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Climate Choices and the Future of Dangerously Hot Days

Union of Concerned Scientists

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This report is available online (in PDF format) at *www.ucsusa.org/killer-heat*.

Cover photo: AP Photo/Ross D. Franklin
In Phoenix on July 5, 2018, temperatures surpassed 112°F. Days with extreme heat have become more frequent in the United States and are on the rise.

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[CHAPTER 1]

Introduction

After working outside in her garden on a sweltering Saturday in late June 2018, a 64-year-old Pennsylvania woman was taken to the hospital, where she died of cardiac arrest. The next day, a 30-year-old man running a trail race in upstate New York collapsed a half mile before the finish line. He was brought to the hospital and died that day. Hundreds of miles apart, these two deaths shared a common culprit: extreme heat. By the time the week was out, heat would claim the lives of at least three more people in the United States (Miller and Park 2018; Palmer 2018).

North of the border in Quebec, where many homes are not air-conditioned, the same heat wave pushed "feels like" temperatures as high as 104°F, killing more than 70 people. During July of that same year, record temperatures occurred around the Northern Hemisphere, with actual temperatures in Siberia topping 90°F; the African continent setting a new heat record in Algeria at 124°F; and Japan's scorching heat sickening more than 22,000 people in a single week (Masters 2018; Pitofsky 2018).

Extreme heat is among the deadliest weather hazards society faces. During extremely hot days, heat-related deaths spike and hospital admissions for heat-related illnesses rise, especially among people experiencing poverty, elderly adults, and other vulnerable groups (NWS 2018; CDC 2017a).

Temperatures around the world have been increasing for decades in response to rising heat-trapping emissions from human activities, primarily the burning of fossil fuels. These rising temperatures are causing more days of dangerous—even deadly—heat locally. This Union of Concerned Scientists (UCS) analysis shows that if we stay on our current global emissions path, extreme heat days are poised to rise steeply in frequency and severity in just the next few decades. This heat would cause large areas of the United States to become dangerously hot and would threaten the health, lives, and livelihoods of millions of people. Such heat could also make droughts and wildfires more severe, harm ecosystems, cause crops to fail, and reduce the reliability of the infrastructure we depend on.

[*Temperatures around the world have been increasing for decades in response to rising heat-trapping emissions.*]

Climate change and its consequences are already manifesting in the form of deadlier storms, rising sea levels, droughts, wildfires, and floods. Yet the heat extremes forecast in this analysis are so frequent and widespread that it is possible they will affect daily life for the average US resident more than any other facet of climate change. But this analysis also finds that the intensity of the coming heat depends heavily on our near-term choices. By cutting emissions quickly and deeply, we can slow global warming and limit the increase in the number of extremely hot days. Every 10th of a degree we avoid in increased temperatures will matter to our overheating world.

If we wish to spare people in the United States and around the world the mortal dangers of extreme and relentless heat, there is little time to do so and little room for half measures. We need to employ our most ambitious actions to prevent the rise of extreme heat—to save lives and safeguard the quality of life for today's children, who will live out their days in the future we're currently creating.

Examining Future Extreme Heat and Emissions Choices

This UCS analysis provides a detailed view of how extreme heat events caused by dangerous combinations of temperature and humidity are likely to become more frequent and widespread in the United States over this century. It also describes the implications for everyday life in different regions of the country.

We have analyzed where and how often in the contiguous United States the heat index—also known as the National Weather Service (NWS) "feels like" temperature—is expected to top 90°F, 100°F, or 105°F during future warm seasons (April through October). While there is no one standard definition of "extreme heat," in this report we refer to any individual days with conditions that exceed these thresholds as extreme heat days.[1] We also analyzed the spread and frequency of heat conditions so extreme that the NWS formula cannot accurately calculate a corresponding heat index. The "feels like" temperatures in these cases are literally off the charts.

> ***For the greatest odds of securing a safe climate future, we need to take aggressive action. Our challenge is great, but the threat of not meeting it is far greater.***

We have conducted this analysis for three global climate scenarios associated with different levels of global heat-trapping emissions and future warming. These scenarios reflect different levels of action to reduce global emissions, from effectively no action to rapid action. Even the scenario of rapid action to reduce emissions does not spare our

AP Photo/John Locher

A woman works as an advertising sign holder in Las Vegas during a heat wave in July 2014. While extreme heat already affects the lives of many US residents—killing hundreds each year and sending many more to the hospital with heat-related illnesses—continued global warming will cause a steep increase in extreme heat conditions nationwide.

communities a future of substantially increased extreme heat. For the greatest odds of securing a safe climate future for ourselves and the ecosystems we all depend on, we would need to take even more aggressive action, in the US and globally, than outlined in any of the scenarios used here. Our challenge is great, but the threat of not meeting it is far greater.

A Snapshot of Results

Our results show that, with no action to reduce heat-trapping emissions,[2] by midcentury (2036–2065), the following changes would be likely in the United States,[3] compared with average conditions in 1971–2000:

- The average number of days per year with a heat index above 100°F will more than double, while the number of days per year above 105°F will quadruple.
- More than one-third of the area of the United States will experience heat conditions once per year, on average, that are so extreme they exceed the current NWS heat index range—that is, they are literally off the charts.
- Nearly one-third of the nation's 481 urban areas with a population of 50,000 people or more will experience an average of 30 or more days per year with a heat index above 105°F, a rise from just three cities historically (El Centro and Indio, California, and Yuma, Arizona).
- Assuming no changes in population, the number of people experiencing 30 or more days with a heat index above 105°F in an average year will increase from just under 900,000 to more than 90 million—nearly one-third of the US population.[4]
- Countrywide, more than 1,900 people per year have historically been exposed to the equivalent of a week or more of off-the-charts heat conditions; this number is projected to rise to more than 6 million people by midcentury—again, assuming no population changes.

Late in the century (2070–2099), with no action to reduce heat-trapping emissions, the following changes can be expected:

- The United States will experience, on average, four times as many days per year with a heat index above 100°F, and nearly eight times as many days per year above 105°F, as it has historically.
- At least once per year, on average, more than 60 percent of the United States by area will experience off-the-charts conditions that exceed the NWS heat index range and present mortal danger to people.
- More than 60 percent of urban areas in the United States—nearly 300 of 481—will experience an average of 30 or more days with a heat index above 105°F.
- The number of people who experience those same conditions—still assuming no population change—will increase to about 180 million people, roughly 60 percent of the population of the contiguous United States.
- The number of people exposed to the equivalent of a week or more of off-the-charts heat conditions will rise to roughly 120 million people, more than one-third of the population.

Our results show that failing to reduce heat-trapping emissions would lead to a staggering expansion of dangerous heat. In contrast, aggressive emissions reductions that limit future global warming to 3.6°F (2°C) or less would contain that expansion and spare millions of people in the United States from the threat of relentless summer heat. With these aggressive emissions reductions, the above impacts would, in most cases, be held at or below their midcentury levels and would not grow progressively worse during the second half of the century.

> ***Failing to reduce heat-trapping emissions would lead to a staggering expansion of dangerous heat.***

The Heat Index: What Extreme Heat "Feels Like"

The outside temperature according to a car dashboard may be 90°F, but what we feel when we step out could be worlds apart depending on whether we are parked in Arkansas or Arizona. It is not only hot in Arkansas but also often humid. To our bodies' cooling systems, humidity makes all the difference. People sweat to release heat because when sweat evaporates, it has a cooling effect. A breeze or a fan can help us to cool down by quickening the pace of that evaporation. But humidity in the air around us limits the evaporation of sweat and reduces the associated cooling effect. So high temperature and humidity cause our bodies to accumulate heat. For this reason, temperature is generally considered in tandem with humidity to measure heat stress conditions, or those in which the human body has difficulty cooling itself (CDC 2017b).

When exposed to such conditions, our bodies' temperature rises, and heat-related illnesses (ranging in severity from mild heat cramps to life-threatening heat stroke) can occur. In general, adults over the age of 65, young children, people who are sick, people with mental or physical disabilities, people in low-income communities (who often lack access to air-conditioning or the means to pay for its use), outdoor workers, and military personnel who must exert themselves outdoors are among the most vulnerable to extreme heat, given their greater exposure and/or their bodies' diminished ability to cope (Morris et al. 2019; Reid et al. 2009). Over the last 30 years, on average, exposure to extreme heat was the top cause of weather-related deaths in the United States (NWS 2018). Between 1999 and 2010, exposure to extreme heat was implicated in 7,415 deaths in the United States—an average of more than 600 per year (CDC 2012)—but likely contributed to many more (Berko et al. 2014; Luber and McGeehin 2008; Donoghue et al. 1997).

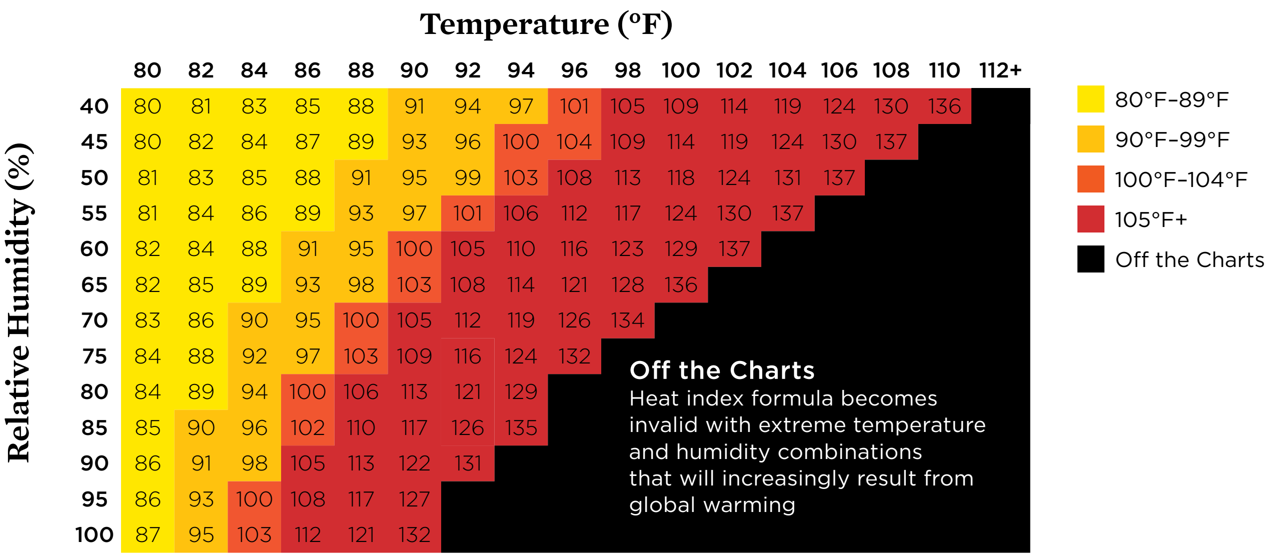
> ***To our bodies' cooling systems, humidity makes all the difference.***

To warn people of anticipated or ongoing conditions that could cause heat-related illnesses or death, the NWS combines temperature and relative humidity to produce a heat index, or a "feels like" temperature (NWS n.d. a) (see Figure 1, p. 5, and box, p. 7).[5] The NWS uses heat index–based thresholds as the basis for issuing heat advisories and excessive heat warnings. For example, when relative humidity is low, at 45 percent, a temperature of 94°F would result in a heat index of 100°F. However, at a higher relative humidity of 70 percent, a temperature of only 88°F would result in that same heat index. In humid locations such as Arkansas, the heat index may be much higher than the air temperature, whereas in arid locations such as Arizona, the temperature and heat index may be the same.

How and Why the National Weather Service Uses Heat Index Thresholds

While health risks exist at all heat index values above 80°F, the severity of those risks varies depending on who is exposed, whether they are engaged in physical activity, and how long the exposure lasts (Morris et al. 2019). Conditions that are manageable for some people can be dangerous—or even fatal—for others (Morris et al. 2019; Grundstein et al. 2010). Age, underlying health, physical fitness, access to

FIGURE 1. How Temperature and Humidity Create the Heat Index



Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112+
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136	
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137		
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137			
55	81	84	86	89	93	97	101	106	112	117	124	130	137				
60	82	84	88	91	95	100	105	110	116	123	129	137					
65	82	85	89	93	98	103	108	114	121	128	136						
70	83	86	90	95	100	105	112	119	126	134							
75	84	88	92	97	103	109	116	124	132								
80	84	89	94	100	106	113	121	129									
85	85	90	96	102	110	117	126	135									
90	86	91	98	105	113	122	131										
95	86	93	100	108	117	127											
100	87	95	103	112	121	132											

Off the Charts
Heat index formula becomes invalid with extreme temperature and humidity combinations that will increasingly result from global warming

🟨 80°F–89°F
🟧 90°F–99°F
🟧 100°F–104°F
🟥 105°F+
⬛ Off the Charts

Heat is more harmful to human health when humidity is high because humid air hinders the evaporation of sweat, and thus reduces the body's ability to cool itself. To determine the effect of both heat and humidity, the National Weather Service formulated the heat index based on the range of warm-season conditions we typically see on Earth. As our climate warms, we will increasingly find ourselves outside the range of reliably calculable heat index values, or, quite literally, off the charts. Colors reflect the categories of heat index conditions examined in this study.

SOURCE: STEADMAN 1979A; NWS N.D. A.

cooling, and a person's surroundings (e.g., whether they live in a city or a rural environment) are among the many factors that determine overall heat health risks.

When developing its guidance for the use of the heat index in forecasts and alerts in the 1980s, the NWS considered the impacts of a range of heat index values on human health (NWS 1984). The language used by the NWS in heat alerts today reflects both the general risks extreme heat poses to the public and considerations of the groups most at risk during an extreme heat event.

National guidance from NWS suggests, in general, that a local heat advisory be issued when the heat index in a region is expected to reach or exceed 100°F for 48 hours and that an excessive heat warning be issued when the heat index reaches or exceeds 105°F for 48 hours (NWS n.d. b). These thresholds have been established because these conditions can be dangerous, even deadly (see Figure 2, p. 6). While the thresholds are somewhat arbitrary, given that the impacts of heat are highly individual (Watts and Kalkstein 2004), NWS guidance and additional research point to the following:

> ***Conditions that are manageable for some people can be dangerous—or even fatal—for others.***

- With a heat index around 90°F, sun stroke, heat cramps, and heat exhaustion are possible for certain risk groups (NWS 1984). In particular, those who engage in physical exertion outdoors (e.g., outdoor workers, military personnel, athletes) without being accustomed to the heat are susceptible to heat stress at this threshold (Morris et al. 2019; OSHA n.d.).
- At a heat index of 100°F, NWS heat advisories state that "heat stress or illnesses are possible, especially for elderly adults and those sensitive to heat," which includes children (Iowa State University 2019). Advice such as "Drink plenty of fluids" and "Check up on relatives and neighbors" frequently accompanies NWS heat advisories at this level.
- At a heat index of 105°F, even healthy adults are at risk of heat-related illness with prolonged exposure. NWS excessive heat warnings issued at this level often state

that “heat illness is likely.” Warnings such as “When possible, reschedule strenuous activities to early morning or evening”; “The very young, the elderly, those without air conditioning, and those participating in strenuous outdoor activities will be the most susceptible”; and “Car interiors can reach lethal temperatures in a matter of minutes” usually accompany these alerts (Iowa State University 2019).

- For heat index values above 130°F, NWS has no standard guidance, though one source indicates that heat stroke is “highly likely with continued exposure” (NWS 1984).
- The Occupational Safety and Health Administration (OSHA) advises that exposure to direct sun can increase the heat index by as much as 15 degrees.

Local environmental conditions and the degree to which people are acclimatized—or accustomed—to extreme heat affect health outcomes in different regions. Because of this, nearly half of local NWS Weather Forecast Offices have developed their own revised policies around extreme heat (Hawkins, Brown, and Ferrell 2017).[6] NWS offices in South Carolina, for example, where the population is accustomed to extreme heat, have raised the threshold for excessive heat warnings from 105°F to 115°F. The policies of other local offices include factors such as elevation, nighttime temperatures, and time of year (Hawkins, Brown, and Ferrell 2017).

However, rising numbers of heat-related deaths in places such as Phoenix, Arizona—where we might expect residents to be accustomed to the heat—suggest that warming temperatures and a range of socioeconomic factors (such as access to functional air-conditioning, age, and race) require greater consideration when defining the local risk posed by extreme heat (Maricopa County Public Health 2017; Hayden, Brenkert-Smith, and Wilhelmi 2011; Stone, Hess, and Frumkin 2010). And while access to ubiquitous air-conditioning has been shown to reduce heat-related mortality, true physiological acclimatization to heat requires consistent outdoor daily exertion over an extended period of time. The facts of this process suggest that constant access to air-conditioning may preclude acclimatization (Nordio et al. 2015; Acosta 2009).

In many northern states, where heat-related mortality is more prevalent, incidences of heat-related illness start to rise with a heat index as low as 80°F to 85°F (Vaidyanathan et al.

