Human Health

Key Messages:

- Significant increases in the risk of illness and death related to extreme heat and heat waves are very likely.
- Climate change is expected to contribute to poor air quality, adversely affecting health.
- Physical and mental health impacts due to extreme weather events are projected to increase.
- Some infectious diseases transmitted by food, water, and insects are likely to increase.
- Allergies and asthma are on the rise, with emerging evidence that climate change will play a role in the future.
- Certain groups, including children, the elderly, and the poor, are most vulnerable to the range of health effects.

Climate change poses unique challenges to human health. Unlike health threats caused by a particular toxin or disease pathogen, there are many ways that climate change can lead to potentially harmful health effects. There are direct health impacts from heat waves and severe storms, ailments caused or exacerbated by air pollution and airborne allergens, and many climate-sensitive infectious diseases[1].

Realistically assessing the potential health effects of climate change must include consideration of the capacity to manage new and changing climatic conditions[1]. Whether or not increased health risks due to climate change are realized will depend largely on societal responses and underlying vulnerability. The probability of exacerbated health risks due to climate change points to a need to maintain a strong public health infrastructure to help limit future impacts[1].

Increased risks associated with diseases originating outside the United States must also be considered because we live in an increasingly globalized world. Many poor nations are expected to suffer even greater health consequences from climate change[2]. With global trade and travel, disease flare-ups in any part of the world can potentially reach the United States. In addition, weather and climate extremes such as severe storms and drought can undermine public health infrastructure, further stress environmental resources, destabilize economies, and potentially create security risks both within the United States and internationally[3].

Significant increases in the risk of illness and death related to extreme heat and heat waves are very likely.

Temperatures are rising and the probability of severe heat waves is increasing. Analyses suggest that currently rare extreme heat waves will become much more common in the future[4]. At the same time, the U.S. population is aging, and older people are more vulnerable to hot weather and heat waves. The percentage of the U.S. population over age 65 is projected to be 13 percent by 2010 and 20 percent by 2030 (over 50 million people)[1], growing dramatically as the Baby Boomers join the ranks of the elderly[5]. Diabetics are also at greater risk of heat-related death, and the prevalence of obesity and diabetes is increasing. Heat-related illnesses range from heat exhaustion to kidney stones[6,7].

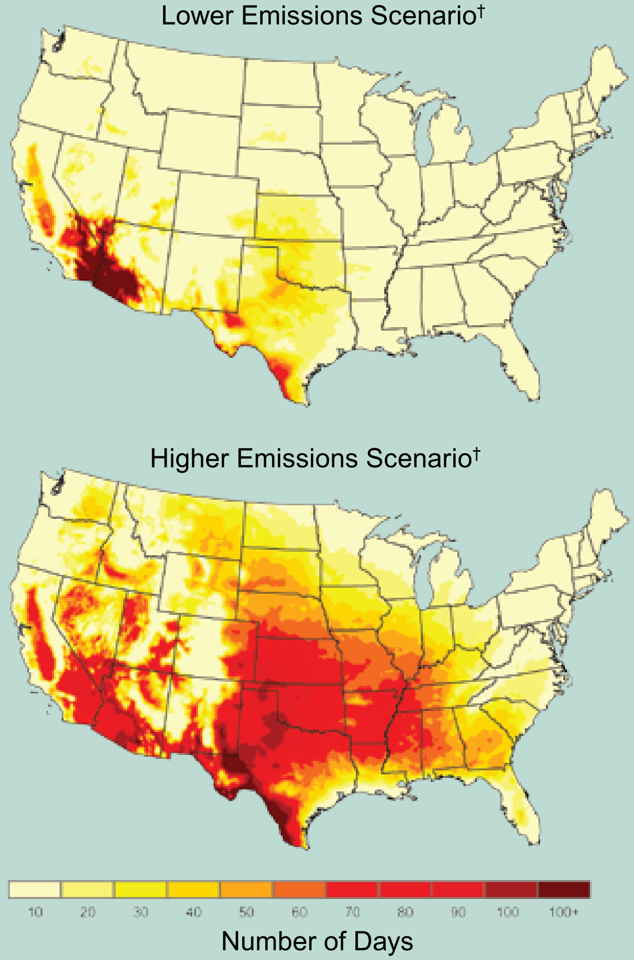
Heat is already the leading cause of weather-related deaths in the United States, responsible for more than 3,400 deaths between 1999 and 2003. From the 1970s to the 1990s, however, heat-related deaths declined[8]. This likely resulted from a rapid increase in the use of air conditioning. In 1978, 44 percent of households were without air conditioning, whereas in 2005, only 16 percent of the U.S. population lived without it (and only 3 percent did not have it in the South)[9,10,11]. With air conditioning reaching near saturation, a recent study found that the general decline in heat related deaths seem to have leveled off since the mid-1990s[12].

As human-induced warming is projected to raise average temperatures by about 6 to 11ºF in this century under a higher emissions scenario†, heat waves are expected to continue to increase in frequency, severity, and duration[4,13]. For example, by the end of this century, the number of heat-wave days in Los Angeles is projected to double[14], and the number in Chicago to quadruple[15], if emissions are not reduced.

