectors that carry diseases such as West Nile Virus or Lyme Disease, and by increasing both the prevalence and the pollen-producing capacity of allergenic plants. Here, we assess the potential for both direct and indirect effects of climate change on human health in Chicago. Where possible, we distinguish between the impacts expected under a higher vs. a lower future emissions scenario, to highlight the important dual roles of both mitigation (in limiting the amount of future change expected) as well as adaptation to future change likely to occur even under a lower emissions scenario.

Heat-related impacts on human health

Introduction

In July of 1995, Chicago experienced a heat wave unprecedented in the 123-year-old weather records of the City.[7] Maximum daily temperatures were equal to or greater than 90°F for seven consecutive days, and greater than 100°F for two days at the peak of the heat wave (Figure 4.1). Even more importantly, there was no relief at night, as nighttime minimum temperatures were over 80°F during the hottest days, with relative humidity reaching more than 90% well into the evening hours. The effects of the heat wave were likely enhanced by micrometeorological effects such as the urban heat island (higher temperatures at stations closer to the center of Chicago, lower maximum daily temperatures at suburban sites), and the fact that the moderating effect of the lake was minimized by the southerly winds prevailing during the heat wave, virtually eliminating cooling lake breezes.

This heat wave illustrated in a graphic way the potentially dramatic impacts of extreme heat on human morbidity (illnesses) and mortality (deaths) in the City of Chicago. During the 1995 heat wave, there were 739 "excess" (i.e., above average) deaths recorded[8,9]. 514 of these were initially classified as heat-related[10], but a recent reanalysis[11] estimates a greater total of 697 heat-related deaths during the 1995 heat wave. Some of these deaths, of course, may have merely been anticipated by the heat wave by a few days to weeks; however, it was estimated that only 26% of deaths were due to this type of displacement[12], leaving over 500 deaths being due to the heat wave alone – i.e., not anticipated to have occurred otherwise. During the 1995 heat wave there were also more than 3000 excess emergency department visits[13], and more than 1000 hospital admissions above what would normally be expected at

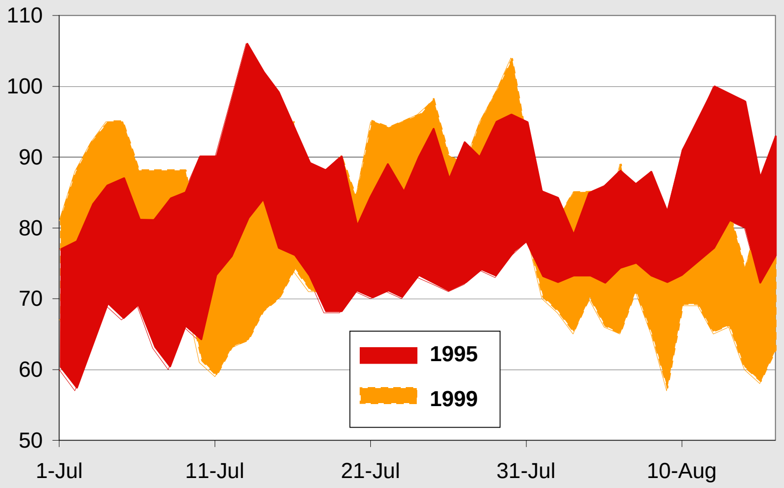

Figure 4.1. Range of daily observed temperatures from July 1st through August 15th at Chicago Midway for the summers of 1995 (red) and 1999 (orange). Peak heat wave days were July 13-14 in 1995 and July 29-30 in 1999 (Units = degrees F).

that time of the year[14]. Most hospital admissions were due to dehydration, heat stroke, and heat exhaustion among people with underlying medical conditions (e.g., cardiovascular diseases, diabetes, renal diseases, nervous system disorders, emphysema, epilepsy). Of those admitted with heat stroke, 21% died in hospital and 28% during the following year[15].

A number of factors contributed to enhanced risk in Chicago during extreme heat conditions. A study the year after[16] highlighted several of these, including an inadequate heat wave warning system, power failures, inadequate ambulance service & hospital facilities, the heat island effect, an aging population, and improper ventilation due to lack of resources (unable to afford air conditioning) or even, for some neighborhoods, the simple fact that people were afraid to open their windows due to crime. Further analyses focused on statistically correlating risk factors with mortality. These studies were able to rank the different risk factors, with their results emphasizing the importance of access to air conditioning (central air being significantly better than window units[17],[18]), and vulnerability due to existing medical conditions and/or social isolation, as in not being able to leave the house.[19],[20]

Age, race, and social class were also contributing factors. For people ages 65 and up, hospital admissions were up by 35% during the heat wave, as opposed to an increase of 11% for the general population, and mortality rates for that age group were also higher[21],[22]. In terms of race, heat-related deaths were disproportionately larger in the black community and smaller in the Hispanic community, as compared to the Chicago-wide average[23],[24]. Independent of race, the relative affluence levels of neighborhoods were also a mitigating factor, with wealthier and more commercially successful areas showing lower mortality rates, likely because more of their inhabitants were better able to afford central air conditioning[25],[26].

Many of the lessons learned during the 1995 heat wave have already been acted on. A second heat wave in 1999, just slightly less severe than the 1995 event (Figure 4.1), resulted in only 114 excess deaths attributed to heat[27]. Furthermore, more than half the deaths were for people less than 65 years old, suggesting that adaptation strategies focused on the elderly population were succeeding[28].

Over the coming century, however, climate change is expected to increase not only average summer temperatures but also the frequency of extremely hot summers associated with heat wave events, as discussed in Chapter 2.

Furthermore, climate model simulations indicate that the atmospheric circulation patterns associated with both the severe 1995 heat waves in Chicago as well as the Paris heat wave in 2003 are expected to become more intense, more frequent, and longer-lasting in the second half of the 21st century[29]. Finally, as also discussed in Chapter 2, 1995-like heat waves (defined as at least a week of daily maximum temperatures greater than 90^{o}F and nighttime minimum temperatures greater than 70^{o}F, with at least two consecutive days where daily temperatures soar over 100^{o}F and nighttime temperatures remain above 80^{o}F) may be occurring as frequently as every other year by mid-century, and up to several times per year by end-of-century, under a higher emission scenario. Thus, even though the people of Chicago are likely to become more acclimatized to higher temperatures over time (e.g., with increasing temperatures more people will choose to install air conditioners), aggressive adaptation measures will be needed to prevent climate change-induced increases in extreme heat from taking their toll on Chicago's population.

Here, we estimate the projected impacts of climate change on public health in Chicago in three different ways. First, we discuss the likely effects of increasing temperatures on heat-related morbidity, or illnesses. Next, we calculate projected future changes in the frequency and intensity of oppressive heat events that have been associated with elevated heat-related mortality in the past. These changes are then used to estimate future trends in heat-related mortality, or deaths. Finally, we use a novel "analog city" approach that superimposes the meteorological conditions that lead to the Paris Heat Wave of 2003 (responsible for approximately 15,000 deaths in France and over 40,000 deaths across Europe[30]) on the city of Chicago to estimate what would be the likely impacts of such a severe heat wave on the city.

Heat-related morbidity

The first way in which prolonged periods of extreme heat can affect human health is through increasing morbidity, or illness. Heat stress demands more cardiac output in order to increase skin surface blood circulation to facilitate heat loss and cool down the body; volume depletion or dehydration can limit this cardiovascular process, as can some medications that are widely used. Prolonged heat exposure is associated with heat cramps, heat syncope, heat exhaustion, heatstroke[31], and even acute renal failure[32]. Those most at risk include the elderly, children, and those with pre-existing health conditions that can be exacerbated by extreme heat and heat stress. A recent study[33], for example, showed that hot temperatures are generally associated with increased hospital admissions for cardiovascular disease for the elderly (over the ages of 65). Other illnesses at risk from being exacerbated by extreme heat include respiratory and kidney diseases in children[34].

It is not surprising, therefore, that elevated hospital admission rates occur during heat waves such as the 1995 event in Chicago. Given our present understanding of the way the human body is affected by temperature, significant morbidity (measured in terms of hospital and ER admissions) would be expected during future heat waves[35]. If heat wave events such as the Chicago 1995 heat wave were to become relatively frequent due to climate change (i.e., occurring as often as once every other year, as suggested by climate projections), some acclimatization would of course be expected, as the population became accustomed to dealing with extreme heat and, over time, building codes changed and the use of air conditioners became more widespread. However, such frequent heat wave events would still continue to put stress on public health, particularly those most vulnerable to heat stress including the elderly, sick, young, and socially isolated.