FIGURE 2. More People Are at Risk as the Heat Index Rises

Heat Index Above 90°F	Heat Index Above 100°F	Heat Index Above 105°F	Heat Index Off the Charts
Outdoor workers become more susceptible to heat-related illness.	Children, elderly adults, pregnant women, and people with underlying conditions are at heightened risk of heat-related illness.	Anyone could be at risk of heat-related illness or even death as a result of prolonged exposure.	Undetermined: any level of exposure is presumed extremely dangerous for all people and likely to result in heat-related illness or even death.

Left to right: AP Photo/Napa Valley Register, Lianne Milton; AP Photo/Julio Cortez; lzf/iStock; logoboom/Shutterstock

Heat index conditions as low as 80°F can affect human health. Extreme heat exposure affects people differently depending on their health and environment. Certain groups of people may become more susceptible to heat-related illness as the heat index rises.

SOURCES: IOWA STATE UNIVERSITY 2019; MORRIS ET AL. 2019; NWS 1984; NWS N.D. B; OSHA N.D.

AP Photo/Richmond Times-Dispatch, P. Kevin Morley

Extreme heat caused hundreds of cases of heat-related illness during the Boy Scouts of America's 2005 National Jamboree in Virginia. Susceptibility to heat-related illness depends on many factors, including a person's age and fitness and how acclimated they are to extreme heat.

2018; Curriero et al. 2002). Because of this, some individual states and localities have revised their advisory thresholds downward (Wellenius et al. 2017; NHDPHS n.d.). Officials also now consider how long the heat event is expected to last and the time of year it occurs, as heat events occurring earlier in the year, before people are acclimatized to warmth, have a greater impact on human health than those occurring later in the summer or early fall (Sheridan and Lin 2014; Anderson and Bell 2011).

Off-the-Charts Days

The heat index was originally formulated to capture all but the most extreme combinations of temperature and relative humidity occurring on Earth (Steadman 1979a). In heat that exceeds the ranges of the temperature and relative humidity values that were considered, skin moisture levels are so high that sweating is significantly inhibited and the equations used by the National Weather Service (NWS) to calculate the heat index become unreliable (Alber-Wallerström and Holmér 1985) (see Figure 1, p. 5).

Without a reliable estimate of the heat index, the NWS cannot adequately communicate the gravity of associated risks to public health. Historically, such incalculable conditions have represented the world's most oppressively hot, dangerous, and, fortunately, rare days—those with a heat index well above 130°F. The only place in the contiguous United States that has had off-the-charts days in an average year is the Sonoran Desert, where Southern California meets Arizona. Our analysis projects that, as our overall climate warms, this will change.

As global average temperatures continue to warm, driven by our heat-trapping emissions, not only will the frequency of extreme heat events increase (USGCRP 2017), but high heat index conditions will also become more extreme, surpassing dangerous thresholds more frequently and heading—for the first time in most regions—into unprecedented territory holding even greater risk of illness and mortality for residents. Within the next 20 years, many people in the United States will be faced with heat unlike any they have dealt with before.

> ***Those not accustomed to extreme heat conditions are more susceptible to heat-related illness and mortality.***

How Heat Harms Our Bodies

When extreme heat conditions prevent our bodies from adequately cooling, our core temperatures rise, causing a variety of symptoms (see Figure 3). This can be made worse by the environment surrounding us—a blacktop playground with no shade, for example, or a room with no air-conditioning—and by underlying health conditions. During heat waves, calls to emergency medical services and hospital admissions rise (Davis and Novicoff 2018; Zhang, Chen, and Begley 2015; Dolney and Sheridan 2006; Medina-Ramón et al. 2006). Cooler nighttime temperatures typically provide relief from a hot day and give our bodies a chance to cool down, but when nights remain hot, health risks rise, especially for those without access to air-conditioning or for whom the choice of turning on the air-conditioning presents difficult financial trade-offs (Anderson and Bell 2011) (see chapter 5, p. 22).

The longer our bodies remain overheated, the greater the risk of heat-related illnesses (such as heat cramps, heat exhaustion, and heat stroke) and the greater the risk of death (CDC 2017b; Choudhary and Vaidyanathan 2014).

> ***The longer our bodies remain overheated, the greater the risk of heat-related illnesses and the greater the risk of death.***

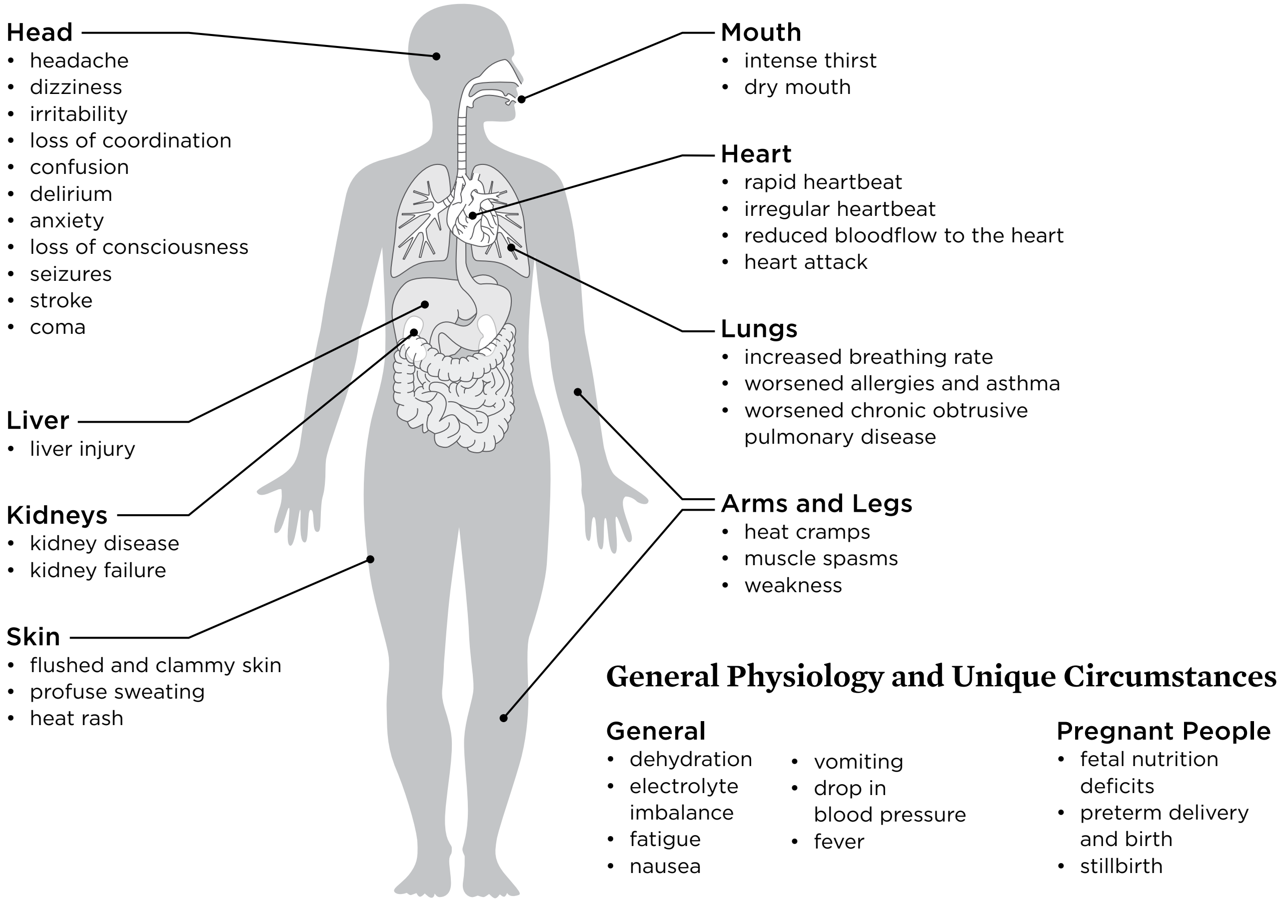
Heat-Related Illnesses and Deaths

With heat cramps, people experience cramping or pain in the stomach, arms, or legs as a result of excessive sweating that causes loss of large amounts of salt and water from the body. Heat exhaustion can cause dizziness, a weak pulse, nausea, and fainting. The most severe heat-related illness, heat stroke, can occur when the body's core temperature rises from its usual 98.6°F to 104°F or higher. High body temperature is associated with increased heart and respiratory rates and, at extreme levels, damage to the brain, heart, lungs, kidneys, and liver (Seltenrich 2015). This can be fatal (CDC 2017b).

Without cooling, heat-related deaths can occur quickly—typically the same day or the day after outside temperature spikes—which signals the need for a quick response to extreme heat conditions by public health officials and either the people exposed or their caregivers (Anderson and Bell 2011). However, health impacts from heat can also occur one or more days after the exposure to extreme heat, and each additional consecutive day of extreme heat increases heat-related mortality rates (Chen et al. 2017; Hajat et al. 2006). While one-day heat events are enough to raise the rates of heat-related illness, longer heat waves are more likely to have a larger effect on a variety of adverse health outcomes (Basu et al. 2012).

In addition to deaths caused by heat-related illness, extreme heat conditions increase rates of heart attacks, cardiovascular mortality, and respiratory mortality (Mastrangelo et al. 2007; Medina-Ramón et al. 2006; Braga, Zanobetti, and Schwartz 2002; Curriero et al. 2002).

FIGURE 3. How Heat Affects Our Bodies



When temperature and humidity climb during extreme heat events, the body's cooling mechanisms become less effective. The symptoms shown here—ranging from minor annoyances to truly life-threatening issues—include both those that are indicative of heat-related illness and those that are signs of pre-existing conditions exacerbated by extreme heat.

SOURCES: BASU ET AL. 2012; BECKER AND STEWARD 2011; CURRIERO ET AL. 2002; DONOGHUE ET AL. 1997; GARCÍA-TRABANINO ET AL. 2015; GLAZER 2005; LUBER AND MCGEEHIN 2008; LUGO-AMADOR, ROTHENHAUS, AND MOYER 2004; AND SEMEZA ET AL. 1999.

Child Bodies

Infants and small children are among the most susceptible to heat-related illness. As temperatures climb, smaller bodies lose water at a faster rate than larger bodies do, which can lead to dehydration (Stillman 2019; Li et al. 2015). Physiologically, children have a higher ratio of body surface area to mass and a lower total sweating rate compared with adults (Rowland 2008; Bar-Or 1994). The latter can lead to a slow acclimatization to heat. Children are also less likely to read their body cues and know they need to rehydrate (Rosman 2017). Extreme heat can also increase the incidence of allergy attacks, electrolyte imbalance, fever, and kidney disease in children (Xu et al. 2012).

Elderly Bodies

People aged 65 and older—and especially 75 and up—have an elevated risk of heat-related illness relative to younger adults (Basu et al. 2012). Extreme heat is associated with increases in cardiovascular and respiratory-related deaths among older adults (Bunker et al. 2016; Anderson and Bell 2011; Åström, Forsberg, and Rocklöv 2011). For seniors, illnesses and medications can also slow the body's cooling mechanisms (Stöllberger, Lutz, and Finsterer 2009). Although the increased use of air-conditioning by elderly US residents has reduced their rates of heat-related deaths, the percentage of elderly individuals in the United States is increasing, which means more vulnerable individuals are being exposed to dangerous heat (Barnett 2007).

AP Photo/Daily News, Miranda Pederson

Children cool off in a stream of water from a fire hydrant in Bowling Green, Kentucky, in 2011. As extreme heat becomes increasingly frequent and dangerous, outdoor play could be severely curtailed or require a level of risk management all but inconceivable in much of the country today.

Bodies with Special Conditions and Needs

People with medical conditions, both physical (such as respiratory or cardiovascular disease) and psychiatric, have an increased risk of heat-related death (Bouchama et al. 2007). In fact, many commonly prescribed medications inhibit the body's ability to regulate its temperature (Westaway et al. 2015). Being confined to bed or home, depending on the care of another person, or not understanding the need for water or cooling also significantly increases the risk of heat-related death (Bouchama et al. 2007). Underlying mental health disorders in combination with alcohol or substance abuse can also contribute to higher heat-related-illness hospitalization rates and deaths (Schmeltz and Gamble 2017; Hansen et al. 2008).

Exposure to extreme heat can cause complications for pregnant women and their developing babies (Basu, Sarovar, and Malig 2016; Basu, Malig, and Ostro 2010). Heat-induced dehydration during pregnancy can reduce blood flow to the uterus, which can lead to premature labor and delivery. It can also reduce blood flow to the placenta, which can lead to fetal nutrition deficiencies. In turn, stillbirths can result. An association between exposure to heat and both preterm delivery and stillbirths has been found among younger mothers, likely reflecting the effects of lower socioeconomic status (Basu, Sarovar, and Malig 2016; Basu, Malig, and Ostro 2010).

> [***Infants and small children, elderly adults, and people with medical conditions have an increased risk of heat-related death.***]

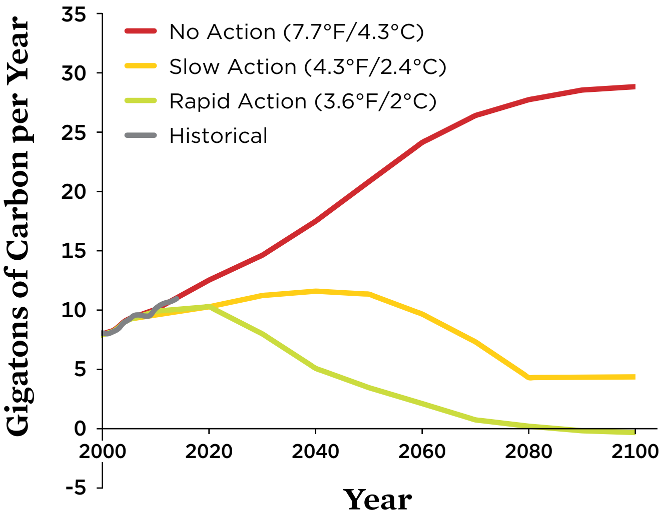
Findings: The Future of Dangerously Hot Days

In this analysis we calculate the number of days per year with heat index values above 90°, 100°, and 105°F—as well as the number of off-the-charts days, when conditions fall outside the range of the current heat index formulation—between now and the end of the century. The numbers presented here represent the average over 30-year periods—a historical baseline (1971–2000), midcentury (2036–2065), and late century (2070–2099)—and the average of 18 independent climate models.[7] We present results nationally, by region, by state, and by "urban area," defined as a city with more than 50,000 people (US Census Bureau 2019). We calculated the number of people exposed to extreme heat conditions based on 2010 population statistics and assume no growth in population or change in distribution (CIESIN 2017; US Census Bureau 2010a).

Our analysis includes three scenarios associated with different levels of global heat-trapping emissions and future warming (Van Vuuren et al. 2011) (Figure 4):

1. A "no action" scenario,[8] in which heat-trapping emissions continue to rise throughout the 21st century and global average temperatures warm by nearly 8°F (4.3°C) above pre-industrial levels by the year 2100. This scenario is consistent with our current and historical emissions growth.
2. A "slow action" scenario, in which heat-trapping emissions start to decline at midcentury. This scenario projects a most likely warming of 4.3°F (2.4°C) globally by the year 2100.
3. A "rapid action" scenario, in which future global average warming is limited to 3.6°F (2°C) above pre-industrial temperatures, as prescribed by the 2015 Paris Agreement (UNFCCC 2015). Results for this scenario are presented alongside late-century results for other emissions scenarios, as this warming threshold could be reached during a range of years in the second half of the century.[9]

FIGURE 4. Future Warming Depends on Our Emissions Choices



The growth or reduction of global heat-trapping emissions in the coming decades will determine how much more frequent extreme heat events will become in the United States. This analysis examined three scenarios: "no action," "slow action," and "rapid action" to reduce global emissions.

SOURCES: LE QUÉRÉ ET AL. 2015; IIASA 2009.

If we take no action and global heat-trapping emissions continue to rise unabated, as they have in recent decades, our findings indicate that, across broad swaths of the United States, extreme heat conditions once measured in days per year would need to be measured in weeks or months by midcentury. And by late century, few refuges from extreme heat will remain (see Table 1). Yet this future—in which summer becomes a time when being outside is dangerous—is not inevitable. Our findings show that with rapid action to reduce emissions, many places can avoid prolonged, dangerous heat.