Projections for 21 U.S. cities suggest that the average number of deaths due to heat waves would more than double by 2050, even though it assumed that people would take actions such as limiting outdoor activities, increasing fluid intake, and purchasing and using air conditioners. The greatest increases in deaths are projected to occur in major, mid-latitude cities, including New York, Chicago, and Philadelphia. Over 10,000 additional heat-wave deaths due to global warming are projected for just those three cities between now and 2050, with over 23,000 additional deaths projected for the 21 cities studied[5]. Higher emissions scenarios† would result in more deaths than lower emissions scenarios†.

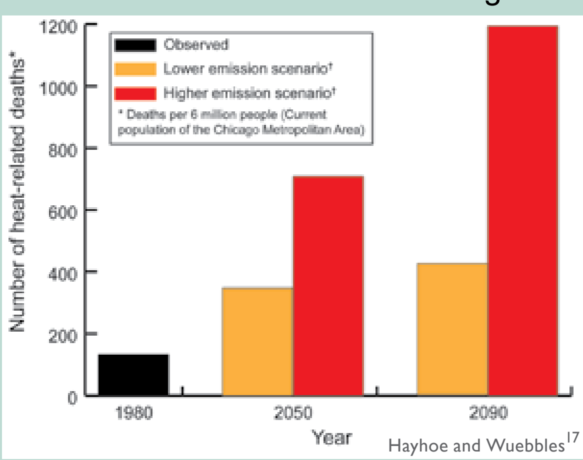
The full effect of global warming on heat-related illness and death involves a number of factors including actual changes in temperature (averages, highs, and lows); and human population characteristics, such as age, wealth and fitness. In addition, adaptation at the scale of a city

Projected Increase in Number of Days with Heat Index Over 100ºF



The number of days with a heat index (a measure that combines temperature and humidity to determine how hot it feels) over 100°F by late this century, compared to the 1960s and 1970s, is projected to increase strongly across the United States. For example, the center of the nation is expected to experience 60 to 90 additional days per year in which the heat index is over 100°F.

Projected Increase in Heat-Related Deaths in Chicago



Increases in heat-related deaths are projected in cities around the nation, especially under higher emissions scenarios. This analysis included some adaptation measures. The graph shows projections for the City of Chicago for the middle and end of this century under lower and higher emissions†.

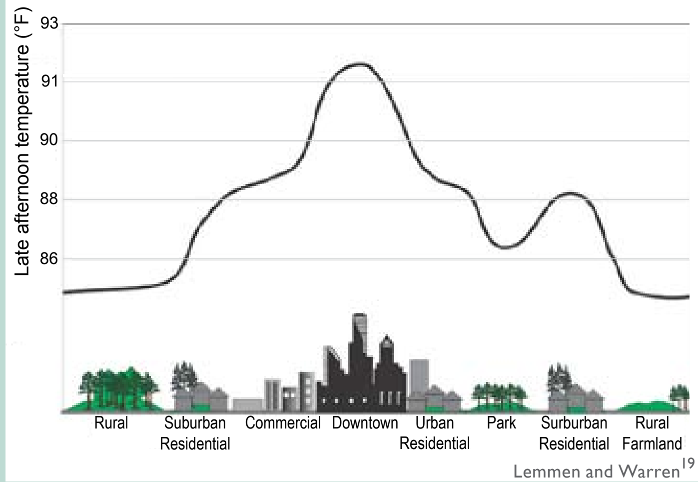
includes options such as heatwave early warning systems, urban design to reduce heat loads, and enhanced services during heatwaves[1].

Reduced extreme cold

In a warmer world, the number of deaths caused by extremely low temperatures would be expected to drop, although in general, it is uncertain how climate change will effect net mortality[1]. Neverthe-less, a recent study that analyzed daily mortality and weather data with regard to 6,513,330 deaths in 50 U.S. cities between 1989 and 2000 shows a marked difference between deaths resulting from hot and cold temperatures. The researchers found that, on average, cold snaps increased death rates by 1.6 percent, while heat waves triggered a 5.7 per-cent increase in death rates[18]. The study concluded that the reduction in deaths as a result of relatively milder winters attributable to global warming will not make up for the more severe health effects of summertime heat extremes[18].

It has been suggested that because death rates are higher in winter than in summer, warming might decrease deaths overall, but this ignores the fact that influenza and pneumonia cause many winter deaths, and it is unclear how these highly seasonal diseases are affected by temperature[1].

Urban Heat Island Effect



Large amounts of concrete and asphalt in cities absorb and hold heat. Tall buildings prevent heat from dissipating and reduce air flow. At the same time, there is generally little vegetation to provide shade and evaporative cooling. As a result, parts of cities can be up to 10°F warmer than the surrounding rural areas, compounding the temperature increases that people experience as a result of human-induced warming.