Heat-related mortality

Excessive heat is currently the leading cause of weather-related deaths across the U.S. During the summer of 1980, as many as 10,000 deaths in the U.S. may have been associated with oppressive heat[36], while the summer heat wave of 2003 claimed over 15,000 lives in France and 40,000 throughout Europe[37]. Though some research has suggested an overall decrease in heat vulnerability in recent decades[38], especially as air-conditioning has become more commonplace[39], there is still a clear vulnerability to heat, and dramatic mortality episodes have occurred in the U.S. within the last ten years[40].

Estimates of future heat-related mortality can be determined by projections of threshold meteorological conditions beyond which mean mortality has been observed to display a statistically significant increase. Estimates do not account for changes in population, but are rather presented as mortality rates per 100,000. Similarly, they do not account for changes in demographic structure. Coupling the observed elevated risk for people over the age of 65 with the likely future increase in the proportion of higher demographic levels in the future means that this approach may in fact underestimate the vulnerability of future population to extreme heat and oppressive air mass events. On the other side, however, these estimates also have the potential to be significantly reduced through the success of adaptation techniques to reduce mortality rates (as already suggested through the reduced mortality rates for the >65 age group during the 1999 heat wave as compared to 1995[41].

To estimate future changes in heat-related mortality, we first classify past days according to the holistic Spatial Synoptic Classification (SSC) air mass[42]. For Chicago, two "oppressive" air mass types, Dry Tropical (DT) and Moist Tropical Plus (MT+), have been primarily associated with increased mortality in the past, although some mortality can also occur under warmer conditions with other air masses. In particular, the MT+ air mass is characterized by hot and humid conditions with high overnight temperatures – exactly the conditions during the 1995 and 1999 heat wave events. Variations of standardized mortality within oppressive air masses are then assessed by developing an algorithm that relates mortality to apparent temperature and time of season. These algorithms include environmental factors responsible for explaining the variability in mortality during oppressive weather. Both meteorological (maximum and minimum air temperature, maximum and minimum apparent temperature and dew point, cloud cover, wind speed and direction, and sea level pressure) as well as non-meteorological (consecutive days of oppressive weather, time of season when oppressive weather occurs) factors were potential independent variables within this algorithm. The final algorithms for Chicago are as follows:

If day is classified as DT or MT+,

$$\mathrm{MORT} = -26.74 + 4.62\,\mathrm{DIS} + 0.777\,\mathrm{AT} \qquad (4.1)$$

If day is classified as another air mass,

$$\mathrm{MORT} = -7.8 + 0.266\,\mathrm{AT} \qquad (4.2)$$

where MORT = anomalous mortality, AT is the apparent temperature (°C) at 5 pm, and DIS is the day's position in a sequence of consecutive days with maximum apparent temperatures equal to or exceeding the apparent temperature threshold associated with excess mortality (suggesting that the longer the offensive air mass persists, the deadlier it becomes). Previous research for other cities has shown a statistically significant decrease in sensitivity as the population acclimatizes over the course of the summer, but for Chicago's population this was not an important factor (in other words, Chicago's population does not appear to acclimatize over the summer).

Mortality data for the entire U.S. are available in digital format since 1975, and include date and cause of death, and the county in which the deceased had passed away. These data are derived from files at the National Center for Health Statistics[43], and are standardized to remove as much variation on mortality as possible that is related to non-meteorological causes, such as trends in population during the period of evaluation. Total deaths per day are evaluated in this analysis, as this has been shown to be superior than subdividing deaths into individual causes[44].

Simulated past and future changes in temperature, dewpoint, wind speed and direction, sea level pressure, and cloudiness as simulated by the three climate models used in this assessment were then downscaled to the Chicago Midway Airport weather station[45], and interpolated to provide six-hour instantaneous values for each day from 1960 to 2099. Meteorological variables were then analyzed to identify the frequency of oppressive air mass events in the climate model simulations. A large body of literature suggests that, rather than responding in isolation to individual weather elements, we are affected by the interactions from a much larger suite of meteorological conditions that constitute an “offensive air mass”[46],[47].

For the 30-year historical period 1961-1990, weather records indicate oppressive air masses over Chicago on average about 16 days per year. Historical model simulations for the same time period produce oppressive air mass events on average 13 to 15 days per year, indicating that the models may slightly under-estimate the frequency of such events (Figure 4.2). In the future, however, all model simulations agree that the frequency of oppressive air mass events over Chicago is likely to increase. Over the next few decades, about 10 more such days per year are projected. By the middle of the century, there may be an average of almost 30 days per year under a lower emissions scenario and almost 50 days under the higher. By the end of the century, the average number of days per year that experience oppressive air mass events is projected to more than double under the lower emissions scenario, for a total of 34 days or more than a month. Under the higher emissions scenario, even greater increases of more than four times historical values are projected, for an average of 72 days or almost two and a half months per year (Figure 4.2). Although oppressive air mass events do not necessarily imply a heat wave (as the event is required to last longer than a day or two in order to be classified as a heat wave), these results are consistent with previous research[48], which found that the circulation pattern associated with the 1995 heat wave is expected to become more frequent and be intensified by climate change, producing a greater number of “heat wave days” in the future.

Based on the model-simulated increases in oppressive air mass days, we then use the mortality equation for the City of Chicago, derived from observed weather patterns and mortality rates, to estimate future mortality rates under the higher and lower emissions scenario.

In Table 4.1, projected future mortality rates for the population of Chicago given, are standardized to values per 100,000 by the average population for the Chicago metro area. The population of Chicago was assumed to be 6.07 million as given by the 1990 census, as this represents the closest population estimate to the mid-point of the historical mortality data. Comparing model-simulated with observed mortality rates for the historical period, once again it is evident that the model-based estimates are slightly lower than observed; this is likely a factor of the models under-estimating the number of oppressive air mass events as noted previously. Note that mortality rates are not age-adjusted (i.e., we did not try to predict shifts in Chicago's demographic profile over time).

Over coming decades, climate change simulations indicate that average annual mortality rates are projected to increase significantly. For comparison, the mortality rate during the 1995 heat (using an estimate of 697 heat-related deaths in Cook County, with a metropolitan population of 6.07 million) was 11.5 per 100,000. By the middle of the century under the higher emission scenario, therefore, the average summer mortality rate for *each year* is expected to be similar to that during the actual heat wave in 1995 and by the end of the century the average mortality rate is projected to be almost twice that (not accounting for any change in demographics over that time). Under the lower emissions scenario, increases of half that are expected, highlighting the important role of mitigation in minimizing the effects of extreme heat on urban mortality rates. It is important to note, however, that even over the next few decades mortality rates are projected to double relative to their historic values. It is therefore essential to put in place adaptation strategies as well, as no mitigation strategy will be able to prevent changes over that time period that have already been built into the system by our past emissions.

		Model-Simulated	
	Observed	Lower emissions	Higher emissions
1961-1990	2.6	2.2 (2.0 – 2.3)	
2010-2039	-	4.5 (2.8-6.1)	4.8 (2.9-8.2)
2040-2069	-	5.8 (4.2-8.4)	11.8 (4.9-20.6)
2070-2099	-	7.1 (4.0-10.8)	19.9 (7.8-32.6)

Table 4.1. Observed and model-simulated heat-related mortality rates. The 3-model average is given, with the range based on 3 different climate models shown in parenthesis. Units are average annual deaths per 100,000, based on a 1990 population estimate of 6.07 million for the Chicago metro area. Note that these results don't take into account behavioural changes, changes in the way buildings are cooled, etc.