> ***If we take no action and global heat-trapping emissions continue to rise unabated, by late century, few refuges from extreme heat will remain.***

TABLE 1. Extreme Heat Will Become More Frequent and More Severe in All Regions of the Country[10]

Time Period	Scenario	Heat Index Threshold	Mid-west	North-east	N. Plains	North-west	South-east	S. Plains	South-west	US
Historical	-	90°F	25	13	13	6	69	71	37	41
Midcentury	No Action	90°F	62	40	36	20	113	109	60	69
Midcentury	Slow Action	90°F	54	32	31	16	105	102	54	63
Late Century	No Action	90°F	90	70	57	37	140	134	84	93
Late Century	Slow Action	90°F	63	39	37	21	113	109	60	70
–[9]	Rapid Action	90°F	56	34	32	17	107	104	56	65
Historical	-	100°F	6	3	3	1	15	21	23	14
Midcentury	No Action	100°F	30	14	12	4	65	61	24	36
Midcentury	Slow Action	100°F	22	10	8	3	51	51	22	30
Late Century	No Action	100°F	53	32	24	11	96	88	35	54
Late Century	Slow Action	100°F	27	12	10	4	60	57	24	34
–	Rapid Action	100°F	22	10	8	3	52	52	22	31
Historical		105°F	3	2	2	0	4	7	13	5
Midcentury	No Action	105°F	17	8	6	2	40	39	17	24
Midcentury	Slow Action	105°F	12	5	4	1	27	30	17	18
Late Century	No Action	105°F	38	20	14	5	73	66	22	40
Late Century	Slow Action	105°F	15	7	5	2	34	35	17	22
–	Rapid Action	105°F	12	5	4	1	27	30	18	19
Historical	-	Off the Charts	0	0	0	0	0	0	2	0
Midcentury	No Action	Off the Charts	2	1	1	1	3	3	8	3
Midcentury	Slow Action	Off the Charts	2	1	1	0	2	2	6	2
Late Century	No Action	Off the Charts	7	3	3	2	12	12	10	9
Late Century	Slow Action	Off the Charts	2	1	1	1	2	3	7	3
–	Rapid Action	Off the Charts	2	1	1	0	2	2	7	2

As heat-trapping emissions rise, each region of the country is projected to experience an increase in the average number of days per year with heat above the thresholds analyzed in this study.

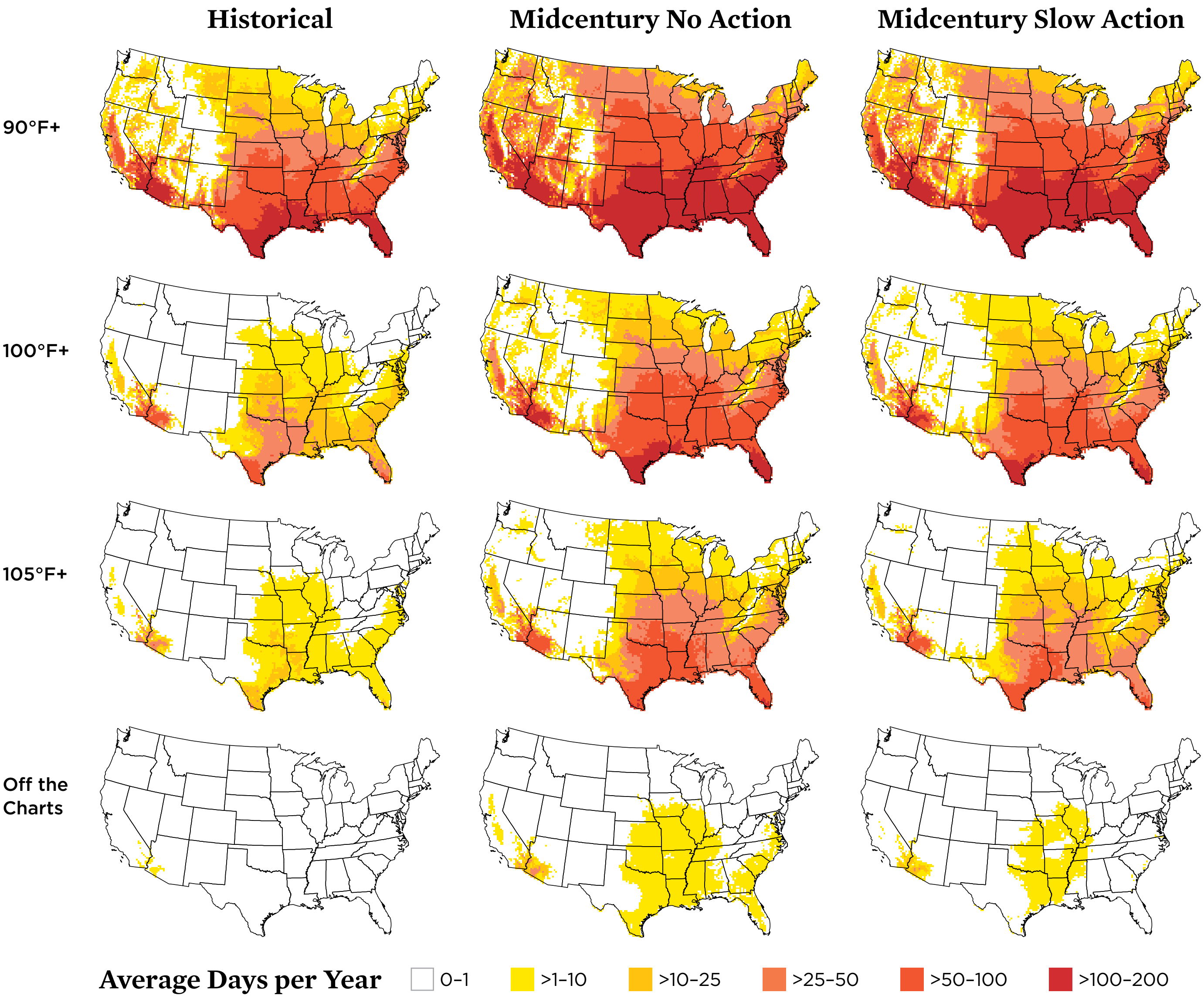
Midcentury Results (2036–2065)

THE NATION, WITH NO ACTION TO REDUCE EMISSIONS

Across the United States, with few exceptions, the frequency and geographic range of extremely high heat index days would increase markedly by midcentury if we take no action to reduce emissions (Figure 5). Midcentury reflects the time frame in which many of today's working-age adults will live out their retirements and many of today's children will raise families.

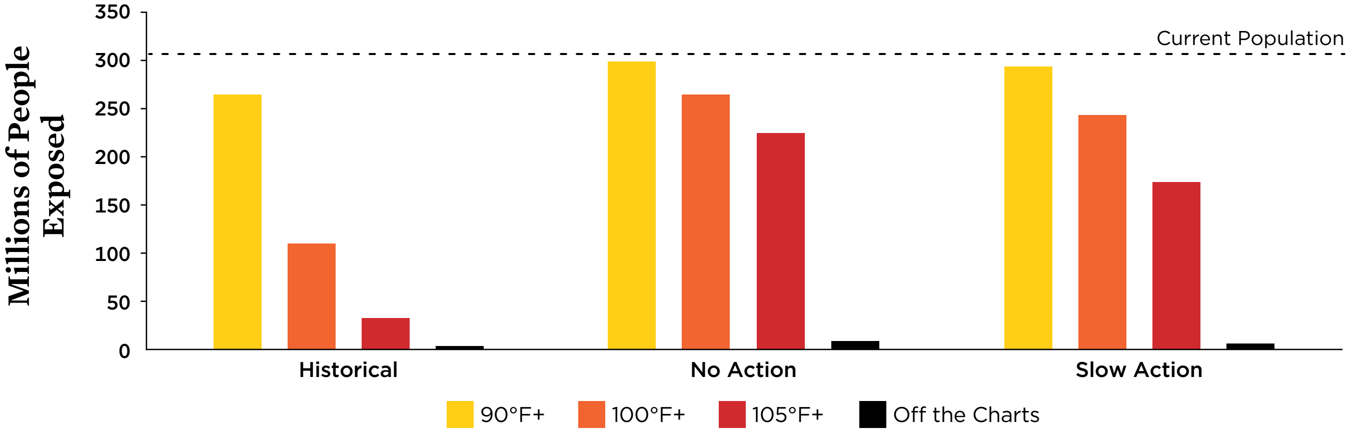
Nationwide, with no action, the average number of days per year with a heat index above the 90°F threshold would increase by 70 percent from a historical baseline of 41 to 69. The number of days with a heat index above the heat advisory threshold of 100°F would increase, from 14 historically to 36. The number of days above the NWS excessive heat warning threshold of 105°F would more than quadruple,

FIGURE 5. Extreme Heat by Midcentury Becomes More Frequent and Widespread



By midcentury (2036–2065), regions of the United States with little to no extreme heat in an average year historically—such as the upper Midwest and New England—would begin to experience such heat on a regular basis. Heat conditions across the Southeast and Southern Great Plains regions are projected to become increasingly oppressive, with off-the-charts days happening an average of once or more annually.

FIGURE 6. Millions More People Will Face Extreme Heat by Midcentury



Taking no action or slow action to reduce global heat-trapping emissions would expose millions more US residents to an average of seven or more days per year of extreme heat index conditions by midcentury, even when assuming no changes in population.

from 5 historically to 24. Whereas off-the-charts conditions occurring once a year or more have historically affected less than 1 percent of the country by area, more than 36 percent of the country by area would experience such conditions, on average, once a year or more in this time frame.

As extreme heat grips more of the country, growing numbers of people would be exposed to dangerous conditions (Figure 6). Based on 2010 population data, and assuming no changes in population size or distribution, the number of people in the United States exposed to an average of 30 or more days per year with a heat index above 105°F would increase roughly 100-fold, from just under 900,000 historically to more than 90 million—or roughly 30 percent of the population—in the no action scenario.[11] Historically, all of the people exposed to the equivalent of a week or more of off-the-charts conditions in an average year (more than 1,900) would fit into a large theater. By midcentury, more than 6 million people—equivalent to roughly the entire population of Missouri—would experience such conditions.

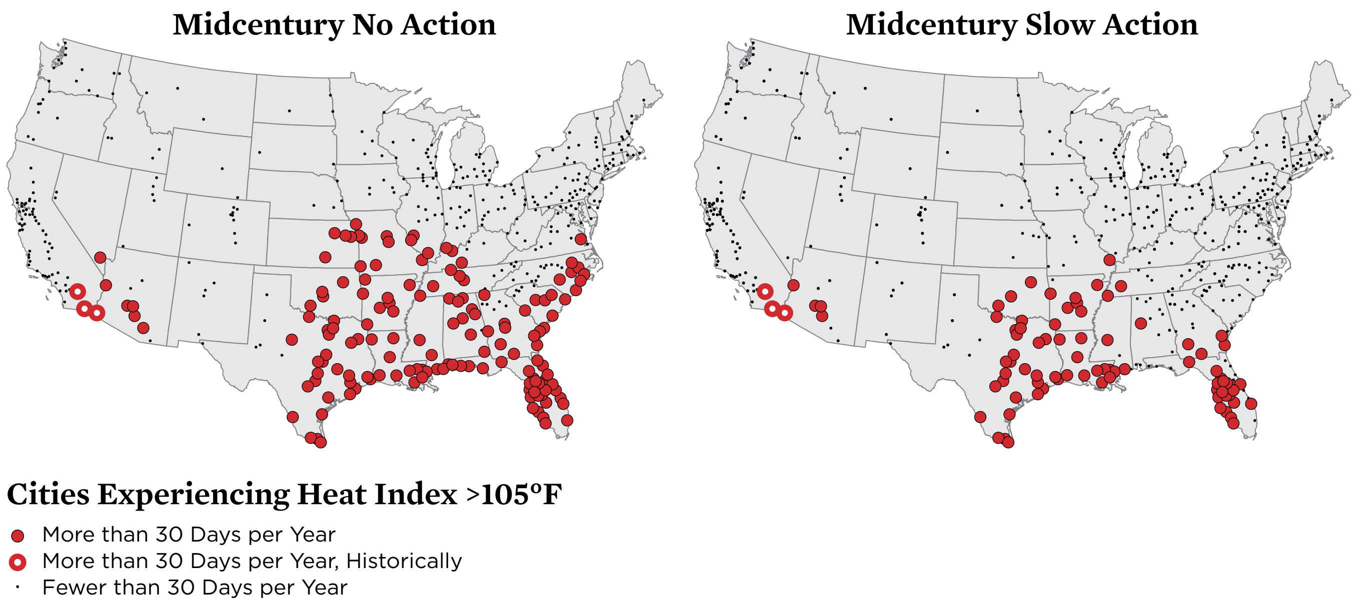
> ***Rapid action to reduce global emissions could make a significant difference in exposure to extreme heat by midcentury.***

Historically, 29 of 481 US urban areas have experienced 30 or more days with a heat index above 100°F. With no action to reduce heat-trapping emissions, that number would rise to 251 cities by midcentury and include places that have not historically experienced such frequent extreme heat, such as Cincinnati, Ohio; Omaha, Nebraska; Peoria, Illinois; Sacramento, California; Washington, DC; and Winston-Salem, North Carolina (see Figure 7, p. 15). Nearly one-third of all urban areas—152 out of 481—would experience an average of 30 or more days per year with a heat index above 105°F, compared with just three historically. Cities have unique land surface properties that tend to make them hotter than the surrounding areas—a phenomenon known as the urban heat island effect. Because that effect is not included in the models used in this analysis, these statistics for cities experiencing extreme heat index days likely underestimate the scale of the problem.

THE NATION, WITH SLOW ACTION TO REDUCE EMISSIONS

With slow action to reduce heat-trapping emissions, most of the contiguous United States would face frequencies of extreme heat far higher than those of today (Figure 5, p. 13). However, the frequency of high heat index days would be between 9 and 23 percent lower than with no action, as outlined above. Slow action would lead to an average of 18 days per year with a heat index above 105°F, about five fewer than projected with no action. With this scenario, more than 30 million people would avoid exposure to 30 or more days with a heat index above 105°F (Figure 6, p. 14), and 84 urban areas would be exposed to that frequency of heat—compared

FIGURE 7. Urban Areas Face Frequent, Extreme Heat by Midcentury


Midcentury No Action

Midcentury Slow Action

Cities Experiencing Heat Index >105°F

- ● More than 30 Days per Year
- ○ More than 30 Days per Year, Historically
- · Fewer than 30 Days per Year

Historically, only three of 481 urban areas (cities with populations of 50,000 or more) in the contiguous United States have experienced 30 or more days per year with a heat index above 105°F. With slow action to reduce global emissions, more than 80 urban areas would experience these conditions by midcentury. And with no action, more than 150 urban areas would.

with 152 with no action (Figure 7). These findings show that emissions choices make a difference even in this time frame; that significant changes are still in store; and that faster, more aggressive action to reduce emissions would be needed to avoid those changes.

REGIONAL HIGHLIGHTS[10]

Northeast. By midcentury, the Northeast is projected to regularly experience extreme heat that has, historically, been rare. Connecticut, Massachusetts, and Rhode Island, for example, have historically averaged seven to 10 days per year with a heat index above 90°F. By midcentury, with no climate action, these New England states can expect the equivalent of four to six *weeks* of such conditions, on average, each year (see Table 2 for findings about select cities). And while these states typically don't experience days with a heat index higher than 100°F in the average year, by midcentury, with no action, they are projected to experience an average of 10 to 13 such days per year, and four to five days with a heat index above 105°F.

In an average year, historically, no Northeast residents have experienced 30 days with a heat index above 100°F. With no climate action, and assuming no population growth or change in where people live, more than 11 million residents of the Northeast would experience such conditions. In Maryland alone, more than 5 million people would be exposed to such heat, 94 percent of the total population.

TABLE 2. Northeast Cities Face Steep Increases in Days per Year Above 90°F by Midcentury

	Historical	No Action	Slow Action
Bangor, ME	3	24	16
Boston, MA	11	41	32
Burlington, VT	5	30	22
Dover, NH	11	40	32
Hartford, CT	11	44	34
New York City, NY	16	51	41
Pittsburgh, PA	11	53	42
Trenton, NJ	24	65	55

Populous cities in the Northeast, including the sampling shown here, are projected to experience a doubling or more of the number of days per year with a heat index above 90°F between now and midcentury with no action or slow action to reduce global heat-trapping emissions.

Anthony Behar/Sipa Press via AP Images

In regions where extreme heat occurs infrequently today, such as the Northeast, air-conditioning of homes and workplaces is not universal. This and other factors have led some cities, including New York City, shown here in 2011, to issue heat advisories at a lower heat index than recommended by the National Weather Service.

TABLE 3. Southeast and Southern Great Plains Cities Will Face Many More Days per Year with a Heat Index Above 105°F by Midcentury

	Historical	No Action	Slow Action
Austin, TX	5	59	42
Baton Rouge, LA	5	57	37
Columbia, SC	5	37	24
Jackson, MS	6	52	36
Montgomery, AL	4	44	29
Oklahoma City, OK	4	43	29
Raleigh, NC	3	26	16
Tallahassee, FL	5	50	32

Historically, cities in the Southeast and Southern Great Plains regions have experienced fewer than a week's worth of days with a heat index above 105°F in an average year. With no action or slow action to reduce global heat-trapping emissions, the sampling of cities shown here would experience at least quadruple the number of such days by midcentury.

With slow action to reduce emissions, the states in this region would experience one-third fewer days with heat index conditions above 100°F or 105°F, compared with the no action case. Perhaps most strikingly, slow action would reduce the number of people exposed to 30 or more days with a heat index above 100°F to fewer than 1 million, sparing 10 million people per year from exposure to such conditions.