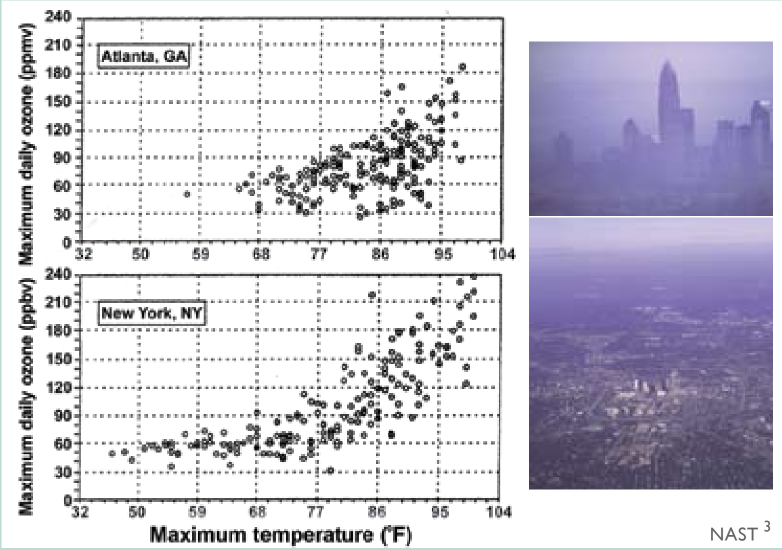
Climate change is expected to contribute to poor air quality, adversely affecting health.

Poor air quality, especially in cities, is a serious concern across the United States. Half of all Ameri-cans live in counties where air pollution exceeds national health standards. While the Clean Air Act has improved air quality, higher temperatures and associated stagnant air masses can potentially reverse these trends in air quality, particularly for ground-level ozone (smog)[22]. It has been firmly established that breathing ozone results in short-term decreases in lung function and damages the cells lining the lungs. It also increases the incidence

Adaptation: Reducing Deaths During Heat Waves

Some U.S. cities have implemented systems for reducing the risk of death during heat waves, notably Philadelphia, the first to adopt such a system in the mid-1990s. The city focuses its efforts on the elderly, homeless, and poor. During a heat wave, the weather service issues a heat alert and contacts news organizations with tips on how vulnerable people can protect themselves. The health department and thousands of block captains use a buddy system to check on elderly residents in their homes; electric utilities voluntarily refrain from shutting off services for non-payment; and public cooling places extend their hours. The city operates a “Heatline” where nurses are standing by to assist callers experiencing health problems; if callers are deemed “at risk”, mobile units are dispatched to the residence. The city also has implemented a “Cool Homes Program” for elderly low-income residents, which provides measures such as roof coatings and roof insulation that save energy and lower indoor temperatures. Philadelphia’s system is estimated to have saved 117 lives over its first 3 years of operation[20,21].

Temperature and Ozone

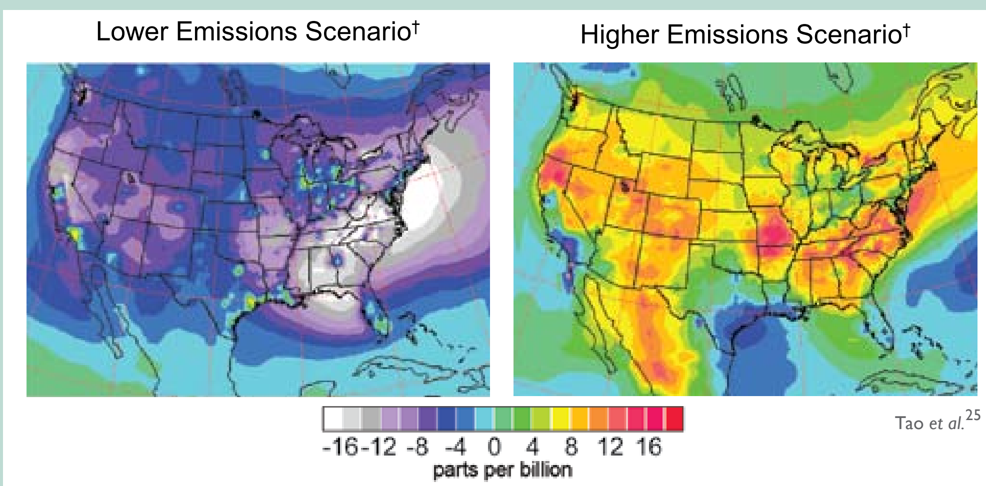


The graphs illustrate the observed association between ground-level ozone (smog) concentration and temperature in Atlanta and New York City (May to October 1988 to 1990) in parts per million by volume (ppmv) and parts per billion by volume (ppbv) respectively[3]. The projected higher temperatures across the United States in this century are likely to increase the occurrence of high ozone concentrations, although this will also depend on emissions of ozone precursors and meteorological factors. Ground-level ozone can exacerbate respiratory diseases and cause short-term reductions in lung function.

of asthma-related hospital visits and premature deaths[2]. Vulnerability to ozone effects is greater for those who spend time outdoors, especially with physical exertion, because this results in a higher cumulative dose to their lungs. As a result, children, outdoor workers, and athletes are at higher risk for these ailments[1].