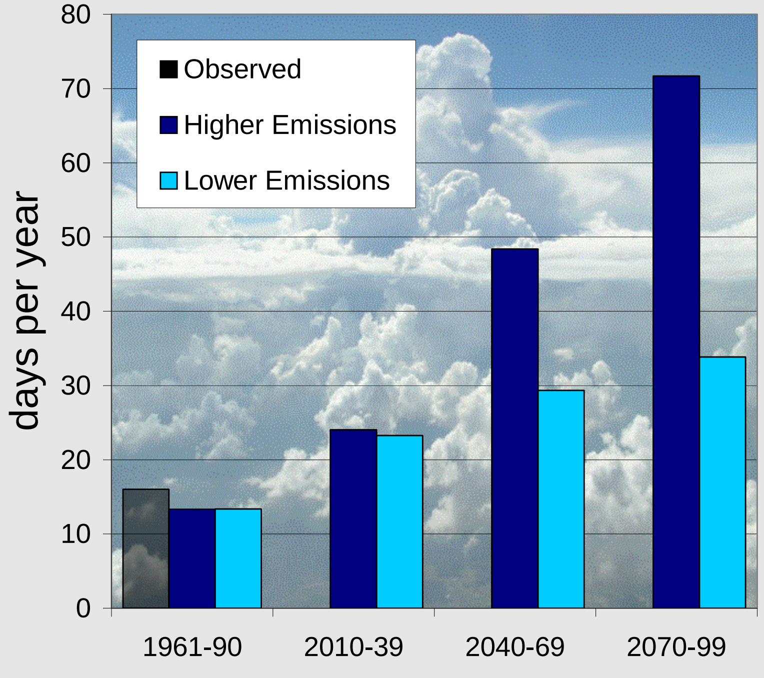

Figure 4.2. Observed (black) and model-simulated (blue) average number of days per year where oppressive air masses (i.e., meteorological conditions that have been associated with elevated

Another important feature of future changes in mortality rates is the projected increase in their year-to-year variability. We have already seen in Chapter 2 that the number of summer "extreme heat" events is projected to increase beyond what would be expected due to changes in the mean average temperature alone. Thus, by the end of the century Chicago could experience summers very similar to those we experience today, side-by-side with summers where 1995-like heat wave conditions prevailed for weeks at a time. Similarly, estimates of projected year-to-year mortality rates over the coming century also indicate that seemingly “normal” summers could occur next to summers with mortality rates for the entire summer similar to or greater than those experienced during the 1995 heat wave. One way of assessing this change in variability is through the standard deviation of the distribution of annual mortality rates, where the standard deviation is a measure of how far from the average value the actual value for an individual summer is likely to be.

Average year-to-year variability during the historical period is estimated to be 2.6 deaths per 100,000 – i.e., mortality rates during any given year was generally within the range of 2.6 ± 2.6 (Table 4.2). Within just a few decades the range is expected to increase to about 4, meaning that mortality rates are likely to be within the range of 4.65 ± 4. In other words, there could still be summers with little to no heat-related mortality, but there could also be summers where heat-related mortality averaged more than 8 deaths per 100,000 over the entire summer. By the end of the century, the standard deviation is estimated to be 5.3 for the lower emissions scenario and 6.4 for the higher, meaning that for any given year, mortality rates per 100,000 could range from zero to 16 under the lower emissions scenario and from about 2 (a normal value for the present day) up to 38 (almost double the mortality rates experienced during the 1995 heat wave) under the higher emissions scenario. This increase in variability has further implications for adaptation strategies, suggesting the need for a built-in flexibility to the public health system such that it is capable of absorbing large numbers of patients during the more extreme summers and next to none during more “normal” summers.

	Lower emissions	Higher emissions
1961-1990	2.6	
2010-2039	3.9	4.0
2040-2069	4.7	6.3
2070-2099	5.3	6.4

Table 4.2. Standard deviation of model-simulated heat-related mortality rates per 100,000 under the higher and lower emissions scenario.

Several caveats must be kept in mind when interpreting these mortality estimates. First, as noted previously, they do not account for changing demographics. Many studies have shown that the elderly are more susceptible to extreme heat; others have indicated that there are racial differences as well, not all of which can be accounted for by socio-economic conditions[49],[50],[51],[52]. In addition, we have not accounted for the potential for adaptation measures such as increased air conditioning use. Although there is nearly complete market saturation of air conditioning in new residential housing, many older houses, apartments, and office buildings rely on window units only. Also, the present-day mortality rates in Chicago almost certainly reflect some contribution from the urban heat island effect[53]. Measures to reduce the urban heat island effect could also contribute to reduced mortality rates. And lastly, the role of "harvesting" or displacement has not been accounted for in these figures. A proportion of the deaths that are attributable to heat are actually people who would have died shortly afterward from other causes[54]; for the 1995 heat wave this value is estimated at 26%[55]. Thus, future estimates include both the actual number of people who would have died of the heat, as well as those who would have died from other causes shortly after the heat event. As the number of oppressive air mass days grows to average many weeks each summer, however, essentially creating one long "heat wave" summer, this effect will become less and less important. In summary, the second and third caveats would indicate that our numbers should be considered an upper bound for estimated heat-related mortality, as they do not factor in adaptation measures nor displacement effects. The first caveat, however, suggests that these projections may be under-estimating future changes, since they do not factor in future demographic changes that are likely to increase the average vulnerability of the population.

From this analysis, it is clear that extreme heat represents a growing threat to the City of Chicago—a threat shared by many other urban centers around the country. Precise mortality rates are uncertain given the importance of behavioral and infrastructure changes. However, increases in summer temperatures combined with more frequent, longer, and more intense extreme heat events to suggest that climate change could continue to pose a significant risk to human health over coming decades. Significant increases in heat-related mortality are projected in the future. Model uncertainties notwithstanding, extreme heat and associated human health risks under the lower emissions scenario are less than twice those projected to occur under higher emissions scenarios by end-of-century.

It is important to note that demographic changes, societal decisions affecting adaptation, and changes in the health care sector will determine actual mortality rates. Significant efforts will have to be undertaken to provide effective early warning systems, public education, air conditioning, "cooling centers," and other adaptations (especially for the elderly, children, poor, and those already ill) to avoid major increases in the number of heat-related death. The urgency for such measures only grows in light of expected population increases and demographic shifts. Heat watch-warning systems presently in operation in some major U.S. cities have already been shown to save a number of lives when coupled with effective intervention plans[56]. Thus, such systems should prove to be an effective adaptive response tool if the climate warms as the models suggest.

European analog heat wave event

An alternative way to assess the vulnerability of Chicago's population to a single extreme heat wave event is through an "analog city" analysis. Here, the impact of a European 2003-like heat wave on the city of Chicago is estimated by transposing the meteorological conditions that occurred over Europe in the summer of 2003 to central North America instead. This analysis does not use any climate model projections; rather, it simply assesses the potential impact of a single event on Chicago regardless of when it might be projected to occur.

During the summer of 2003, western Europe was impacted by a heat wave of historic proportions. For most of that summer, temperatures were well above average across a broad region extending from the British Isles to the Iberian Peninsula and eastward to Germany and Italy (Figure 4.3). The most extreme conditions centered in France where in Paris, maximum temperatures equaled or exceeded 100°F for six days, and the heat broke long-standing maximum and minimum temperature records during August 3-13[57]. The temporal extent of this heat wave event was also unprecedented. For June 1 through August 31, 2003, maximum temperatures were above average for all but eight days in Paris and, for at least half of those days, average maximum temperatures were exceeded by 10°F or more (Figure 4.3). Minimum daily temperatures were also abnormally above average.

As we have already seen, the European Heat Wave (EWH) of 2003 was responsible for over 40,000 deaths across northern Europe[58]. During that time, the city of Paris reported 2600 excess emergency room visits, 1900 excess hospital admissions, and 475 excess deaths[59]. With a population of 2.15 million, this resulted in an average mortality rate over the duration of the heat wave of 22.1 per 100,000, slightly larger than that experienced in the Chicago 1995 heat wave.

Even though an analysis of the 2003 EWH indicates that its duration and magnitude is beyond anything that has occurred in the United States or Europe over the last 150 years, there is still a well-documented pattern of increased mortality in U.S. cities as a result of extreme heat waves (e.g., St. Louis, 1966, 1980, 2006; New York, 1975, 1984, 2006; Philadelphia, 1991, 1993; Chicago, 1995, 1999). The impact of the European Heat Wave raises the question of what the health impacts of a similar event would be for Chicago.

Here, we use an air mass-based meteorological method to develop analogs to the 2003 European and calculate the potential excess mortality if such an event were to occur over Chicago. The analog heat wave for Chicago is designed to capture the actual weather conditions of the 2003 EHW, but with the present-day population and infrastructure characteristics of Chicago (i.e., including any adaptation methods already implemented in Chicago, as well as the frequency of air conditioning use in Chicago, the different ways its population has been observed to respond to extreme heat, etc.). To be specific, the "analog city" approach does not assume that Chicago itself is like Paris in any way. Rather, it merely superimposes the weather conditions of the 2003 EHW to Chicago, while all other variables (population, demographics, infrastructure, adaptation) which determine the likely response of the population to the heat wave are those of Chicago itself. The purpose of the analog city analysis is to show what might happen in Chicago if it experienced a heat wave of the same magnitude as the 2003 EHW event.