Southeast and Southern Great Plains. The Southeast and Southern Great Plains are some of the hottest parts of our country today. But future warming will make extreme heat in these regions even more frequent and severe. With no climate action, states across the Southeast and Southern Great Plains regions—including Arkansas, Louisiana, Oklahoma, and Texas—are projected to undergo more than a tripling in the average frequency of days with a heat index above 100°F, from the current 20 to 30 days per year to the equivalent of two to three months per year (see Table 3 for findings about select cities). The average frequency of days with a heat index above 105°F in these four states would increase seven-fold or more, from between five and nine days per year, historically, to six to nine weeks per year. Florida is projected to experience some of the highest frequencies of extreme heat in the nation—in an average year and averaged across the state, 105 days with a heat index over 100°F (up from just 25 days historically) and 63 days with a heat index over 105°F.

The number of days with a heat index topping 120°F—which historically have not occurred in these states—would rise to an average of between two and five days per year for each state. While none of these states have experienced off-the-charts conditions historically, each is projected to experience an average of between two and four such days annually by midcentury.

Assuming no growth in population and no change in where people live, more than 17 million people in Florida and roughly 23 million people in Texas would be exposed to an average of 30 or more days per year with a heat index above 105°F with no action to reduce emissions. Historically, fewer than 50,000 people have been exposed to such frequent extreme heat in both states combined.

Compared with the no action scenario, slow action to reduce emissions would reduce the number of days per year with a heat index above 100°F or above 105°F by an average of two to three weeks per year in Arkansas, Louisiana, Oklahoma, and Texas—and by around three weeks per year in Florida. Roughly 5 million fewer Floridians and half a million fewer Texans would be exposed to 30 or more days with a heat index above 105°F.

> ***Florida could experience as many as 105 days with a heat index over 100°F.***

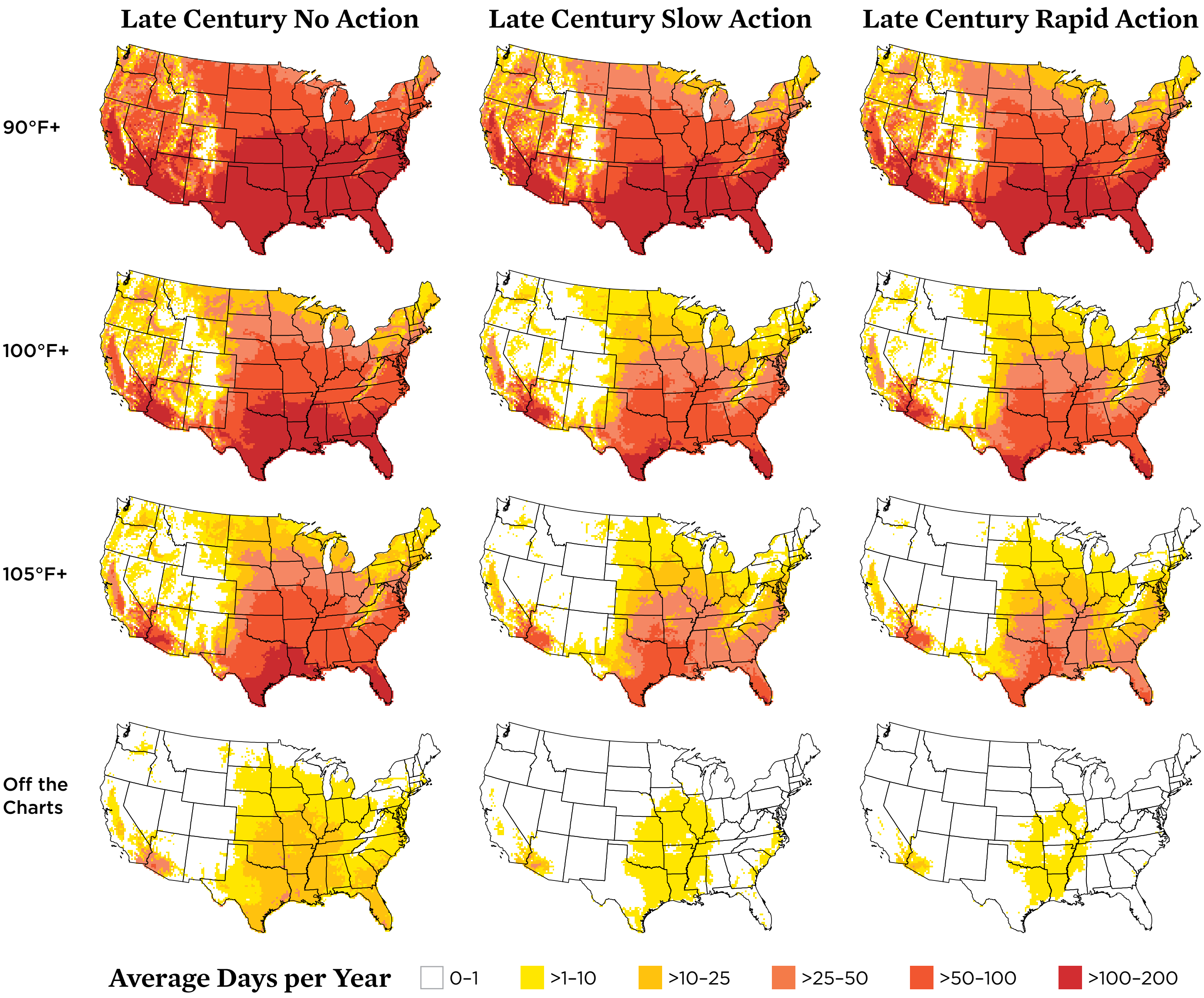
Late-Century Results (2070–2099)

THE NATION, WITH NO CLIMATE ACTION

With no action to reduce heat-trapping emissions, the country would experience a two-fold increase in the average number of days with a heat index above 90°F; a four-fold increase in the average number of days per year with a heat index above 100°F; and a nearly eight-fold increase in average number of days with a heat index above 105°F, compared with the historical baseline (Figure 8). With this scenario, nearly two-thirds of the country would experience off-the-charts conditions at least once per year, on average.

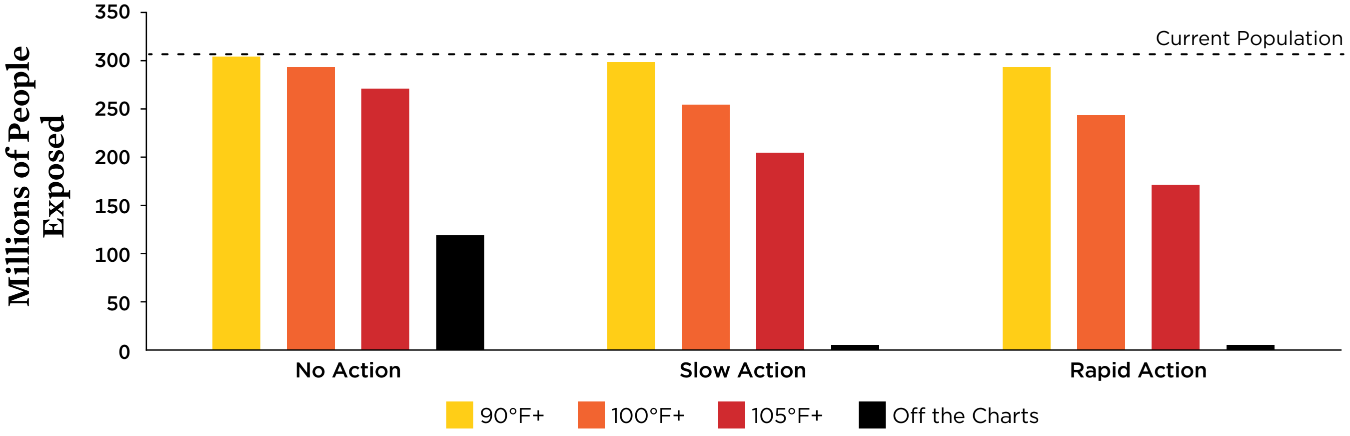
Compared with the historical average, the number of people exposed to multiple days with a heat index above 105°F by late century would be staggering, assuming no growth in population or change in where people live

FIGURE 8. Frequency of Extreme Heat by Late Century Depends on the Choices We Make



The emissions choices we make in the coming decades will profoundly shape the frequency and severity of extreme heat later this century. With no action to reduce global emissions, the contiguous United States would face an average of twice as many days with a heat index above 105°F in late century as it would with rapid action.

FIGURE 9. Rapid Action Could Limit the Number of People Facing Frequent, Extreme Heat



Warming between now and late century under all three scenarios analyzed would expose millions more US residents to seven or more days per year of extreme heat index conditions. Assuming no population change and with no action to reduce emissions, 100 million more people would experience seven or more days with a heat index above 105°F, compared with the rapid action scenario.

(see Figure 9). Historically, fewer than 1 million people in the contiguous United States have experienced 30 or more days per year with a dangerously hot heat index above 105°F, and virtually none have experienced 60 or more such days per year. By late century, about 180 million—more than half the population—would experience 30 or more of these days, and more than 95 million people (nearly one-third of the population) would experience 60 or more such days per year.

The number of people exposed to off-the-charts days is also projected to increase steeply. By late century, nearly 120 million US residents—more than one-third of the population—would face a week's worth of off-the-charts conditions. Historically, such conditions affect fewer than 2,000 people and occur only in our country's hottest desert environment.

By late century, 98 percent of urban areas in the country (469 out of 481) would experience an average of 30 or more days with a heat index above 90°F—nearly doubling the number that have experienced such conditions historically (see Figure 10). The spread of such conditions to cities such as Bangor, Maine; Duluth, Minnesota; and Portland, Oregon could fundamentally alter ways of life in places that today are—and through midcentury would be—refuges from the heat. Sixty percent of these urban areas, nearly 300 of 481, would experience 30 or more days per year with a heat index above 105°F.

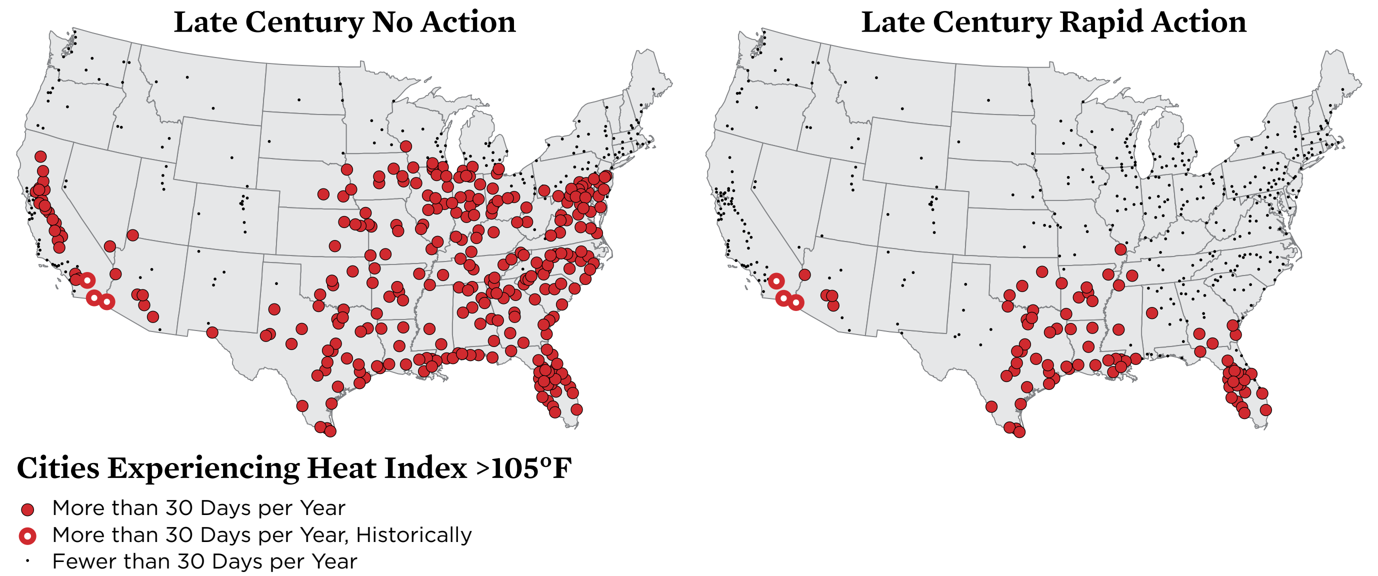
> ***By late century, nearly two-thirds of the country would experience off-the-charts conditions in an average year.***

THE NATION, WITH RAPID ACTION TO REDUCE EMISSIONS

Steep, rapid emissions reductions that result in future warming of 2°C or less would result in roughly half as many days with a heat index above 105°F nationwide, and about 125 million fewer people would be exposed to a month or more of such conditions, compared with the no action scenario. If aggressive measures are taken to bring down global heat-trapping emissions, roughly 114 million people in the United States—the equivalent of the populations of California, Florida, Illinois, Pennsylvania, Texas, and Virginia combined—would avoid exposure to the equivalent of a week or more of off-the-charts conditions.

While this future is one that would limit the impacts of extreme heat on US residents, it is still one that would be significantly warmer than today. Nearly 200 of the 481 urban areas analyzed across the country would experience an average of 30 or more days per year with a heat index above 100°F, compared with just 29 urban areas historically. And 85 urban areas across the country—18 percent of those analyzed—would be exposed to 30 or more days with a heat index above 105°F, compared with just three historically.

FIGURE 10. Urban Areas Face Frequent, Extreme Heat by Late Century



With rapid action to reduce global emissions and limit future warming to 2°C or less, more than 200 urban areas (cities with a population of 50,000 or more) could avoid experiencing 30 or more days per year with a heat index above 105°F, compared with the no action scenario. With no action to reduce emissions, 292 urban areas would experience this level of extreme heat by late century. With rapid action, 85 would.

REGIONAL HIGHLIGHTS

Midwest and Northern Great Plains. With no global action to reduce emissions, days with a heat index above the 90°F threshold, at which outdoor workers are increasingly susceptible to heat-related illness, would occur an average of more than 100 times per year in Indiana and Illinois, two states at the heart of the agricultural Midwest. Many states in this region—including Ohio, Illinois, Indiana, Iowa, Missouri, and Nebraska—would experience an average of 40 or more days per year with a heat index above 100°F (see Table 4 for findings about select cities). For each of those states (except Nebraska), on more than 30 of those days each year, the heat index would top 105°F. In parts of Missouri and the southern half of Illinois, the heat index would top 120°F for roughly one month's worth of days per year (29), and the majority of those (20) would be off the charts.

All of this adds up to very high levels of exposure to extreme heat for the residents of the Midwest and Northern Great Plains if there is no action to reduce global emissions. Historically, no people in these regions have experienced an average of 30 or more days with a heat index above 100°F. By late century, about 60 million people—including nearly the entire populations of Illinois, Indiana, Iowa, Missouri, and Ohio—would be exposed to such conditions in an average year, assuming no change in population size or distribution.

TABLE 4. Midwest and Northern Great Plains Cities Face Many More Days per Year with a Heat Index Above 100°F by Late Century

	Historical	No Action	Rapid Action
Chicago, IL	3	50	17
Columbus, OH	1	52	16
Fargo, ND	1	31	8
Indianapolis, IN	3	60	22
Lincoln, NE	8	67	30
Minneapolis, MN	2	42	13
Sioux Falls, SD	2	43	13
St. Louis, MO	11	82	46

With no action to reduce global heat-trapping emissions, cities throughout the Midwest and Northern Great Plains regions, including the sampling shown here, would experience dramatic increases in extreme heat by late century. In an average year, each of these cities would face the equivalent of one to three months with a heat index above 100°F. Rapid action to curb global emissions would reduce the number of days per year with a heat index above 100°F in most of the cities shown here by more than half.

AP Photo/Charlie Neibergall

The Midwest already suffers from extreme heat during the summer. Increasingly frequent and more severe heat conditions could threaten Midwestern agriculture, a regional economic lynchpin, as well as long-standing cultural traditions such as the county fair. Here, a boy cools down his cow in preparation for the Polk County Fair in Des Moines, Iowa, in 2011.

Rapid action to reduce emissions would limit the number of extreme heat index days in the Midwest and Northern Great Plains, though both regions would still see a significant increase from historic averages. Even with aggressive action, the number of days per year with a heat index above 90°F would more than double for both the Midwest and Northern Great Plains, to an average of 56 and 32 days per year, respectively. The number of days with a heat index above 100°F would triple or more to an average of 22 and 8 days per year, respectively, for each region.

Southeast, Southern Great Plains, and Southwest. Were we to take no action to reduce heat-trapping emissions, the Sunbelt, stretching from the Carolinas across the South to Southern California, would see the most dramatic and life-threatening jump in the frequency of high heat index days of all regions of the United States. Broad swaths of the Sunbelt are projected to experience an average of 100 or more days per year—the equivalent of more than three months—with a heat index above 100°F, whereas parts of southern Florida would experience 170 such days in an average year (see Table 5 for findings about select cities). In Mississippi and Louisiana the heat index would exceed 105°F for an average of 90 or more days per year statewide. Twenty-five or more of those days would have a heat index above 120°F. People in roughly half of Louisiana and a large band of eastern Texas could expect an average of 20 to 28 days per year of off-the-charts heat.