Ground-level ozone concentrations are affected by many factors including weather conditions, emissions of gases from vehicles and industries that lead to ozone formation (especially nitrogen oxides and volatile organic compounds), natural emissions of volatile organic compounds from plants, and pollution blown in from other places[23]. A warmer climate is projected to increase the natural emissions of volatile organic compounds, accelerate ozone formation, and increase the frequency and duration of stagnant air masses that allow pollution to accumulate, which will exacerbate health symptoms[24]. Increased temperatures and water vapor due to human-induced carbon dioxide emissions have been found to increase ozone more in areas with already elevated concentrations, meaning that global warming tends to exacerbate ozone pollution most in already polluted areas. Under constant pollution emissions,

Projected Change in Ozone, 2090

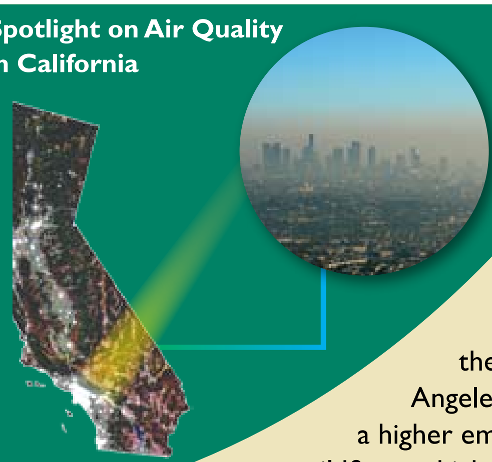


The maps show projected changes in ground-level ozone (smog) for the 2090s, averaged over the summer months (June through August), relative to 1996 to 2000, under lower and higher emissions scenarios†. By themselves, higher temperatures and other projected climate changes would increase ozone levels under both scenarios. However, the maps indicate that future projections of ozone depend heavily on emissions, with the higher emissions scenario† increasing ozone by large amounts, while the lower emissions scenario† results in an overall decrease in ground-level ozone by the end of the century[25].

by the middle of this century, Red Ozone Alert Days (when the air is unhealthy for everyone) in the 50 largest cities in the eastern United States are projected to increase by 68 percent due to warming alone. Such conditions would challenge the ability of communities to meet health-based air quality standards such as those in the Clean Air Act[14].

Finally, it is clear that synergies exist between direct health risks from heat waves and risks from exacerbated air pollution. The formation of ground-level ozone occurs under hot and stagnant conditions—essentially the same weather conditions accompanying heat waves. Such interactions among risk factors are likely to increase as climate change continues.

Spotlight on Air Quality in California



Californians currently experience the worst air quality in the nation. More than 90 percent of the population lives in areas that violate air quality standards for ground-level ozone (smog) or small particles. These pollutants cause an estimated 8,800 deaths and over a billion dollars in health care costs every year in California[26]. Higher temperatures are projected to increase the frequency, intensity, and duration of conditions conducive to air pollution formation, potentially increasing the number of days conducive to air pollution by 75 to 85 percent in Los Angeles and the San Joaquin Valley, towards the end of this century, under a higher emissions scenario[†,27]. Air quality could be further compromised by wildfires, which are increasing as a result of warming. Recent analysis suggests that if heat-trapping emissions are not significantly curtailed, large wildfires could become up to 55 percent more frequent toward the end of this century[I].

Adaptation: Improving Urban Air Quality

The 1996 summer Olympics in Atlanta offered a unique natural experiment of the direct respiratory health benefits of removing cars and their tailpipe emissions from an urban environment. During the Olympics, peak morning traffic decreased by 23 percent, and peak ozone levels dropped by 28 percent. As a result, childhood asthma-related emergency room visits fell by 42 percent[28]. In short, improved mass transit and less reliance on automobiles in U.S. cities will directly improve respiratory health, not to mention increase exercise and physical fitness.

Like many other areas in the country, the Air Quality Alert program in Rhode Island encourages residents to reduce air pollutant emissions by limiting car travel and the use of small engines, lawn mowers, and charcoal lighter fluids. Television weather reports include alerts when ground-level ozone (smog) is high, warning especially susceptible people to limit their time outdoors. To help cut down on the use of cars, all regular bus routes are free on Air Quality Alert days.