To capture the meteorological characteristics of the 2003 EHW, we first calculate the daily deviations from long-term averages for key meteorological variables in Paris, expressed as a multiple of the standard deviation for each variable's long-term average. Relevant meteorological variables include six-hour temperature, dewpoint, cloud cover, sea level pressure, and daily temperature range. The statistical characteristics of the heat wave in Paris are then transferred to Chicago by multiplying Chicago's average summer climatology by the corresponding standard deviation for each variable as occurred in Paris, to produce analog meteorological variables. For example, if on June 1, 2003, Paris' temperature at 6am was 2.0 standard deviations above the day's average, then Chicago would have a 6am temperature for that day that was 2.0 standard deviations above its own average. This process was repeated for each day and each of the meteorological variables, such that a complete set of meteorological conditions analogous to Paris 2003 was developed for Chicago.

Using the analog daily data for Chicago, we next developed an air mass calendar for each city using the identical approach as used above in the heat-related mortality calculations[60], and calculated excess mortality using the Chicago-specific air-mass algorithm given previously in equation (4.1). In this way, the characteristics of Chicago that differ from those in Paris (its population, demographics, air conditioning use, and other factors affecting heat-related mortality rates) are taken into consideration[61].

During a typical Paris summer, only 10% of summer days are classified as being within offensive air masses (either Dry Tropical or Moist Tropical Plus[62]). For Chicago, these same types of oppressive air masses are typically present on 16 summer days or for about 17% of the summer. During the summer of 2003, however, almost half the days in Paris lay within an oppressive air mass. Similarly, for the Chicago analog summer modeled here, oppressive air masses were estimated to be present on 50 days or 54% of the summer – an exceptional event that has not occurred over the historical record. For both cities, more of the oppressive air mass days are categorized as DT rather than MT+.

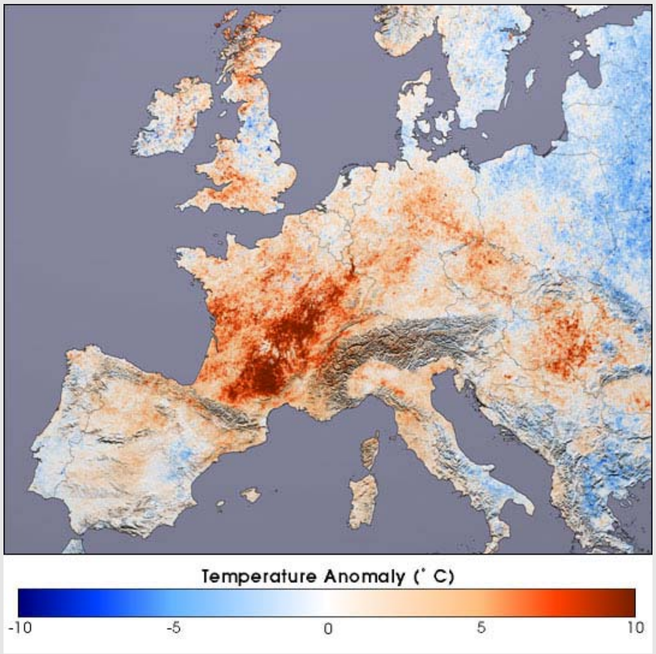

Figure 4.3. July daytime land surface temperatures as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite – difference between 2001 and 2003. A blanket of deep red across southern and eastern France (left of center) shows where temperatures were 10°C degrees Celsius (18°F) hotter in 2003 than in 2001. White areas show where temperatures were similar, and blue shows where temperatures were cooler in 2003 than 2001. (Source: NASA www.earthobservatory.nasa.gov)

The number of consecutive days within offensive air masses is also very unusual for the analog summer in both Paris and Chicago. Both cities experience three extended periods with consecutive offensive air mass days over the course of the summer. For Chicago, the summer begins with a string of 14 MT+ days in June (with two transition days imbedded during that time), continues with a second string of 14 DT days in July (again with two transition days), and finishes with 15 consecutive DT days in August, with each string being approximately equal to the entire summer average on a "normal" year.

Maximum and minimum temperature records during summer 2003 in Paris and for the analog summers for Chicago also exceed anything in recorded history (Figure 4.4). In Paris, the all-time August maximum temperature record, set in 1911, was broken by almost 3.6°F six times during the month, during two three-day consecutive periods. From August 6 through 14, each day broke a daily maximum temperature record. For the Chicago analog, a similar number of maximum temperature records would be broken, relative to the historical record (since 1926).

Minimum temperatures were equally oppressive during summer 2003 in Paris and the analog summer in Chicago. In Paris, the all-time summer high-minimum temperature record was broken by 2.7°F, and the all-time August record was broken by almost 5.4°F[63]. Five days broke the all-time August high-minimum temperature record, comprising a three-consecutive day and a two-consecutive day string. Seven days in August broke the daily high-minimum temperature record during eight days between August 5th and 12th. In Chicago, 12 daily maximum and minimum temperature records would be broken relative to the historical weather observations for Chicago dating back to 1926 (Figure 4.4b). Even more startling is the fact that four days would surpass the all time maximum temperature record for Chicago and eight days would exceed the all time high minimum temperature record. Many of these days would occur consecutively. It is important to note that heat-related illnesses and deaths are generally more sensitive to minimum, rather than maximum, temperatures, since overnight heat provides little relief in non-air conditioned dwellings.

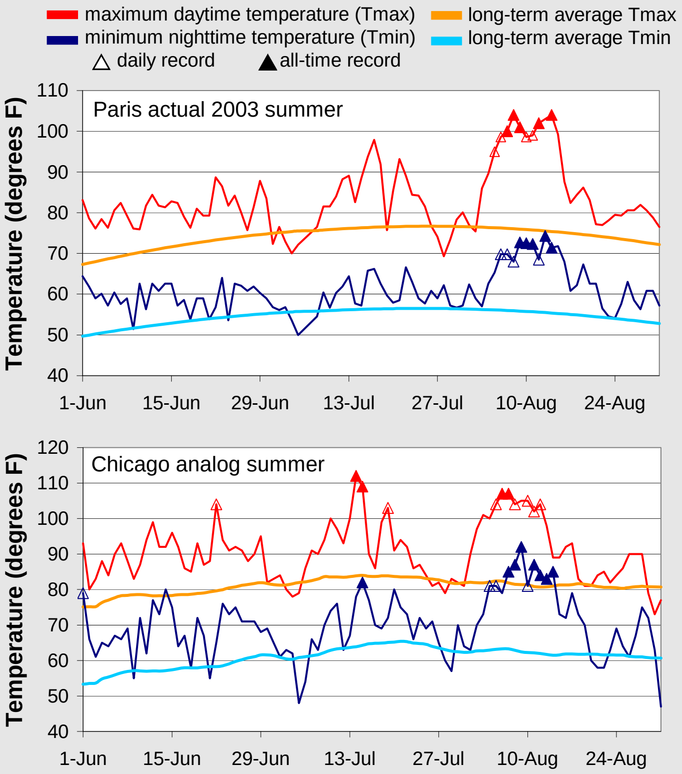

Figure 4.4. Actual & average maximum and minimum temperatures for (a) Paris during 2003 summer and (b) Chicago during a 2003-analog summer. Days marked with open triangles exceed the historical maximum and/or minimum temperature record for that day; days with solid triangles exceed the all-time August record.

So what would a heat wave like this mean for heat-related mortality in Chicago? Our analysis shows that such a heat wave in Chicago would have a devastating impact on public health, exceeding that of the 1995 heat wave. Chicago's metro area now has slightly over 8 million people based on the year 2000 census, which would give Chicago a mortality rate for this heat wave of 13.4 deaths per 100,000 (in comparison, the 1995 heat wave, assuming a population of 6 million, had a mortality rate of 11.5 per 100,000). This indicates that Chicago's population is more sensitive to extreme heat than that of Detroit, Philadelphia, and Washington, but less sensitive than New York City and St. Louis[64]. To put this into further perspective, during an average summer in Chicago, about 94 people die from the heat. The analog city death total of 1073 is over 10 times that total. Clearly, a heat wave of this magnitude would tax the health care system even more than the heat wave of 1995.

How soon could such a heat wave be expected? As the importance of such a heat wave is in its actual impact on human health – which, as we have already seen, is a complex function of the duration, timing, and frequency of certain oppressive air mass types – rather than calculate the air mass conditions that would lead to such an event, instead we simply cross-reference these mortality estimates with the year-to-year heat-related mortality estimates calculated in the heat-related mortality analysis previously, as this analysis was also based on the same air mass approach and mortality equations.

Doing so suggests that a EHW-like event is extremely likely to occur before the middle of the century, with model simulations indicating at least one summer with mortality estimates over 1000 by 2050 (Figure 4.5). The fact that an EHW-like summer is projected to occur under either the higher or the lower emissions scenario has important implications for adaptation, suggesting that even with stringent mitigation strategies in place, adaptive measures should be put in place to deal with such a situation.