In each of the Southeast and Southern Great Plains states, more than 90 percent of the population—almost 105 million people—would be exposed to 30 or more days with a heat index above 105°F were we to take no action to reduce emissions. Fewer than 50,000 people in these states have been exposed to such frequent extreme heat historically. These results suggest that when today's children approach retirement, extreme heat in much of the Sunbelt region of the United States could render daily life challenging or even dangerous. Rather than continuing its trend of rapid population growth (US Census Bureau 2017) and attracting seasonal "snowbirds" from cooler climes, the region could see an exodus.

TABLE 5. Sunbelt Cities Face More Frequent Days with a Heat Index Above 105°F in Late Century

	Historical	No Action	Rapid Action
Dallas, TX	8	100	48
Fresno, CA	3	59	18
Jackson, MS	6	92	37
Memphis, TN	6	82	39
Montgomery, AL	4	84	29
Phoenix, AZ	16	97	57
Sarasota, FL	2	126	47
Topeka, KS	5	64	25

With no action to reduce heat-trapping emissions, cities throughout the Sunbelt region—stretching from the Carolinas to California—would, like the sampling shown here, face the equivalent of two to four months' worth of days per year with a heat index above 105°F by late century.

While higher-altitude regions within southwestern states are projected to be spared from the most extreme heat conditions, lower-altitude regions would be affected in unprecedented ways. The Central Valley region of California, for example, is projected to experience an average of more than 25 days per year with a heat index above 105°F. Across California, nearly 11 million people would be exposed to 30 or more days with a heat index above 105°F in an average year. Given that the Central Valley produces 40 percent of the nation's fruits and nuts, such changes could have profound impacts on the region's agricultural workers and the country's access to California-grown produce (USGS n.d.). Importantly, because the Southwest experiences a high degree of exposure to direct sunlight in the summer months, the heat index could be up to 15°F higher than that calculated in this analysis (OSHA n.d.).

Assuming no change in population size or distribution, aggressive and rapid emissions reductions would lead to the exposure of more than 50 million people in the Southeast and Southern Great Plains regions to an average of 30 or more days with a heat index above 105°F. That would be a staggering increase, compared with the 50,000 people exposed to such conditions in those regions historically. However, it is roughly half the number of people who would be exposed to such conditions were we to take no action to reduce emissions.

AP Photo/Rich Pedroncelli

Farmworkers, like these strawberry pickers in California's Central Valley in 2007, will face heightened risks with an increased number of days surpassing the worker-safety threshold of 90°F. Heat-related illness among farmworkers, already a significant threat, is almost certainly underreported, as many workers fear punitive action for reporting such incidents.

[CHAPTER 5]

Implications: How the Heat We Create Threatens Us All—but Some More Than Others

For many people in the United States, the warm months are spent outdoors—enjoying weekend backyard barbeques; going to the park; taking day trips to the beach, lake, or public pool; waiting in line at the ice cream stand on a muggy evening. However, a growing number of us also spend summer days and nights waiting out the heat at home, in malls, at movie theatres, and even in cooling centers, as temperatures rise and heat advisories caution us to stay indoors. And some of us must spend those days working outdoors and sweltering in homes without air-conditioning. With both heat and population on the rise,[12] we can expect many more people to be harmed. But some are more vulnerable to heat today and would be exceptionally so in an overheated future. Here, we outline some of the implications for key overlapping segments of the US population.

Outdoor Workers

With the number and intensity of hot days projected to climb steeply across much of the United States even by midcentury, millions of outdoors workers already at elevated risk of heat stress—including construction workers, farmworkers, landscapers, military personnel, police officers, postal workers, road crews, and others—would face greater challenges.

> ***With the number and intensity of hot days projected to climb steeply, millions of workers already at elevated risk of heat stress would face greater challenges.***

Construction workers, who currently account for about one-third of occupational heat-related deaths and illnesses, may be at particular risk (Morris et al. 2019; Gubernot, Anderson, and Hunting 2015). For example, Texas and Florida, two states with some of the highest proportions of people employed in the construction sector, are poised to experience an additional month's worth—or more—of days with a heat index above the worker-safety threshold of 90°F in an average year by midcentury (BLS 2018).

Similarly at risk are those employed in the agriculture, fishing, forestry, and hunting sectors, which account for about 20 percent of heat-related deaths and about 10 percent of heat-related illnesses reported to the Occupational Safety and Health Administration (OSHA) (Morris et al. 2019; Gubernot, Anderson, and Hunting 2015; OSHA n.d.). These workers will experience more risk even by midcentury. Much of this outdoor work, including agricultural work and roofing, requires being in direct sun, often for extended periods of time. Exposure to direct sun can raise heat index values by as much as 15°F.

Within this sector, migrant farmworkers face significant barriers to preventing heat-related illness. These workers often lack access to regular breaks, shade, medical services, health insurance, and training in prevention techniques (Fleischer et al. 2013; Rosenbaum et al. 2005). Despite clear risks, some agricultural business models make occupational heat-related injury and illness more likely by creating incentives for workers to push themselves beyond safe limits. For example, farmworkers are often paid by the amount they harvest, which incentivizes them to skip breaks and overexert themselves (Gubernot, Anderson, and Hunting 2015). Heat-related illness is almost certainly underreported among migrant farmworkers, as they are less likely to report their symptoms to supervisors and more likely to self-treat (Bethel and Harger 2014; Jackson and Rosenberg 2010). One reason for the underreporting is that noncitizens or undocumented workers may fear punitive action upon reporting a workplace injury or illness and have little to no recourse (North 2016; Fussell 2011).

Evidence suggests that, in addition to direct health impacts, increasingly extreme heat has already reduced global labor capacity, as it is more difficult to do the heavy work associated with industries such as agriculture and construction when it is extremely hot (Kjellstrom et al. 2016; Dunne, Stouffer, and John 2013). Continued warming throughout the 21st century is projected to further reduce labor capacity and productivity (Kjellstrom et al. 2016; Dunne, Stouffer, and John 2013). By the year 2100, estimates for the no action scenario suggest that lost labor hours would represent more than $170 billion in lost wages (EPA 2015).

> ***Many of these outdoor jobs require being in direct sun, often for extended periods of time.***


AP Photo/Charlie Riedel

Work proceeds on this Kansas highway in July 2016 as temperatures rise to 102°F. Outdoor workers suffer higher rates of heat-related illness and death during extreme heat events. Some jobs, such as construction and landscaping, require long hours in direct sun or in hot protective gear, which necessitates additional precautions to keep workers safe.

City Dwellers

Our results show that even by midcentury, cities throughout the country can expect frequent, intense heat to a degree that is historically unprecedented. These increases in urban heat will likely be compounded by the heat-exacerbating characteristics of city environments, known collectively as the urban heat island effect. In addition to experiencing the effects of global temperature increases, cities tend to be hotter than the surrounding area on any given day because they contain relatively fewer shade-providing trees and an abundance of heat-retaining materials and surfaces, such as asphalt, cement, and pavement (UCAR 2011). The extra heat absorbed during the day is then re-radiated at night, keeping air temperatures in urban areas up to 22°F warmer than their surroundings (EPA 2019). Moreover, nighttime air-conditioning releases additional heat into the city environment (EPA 2019; Salamanca et al. 2014).

During heat waves, the urban heat island effect can be particularly harmful, as it reduces or eliminates the cooler hours when people can get physical and mental relief (Stone, Hess, and Frumkin 2010; Rosenzweig et al. 2005). Not surprisingly, violent crime often spikes in cities during heat waves (Schinasi and Hamra 2017; Mares 2013). While this analysis only examined daily maximum heat index values, nighttime conditions—when the heat index is most likely to be at a minimum—are particularly important in determining the overall health impacts of an extreme heat event in cities.

Because of the urban heat island effect, heat-related death rates have been generally higher in urban areas than in rural areas (Seltenrich 2015). With future climate change, nighttime temperatures are projected to warm faster than daytime temperatures, and more people are projected to be exposed to heat stress in urban areas than in rural areas (Andrews et al. 2018). Recent heat and population projections for 49 US cities show that without additional adaptation or acclimatization, a no action scenario would result in an additional 9,300 heat-related deaths across the country annually (USGCRP 2018).

Cities tend to be hotter than surrounding areas, which increases the risk of heat-related illness for urban residents during heat waves.

AP Photo/Bebeto Matthews

Keeping cool on extremely hot days can be especially hard for city dwellers. Urban neighborhoods, especially poorer ones, often lack tree cover, green space, and other places to retreat from the heat. Here, children cool off in an inflatable pool during a heat wave in New York City in 2011.

Cities also contend with high levels of ground-level ozone pollution, which are worsened during hot weather, leading to spikes in hospital admissions for respiratory illness (Bernstein and Rice 2013). Ground-level ozone is created when heat triggers chemical reactions between some of the common pollutants associated with electric utilities, industrial facilities, and vehicles (Martin Perera and Sanford 2011). As temperatures rise, ozone concentrations are projected to rise as well, and the health consequences of ozone exposure—including the exacerbation of asthma and other respiratory diseases—are expected to worsen (Martin Perera and Sanford 2011; Jacob and Winner 2009). As with exposure to extreme heat on its own, children, elderly adults, and people with underlying health conditions are among the most susceptible to illness and premature death when ozone levels rise (Martin Perera and Sanford 2011).

Because the effects of the urban heat island effect and ozone levels are not represented in these results, this analysis may underestimate the threat of extreme heat to city dwellers (Fischer, Oleson, and Lawrence 2012).

Rural Residents

The high heat index conditions we project in places such as eastern Kentucky, western Kansas, and many swaths of rural America pose a serious threat to the health and quality of life of rural residents. While studies suggest people in urban areas generally have a higher risk of heat-related illness than do rural residents, rural areas in the South and West have some of the country's highest heat-related hospitalization and death rates (Seltenrich 2015; Berko et al. 2014).

Rural counties employ higher percentages of people in farming and construction than do urban counties (BEA 2017; US Census Bureau 2010b).[13] The prevalence of outdoor labor and lower access to and usage of air-conditioning in rural settings may elevate these risks for some rural populations (Hess, Saha, and Luber 2014). Distance to health care and cooling facilities, and lack of health insurance may contribute to delays in seeking and receiving care, and can lead to worsened heat illness (Cheeseman Day 2019; Schmeltz et al. 2015).

In addition to impacting health, heat extremes affect the economy of rural areas, as both crop and livestock production decline with extreme temperatures (Gowda et al. 2018; Key, Sneeringer, and Marquardt 2014; Lobell et al. 2013). Dairy livestock are particularly sensitive to heat stress. As a result, heat stress currently costs the average US dairy an estimated $39,000 annually—a cost that is projected to increase with future warming (Key, Sneeringer, and Marquardt 2014).

People and Neighborhoods with Low Income or Experiencing Poverty

Even within a given setting, such as a city, vulnerability to heat is not equally distributed (Harlan et al. 2013; Reid et al. 2009; Harlan et al. 2006). Centuries of social discrimination and subsequent uneven opportunities for economic advancement have forced part of our population—disproportionately minorities and people experiencing poverty—into a state of heightened exposure and vulnerability to climate-related threats (Harlan et al. 2019). US residents who are not white, have low or fixed incomes, are homeless, and those in other historically disenfranchised groups are particularly at risk of heat-related illness and injury for a multitude of reasons, including lack of access to air-conditioning or transportation to cooling centers and residence in the hottest parts of cities (Hayden et al. 2017; Schmeltz, Petkova, and Gamble 2016; Schmeltz et al. 2015; Harlan et al. 2013; Fiscella et al. 2000). The 1995 Chicago heat wave claimed the lives of more than 700 people (Davis et al. 2003) and is seen as not simply a natural disaster, but a societal one as well, with isolated, elderly African Americans suffering a disproportionate death toll because they were unable to flee overheated, non-air-conditioned apartments (Klinenberg 2002).

With one in three households in the United States already struggling to afford the cost of energy and few state-level policies banning utility disconnection during extreme heat events, the inability to pay for air-conditioning also raises the risk of heat-related illness for low-income people and families (LIHEAP 2019; USEIA 2018). Socioeconomic status is consistently identified as a factor in heightened heat health risk (Li et al. 2015; Seltenrich 2015; Curriero et al. 2002).

People Exposed to Other Extremes

On its own, an extreme heat event can be deadly, but for those who live in areas prone to other natural disasters—such as flooding, hurricanes, and wildfires—extreme heat can heighten risks even further. As frequent and extreme heat conditions expand to claim more, and then most, of the country, they could overlap with disasters, with potentially compounding effects. For example, even relatively short power outages in the wake of a hurricane can prove fatal when they occur during high heat index days, as happened in the wake of Hurricane Irma. In the days following Irma's landfall in Florida, the heat index hovered around 100°F;[14] widespread power outages and the subsequent lack of air-conditioning were implicated in 17 heat-related deaths (Issa et al. 2018; Weather Underground 2017), including those of 14 elderly residents of one particular nursing home (Cangialosi, Latto, and Berg 2018).

AP Photo/Gerald Herbert

During weather-related disasters, power outages—and thus loss of air-conditioning—are common. When they coincide with extreme heat, the situation can quickly become life-threatening. Here, a woman is evacuated from her assisted living facility in Orange, Texas, during Hurricane Harvey in 2017.

[CHAPTER 6]

Our Challenge and Our Choices: Limiting Extreme Heat and Its Accompanying Harm

The implications of this analysis are profound: in many places around the nation, extreme heat will lead to an increase in deaths or illnesses, disrupt long-standing ways of life, force people to stay indoors to keep cool, and perhaps even drive large numbers of people away from places that become too unpleasant or impractical to live. Outdoor work and play would need to be severely curtailed during the summer months. Power grids could be severely strained. Air and rail travel could be disrupted. Other impacts associated with heat—such as water stress, wildfires, agricultural losses, and ecosystem changes—would become more frequent or severe.

Our communities'—and our country's—ability to cope with extreme heat depends on our level of resilience to that heat and its consequences. The degree to which we are unprepared for the damaging effects of climate change—such as days with potentially lethal heat—has been called the "climate resilience gap" (Spanger-Siegfried et al. 2016). Addressing that gap for extreme heat will require both adaptation to our warmer world and mitigation of the warming itself. It will require us to invest in commonsense measures to better protect people's health, their livelihoods, and our nation's critical infrastructure while contributing to global emissions reductions that limit the magnitude of future heat extremes. Only by doing so in an equitable manner that addresses long-standing socioeconomic problems can we truly close the resilience gap.

We also face a clear choice: our analysis shows that making swift and deep cuts in global carbon emissions will significantly constrain the amount of future warming with which we will need to contend. The emissions paths before us create radically different heat futures. We need to choose the one that limits the worst impacts.

The more we allow extreme heat to rise in frequency and severity, the more it will disrupt our lives and drive larger socioeconomic and ecosystem shifts. Many of the profound climate threats we face will require bold and visionary solutions. But many of the choices we face today that would help keep people safe, maintain economic prosperity, transition to a low-carbon economy, and advance equitable outcomes are practical and clear.

Keeping People Safe from Extreme Heat

To help keep people safe, especially those most vulnerable to the effects of extreme heat, we need to ramp up our public health apparatus to preempt and respond to heat risks. Heat warning systems and protective measures based on public

> ***We must act to reduce heat-trapping emissions in order to help keep people safe as temperatures rise.***

health guidance are vital. These measures should also address health problems associated with and exacerbated by hot, stagnant air and ground-level ozone pollution (a compound risk not included in our analysis). To increase protection against extreme heat, the following actions should be taken:

1. The federal government must invest in scientific research, data, tools, and public communication related to extreme heat risks and protective actions, including fully implementing the NWS Weather-Ready Nation Strategic Plan (NOAA 2019; EPA 2016). This should include: a national extreme heat early warning system; research into and development of heat metrics supported by public health research that are applicable to the full range of future temperatures; a national system for systematic tracking of reliable data on extreme heat and heat-related illness; [15] close coordination across federal agencies—including the Centers for Disease Control and Prevention, the Department of Agriculture, the Department of Health and Human Services, the Department of Labor, the Department of Transportation, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration—to help plan, resource, and implement resilience measures well ahead of and during heat emergencies; support for state and local efforts to build resilience to extreme heat; and targeted interventions for vulnerable populations.
2. State and local governments will need to invest in developing localized heat adaptation plans and heat emergency response plans,[16] especially in places that are unaccustomed to heat but will increasingly be at risk. These plans should specifically respond to the challenges posed by climate change, including modifying heat early warning systems iteratively to improve their effectiveness (Hess and Ebi 2016). The plans should: identify high-risk populations—such as elderly adults, people who are disabled or homeless, and other particularly vulnerable or disadvantaged groups—and include a strategy for outreach to them; set up local warning systems; establish guidance on heat safety standards for outdoor activities at schools and athletic events, and for outdoor work; include information about cooling centers and energy cost assistance programs; and be developed in coordination with local stakeholders, community leaders, emergency responders, and health care and power providers. Some cities and states already have plans or are developing them. Efforts such as the Los Angeles Urban Cooling Collaborative, the Philadelphia Hot Weather-Health Watch/Warning System, and the Phoenix HeatReady City program could serve as models for other places (Phoenix 2019; Tree People 2019; Kalkstein et al. 1996).
3. Federal and state governments should expand funding for programs to provide cooling assistance to low- and fixed-income households, especially for elderly people and those with medical conditions that may be worsened by extreme heat. This funding could include financial incentives such as grant programs, rebates, and tax credits for purchasing air conditioners; grants for energy efficiency improvements; and help with paying energy bills through the Low Income Home Energy Assistance Program and state and community-level cooling programs.[17] Bill assistance programs and other help should be targeted to households in need—with simplified, accessible instructions translated into locally relevant languages and streamlined administrative requirements.
4. State utility regulators and legislators should require utilities to provide uninterrupted power service for residents—especially elderly adults, sick people, and people with disabilities—during periods of extreme heat. Standards based on public health data should be set for heat emergencies, and utility disconnection banned during those times for any reason, including nonpayment of bills (NAACP 2017).[18] Disconnect policies currently vary by state; some states do not have protections in place for periods of extreme heat.[19]
5. Congress should direct OSHA to set health-protective national occupational heat standards for outdoor and indoor workers under the Occupational Safety and Health Act. Such standards can be based on 2016 recommendations from the National Institute of Occupational Safety and Health (Jacklitsch et al. 2016). While OSHA has general guidance for employers to protect their workers when the heat index is high[20]—and California, Minnesota, and Washington have set enforceable standards—mandatory national standards are urgently needed. Heat-related guidance for the US military may also need to be updated in light of growing heat risks (Lilley 2017; Hunt et al. 2016).