Pennsylvania offers the following suggestions for high ozone days:

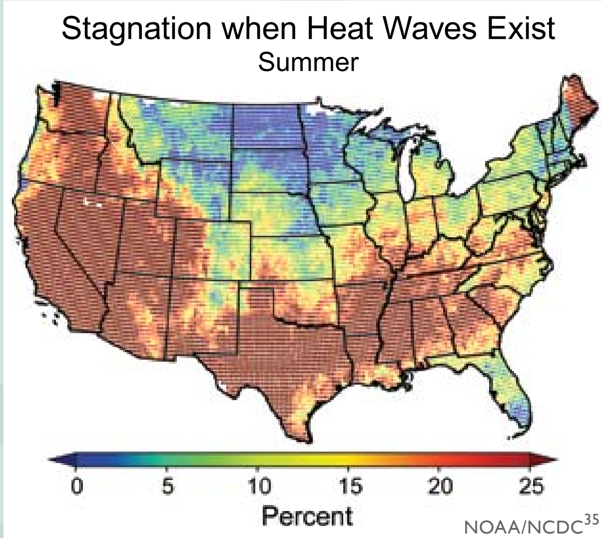
- Refuel vehicles after dark. Avoid spilling gasoline and stop fueling when the pump shuts off automatically.
- Conserve energy. Don't overcool homes. Turn off lights and appliances that are not in use. Wash clothes and dishes only in full loads.
- Limit daytime driving. Consider carpooling or taking public transportation. Properly maintain vehicles, which also helps to save fuel.
- Limit outdoor activities, such as mowing the lawn or playing sports, to the evening hours.
- Avoid burning leaves, trash, and other materials.

Heat, Drought, and Stagnant Air Degrade Air Quality

Heat waves, drought, and stagnant air often occur simultaneously, resulting in poor air quality that threatens human health. One such event occurred during the summer of 1988. More than 7,000 deaths and economic losses of more than $70 billion were estimated to have occurred in the United States due to extreme drought and excessive heat that year[29]. Half of the nation was affected by drought, and 5,994 all-time daily high temperature records were set around the country in July alone (more than three times the most recent 10-year average)[30]. Poor air quality contributed to the many deaths that occurred, as lack of rainfall, high temperatures, and stagnant conditions led to an unprecedented number of unhealthy air quality days throughout large parts of the country[31,32]. Continued climate change is projected to increase the likelihood of such episodes.

Although heat waves, drought, and poor air quality can occur independently, and threaten vulnerable populations, experience and research have shown that these events are interrelated. Atmospheric conditions that produce heat waves are often accompanied by stagnant air masses and poor air quality[33]. While heat waves and poor air quality threaten the lives of thousands of people each year, the simultaneous occurrence of these hazards compounds the threat to vulnerable populations such as the elderly, children, and people with asthma.

Interactions such as those between heat wave and drought will affect adaptation planning. For example, peak electricity use increases during heat waves due to increased air conditioning demand[34]. And during droughts, cooling water availability is at its lowest. Thus, during a simultaneous heat wave and drought, electricity demand for cooling will be high when power plant cooling water availability is at its lowest of the year.



The map shows the frequency of occurrence of stagnant air conditions when heat wave conditions were also present. Since 1950, air stagnation and heat waves have simultaneously occurred more than 25 percent of the time from the Mid-Atlantic to the Deep South, southern Plains and across most of the West.

Physical and mental health impacts due to extreme weather events are projected to increase.

Injury, illness, emotional trauma, and death are projected to increase as the number and intensity of extreme weather events rises. Human health impacts in the United States are generally projected to be less severe than in poorer countries where the public health infrastructure is less developed. This assumes that medical and emergency relief systems in the United States will function well and that timely and effective adaptation measures will be developed and deployed. There have already been serious failures of these systems in the aftermath of hurricanes Katrina and Rita, so coping with future impacts will require significant improvements.

Extreme storms

Over 2,000 Americans were killed in the 2005 hurricane season, more than double the average number of lives lost to hurricanes in the United States over the previous 65 years[1]. But the human health impacts of extreme storms go beyond direct injury and death to indirect effects such as carbon monoxide poisoning from portable electric generators in use following hurricanes, an increase in stomach and intestinal illness among evacuees, and mental health impacts such as depression and post-traumatic stress disorder. Failure to fully account for both direct and indirect health impacts might result in inadequate preparation for and response to future extreme weather events[1].

Floods

Heavy downpours have increased in recent decades and are projected to increase further as the world continues to warm. In the United States, the amount of precipitation falling in the heaviest 1 percent of rain events increased by 20 percent in the past century, while total precipitation increased by 7 percent. Over the last century, there was a 50 percent increase in the frequency of days with precipitation over 4 inches in the upper Midwest[13]. Other regions, notably the South, also have seen strong increases in heavy downpours, with most of these coming in the warm season and almost all of the increase coming in the last few decades.

Heavy rains can lead to flooding, which can cause health impacts including direct injuries as well as increased incidence of water-borne diseases due to bacteria, such as *Cryptosporidium* and *Giardia* (also noted under the section on infectious disease)[1]. Downpours can trigger sewage overflows, contaminating drinking water and endangering beachgoers. The consequences will be particularly severe in the 950 U.S. cities and towns, including New York, Chicago, Washington DC, Milwaukee, and Philadelphia, that have "combined sewer systems"; an older design that carries storm water and sewage in the same pipes. During heavy rains, these systems often cannot handle the volume, and raw sewage spills into lakes or waterways, including drinking-water supplies and places where people swim.