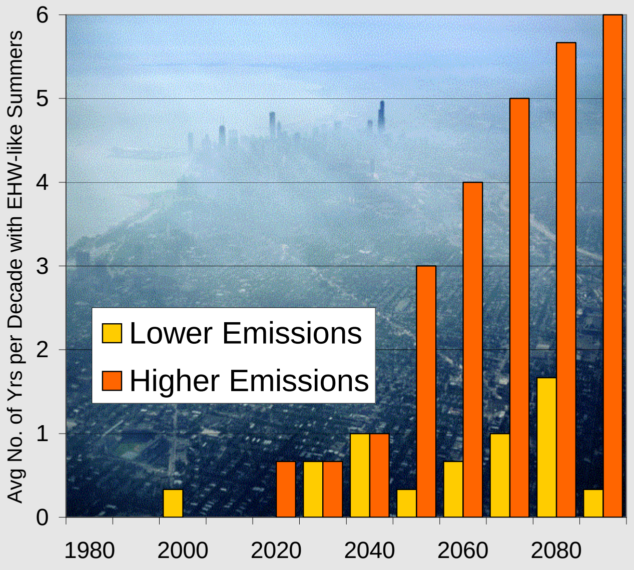

Figure 4.5. Average number of summers per decade with mortality rates projected to equal those of the Chicago analog to the European Heat Wave of 2003. Values shown are the average of three climate models for higher (orange) and lower (yellow) emission scenarios for each decade from 1980 to 2090.

EHW-like summers are likely to become even more frequent during the second half of the coming century. Under the lower emissions scenario, on average 5 more such summers are projected to occur before the end of the century, with the timing of the summers being primarily determined by random variability. Under the higher emissions scenario, however, 25 more EHW-like summers are projected to occur before the end of the century. By 2070, *every second summer* is projected to have mortality rates similar to or greater than those of the EHW analog summer (Figure 4.5).

Air quality

As temperatures warm and atmospheric circulation patterns change, bringing oppressive summer weather patterns to Chicago earlier in the year and making them last longer, air quality is also expected to get worse over the city, unless ozone (O_3) precursor emissions are stringently controlled and not maintained at present-day levels (or increased) as assumed in the studies presented here. We present the results of an analysis showing projected changes in summer ozone air quality and extreme events using two complementary approaches: first, analysis of existing regional model-based air quality simulations; and second, analyses of the frequency and duration of individual extreme events using statistical downscaling methods. Both methods have used the higher and lower emission scenarios to illustrate the differences between the two.

The 2007 international scientific assessment of climate change sponsored by the Intergovernmental Panel on Climate Change (IPCC) Working Group II refers to increases in surface O_3 as one of the top five global health impacts of climate change[65]. The threat of climate-related O_3 increases may be particularly severe in areas of the U.S. that are already in violation of the U.S. Environmental Protection Agency's (EPA) eight hour average National Ambient Air Quality Standard (NAAQS) for O_3 of 0.08 ppm (84 ppb). A county is defined to go out of attainment with this standard if the 3-year average of the annual 4th highest maximum 8-hour average exceeds 84 ppb. States are required to enact policies to ensure air quality meets the federal standard, so non-attainment counties face a range of extra regulations, impacting industries, power plants, and vehicle owners.

Densely populated areas with warm summers are particularly likely to experience high levels of surface O3. These regions tend to have high levels of O_3 precursor emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) that react in the presence of sunlight, with key reactions proceeding faster at higher summer temperatures.

Chicago, like many other major U.S. cities, has struggled with air pollution since the beginning of the industrial revolution. In fact, Chicago and Cleveland were the first cities in the U.S. to pass municipal air quality regulation in the 1880's – nearly a century before the federal Clean Air Act developed the NAAQS[66]. Although emissions and concentrations of many species have decreased through the late 20th century, and summertime ozone (O_3) levels have significantly decreased since the late 1970's, O_3 in Chicago has never been in compliance with standards set by the EPA to protect public health. Looking out over the coming decades, many changes are likely to affect ground level O_3 in Chicago: energy use, emission control technologies, regulatory policies, land cover, and climate. Here, we assess the change in O_3 over Chicago that would be expected due to projected climate change alone.

In the first of the two approaches used in this assessment, a combination of global and regional numerical models of the chemical and physical processes affecting climate and air quality are used. The air quality projections derived here focus only on the effects of changes in climate and assume that regional human-related emissions of ozone precursors remain fixed at present-day levels[67]. These analyses do allow, however, for the responses of biogenic emissions (organic compounds, VOCs, released from plants) from the changes in climate. Based on regional climate and air quality simulations driven by temperature changes at the lower end of the range examined here, average daily summer ozone levels in the City could increase by about 13% by the end of the century (by a smaller 7% increase over the Chicago six county region). For the higher emissions scenario, average daily summer ozone levels in the City could increase by about 22% due to climate change alone (and by 18% over the Chicago region). Much smaller changes, on the order of 2-3%, would be expected at mid-century. Ozone variability almost doubles under the higher emissions scenario but decreases by 20-30% under the lower scenario, implying that lower temperature changes could lead to weaker variations in pollution levels and hence fewer occurrences of extreme ozone days, while higher temperature changes could increase both ozone background levels as well as the frequency of ozone exceedance days.

An alternative method used in the assessment for calculating changes in future surface ozone levels is based on statistical correlations between historical observations and large-scale atmospheric circulation patterns[68]. This approach calculates historic relationships between meteorology and O_3, and considers how future meteorology would affect ground-level O_3, if these relationships remain constant. Ozone concentrations over Chicago are found to be most sensitive to surface temperature, horizontal surface winds, surface relative humidity, incoming solar radiation, and cloud cover. This approach yielded similar results when applied using the same temperature projections as the model simulations above (based on PCM and HadCM3) – increases of about 4-17% to about 19-27% by 2070-2099 under the lower and higher emission scenarios, respectively. However, additional calculations using the higher end of the possible temperature range indicate that, under higher emissions, summer ozone levels could increase by as much as 50% by end-of-century. In addition, this approach was also used to evaluate the potential changes in the number of days of exceedances of the 84 ppb NAAQS for O_3. A 5-15 day increase per year in exceedances is found by the 2040-2069 period for the high climate change scenario and 0-4 days for the lower scenario. For the 2070-2099 period, exceedances relative to present increase by 11-24 days for the high scenario and 1-7 days for the low scenario. This is approximately a 3-fold to 8-fold increase in the number of exceedances relative to the present climate.

These analyses assume ozone precursor emissions are maintained at present-day levels. Clearly, reducing local emissions of nitrogen oxides, volatile organic compounds, and other pollutants that react to form ground-level ozone is a key adaptation measure to reduce ozone levels even while temperatures continue to warm.

Changes in vector-borne diseases

Vector-borne pathogens are those disease agents for which the route of transmission from one host to another involves an insect or other arthropod, such as a tick or a mite. It was not until 1877 that it was established that the illness filariasis (or lymphatic filariasis) was transmitted by mosquitoes. In the following decades, malaria, yellow fever, dengue and many others, including Rocky Mountain spotted fever joined the list of known vector-borne illnesses[69]. Concerns today are of increased incidence of such illnesses in light of drug resistance, land cover change with growing human population, and global warming.

While many vector-borne illnesses are associated with the tropics, the Chicago region is not immune. In Illinois, the two most common vector-borne diseases currently are West Nile virus illness, carried by mosquitoes, and Lyme disease, carried by ticks. Looking back in time to August, 1901, a story in the New York Times reported that in Chicago's 19th Ward, "dirty streets, filthy alleys, impure water cause[d an] epidemic of typhoid fever and malaria"[70] . Malaria was endemic in the young United States, and in 1882 the malarious region extended from the Gulf of Mexico north to Minnesota. This region shrank to a focus primarily in the southeastern U. S. by the 1930s. Draining of swamps, improved pesticides and better management of water resources contributed to the eradication of malaria in the US shortly after World War II[71].

With the danger of malaria behind, mosquitoes were seen primarily as pests. The interest and concern for vector-borne illness in Chicago waned until 1975, when an outbreak of St. Louis Encephalitis (SLE) in the area left hundreds of people ill and thirty-six people dead[72]. SLE is carried by *Culex* species mosquitoes, and is a disease similar to that caused by WNV. Renewed mosquito abatement for vector control followed, but had again waned, when, in 2002, the sudden outbreak of West Nile virus illness brought the issue of mosquito control and disease prevention into sharp focus. The counties of Cook and DuPage have reported almost 1100 cases of human illness from WNV during the years from 2002 to 2007. The bacteria that causes Lyme disease, *Borrelia burgdorferi*, too, has emerged in the region recently, spreading with the *Ixodes* tick known commonly as the deer tick as it spreads west along forested river corridors[73].