> ***Heat warning systems and protective measures based on public health guidance are vital.***

AP Photo/David Goldman

During a stretch of record-breaking heat in Baltimore, Maryland, in June 2011, city officials designated facilities—such as this senior center—as cooling stations. To keep people safe during increasingly frequent and severe extreme heat events, local heat adaptation and emergency response plans must include information about cooling centers.

Investing in Heat-Smart Infrastructure

While this analysis has focused on heat as it relates to people's health and safety, the infrastructure we rely on is also subject to heat-related stresses, including road surfaces and airport runways melting, railway tracks buckling, homes and other buildings becoming dangerously hot, electricity being disrupted because of power grid equipment failures or increased power demand, and air travel being disrupted because extreme heat can affect the upward aerodynamic force or lift that planes need to take off (Borenstein and Koenig 2017). Infrastructure stressed by heat directly and indirectly affects our health and livelihoods. The infrastructure investments we make henceforth need to reflect this threat and increasingly protect our households, communities, and economies against it. To achieve this, the following actions should be taken:

1. Federal and state agencies and private companies should develop climate-resilient design standards and invest in upgrading critical infrastructure to meet these standards (Rogers Gibson 2017). This includes heat-resilient standards for public buildings, facilities, and critical infrastructure; transportation infrastructure, such as highways, rail, and airports; and energy infrastructure, such as the power grid.
2. The federal government should upgrade public housing to account for projections of extreme heat, and the Federal Housing Administration should set minimum cooling standards for public housing properties, similar to the 2016 Minimum Heating Standards.[21]

> ***We must consider the threat of extreme heat when investing in our infrastructure.***

3. Congress should expand federal grants and state revolving loan programs for state and local infrastructure initiatives that build heat resilience and increase energy efficiency, including investing in cool roofs and pavements, urban forestry and creation of shade, cooling centers, retrofitting of schools and other public spaces to enhance cooling, and programs to help buy new air conditioners or replace older, less efficient ones.
4. Designers, planners, and building owners should invest in buildings and communities with climate-smart design features, such as passive cooling, shading and trees, and cool roofs that keep spaces comfortable without drawing on large additional energy use. These features are especially vital in urban areas that suffer additionally from the urban heat island effect and should be prioritized in neighborhoods with large vulnerable populations that have had a historical deficit in green spaces and tree cover. Innovative public-private partnerships, such as the Los Angeles Urban Cooling Collaborative, can serve as a model for these types of efforts (Tree People 2019).

Investing in Climate-Smart Power Systems

Coping with rising heat will require significant increases in power demand for cooling. Investments in low-carbon, energy-efficient power systems, appliances, and design features can help cut heat-trapping emissions and other pollutants while providing access to affordable, reliable ways to help cool homes and businesses. The following actions should be taken:

1. Federal, state, and local authorities should set standards and provide incentives for utilities, businesses, and homes to increase reliance on renewable energy, energy efficiency, energy storage, and microgrids. These resources can help limit power outages during extreme heat events, curb heat-trapping emissions, and limit spikes in power prices. They also lead to less localized air pollution and associated health problems, for example, by helping to replace polluting natural gas “peaker” plants.[22]
2. The federal government should increase efficiency standards for refrigerators and air conditioners and implement regulations to phase out use of hydrofluorocarbons, which are powerful heat-trapping gases used in these appliances, as agreed under the Kigali Amendment to the Montreal Protocol.
3. Utilities should implement flexible demand solutions that help shift demand away from times of peak energy consumption, such as that which might occur during extreme heat days (McNamara, Jacobs, and Wisland 2017). Time-of-use electricity rates, for example, vary the rates customers pay depending on the typical level of demand during different hours of the day.
4. Utilities should invest in increasing the resilience of the electricity system by protecting generation, transmission, and distribution systems from heat-related threats, such as droughts and wildfires. This includes investing in backup power supplies—preferably from storage and microgrid solutions rather than polluting diesel generators or other fossil fuel sources—to reduce the length of or prevent power outages. State utility regulators should require utilities to include resilience planning as part of their integrated resource plans.

Putting the Nation on a Rapid Path to Reduced Emissions

If we are serious about keeping people safe in the long term from extreme heat, the most consequential thing the world’s wealthiest nations (including the United States) can do is make deep cuts in our heat-trapping emissions and continue to implement and strengthen the Paris climate agreement.

We already know the path to a low-carbon economy: it includes transitioning our energy system to low-carbon energy sources; ramping up energy efficiency; electrifying as many energy systems as possible across the transportation, buildings, and industrial sectors; and investing in land use and forest management practices that help store carbon in soils, trees, and vegetation. To give ourselves the best chance of keeping global average warming below 3.6°F (2°C), in line with the goals of the Paris Agreement, the United States must invest in these and other bold solutions alongside robust global action, to get to net-zero carbon dioxide (CO_2) emissions by midcentury (IPCC 2018; White House 2016; Rogelj et al. 2015).

To make these deep emissions cuts, the United States should implement a suite of federal and state policies, including:

1. An economywide price on carbon to help ensure that the costs of climate change are incorporated into our production and consumption decisions and encourage a shift

> ***The most consequential thing the world’s wealthiest nations can do is make deep cuts in our heat-trapping emissions.***

away from fossil fuels to low-carbon energy options. Revenue from carbon-pricing policies can be used to support investments in energy efficiency, low-carbon technologies, adaptation, energy rebates for low-income families, and transition assistance for fossil fuel–dependent workers and communities

2. A low-carbon electricity standard that helps drive more renewable and zero-carbon electricity generation and helps deliver significant public health and economic benefits
3. Policies to cut transportation sector emissions, including increasing fuel economy and heat-trapping emissions standards for vehicles (UCS 2016); increased investment in low-carbon public transportation systems, such as rail systems; replacing gas-powered public bus fleets with electric bus fleets; incentivizing deployment of more electric vehicles, including through investments in charging infrastructure; and research on highly efficient conventional vehicle technologies, batteries for electric vehicles, cleaner fuels and emerging transportation technologies
4. Policies to cut emissions from the buildings and industrial sectors, including efficiency standards and electrification of heating, cooling, and industrial processes
5. Policies to increase carbon storage in vegetation and soils, including through climate-friendly agricultural and forest management practices
6. Investments in research, development, and deployment of new low-carbon energy technologies and practices
7. Measures to cut emissions of methane, nitrous oxide, and other major non-CO_2 heat-trapping emissions
8. Policies to help least developed nations make a rapid transition to low-carbon economies and cope with the impacts of climate change

While emissions reductions must be our first-line solution to limiting climate change, scientific studies show that to meet the goals of the Paris Agreement, we will likely also need to deploy "carbon dioxide removal (CDR) technologies," a term used to describe a range of options to actively remove CO_2 from the atmosphere (IPCC 2018.[23] It is vital that we establish policies and governance frameworks to ensure that policymakers, scientists, private companies, and other stakeholders have a thorough understanding of the costs, benefits, uncertainties, and potential harms associated with various CDR options, and that we invest in the research needed to make informed decisions. Engagement with a diverse set of stakeholders who would be affected by the use of such strategies should occur ahead of making any major decisions or large investments.

Effectively closing the climate resilience gap will require us to acknowledge and prepare for the scale of the problem that lies ahead while working to limit its future magnitude by transitioning to a low-carbon economy. In the years to come, we will need to find ways to adapt to and cope with extreme heat through just and equitable policies. Collaborations among federal, state, and local governments, the private sector, and community-based groups will be vital to ensuring the safety of all people as the risks of extreme heat grow. At the same time, and critically, the United States must also play a leadership role in contributing to global efforts to sharply limit heat-trapping emissions and in helping communities around the world cope with the dire consequences of climate change.

> ***We have precious little time to substantially reduce emissions in order to limit future warming.***

Holding the Line against an Unrecognizably Hot Future

Our analysis points to a future in which dangerous, even deadly heat becomes a regular occurrence for most parts of the country from April through October. Even in scenarios with significant emissions reductions, a consequential amount of warming is projected between now and midcentury.

But we can hold the line against an unrecognizably hot US future—against heat that for large parts of the year confines childhood to the safety of air-conditioned rooms, shifts much more of our lives and activities indoors, makes outdoor jobs life threatening, and compounds the strain faced by society's most vulnerable groups.

As the most recent report by the Intergovernmental Panel on Climate Change makes clear, we have precious little time to substantially reduce emissions in order to limit future warming to less than 3.6°F (2°C) (IPCC 2018). And as this analysis brings into focus, if we fail to act or act too slowly, the children of today, across swaths of the country, could reach retirement in a world where simply spending time outdoors in the warm months is an intolerably risky health hazard. And for their children, even greater risks would be mounting. The future heat caused by unchecked emissions would bring relentless health emergencies, public health crises, and necessary changes to where, and how, we live.

Ben Stansall/Getty Images

Poised to inherit a potentially stark future, today's youth demand and deserve a response from those whose actions have contributed to a hotter, more dangerous future.

Many consequences of climate change will be difficult to forestall or avoid. But with rapid action, extreme heat is among the most avoidable. Actions we take now to curb warming can help contain the future scale of the problem and bolster our ability to cope and adapt. Every 10th of a degree of warming we prevent globally would mean dangerously hot days avoided on the ground, in our lifetimes.

Our future promises a hotter climate; there is no avoiding that basic outcome. It is not a future the children of the 21st century would choose for themselves. The rest of us chose for them. We now face another choice: to protect what we can of that future and ensure it is recognizable and safe for today's children and youth as they live out their lives. Or to let us all, but especially them, face the gravest consequences of the course we have set. The people who will inhabit and steward this rapidly changing century deserve our hardest, most ambitious work today to hold the line and defend the future.

> ***We now face a choice: to protect what we can of the future for today's children and youth, or to let them face the gravest consequences of the course we have set.***

Methodology

What Models Did We Use in This Analysis?

This analysis uses a set of 18 climate models to project changes in the heat index in the coming decades. Each model was originally developed to cover the whole globe at a low resolution and was part of the fifth Coupled Model Intercomparison Project. Abatzoglou and Brown (2012) then statistically downscaled the models using the Multivariate Adaptive Constructed Analogs method (MACA) to cover the contiguous United States at a much higher resolution and optimized them to best match the climate of the United States. We used these downscaled models in this analysis.

What Emissions Scenarios Did We Use?

Each model was run with two different future emissions scenarios: the no action (RCP 8.5) scenario, under which no substantial reductions in emissions are pursued through late century, and the slow action (RCP 4.5) scenario, under which emissions start to decline around midcentury. To construct the rapid action scenario, we used results from the slow action (RCP 4.5) scenario for the years 2046–2065 from each model, when global average warming is projected to reach 2°C above pre-industrial temperatures (IPCC 2013). Depending on how global emissions change over time, this 2°C future could be reached as early as about 2055 or as late as the year 2100 (IPCC 2018).

How Did We Project Days with Extreme Heat Index Values?

We used daily maximum temperature and daily minimum relative humidity output from the downscaled models to calculate the maximum heat index for each day in the warm season between 2006 and 2099, as these two variables were shown to have the best fit to observations of daily maximum heat index (Dahl et al. 2019).

For each model's daily heat index projections, we calculated the number of days with a heat index above 90°F, 100°F, or 105°F, as well as the number of off-the-charts days for which a heat index cannot be reliably calculated. We then took the average for each model over a 30-year midcentury period, covering the years 2036–2065, and a 30-year late-century period, spanning 2070 to 2099. Finally, we averaged the results from all the models for each time period. The results presented throughout this report represent the multi-model average for each time period and scenario.

What Are the Key Caveats, Limitations, and Assumptions?

This analysis is intended to provide insight into the nature and impacts of extreme heat across the contiguous United States as our climate changes. When applying these results to any location or population, a number of limitations should be considered:

- The heat index is based on physiological assumptions to assess the impacts of hot and humid weather on humans. Variations in clothing thickness, height, weight, age, health, and physical activity are not accounted for in the heat index calculation (Steadman 1979a). The index also does not include wind speed, cloudiness, shade levels, or any other factors, although those are known to affect heat-related impacts.
- The MACA methodology is intended to capture climate extremes. A different climate downscaling technique (e.g., Localized Constructed Analogs) could produce different results.
- The results we report are averages over 30-year periods. Because substantial warming is projected to occur over the course of those periods, the number of extreme heat index days is likely to be lower than the reported averages at the beginning of each 30-year period and higher at the end.
- We present multi-model averages throughout this report. Results from the individual models encompass a range of potential futures for each time period we examined. For more information, see Dahl et al. (2019).
- We have not examined daily minimum heat index, which typically occurs at night and strongly influences incidences of both heat-related illness and heat-related death (Oleson et al. 2015, Basara et al. 2010, Karl and Knight 1997).
- We examine only the total of individual heat days, although the duration of a given heat event is an important factor in shaping an event's resulting health impacts (Guirguis et al. 2013; Anderson and Bell 2011; Meehl 2004). This tends to make our characterization of the health impacts of these results conservative.
- Because the unique characteristics of urban areas and the associated urban heat island effect are not included in the climate models we used in this analysis, our results likely underestimate the number of high heat index days in cities. Similarly, our projections do not consider future urban development or land-cover changes that would influence future heat extremes. This analysis, therefore, likely underestimates the number of high heat index days in cities.
- Statistics for the number of people exposed to extreme heat conditions are based on 2010 Census statistics and assume no growth in population or change in distribution (CIESIN 2017; US Census Bureau 2010a). When tabulating population exposure, we used a gridded, Census-based population dataset (CIESIN 2017).
- We do not consider acclimatization or adaptation. Health impacts are affected by individual acclimatization (physiological adaptation and/or behavioral changes) and external adaptive measures, such as air-conditioning, which can help reduce exposure and vulnerability to heat and lower rates of heat-related illnesses and mortality (Vaidyanathan et al. 2019; USEIA 2018). There are, however, limits to the human ability to adapt to heat (Pal and Eltahir 2016).
- We do not assess different exposures in vulnerable subsegments of the population due to socioeconomic status, lack of resources for adaptation, or physiological inability to acclimatize.