In 1994, the EPA established a policy that mandates that communities substantially reduce or eliminate their combined sewer overflow. However, in 2000 the EPA estimated it would cost $50 billion over the next 20 years to reduce the nation's combined sewer overflow volume by 85 percent[36]. Using 2.5 inches of precipitation in one day as the threshold for initiating a combined sewer overflow event, the frequency of these events in Chicago is expected to rise by 50 percent to 120 percent by the end of this century[37], posing further risks to drinking and recreational water quality.

Wildfires

Wildfires in the United States are already increasing due to warming. In the West, there has been a nearly fourfold increase in large wildfires in recent decades, with greater fire frequency, longer fire durations, and longer wildfire seasons[1,38]. This increase is strongly associated with increased spring and summer temperatures and earlier spring snowmelt, which have caused drying of soils and vegetation[1,38]. In addition to direct injuries and deaths due to burns, wildfires can cause eye and respiratory illnesses due to fire-related air pollution.

Some infectious diseases transmitted by food, water, and insects are likely to increase.

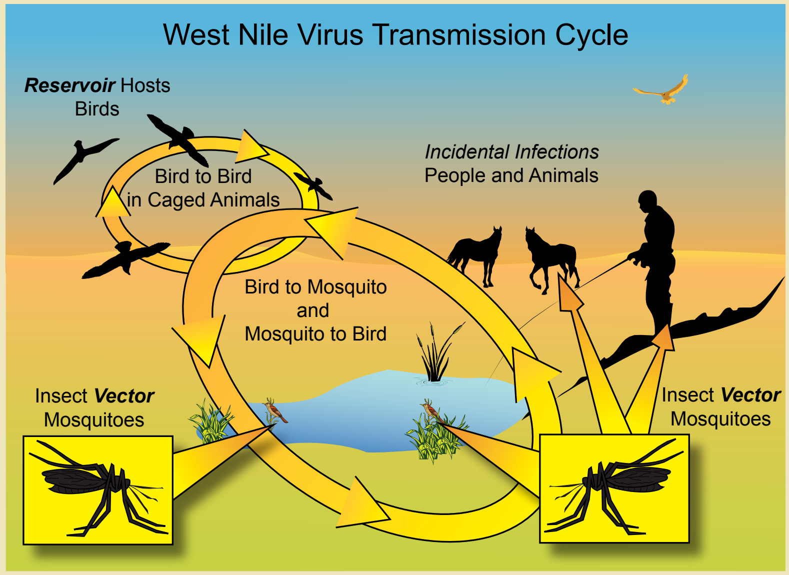
A number of important disease-causing agents (pathogens) commonly transmitted by food, water, or animals are susceptible to changes in replication, survival, persistence, habitat range, and transmission as a result of changing climatic conditions such as increasing temperature, precipitation, and extreme weather events[1].

- Cases of food poisoning due to *Salmonella* and other bacteria peak within one to six weeks of the highest reported ambient temperatures[1].
- Cases of water-borne *Cryptosporidium* and *Giardia* increase following heavy downpours. These parasites can be transmitted in drinking water and through recreational water use[1].
- Climate change affects the life cycle and distribution of the mosquitoes, ticks, and rodents that carry West Nile virus, equine encephalitis, Lyme disease, and *Hantavirus*. However, moderating factors such as housing quality, land use patterns, pest control programs, and a robust public health infrastructure are likely to prevent the large-scale spread of these diseases in the United States[1,39].

Spotlight on West Nile Virus

The first outbreak of West Nile virus in the United States occurred in the summer of 1999, likely a result of international air transport. Within 5 years, the disease had spread across the continental United States, transmitted by mosquitoes that acquire the virus from infected birds. While bird migrations were the primary mode of disease spread, during the epidemic summers of 2002 to 2004, epicenters of West Nile virus were linked to locations with either drought or above-average temperatures.

Since 1999, West Nile virus caused over 24,000 reported cases and over 1,000 Americans have died from it[41]. During 2002, a more virulent strain of West Nile virus emerged in the United States. Recent analyses indicate that this mutated strain responds strongly to higher temperatures, suggesting that greater risks from the disease may result from increases in the frequency of heatwaves[42], though the risk will also depend on the effectiveness of mosquito control programs.



While West Nile virus causes mild flu-like symptoms in most people, about one in 150 infected people develop serious illness, including the brain inflammation diseases encephalitis and meningitis.