Vector-borne disease in the Chicago area is currently a low-level ongoing health concern that has increased over recent decades. Warmer weather and changes in precipitation patterns could accelerate current trends of increased risk of exposure to vector-borne pathogens in the region. The route of transmission of a vector-borne disease is complicated by the life cycle of the vector and by the characteristics of the various vertebrate hosts. In terms of risk of transmission, each disease agent needs to be considered separately in light of specific environmental conditions and the zoonotic transmission cycle – that which occurs among vectors and non-human hosts. In the section below, we describe how changes in climate could impact the risk for vector-borne disease in the Chicago area using Lyme disease and illness from WNV as examples.

Many illnesses are seasonal. Just as the “flu season” in the United States is from November to March, vector-borne diseases in Illinois are most often seen in the warmer months, tied mostly to the life cycle of the vector and people’s tendency to be outside in the summer time. Illness from WNV, for example, peaks in mid-August in the Chicago area, and nearly all cases reported in the years 2002 to 2006 occurred between mid-July and the end of September, when the *Culex pipiens* mosquito vector is most abundant[74].

The onset of cases of Lyme disease is most common in June and July. The *Ixodes* tick goes through three stages over two years as the larval tick matures to a nymph and then becomes an adult. The tick requires a blood meal to mature to each stage. The tick poses the greatest risk to humans in the spring and summer of its second year when it is a nymph. At that point, it may have become infected as a larva and can now infect its new host. In the later summer and fall, in the adult stage, it prefers a deer host but can also infect humans during that period[75].

With elevated risk in the warmer months, it is not surprising that an increase in average temperature will raise concern about vector-borne disease. The *Culex* mosquito that transmits WNV is affected in several ways by increased temperatures. A female *Culex* mosquito deposits eggs about 5-6 times during her life. With a longer period in which warm temperatures prevail, more opportunities for depositing eggs are available. Mosquitoes develop from larvae to pupae to adult. They develop faster when temperatures are warmer. When temperatures reach about 17 °C (63 °F) and daylight is reduced, mosquitoes either die off or enter their winter state of inactivity called diapause[76]. Currently in the Chicago area, there are about 18 weeks a year in which temperatures are, on average, above 17 °C. Under the higher emissions scenario, there could be as many as 24 such weeks per year on average by the end of the century; under the lower emissions scenario, the number of weeks could be as high as 21. During the spring, the active season for mosquitoes could become earlier, as well, since water temperatures of greater than 15 °C (59 °F) allow for their proliferation.

Culex pipiens mosquitoes are recognized as an important carrier of the WNV to humans. This is based partly on association, since the number of infected mosquitoes found in this species is highest during the period when people are contracting the disease. A close cousin to the *C. pipiens* is the *Culex restuans* mosquito. *C. restuans* is most abundant in Illinois in the early part of the summer, while *C. pipiens* is most common later. Research by the Illinois State Natural History Survey and the Illinois Water Survey indicates that the point at which there are equal numbers of *C. pipiens* and *C. restuans* immediately precedes outbreaks of WNV. Based on data from fifteen years time, they found the average day when equal numbers of the two types of mosquitoes are seen is about August 9. They then estimate that the crossover from *C. restuans* to *C. pipiens* occurs 1.4 days earlier than the average day for each day in which the maximum temperature exceeds 27 °C (81 °F). In other words, warmer summer temperatures will make this crossover occur earlier, again lengthening the season with higher risk for WNV in Illinois[77].

In addition to the potential for more vector mosquitoes to be present, those mosquitoes will be more efficient at transmitting the virus when temperatures are warmer. The time it takes from when a mosquito receives the virus until it is able to transmit the virus to its next host, is called the extrinsic incubation period. We do not know the exact relationship between all temperatures and the extrinsic incubation period, but research has provided some insight. For example, at 18 °C (64 °F), this time period can be more than three weeks. At 30 °C (86 °F), the incubation period can be as few as just four days. Overall, the replication of the virus is temperature-dependent, and warmer temperatures increase the replication rate[78].

People often equate rain with more mosquitoes. For the pesky floodwater mosquitoes common in Chicago, the *Aedes vexans*, this is generally true; but for the *Culex* mosquitoes this is not always the case. This is more easily understood when taking into account the preference for these mosquitoes to deposit eggs in stagnant water. Water becomes stagnant after it has stood long enough for leaves, grass and other organic material to enter it during a dry period. This makes the relationship between rain and West Nile virus especially complex. Some rain is necessary for the mosquitoes to survive, but the combination of rain followed by a period of dry hot weather is ideal. The risk of illness from WNV is greatest when these fluctuating conditions occur during the time when *Culex pipiens* populations are largest, in the middle to end of the summer.

Some studies have been carried out where historic data on SLE have been used to consider the role of precipitation on outbreaks. In Florida, this was illustrated by the observation that spring drought followed by summer rainfall increases the risk for SLE and for WNV illness[79]. In California, SLE was more likely in the overall absence of rainfall[80]. In depth studies in Illinois have not been completed, but the conditions in which illness has occurred in higher amounts has included very warm temperatures (2002) and very dry conditions (2005). At this point, it is not clear if the projected changes in climate will be followed by conditions that increase risk or are preventative for WNV illness.

The arrival to the Chicago area of the bacteria and ticks associated with Lyme disease is a recent phenomenon. Though new to this area, the factors related to Lyme disease have been examined in some detail in Illinois and neighboring states as well as in the northeastern region of the United States where the great majority of cases of illness are found[81]. The tick vector, *I. scapularis* is sensitive to lack of moisture and is less plentiful in drought conditions. At Castle Rock State Park, for example, an eight-year study of ticks found very few larval stage ticks the years following the droughts of 1991 and 1995, when rainfall was about 50% of normal amounts. Dry conditions also dramatically reduced the number of the mice which host the ticks. On the other hand, when looking only at temperature and considering questing ticks on the ground (looking for hosts), the warmer the temperature, the more ticks were found[82]. Research in the northeast found that while ticks survived better in wet conditions, temperature was not a dominant factor in survival[83].

Temperature and CO_2 Effects on Allergens and Allergies

Another concern of climate change is the effect on asthma prevalence and attacks. This is difficult to predict for several reasons. Some common asthma triggers are dust mites and molds, both of which are higher indoors than outdoors. Both require a relatively humid environment for survival. Consequently, if the climate becomes drier, or drought periods increase, little impact on these triggers would be expected. However, both will respond to higher humidity with increased growth, and these triggers will become more significant. Many asthmatics are allergic to various plant pollens. Plants and trees typically have pollination seasons that last a few weeks per year. To the extent that pollen seasons lengthen or become more intense in response to climate change, the season for particular pollens could become longer and lead to increased asthma exacerbation.

The risk of Lyme disease may be most closely related to the presence of appropriate hosts for the ticks. Deer were not found to be important in terms of predicting risk in one recent study but the density of ticks was related to the density of chipmunks and white-footed mice[84] [7]. There are indications that variable acorn crops can mediate the food supply and thus the population of the rodents. The indirect path of climate affecting the acorn crop, acorns affecting the number of rodents (and deer) in an area, the influence on the number of ticks at various stages and then having an effect on disease occurrence is illustrative of the ecological web that needs to be unraveled by scientists, public health personnel and policy makers in light of climate change.

The complexity of vector-borne diseases is rooted in the myriad relationships among factors that often are not clearly defined quantitatively (or even understood completely), and research results are not always consistent in the details of thresholds or critical values. At the same time, the emergence of WNV in North America demonstrates the potential for a new disease to take hold, and other viruses carried by mosquitoes are also a concern. For example, the Asian Tiger mosquito (Aedes albopictus) can transmit a number of viruses, and was involved in a 2007 outbreak of chikungunya virus infection in Northern Italy. This disease of the tropics had not been seen in an outbreak in Europe prior to this time. Chicago is currently the northernmost known range of the Asian Tiger mosquito in the U.S. Warmer winters may provide more opportunities for establishment of these mosquitoes farther north, increasing the risk of the vector-borne diseases they carry. Even in the absence of complete data, as we move forward with policy decisions and responses to possible climate changes, we need to take seriously the possible effects on the transmission of vector-borne illness and be alert to new conditions that could trigger an increase in these illnesses.