[ENDNOTES]

1. Conditions considered extreme in one place may not be considered extreme in another. For example, a day with a heat index of 105°F would be extreme in Maine, but less so in Arizona. For more information on how extreme heat can be defined, refer to UCS (2018).
2. There are significant efforts currently underway to reduce emissions. However, the no action scenario implies a business-as-usual emissions path in which such emissions reductions are outweighed by increases.
3. US results presented here apply to the 48 contiguous states only.
4. All population statistics presented here are based on 2010 Census data for the contiguous United States. These results assume no growth or movement of the US population from one location to another.
5. The heat index is not the only metric used to measure the effect of heat on the human body. Others include wet-bulb globe temperature, net effective temperature, and humidex, which is used by Canadian meteorologists (WMO and WHO 2015). These metrics all incorporate temperature and humidity in some way, but they differ in how or if they account for other factors, such as radiation and wind speed.
6. In 2018 the NWS Western Region adopted a new approach to measuring heat conditions called HeatRisk, which shifts away from heat index thresholds. HeatRisk provides a continuous seven-day forecast of heat conditions that could affect vulnerable groups and is intended to complement the official NWS heat alert system. HeatRisk accounts for the local significance of a given temperature, time of year, duration of a heat event, and the risk of health-related complications from heat (NWS 2018).
7. Projections based on a suite of climate models are considered more robust than those based on a single model (e.g., Zhao et al. 2015). Even when run with the same conditions, different models will return different results because each climate model is unique. A 30-year period, as used here, is considered a climatological average. Warming trends occur within each 30-year period. Thus, the number of high heat index days will tend to be lower at the start and higher at the end of each 30-year period.
8. See endnote 2.
9. If our current rate of warming continues, global average temperatures would rise to 2°C above pre-industrial levels in the 2060s (IPCC 2018). Aggressive emissions reductions that slow the pace of warming could prevent warming to the 2°C level even by the end of the century.
10. This analysis uses regions of the United States as defined in the Fourth National Climate Assessment (USGCRP 2018). The following states (along with the District of Columbia) are included in each region: Northeast—CT, DC, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, WV; Northern Great Plains—MT, ND, NE, SD, WY; Northwest—ID, OR, WA; Midwest—IA, IL, IN, MI, MN, MO, OH, WI; Southeast—AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA; Southwest—AZ, CA, CO, NM, NV, UT; and Southern Great Plains—KS, OK, TX.
11. Long-term changes in population can be modeled but are difficult to accurately predict. Recent estimates of the number of people exposed to such heat given expected population growth are substantially higher. See, for example, Dahl et al. (2019) and Jones et al. (2015).
12. Midrange population projections suggest that the US population could grow to 447 million by the end of the century—compared with a 2010 population of about 310 million people—which would increase population exposure to extreme heat conditions (Dahl et al. 2019; Jones et al. 2015).
13. This comparison cross-references 2017 Bureau of Economic Affairs employment data with 2010 Census county classifications. "Rural" refers to counties classified as "all rural" in the 2010 Census, and "urban" refers to counties classified as "mostly urban."
14. Heat index calculated for September 11, 2017, and September 12, 2017, using daily maximum temperature and average dew point.
15. A partnership among 10 federal agencies is piloting the adoption of a National Integrated Heat Health Information System (NIHHIS) in a handful of cities across the country. Extending the NIHHIS nationally could lead to better scientific research and science-informed policies and health outcomes.
16. See, for example, Arizona Department of Health Services (2016), EPA (2016), and WHO (2008).
17. A list of existing state programs can be found by visiting *https://liheapch.acf.hhs.gov/tables/cooling.htm*.
18. Even if an official heat emergency is not declared, temperatures may be hot enough to be unsafe for heat-vulnerable populations. Policies should be in place to ensure that they have uninterrupted power, especially to protect low-income households that may struggle to pay bills.
19. See *https://liheapch.acf.hhs.gov/Disconnect/disconnect.htm*.
20. OSHA notes that "[w]orkers performing strenuous activity, workers using heavy or non-breathable protective clothing, and workers who are new to an outdoor job need additional precautions beyond those warranted by heat index alone" and that working in direct sunlight can add up to 15 degrees to the heat index (OSHA n.d.).
21. Currently, the Federal Housing Administration does not require air-conditioning but says only that if an air-conditioning system is present, it must be operational. See NLIHC (2018) for more information.
22. These are plants that are primarily called on during peak power demand periods and release large amounts of local air pollutants in their ramp-up and ramp-down phases (Wisland 2018).
23. The IPCC special report on 1.5°C (IPCC 2018) defines "CDR" as "Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities."

[REFERENCES]

All links accessed June 3, 2019.

Abatzoglou, J.T., and T.J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology* 32(5):772–780. Online at *https://doi.org/10.1002/joc.2312*.

Acosta, R.W. 2009. The pre-travel consultation. In *CDC health information for international travel*, edited by G.W. Brunette, P.E. Kozarsky, A.J. Magill, D.R. Shlim, and A.D. Whatley. Edinburgh: Mosby, 28–32. Online at *https://doi.org/10.1016/B978-070203481-7.50007-4*.

Alber-Wallerström, B., and I. Holmér. 1985. Efficiency of sweat evaporation in unacclimatized man working in a hot humid environment. *European Journal of Applied Physiology and Occupational Physiology* 54(5):480–487. Online at *https://doi.org/10.1007/BF00422956*.

Anderson, G.B., and M.L. Bell. 2011. Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environmental Health Perspectives* 119(2):210–218. Online at *https://doi.org/10.1289/ehp.1002313*.

Andrews, O., C.L. Quéré, T. Kjellstrom, B. Lemke, and A. Haines. 2018. Implications for workability and survivability in populations exposed to extreme heat under climate change: A modelling study. *The Lancet Planetary Health* 2(12):e540–e547. Online at *https://doi.org/10.1016/S2542-5196(18)30240-7*.

Arizona Department of Health Services. 2016. Extreme weather and public health. Online at *www.azdhs.gov/preparedness/epidemiology-disease-control/extreme-weather/index.php*.

Åström, D.O., B. Forsberg, and J. Rocklöv. 2011. Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. *Maturitas* 69(2):99–105. Online at *https://doi.org/10.1016/j.maturitas.2011.03.008*.

Barnett, A.G. 2007. Temperature and cardiovascular deaths in the US elderly: Changes over time. *Epidemiology* 18(3):369–372. Online at *https://doi.org/10.1097/01.ede.0000257515.34445.a0*.

Bar-Or, O. 1994. Children's responses to exercise in hot climates: Implications for performance and health. *Sports Science Exchange*. 7(2). Online at *https://www.gssiweb.org/sports-science-exchange/article/sse-49-children's-responses-to-exercise-in-hot-climates-implications-for-performance-and-health*.

Bartos, M., M. Chester, N. Johnson, B. Gorman, D. Eisenberg, I. Linkov, and M. Bates. 2016. Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. *Environmental Research Letters* 11(11):114008. Online at *https://doi.org/10.1088/1748-9326/11/11/114008*.

Basara, J.B., H.G. Basara, B.G. Illston, and K.C. Crawford. 2010. The impact of the urban heat island during an intense heat wave in Oklahoma City. *Advances in Meteorology*. 2010: article ID 230365. Online at *https://doi.org/10.1155/2010/230365*.

Basu, R., B. Malig, and B. Ostro. 2010. High ambient temperature and the risk of preterm delivery. *American Journal of Epidemiology* 172(10):1108–1117. Online at *https://doi.org/10.1093/aje/kwq170*.

Basu, R., D. Pearson, B. Malig, R. Broadwin, and R. Green. 2012. The effect of high ambient temperature on emergency room visits. *Epidemiology* 23(6):813–820.

Basu, R., V. Sarovar, and B.J. Malig. 2016. Association Between High Ambient Temperature and Risk of Stillbirth in California. *American Journal of Epidemiology* 183(10):894–901. Online at *https://doi.org/10.1093/aje/kwv295*.

Becker, J.A., and L.K. Steward. 2011. Heat-related illness. *American Family Physician* 83(11):1325–1330. Online at *https://www.aafp.org/afp/2011/0601/p1325.html*.

Beker, B.M., C. Cervellera, A. De Vito, and C.G. Musso. 2018. Human physiology in extreme heat and cold. *International Archives of Clinical Physiology* 1(1). Online at *https://doi.org/10.23937/iacph-2017/1710001*.

Berko, J., D.D. Ingram, S. Saha, and J.D. Parker. 2014. Deaths attributed to heat, cold, and other weather events in the United States, 2006–2010. *National Health Statistics Reports* (76):1–15. Online at *https://stacks.cdc.gov/view/cdc/24418*.

Bernstein, A.S., and M.B. Rice. 2013. Lungs in a warming world: Climate change and respiratory health. *Chest* 143(5):1455–1459. Online at *https://doi.org/10.1378/chest.12-2384*.

Bethel, J.W., and R. Harger. 2014. Heat-related illness among Oregon farmworkers. *International Journal of Environmental Research and Public Health* 11(9):9273–9285. Online at *https://doi.org/10.3390/ijerph110909273*.

Borenstein, S., and D. Koenig. 2017. Science says: Why some airplanes don't fly in high heat. Phys.Org, June 20. Online at *https://phys.org/news/2017-06-science-airplanes-dont-high.html*.

Bouchama, A., M. Dehbi, G. Mohamed, F. Matthies, M. Shoukri, and B. Menne. 2007. Prognostic factors in heat wave–related deaths: A meta-analysis. *Archives of Internal Medicine* 167(20):2170–2176. Online at *https://doi.org/10.1001/archinte.167.20.ira70009*.

Braga, A.L.F., A. Zanobetti, and J. Schwartz. 2002. The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities. *Environmental Health Perspectives* 110(9):859–863.

Bunker, A., J. Wildenhain, A. Vandenbergh, N. Henschke, J. Rocklöv, S. Hajat, and R. Sauerborn. 2016. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: A systematic review and meta-analysis of epidemiological evidence. *EBioMedicine* 6(February):258–268. Online at *https://doi.org/10.1016/j.ebiom.2016.02.034*.

Bureau of Economic Affairs (BEA). 2017. Local area personal income accounts, CAEMP25N: Total full-time and part-time employment by NAICS industry. Online at *https://apps.bea.gov/regional/downloadzip.cfm*.

Bureau of Labor Statistics (BLS). 2018 Occupational employment and wages, May 2018: 47-2061 construction laborers. Online at *www.bls.gov/oes/current/oes472061.htm#st*.

Cangialosi, J.P., A.S. Latto, and R. Berg. 2018. *National Hurricane Center tropical cyclone report: Hurricane Irma*. AL112017. Washington, DC: National Oceanic and Atmospheric Administration. Online at *www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf*.

Center for International Earth Science Information Network (CIESIN). 2017. U.S. Census grids: Summary file 1, v1 (2010). Online at *http://sedac.ciesin.columbia.edu/data/set/usgrid-summary-file1-2010*.

Centers for Disease Control and Prevention (CDC). 2017a. Picture of America. Online at *www.cdc.gov/pictureofamerica/index.html*.

Centers for Disease Control and Prevention (CDC). 2017b. Tips for preventing heat-related illness. Online at *www.cdc.gov/disasters/extremeheat/heattips.html*.

Centers for Disease Control and Prevention (CDC). 2012. QuickStats: Number of heat-related deaths, by sex — National Vital Statistics System, United States, 1999–2010. Online at *www.cdc.gov/mmwr/preview/mmwrhtml/mm6136a6.htm*.

Centers for Disease Control and Prevention and Environmental Protection Agency (CDC and EPA). 2016. *Climate change and extreme heat: What you can do to prepare*. Washington, DC: Publisher, 20. Online at *https://archive.epa.gov/epa/sites/production/files/2016-10/documents/extreme-heat-guidebook.pdf*.

Cheeseman Day, J. 2019. Rates of uninsured fall in rural counties, remain higher than urban counties. United States Census Bureau, April 9. Online at *www.census.gov/library/stories/2019/04/health-insurance-rural-america.html*.

Chen, T., S.E. Sarnat, A.J. Grundstein, A. Winquist, and H.H. Chang. 2017. Time-series analysis of heat waves and emergency department visits in Atlanta, 1993 to 2012. *Environmental Health Perspectives* 125(5):057009. Online at *https://doi.org/10.1289/EHP44*.

Choudhary, E., and A. Vaidyanathan. 2014. Heat stress illness hospitalizations—environmental public health tracking program, 20 states, 2001–2010. *Morbidity and Mortality Weekly Report* 63(December):1–10.

Coffel, E., R.M. Horton, and A.M. De Sherbinin. 2017. Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century. *Environmental Research Letters* 13(1):1–9. Online at *https://doi.org/10.7916/D8SF4759*.

Curriero, F.C., K.S. Heiner, J.M. Samet, S.L. Zeger, L. Strug, and J.A. Patz. 2002. Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology* 155(1):80–87.

Dahl, K., R. Licker, J.T. Abatzoglou, and J. Delet-Barreto. 2019. Projections of the frequency of and population exposure to extreme and unprecedented heat index conditions in the contiguous United States during the 21st century. *Environmental Research Communications*. Published ahead of print, July 16, 2019. Online at *https://iopscience.iop.org/article/10.1088/2515-7620/ab27cf*.

Daniel, J.S., J.M. Jacobs, E. Douglas, R.B. Mallick, and K. Hayhoe. 2014. Impact of climate change on pavement performance: Preliminary Lessons learned through the Infrastructure and Climate Network (ICNet). *International Symposium of Climatic Effects on Pavement and Geotechnical Infrastructure 2013*. Online at *https://ascelibrary.org/doi/abs/10.1061/9780784413326.001*.

Davis, R.E., P.C. Knappenberger, P.J. Michaels, and W.M. Novicoff. 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives* 111(14):1712–1718. Online at *https://doi.org/10.1289/ehp.6336*.

Davis, R.E., and W.M. Novicoff. 2018. The impact of heat waves on emergency department admissions in Charlottesville, Virginia, U.S.A. *International Journal of Environmental Research and Public Health* 15(7):1–16. Online at *https://doi.org/10.3390/ijerph15071436*.

Dolney, T. J., and S.C. Sheridan. 2006. The relationship between extreme heat and ambulance response calls for the city of Toronto, Ontario, Canada. *Environmental Research* 101(1):94–103. Online at *https://doi.org/10.1016/j.envres.2005.08.008*.

Donoghue, E.R., M.A. Graham, J.M. Jentzen, B.D. Lifschultz, J.L. Luke, and H.G. Mirchandani. 1997. Criteria for the diagnosis of heat-related deaths: National Association of Medical Examiners. *The American Journal of Forensic Medicine and Pathology* 18(1):11–14.

Dunne, J.P., R.J. Stouffer, and J.G. John. 2013. Reductions in labour capacity from heat stress under climate warming. *Nature Climate Change* 3(6):563–566. Online at *https://doi.org/10.1038/nclimate1827*.

Ebi, K.L., J. Balbus, G. Luber, A. Bole, A. Crimmins, G.E. Glass, S. Saha, M.M. Shimamoto, J.M. Trtanj, and J.L. White-Newsome. 2018. Human health, impacts, risks, and adaptation in the United States. In *Fourth National Climate Assessment*, volume 2, by US Global Change Research Program. Washington, DC, 539–571. Online at *https://doi.org/10.7930/NCA4.2018.CH14*.

Environmental Protection Agency (EPA). 2019. Heat island effect. Online at *www.epa.gov/heat-islands*.

Environmental Protection Agency (EPA). 2016. *Excessive heat events guidebook*. Washington, DC, 60.

Environmental Protection Agency (EPA). 2015. *Climate change in the United States: Benefits of global action*. EPA-430-R-15-001. Washington, DC, 93. Online at *www.epa.gov/cira/downloads-cira-report*.

Fiscella, K., P. Franks, M.R. Gold, and C.M. Clancy. 2000. Inequality in quality: Addressing socioeconomic, racial, and ethnic disparities in health care. *JAMA* 283(19):2579–2584.

Fischer, E.M., K.W. Oleson, and D.M. Lawrence. 2012. Contrasting urban and rural heat stress responses to climate change. *Geophysical Research Letters* 39(3). Online at *https://doi.org/10.1029/2011GL050576*.

Fleischer, N.L., H.M. Tiesman, J. Sumitani, T. Mize, K.K. Amarnath, A.R. Bayakly, and M.W. Murphy. 2013. Public health impact of heat-related illness among migrant farmworkers. *American Journal of Preventive Medicine* 44(3):199–206. Online at *https://doi.org/10.1016/j.amepre.2012.10.020*.

Fussell, E. 2011. The deportation threat dynamic and victimization of Latino migrants: Wage theft and robbery. *The Sociological Quarterly* 52(4):593–615. Online at *https://doi.org/10.1111/j.1533-8525.2011.01221.x*.

García-Trabanino, R., E. Jarquín, C. Wesseling, R. J. Johnson, M. González-Quiroz, I. Weiss, J. Glaser, et al. 2015. Heat stress, dehydration, and kidney function in sugarcane cutters in El Salvador--A cross-shift study of workers at risk of Mesoamerican nephropathy. *Environmental Research* 142 (October): 746–55. Online at *https://doi.org/10.1016/j.envres.2015.07.007*.

Glazer, J.L. 2005. Management of heatstroke and heat exhaustion. *American Family Physician* 71(11):2133–2140. Online at *https://www.aafp.org/afp/2005/0601/p2133.html*.

Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak. 2018. Agriculture and rural communities. In *Fourth National Climate Assessment,* volume 2, edited by D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart. Washington, DC: US Global Change Research Program, 391–437. Online at *https://doi.org/10.7930/NCA4.2018.CH10*.

Grundstein, A., C. Ramseyer, F. Zhao, J.L. Pesses, P.D. Akers, A. Qureshi, L. Becker, J. Knox, and M. Petro. 2010. A retrospective analysis of American football hyperthermia deaths in the United States. *International Journal of Biometeorology* 56(1):11–20. Online at *https://doi.org/10.1007/s00484-010-0391-4*.

Gubernot, D.M., G.B. Anderson, and K.L. Hunting. 2015. Characterizing occupational heat-related mortality in the United States, 2000–2010: An analysis using the Census of fatal occupational injuries database. *American Journal of Industrial Medicine* 58(2):203–211. Online at *https://doi.org/10.1002/ajim.22381*.

Guirguis, K., A. Gershunov, A. Tardy, and R. Basu. 2013. The impact of recent heat waves on human health in California. *Journal of Applied Meteorology and Climatology* 53(1):3–19. Online at *https://doi.org/10.1175/JAMC-D-13-0130.1*.

Hajat, S., B. Armstrong, M. Baccini, A. Biggeri, L. Bisanti, A. Russo, A. Paldy, B. Menne, and T. Kosatsky. 2006. Impact of high temperatures on mortality: Is there an added heat wave effect? *Epidemiology* 17(6):632–638.

Hansen, A., P. Bi, M. Nitschke, P. Ryan, D. Pisaniello, and G. Tucker. 2008. The Effect of heat waves on mental health in a temperate Australian city. *Environmental Health Perspectives* 116(10):1369–1375. Online at *https://doi.org/10.1289/ehp.11339*.