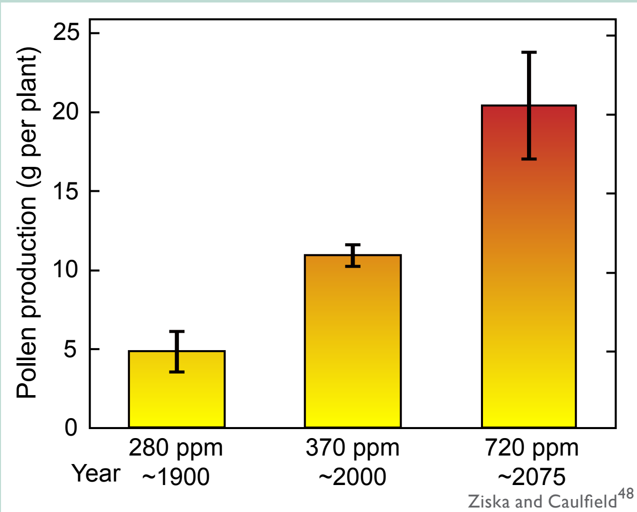
- Heavy rain and flooding can contaminate certain food crops with feces from nearby livestock or wild animals, increasing the likelihood of food-borne disease associated with fresh produce[1].
- *Vibrio* sp. (shellfish poisoning) accounts for 20 percent of the illnesses and 95 percent of the deaths associated with eating infected shell-fish, although the overall incidence of illness from *Vibrio* infection remains low. There is a close association between temperature, *Vibrio* sp. abundance, and clinical illness. The U. S. infection rate increased 41 percent from 1996 to 2006[1], concurrent with rising temperatures.
- As temperatures rise, tick populations that carry Rocky Mountain spotted fever are projected to shift from south to north[40].
- The introduction of disease-causing agents from other regions of the world is an additional threat[1].

Allergies and asthma are on the rise, with emerging evidence that climate change will play a role in the future.

There are over 700 plant species known to induce human illness[43]. Rising carbon dioxide levels have been observed to increase the growth and toxicity of some that are very troublesome. For example, ragweed gets a disproportionately large boost from carbon dioxide compared to many beneficial plants. From a human health perspective, this means a longer and more intense allergy season, and does not bode well for many asthma sufferers, since 70 percent of them also suffer from allergies and find their asthma exacerbated by allergies[44].

Climate change has caused an earlier onset of the spring pollen season for several species in North America. Although data are limited, it is reasonable to infer that allergies caused by pollen also have experienced associated changes in seasonality. Several laboratory studies suggest that increasing

Pollen Counts Rise with Increasing Carbon Dioxide



Pollen production from ragweed grown in chambers at the carbon dioxide concentration of a century ago (about 280 parts per million [ppm]) was about 5 grams per plant; at today's approximate carbon dioxide level, it was about 10 grams; and at a level projected to occur about 2075 under the higher emissions scenario†, it was about 20 grams[48].

carbon dixoide concentrations and temperatures increase ragweed pollen production and prolong the ragweed pollen season[1,2].

Poison ivy growth and toxicity is also greatly increased by carbon dioxide, with plants growing larger and more allergenic. These increases exceed those of most beneficial plants. For example, poison ivy vines grow twice as much per year in air with a doubled pre-industrial carbon dioxide concentration as they do in unaltered air; this is nearly five times the increase reported for tree species in other analyses[45]. Recent and projected increases in carbon dioxide also have been shown to stimulate the growth of stinging nettle and leafy spurge, two weeds that cause rashes when they come into contact with human skin[46,47].

Certain groups, including children, the elderly, and the poor, are most vulnerable to the range of health effects.

Infants and children, pregnant women, the elderly, people with chronic medical conditions, outdoor workers, and people living in poverty are especially at risk from increasing heat stress, air pollution, extreme weather events, and diseases carried by food, water, and insects[1].

Children's small ratio of body mass to surface area and other factors make them vulnerable to heat-related illness and death. Their increased breathing rate relative to body size, additional time spent outdoors, and developing respiratory tracts, heighten their sensitivity to air pollution. In addition, children's immature immune systems increase their risk of serious consequences from water- and food-borne diseases, while developmental factors make them more vulnerable to complications from severe infections such as *E. coli* or *Salmonella*[1].

Pregnant women have increased susceptibility to a variety of climate-sensitive infectious diseases, including food-borne infections[1].

The greatest health burdens related to climate change are likely to fall on the poor, especially those with inadequate shelter, and other resources such as air conditioning[1].