While many of these relationships are not clearly defined quantitatively, and research results are not always consistent in the details of the thresholds or critical values, we do have considerable experience with the diseases described here that pose a current threat to Chicago. As we move forward with policy decisions and responses to possible climate changes, we need to take seriously the possible effects on the transmission of vector-borne illness and be alert to new conditions that could trigger an increase in these illnesses.

References

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[1] Martens, W. J. M. 1998. “Climate change, thermal stress and mortality changes.” Social Science and Medicine 46: 331–344.

[2] McGeehin MA, M. Mirabelli, 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspect 109 Suppl 2: 185-9.

[3] Schär, C., P.L. Vidale, D. Lüthi, C. Frei, Häberli, M.A. Liniger, C. Appenzeller, 2004. The role of increasing temperature variability in the European summer heatwaves. Nature. 427, 332-336.

[4] **No reference citied here**

[5] Ellis, F.P., and F. Nelson, 1978: Mortality in the elderly in a heat wave in New York City, August, 1975. Environmental Research 15: 504-512.

[6] Kalkstein, L.S., and K.M. Valimont, 1987: Climate effects on human health. In: Potential Effects of Future Climate Changes on Forests and Vegetation, Agriculture, Water Resources, and Human Health. EPA Science and Advisory Committee Monograph 25389:122-152.

[7] Livezey, R.E, and R. Tinker, 1996. Some meteorological, climatological, and microclimatological considerations of the severe U.S. heat wave of mid-July 1995. Bull. Amer. Meteor. Soc., 77, 2043-2054.

[8] It is important to note that heat-related deaths reported during a heat wave may be underestimated. Comparing the number of deaths classified as “heat-related” to the number of excess deaths that occurred over the same time provides a measure of the degree to which this was the case for the 1995 heat wave. For example, Shen et al. (1998) found that excess mortality rates during the Chicago heat wave were higher than heat-related mortality (24-26 per 100,000 as opposed to 19 per 100,000), likely due to an overly-narrow classification of what exactly is a heat-related death. Similarly, for July 14 through 20, Whitman et al. (1997) found 485 heat-related deaths but a total of 739 excess deaths.

[9] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[10] Whitman S, G. Good, E.R. Donoghue, N. Benbow, W. Shou, and S. Mou, 1997: Mortality in Chicago attributed to the July 1995 heat wave.” American Journal of Public Health 87: 1515-1518.

[11] Kaiser, R., A.L. Tertre, J. Schwartz, C.A. Gotway, W.R. Daley, and C.H. Rubin. 2007. The effect of the 1995 heat wave in Chicago on all-cause and cause-specific mortality. Am. J. Public Health, 97:S158-162.

[12] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[13] Dematte, J.E., K, O’Mara, J. Buescher, C.G. Whitney, S. Forsythe, Turi, McNamee, R.B. Adiga, and M. Ndukwu. 1998. Near-fatal heat stroke during the 1995 heat wave in Chicago. Annals of Internal Medicine. 129, 3, 173-181.

[14] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[15] Dematte, J.E., K, O’Mara, J. Buescher, C.G. Whitney, S. Forsythe, Turi, McNamee, R.B.

Adiga, and M. Ndukwu. 1998. Near-fatal heat stroke during the 1995 heat wave in Chicago. Annals of Internal Medicine. 129, 3, 173-181.

[16] Changnon, S.A., Kunkel, K.E., Reinke, B.C., 1996: Impacts and responses to the 1995 heat wave: A call to action. Bull. Amer. Meteor. Soc., 77, 1497-1506.

[17] O'Neill, M., A. Zanobetti, and J. Schwartz. 2005. "Disparities by race in heat-related mortality in four US cities: The role of air conditioning prevalence." Journal of Urban Health: Bulletin of the New York Academy of Medicine 82: 191–197.

[18] Naughton, M., A. Henderson, M. Mirabelli, R. Kaiser, J. Wilhelm, S. Kieszak, C. Rubin, and M. McGeehin. 2002. "Heat-related mortality during a 1999 heat wave in Chicago." American Journal of Preventative Medicine 22: 221–227.

[19] Semenza, J., C. Rubin, K. Falter, J. Selanikio, W. Flanders, H. Howe, and J. Wilhelm. 1996. "Heat-related deaths during the July 1995 heat wave in Chicago." The New England Journal of Medicine 335: 84–90.

[20] Naughton, M., A. Henderson, M. Mirabelli, R. Kaiser, J. Wilhelm, S. Kieszak, C. Rubin, and M. McGeehin. 2002. "Heat-related mortality during a 1999 heat wave in Chicago." American Journal of Preventative Medicine 22: 221–227.

[21] Whitman S, G. Good, E.R. Donoghue, N. Benbow, W. Shou, and S. Mou, 1997: Mortality in Chicago attributed to the July 1995 heat wave." American Journal of Public Health 87: 1515-1518.

[22] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[23] Whitman S, G. Good, E.R. Donoghue, N. Benbow, W. Shou, and S. Mou, 1997: Mortality in Chicago attributed to the July 1995 heat wave." American Journal of Public Health 87: 1515-1518.

[24] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[25] Browning, C.R., D. Wallace, S. Feinber, K.A, Cagney. 2006. Neighborhood social processes, physical conditions, and disaster-relataed mortality: the case of the 1995 Chicago hear wave. American Sociological Review, 71, 4, 661-678.

[26] O'Neill, M., A. Zanobetti, and J. Schwartz. 2005. "Disparities by race in heat-related mortality in four US cities: The role of air conditioning prevalence." Journal of Urban Health: Bulletin of the New York Academy of Medicine 82: 191–197.

[27] Palecki, M. A., S. A. Changnon, and K. E. Kunkel. 2001. "The nature and impacts of the July 1999 heat wave in the Midwestern United States: Learning from the lessons of 1995." Bulletin of the American Meteorological Society, 82: 1353–1367.

[28] Naughton, M., A. Henderson, M. Mirabelli, R. Kaiser, J. Wilhelm, S. Kieszak, C. Rubin, and M. McGeehin. 2002. "Heat-related mortality during a 1999 heat wave in Chicago." American Journal of Preventative Medicine 22: 221–227.

[29] Meehl, G.A., and C. Tebaldi, 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305, 5686, 994-997.

[30] Valleron, A.J., and A. Boumendil, 2004. Epidemiology and heat waves: analysis of the 2003 episode in France. C.R. Biol. 327:1125-1141.

[31] McGeehin, M. A., and M. Mirabelli. 2001. "The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States." Environmental Health Perspectives 109: 185–189.

[32] Semenza, J.C. Are electronic emergency department data predictive of heat related mortality? Journal of Medical Systems (1999) 23(5):419-21, 423-4.

[33] Schwartz J, Samet JM, Patz JA (2004). Hospital admissions for heart disease: the effects of temperature and humidity. Epidemiology 15: 755-61.

---

[34] Kovats RS, Hajat S. Wilkinson P. (2004). Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occup Environ Med; 61: 893-898.

[35] Patz JA, McGeehin MA, Bernard SM, Ebi KL, Epstein PR, Grambsch A, Gubler DJ, Reiter P, Romieu I, Rose JB, Samet JM, Trtanj J (2000). The potential health impacts of climate variability and change for the United States: Executive summary of the report of the health sector of the US National Assessment. Environmental Health Perspectives 108: 367-376.

[36] **National Climatic Data Center, 2004**

[37] Valleron, A.J., and A. Boumendil, 2004. Epidemiology and heat waves: analysis of the 2003 episode in France. C.R. Biol. 327:1125-1141.

[38] Davis, R.E., P.C. Knappenberger, W.M. Novicoff, and P.J. Michaels, 2002: Decadal changes in heat-related human mortality in the eastern United States. Climate Research 22: 175-184.

[39] Smoyer, K.E., 1998: A Comparative analysis of heat waves and associated mortality in St. Louis, Missouri – 1980 – 1995. International Journal of Biometeorology 42: 44-50.

[40] Klinenberg, E., 2002: Heat Wave: A Social Autopsy of Disaster in Chicago. U. Chicago Press, Chicago, 328 pp.

[41] Naughton, M., A. Henderson, M. Mirabelli, R. Kaiser, J. Wilhelm, S. Kieszak, C. Rubin, and M. McGeehin. 2002. "Heat-related mortality during a 1999 heat wave in Chicago." American Journal of Preventative Medicine 22: 221–227.

[42] Sheridan, S.C., 2002: The Redevelopment of a Weather-Type Classification Scheme for North America. International Journal of Climatology 22: 51-68.