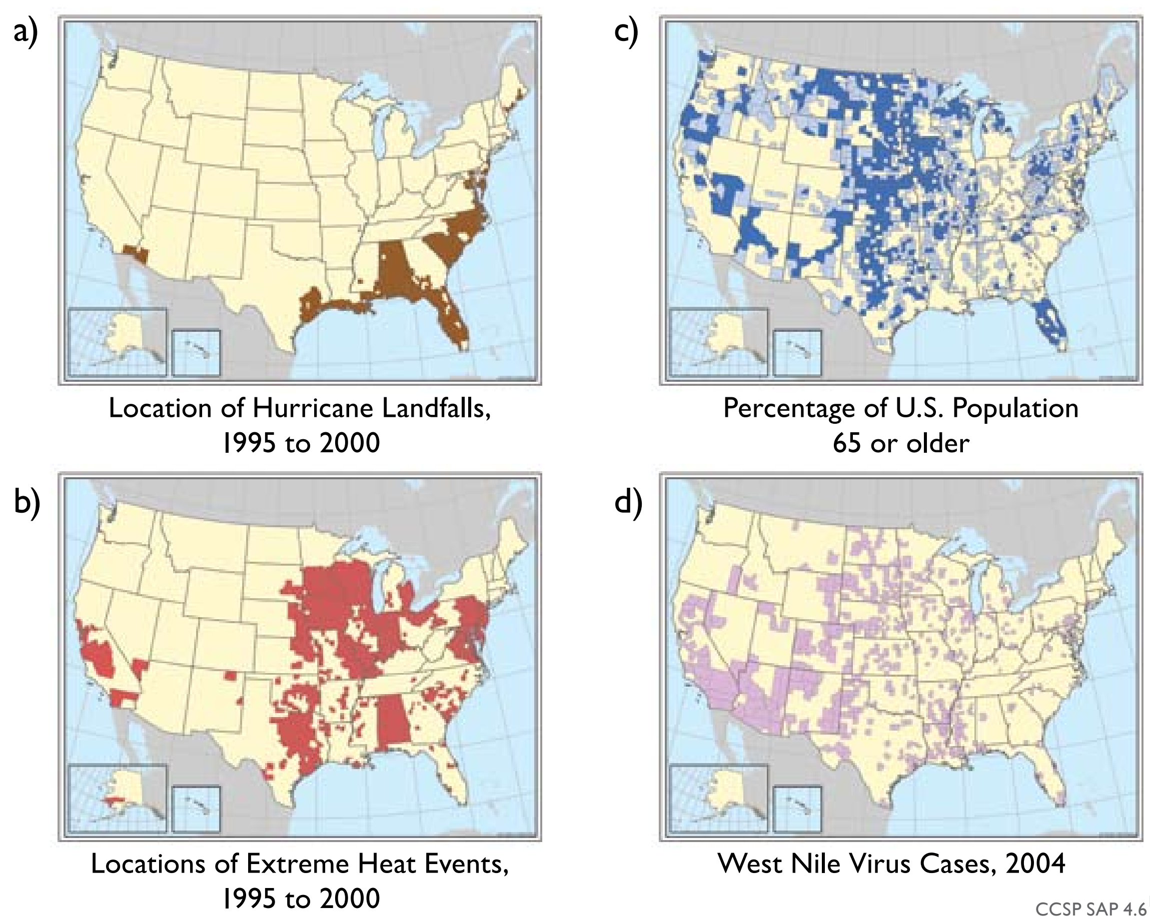
Elderly people are more likely to have debilitating chronic diseases or limited mobility. The elderly are also generally more sensitive to extreme heat for several reasons. They have a reduced ability to regulate their own body temperature or sense when they are too hot. They are at greater risk of heart failure that is exacerbated when cardiac demand increases in order to cool the body during heat waves. Also, people taking medications, such as diuretics for high blood pressure, have a higher risk of dehydration. People 65 years of age and older comprised 72 percent of the heat-related deaths due to the 1995 Chicago heat wave[1].

The multiple health risks associated with diabetes will increase the vulnerability of the U.S. population to increasing temperatures. The number of Americans with diabetes has grown to about 24 million people, or roughly 8 percent of the U.S. population. Almost 25 percent of the population 60 years and older had diabetes in 2007[49]. Fluid imbalance and dehydration create higher risks for diabetics during heat waves. People with diabetes-related heart disease are at especially increased risk of dying in heat waves.

High obesity rates in the United States are a contributing factor in currently high levels of diabetes. Similarly, a factor in rising obesity rates is a sedentary lifestyle and automobile dependence; 60 percent of Americans do not meet minimum daily exercise requirements. Making cities more walkable and bikeable would thus have multiple benefits: personal fitness and weight loss; reduced local air pollution and associated respiratory illness; and reduced greenhouse gas emissions.

The United States has considerable capacity to adapt to climate change, but during recent extreme weather and climate events, actual practices have not always protected people and property. Vulnerability to extreme events is highly variable, with disadvantaged groups and communities, the poor, infirmed and elderly, experiencing considerable damages and disruptions to their lives. Adaptation tends to be reactive, unevenly distributed, and focused on coping rather than preventing problems. Future reduction in vulnerability will require consideration of how best to incorporate planned adaptation into long-term municipal and public service planning, including energy, water and health services, in the face of changing climate-related risks combined with ongoing changes in population and development patterns[50].

Geographic Vulnerability of U.S. Residents to Selected Climate-Related Health Impacts



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Maps indicating U.S. counties with existing vulnerability to climate-sensitive health outcomes: a) location of hurricane landfalls; b) extreme heat events (defined by the Centers for Disease Control as temperatures 10 or more degrees F above the average high temperature for the region and lasting for several weeks); c) percentage of population over age 65 (dark blue indicates that percentage is over 17.6 percent, light blue 14.4 to 16.5 percent); d) locations of West Nile virus cases reported in 2004. These examples demonstrate both the diversity of climate-sensitive health outcomes and the geographic variability of where they occur. Events over short time spans, in particular West Nile virus cases, are not necessarily predictive of future vulnerability.