[43] National Center for Health Statistics, 2000. Standardized Micro-data Mortality Transcripts. U.S. Department of Health, Education, and Welfare.

[44] Ebi, K. L., T. J. Teisberg, L. S. Kalkstein, L. Robinson, and R. F. Weiher. 2004. "Heat Watch/Warning Systems Save Lives: Estimated Costs and Benefits for Philadelphia 1995–1998." Bulletin of the American Meteorological Society 85: 1067–74.

[45] This station was used in the analysis because it is the closest NWS weather station to the majority of Chicago's urban population that has historical records of daily wind direction and speed, sea level pressure, and cloudiness.

[46] Kalkstein, L. S., P. F. Jamason, J. S. Greene, J. Libby, and L. Robinson. 1996. "The Philadelphia Hot Weather-Health Watch/Warning System: Development and Application, Summer 1995." Bulletin of the American Meteorological Society 77(7):1519– 1528.

[47] Sheridan, S. C., and L. S. Kalkstein. 2004. "Progress in Heat Watch-Warning System Technology." Bulletin of the American Meteorological Society 85: 1931–1941.

[48] Meehl, G.A., and C. Tebaldi, 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305, 5686, 994-997.

[49] Whitman S, G. Good, E.R. Donoghue, N. Benbow, W. Shou, and S. Mou, 1997: Mortality in Chicago attributed to the July 1995 heat wave." American Journal of Public Health 87: 1515-1518.

[50] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[51] O'Neill, M., A. Zanobetti, and J. Schwartz. 2005. "Disparities by race in heat-related mortality in four US cities: The role of air conditioning prevalence." Journal of Urban Health: Bulletin of the New York Academy of Medicine 82: 191–197.

[52] Browning, C.R., D. Wallace, S. Feinber, K.A, Cagney. 2006. Neighborhood social processes, physical conditions, and disaster-relataed mortality: the case of the 1995 Chicago hear wave. American Sociological Review, 71, 4, 661-678.

[53] Changnon, S.A., Kunkel, K.E., Reinke, B.C., 1996: Impacts and responses to the 1995

---

heat wave: A call to action. Bull. Amer. Meteor. Soc., 77, 1497-1506.

[54] Kalkstein, L., and J. Greene. 1997. "An evaluation of climate/mortality relationships in large U.S. cities and possible impacts of a climate change." Environmental Health Perspectives 105: 84–93.

[55] Semenza, J.C. , McCullough, J., Flanders, D.W., McGeehin M.A., Lumpkin JR. 1999. Excess hospital admissions during the 1995 heat wave in Chicago, American Journal of Preventive Medicine, 16(4): 269-277.

[56] Ebi, K. L., T. J. Teisberg, L. S. Kalkstein, L. Robinson, and R. F. Weiher. 2004. "Heat Watch/Warning Systems Save Lives: Estimated Costs and Benefits for Philadelphia 1995–1998." Bulletin of the American Meteorological Society 85: 1067–74.

[57] Planton, S., M. Gillet, M. Deque, and J. Manach, 2004: Adaptation to Heat Waves Occurrence in France. Meteo France PowerPoint presentation. Available: http://unfccc.int/files/meetings/workshops/other_meetings/application/vnd.ms-powerpoint/planton.ppt.

[58] Valleron, A.J., and A. Boumendil, 2004. Epidemiology and heat waves: analysis of the 2003 episode in France. C.R. Biol. 327:1125-1141.

[59] Dhainaut, J.F., Y.E. Claessens, C. Ginsburg, and B. Riou. 2004. Unprecendented heat-related deaths during the 2003 heat wave in Paris: consequences on emergency departments. Crit Care. 8, 1-2.

[60] Sheridan, S. C., and L. S. Kalkstein. 2004. "Progress in Heat Watch-Warning System Technology." Bulletin of the American Meteorological Society 85: 1931–1941.

[61] Kalkstein, L.S, J.S. Greene, D.M. Mills, A.D. Perrin, J.P. Samenow, J.C. Cohen. 2007. The development of analog European heat waves for U.S. cities to analyze impace on heat-related mortality. Bulletin of the American Meteorological Society, **volume/pages**.

[62] For both cities, more of the oppressive air mass days are categorized as DT rather than MT+. This is in contrast to other U.S. cities, where MT+ air masses tend to be more common than DT (Kalkstein et al., 2007).

[63] **Meteo France, 2006**

[64] Kalkstein, L.S, J.S. Greene, D.M. Mills, A.D. Perrin, J.P. Samenow, J.C. Cohen. 2007. The development of analog European heat waves for U.S. cities to analyze impace on heat-related mortality. Bulletin of the American Meteorological Society, **volume/pages**.

[65] Intergovernmental Panel on Climate Change, IPCC, Working Group I, The Physical Science Basis, Fourth Assessment Report, Chapter 10, http://ipcc-wg1.ucar.edu/wg1/wg1-report.html, 2007b.

[66] Bachmann, J., Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards, *J. Air & Waste Manage. Assoc.,* 57, 652–697, DOI:10.3155/1047-3289.57.6.652, 2007.

[67] J.-T. Lin, D. J. Wuebbles, H.-C. Huang, Z.-N. Tao, A. Williams, M. Caughey, K. E. Kunkel, Xin-Zhong Liang, and Jin-Hong Zhu, 2007: Effects of Future Climate and Emissions Changes on Surface Ozone Air Quality over the Chicago Area. University of Illinois report.

[68] Holloway, T. S. N. Spak, D. Barker, M. Bretl1, K. Hayhoe, J. Van Dorn, and D. Wuebbles, 2007: Change in ozone air pollution over Chicago associated with global climate change. *J. Geophys. Res.*, submitted.

[69] Gubler DJ: Resurgent vector-borne diseases as a global health problem. Emerg Infect Dis 1998, 4:442-450.

[70] New York Times. Chicago Disease-Ridden. New York Times. 8-17-1901. 8-17-1901.

[71] Centers for Disease Control. Eradication of Malaria in the United States (1949-1951) [Retrieved 1 July 2007: http://www.cdc.gov/malaria/history/eradication_us.htm]

[72] Zweighaft RM, Rasmussen C, Brolnitsky O, Lashof JC: St. Louis encephalitis: the Chicago experience. Am J Trop Med Hyg 1979, 28:114-118.

---

[73] Guerra M, Walker E, Jones C, Paskewitz S, Cortinas MR, Stancil A, Beck L, Bobo M, Kitron U: Predicting the risk of Lyme disease: habitat suitability for Ixodes scapularis in the north central United States. Emerg Infect Dis 2002, 8:289-297.

[74] Illinois Department of Public Health. West Nile virus in Illinois. [Retrieved 8 July 2007: http://www.idph.state.il.us/envhealth/wnv.htm]

[75] Ostfeld RS, Canham CD, Oggenfuss K, Winchcombe RJ, Keesing F: Climate, deer, rodents, and acorns as determinants of variation in lyme-disease risk. PLoS Biol 2006, 4:e145.

[76] Dohm DJ, O'Guinn ML, Turell MJ: Effect of environmental temperature on the ability of Culex pipiens (Diptera: Culicidae) to transmit West Nile virus. J Med Entomol 2002, 39:221-225.

[77] Kunkel KE, Novak RJ, Lampman RL, Gu W: Modeling the impact of variable climatic factors on the crossover of Culex restauns and Culex pipiens (Diptera: culicidae), vectors of West Nile virus in Illinois. Am J Trop Med Hyg 2006, 74:168-173.

[78] Mellor PS: Replication of arboviruses in insect vectors. J Comp Pathol 2000, 123:231-247.

[79] Shaman J, Day JF: Achieving operational hydrologic monitoring of mosquito borne disease. Emerg Infect Dis 2005, 11:1343-1350.

[80] Barker CM, Reisen WK, Kramer VL: California state Mosquito-Borne Virus Surveillance and Response Plan: a retrospective evaluation using conditional simulations. Am J Trop Med Hyg 2003, 68:508-518.

[81] Centers for Disease control. Lyme Disease [Retrieved 7 July 2007: http://www.cdc.gov/ncidod/dvbid/lyme/ld_rptdLymeCasesbyState.htm].

[82] Jones, CJ, Kitron, UD: Populations of Ixodes scapularis (Acari: Ixodidae) are modulated by drought at a Lyme disease focus in Illinois. J Med Entomol 2000, 37:408-415.

[83] McCabe, GG, Bunnell, JE: Precipitation of the occurrence of Lyme disease in the Northeastern United States. Vector-borne and Zoonotic Disease 2004, 4:143-148

[84] Missing Reference