Harlan, S.L., A.J. Brazel, L. Prashad, W.L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine* 63(11):2847–2463. Online at *https://doi.org/10.1016/j.socscimed.2006.07.030*.

Harlan, S.L., P. Chakalian, J. Declet-Barreto, D.M. Hondula, and G.D. Jenerette. 2019. Pathways to climate justice in a desert metropolis. In *People and climate change: Vulnerability, adaptation, and social justice,* edited by L. Reyes Mason and J. Rigg. New York: Oxford University Press. Online at *www.oxfordscholarship.com/view/10.1093/oso/9780190886455.001.0001/oso-9780190886455-chapter-2*.

Harlan, S.L., G. Chowell, S. Yang, D.B. Petitti, E.J. Morales Butler, B.L. Ruddell, and D.M. Ruddell. 2014. Heat-related deaths in hot cities: Estimates of human tolerance to high temperature thresholds. *International Journal of Environmental Research and Public Health* 11(3):3304–3326. Online at *https://doi.org/10.3390/ijerph110303304*.

Harlan, S.L., J.H. Declet-Barreto, W.L. Stefanov, and D.B. Petitti. 2013. Neighborhood effects on heat deaths: Social and environmental predictors of vulnerability in Maricopa County, Arizona. *Environmental Health Perspectives* 121(2):197–204. Online at *https://doi.org/10.1289/ehp.1104625*.

Hawkins, M.D., V. Brown, and J. Ferrell. 2017. Assessment of NOAA National Weather Service methods to warn for extreme heat events. *Weather, Climate, and Society* 9(1):5–13. Online at *https://doi.org/10.1175/WCAS-D-15-0037.1*.

Hayden, M.H., H. Brenkert-Smith, and O.V. Wilhelmi. 2011. Differential adaptive capacity to extreme heat: A Phoenix, Arizona, case study. *Weather, Climate, and Society* 3(4):269–280. Online at *https://doi.org/10.1175/WCAS-D-11-00010.1*.

Hayden, M.H., O.V. Wilhelmi, D. Banerjee, T. Greasby, J.L. Cavanaugh, V. Nepal, J. Boehnert, S. Sain, C. Burghardt, and S. Gower. 2017. Adaptive capacity to extreme heat: Results from a household survey in Houston, Texas. Weather, Climate, and Society 9:787–799. Online at *https://journals.ametsoc.org/doi/10.1175/WCAS-D-16-0125.1*.

Hess, J. J., and K.L. Ebi. 2016. Iterative management of heat early warning systems in a changing climate. *Annals of the New York Academy of Sciences* 1382(1):21–30. Online at *https://doi.org/10.1111/nyas.13258*.

Hess, J.J., S. Saha, and G. Luber. 2014. Summertime acute heat illness in U.S. emergency departments from 2006 through 2010: Analysis of a nationally representative sample. *Environmental Health Perspectives* 122(11):1209–1215. Online at *https://doi.org/10.1289/ehp.1306796*.

Holsinger, H. 2017. Preparing for change. Public Roads 80(4): January/February 2017. Online at *www.fhwa.dot.gov/publications/publicroads/17janfeb/05.cfm*.

Hunt, A. P., D.C. Billing, M.J. Patterson, and J.N. Caldwell. 2016. Heat strain during military training activities: The dilemma of balancing force protection and operational capability. *Temperature: Multidisciplinary Biomedical Journal* 3(2):307–317. Online at *https://doi.org/10.1080/23328940.2016.1156801*.

Intergovernmental Panel on Climate Change (IPCC). 2018. *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emissions pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, 32.

Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate change 2013: The physical science basis*. Online at *www.ipcc.ch/report/ar5/wg1*.

International Institute for Applied Systems Analysis (IIASA). 2009. RCP database (version 2.0). 2009. Online at *www.iiasa.ac.at/web-apps/tnt/RcpDb*.

Iowa State University. 2019. Iowa environmental mesonet daily feature. Online at *https://mesonet.agron.iastate.edu*.

Issa, A., K. Ramadugu, P. Mulay, J. Hamilton, V. Siegel, C. Harrison, C.M. Campbell, C. Blackmore, T. Bayleyegn, and T. Boehmer. 2018. Deaths related to Hurricane Irma—Florida, Georgia, and North Carolina, September 4–October 10, 2017. *Morbidity and Mortality Weekly Report* 67(30):829–832. Online at *https://doi.org/10.15585/mmwr.mm6730a5*.

Jacklitsch, B., W.J. Williams, K. Musolin, A. Coca, J.-H. Kim, and N. Turner. 2016. *Criteria for a recommended standard: Occupational exposure to heat and hot environments*. Publication 2016-106. Cincinnati, OH: US Department of Health and Human Services, Centers for Disease Control and Prevention, and National Institute for Occupational Safety and Health. Online at *www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf*.

Jackson, L.L., and H.R. Rosenberg. 2010. Preventing heat-related illness among agricultural workers. *Journal of Agromedicine* 15(3):200–215. Online at *https://doi.org/10.1080/1059924X.2010.487021*.

Jacob, D.J., and D.A. Winner. 2009. Effect of climate change on air quality. *Atmospheric Environment* 43(1):51–63. Online at *https://doi.org/10.1016/j.atmosenv.2008.09.051*.

Jones, B., and B.C. O'Neill. 2013. Historically grounded spatial population projections for the continental United States. *Environmental Research Letters* 8(4):044021. Online at *https://doi.org/10.1088/1748-9326/8/4/044021*.

Jones, B., B.C. O'Neill, L. McDaniel, S. McGinnis, L.O. Mearns, and C. Tebaldi. 2015. Future population exposure to US heat extremes. *Nature Climate Change* 5(7):652–655. Online at *https://doi.org/10.1038/nclimate2631*.

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. Online at *https://doi.org/10.1175/1520-0477(1996)077<1519:TPHWHW>2.0.CO;2*.

Karl, T.R., and R.W. Knight. 1997. The 1995 Chicago heat wave: How likely is a recurrence? *Bulletin of the American Meteorological Society* 78(6):1107–1120. Online at *https://doi.org/10.1175/1520-0477(1997)078<1107:TCHWHL>2.0.CO;2*.

Key, N., S. Sneeringer, and D. Marquardt. 2014. *Climate change, heat stress, and US dairy production*. Washington DC: US Department of Agriculture. Online at *www.ers.usda.gov/webdocs/publications/45279/49164_err175.pdf?v=41913*.

Kjellstrom, T., D. Briggs, C. Freyberg, B. Lemke, M. Otto, and O. Hyatt. 2016. Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. *Annual Review of Public Health* 37(1):97–112. Online at *https://doi.org/10.1146/annurev-publhealth-032315-021740*.

Klinenberg, E. 2002. *Heat wave: A social autopsy of disaster in Chicago*, second edition. University of Chicago. Press.

Le Quéré, C., R. Moriarty, R.M. Andrew, J.G. Canadell, S. Sitch, J.I. Korsbakken, P. Friedlingstein, G.P. Peters, R.J. Andres, T.A. Boden, R.A. Houghton, J.I. House, R.F. Keeling, P. Tans, A. Arneth, D.C.E. Bakker, L. Barbero, L. Bopp, J. Chang, F. Chevallier, L.P. Chini, P. Ciais, M. Fader, R.A. Feely, T. Gkritzalis, I. Harris, J. Hauck, T. Ilyina, A.K. Jain, E. Kato, V. Kitidis, K. Klein Goldewijk, C. Koven, P. Landschützer, S.K. Lauvset, N. Lefèvre, A. Lenton, I.D. Lima, N. Metzl, F. Millero, D.R. Munro, A. Murata, J.E.M.S. Nabel, S. Nakaoka, Y. Nojiri, K. O'Brien, A. Olsen, T. Ono, F.F. Pérez, B. Pfeil, D. Pierrot, B. Poulter, G. Rehder, C. Rödenbeck, S. Saito, U. Schuster, J. Schwinger, R. Séférian, T. Steinhoff, B.D. Stocker, A.J. Sutton, T. Takahashi, B. Tilbrook, I.T. van der Laan-Luijkx, G.R. van der Werf, S. van Heuven, D. Vandemark, N. Viovy, A. Wiltshire, S. Zaehle, and N. Zeng. 2015. Global carbon budget 2015. *Earth System Science Data* 7(2):349–396. Online at *https://doi.org/10.5194/essd-7-349-2015*.

Li, M., S. Gu, P. Bi, J. Yang, and Q. Liu. 2015. Heat waves and morbidity: Current knowledge and further direction—a comprehensive literature review. *International Journal of Environmental Research and Public Health* 12(5):5256–5283. Online at *https://doi.org/10.3390/ijerph120505256*.

Lilley, K. 2017. Heat Illness remains "significant threat" to troops, despite warnings and guidance. *Military Times*, August 8. Online at *www.militarytimes.com/off-duty/military-fitness/2017/07/19/heat-illness-remains-significant-threat-to-troops-despite-warnings-and-guidance*.

Lindsey, R. 2018. Extreme overnight heat in California and the Great Basin in July 2018. NOAA Climate.Gov, August 8. Online at *www.climate.gov/news-features/event-tracker/extreme-overnight-heat-california-and-great-basin-july-2018*.

Lobell, D.B., G.L. Hammer, G. McLean, C. Messina, M.J. Roberts, and W. Schlenker. 2013. The critical role of extreme heat for maize production in the United States. *Nature Climate Change* 3:497–501. Online at *www.nature.com/articles/nclimate1832#ref1*.

Low Income Home Energy Assistance Program (LIHEAP). 2019. State disconnection policies. Online at *https://liheapch.acf.hhs.gov/Disconnect/disconnect.htm*.

Luber, G., and M. McGeehin. 2008. Climate change and extreme heat events. *American Journal of Preventive Medicine* 35(5):429–435. Online at *https://doi.org/10.1016/j.amepre.2008.08.021*.

Lugo-Amador, N.M., T. Rothenhaus, and P. Mouyer. 2004. Heat-related illness. *Emergency Medicine Clinics of North America* 22:315–327. Online at *https://doi.org/10.1016/j.emc.2004.01.004*.

Magill, D., A.M. Kaspar, and M.S. Kozdras. 2014. Calibrated bypass structure for heat exchanger. Online at *https://patents.google.com/patent/US8857503B2/en*.

Mares, D. 2013. Climate change and levels of violence in socially disadvantaged neighborhood groups. *Journal of Urban Health* 90(4):768–783. Online at *https://doi.org/10.1007/s11524-013-9791-1*.

Maricopa County Public Health. 2017. Heat reports. Online at *www.maricopa.gov/1858/Heat-Surveillance*.

Martin Perera, E., and T. Sanford. 2011. *Climate change and your health: Rising temperatures, worsening ozone pollution*. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/climate-change-and-ozone-pollution.pdf*.

Masters, J. 2018. Africa's hottest reliably measured temperature on record: 124.3°F on Thursday in Algeria. Weather Underground, July 6. Online at *www.wunderground.com/cat6/Africas-Hottest-Reliably-Measured-Temperature-Record-1243F-Thursday-Algeria*.

Mastrangelo, G., U. Fedeli, C. Visentin, G. Milan, E. Fadda, and P. Spolaore. 2007. Pattern and determinants of hospitalization during heat waves: An ecologic study. *BMC Public Health* 7(August):200. Online at *https://doi.org/10.1186/1471-2458-7-200*.

McNamara, J., M. Jacobs, and L. Wisland. 2017. *Flipping the switch for a cleaner grid*. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/clean-energy/increase-renewable-energy/time-varying-rates*.

Medina-Ramón, M., A. Zanobetti, D.P. Cavanagh, and J. Schwartz. 2006. Extreme temperatures and mortality: Assessing effect modification by personal characteristics and specific cause of death in a multi-city case-only analysis. *Environmental Health Perspectives* 114(9):1331–1336. Online at *https://doi.org/10.1289/ehp.9074*.

Meehl, G.A. 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. *Science* 305(5686):994–97. Online at *https://doi.org/10.1126/science.1098704*.

Miller, B., and M. Park. 2018. Heat wave turns deadly and is expected to last through the Fourth of July. CNN, July 3. Online at *www.cnn.com/2018/07/03/us/heat-wave-wxc/index.html*.

Morris, C.E., R.G. Gonzales, M.J. Hodgson, and A.W. Tustin. 2019. Actual and simulated weather data to evaluate wet bulb globe temperature and heat index as alerts for occupational heat-related illness. *Journal of Occupational and Environmental Hygiene* 16(1):54–65. Online at *https://doi.org/10.1080/15459624.2018.1532574*.

NAACP. 2017. Lights out in the cold: Reforming utility shut-off policies as if human rights matter. Online at *www.naacp.org/climate-justice-resources/lights-out-in-the-cold*.

National Academies of Sciences, Engineering, Medicine (NAS). 2018. National Academies launching new study on sunlight-reflection research. Online at *www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=10162018*.

National Low Income Housing Coalition (NLIHC). 2018. HUD issues guidance on HOTMA minimum heating standards in public housing. Online at *https://nlihc.org/resource/hud-issues-guidance-hotma-minimum-heating-standards-public-housing*.

National Oceanic and Atmospheric Administration (NOAA). 2019. *Building a weather-ready nation: 2019–2022 strategic plan*. Washington, DC: US Department of Commerce. Online at *https://www.weather.gov/media/wrn/NWS_Weather-Ready-Nation_Strategic_Plan_2019-2022.pdf*.

National Research Council (NRC). 2015. *Climate intervention: Reflecting sunlight to cool Earth*. Washington, DC: The National Academies Press. Online at *https://doi.org/10.17226/18988*.

National Weather Service (NWS). 2018. 79-year list of severe weather fatalities. Online at *https://www.nws.noaa.gov/om/hazstats/resources/79years.pdf*.

National Weather Service (NWS). 1984. Transmittal memorandum for operations manual issuance 84-11, July 11. Silver Spring, MD. Online at *https://web.archive.org/web/20020823043407/http:/www.nws.noaa.gov/wsom/manual/archives/NC118411.HTML#z12*.

National Weather Service (NWS). No date a. Heat index. Online at *www.weather.gov/safety/heat-index*.

National Weather Service (NWS). No date b. Heat watch vs. warning. Online at *www.weather.gov/safety/heat-ww*.

New Hampshire Division of Public Health Services (NHDPHS). No date. Understanding the impacts of heat on health. Online at *www.nh.gov/epht/highlights/documents/heat-success-story.pdf*.

Nordio, F., A. Zanobetti, E. Colicino, I. Kloog, and J. Schwartz. 2015. Changing patterns of the temperature—mortality association by time and location in the US, and implications for climate change. *Environment International* 81(August):80–86. Online at *https://doi.org/10.1016/j.envint.2015.04.009*.

North, S. 2016. Agricultural workers and extreme heat in the age of climate change. *US Climate and Health Alliance*. Blog. August 12. Online at *http://usclimateandhealthalliance.org/agricultural-workers-extreme-heat-age-climate-change*.

Occupational Safety and Health Administration (OSHA). No date. About the heat index. Online at *www.osha.gov/SLTC/heatillness/heat_index/about.html*.

Oleson, K.W., A. Monaghan, O. Wilhelmi, M. Barlage, N. Brunsell, J. Feddema, L. Hu, and D.F. Steinhoff. 2015. Interactions between urbanization, heat stress, and climate change. *Climatic Change* 129(3):525–541. Online at *https://doi.org/10.1007/s10584-013-0936-8*.

Pal, J.S., and E.A.B. Eltahir. 2016. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change* 6:197–200.

Palmer, E. 2018. Heat wave continues across U.S. as death toll climbs. Newsweek, July 4. Online at *www.newsweek.com/heat-wave-continues-across-us-death-toll-climbs-1008162*.

Phoenix. 2019. Phoenix summer heat safety. Online at *www.phoenix.gov/pio/summer/heat*.

Pitofsky, M. 2018. Historic, deadly heat wave slams Japan with blistering temperatures headed into August. *USA Today*, July 24. Online at *www.usatoday.com/story/news/world/2018/07/24/japan-record-heat-tokyo-kumagaya/825549002*.

Reid, C.E., M.S. O'Neill, C.J. Gronlund, S.J. Brines, D.G. Brown, A.V. Diez-Roux, and J. Schwartz. 2009. Mapping community determinants of heat vulnerability. *Environmental Health Perspectives* 117(11):1730–1736. Online at *https://doi.org/10.1289/ehp.0900683*.

Rogelj, J., G. Luderer, R.C. Pietzcker, E. Kriegler, M. Schaeffer, V. Krey, and K. Riahi. 2015. Energy system transformations for limiting end-of-century warming to below 1.5°C. *Nature Climate Change* 5(6):519–527. Online at *https://doi.org/10.1038/nclimate2572*.

Rogers Gibson, J. 2017. *Built to last: Challenges and opportunities for climate-smart infrastructure in California*. Cambridge, MA: Union of Concerned Scientists.

Rosenbaum, S., P. Shin, Center for Health Services Research and Policy, and The George Washington University. 2005. *Migrant and seasonal farmworkers: Health insurance coverage and access to care*. Oakland, CA: Kaiser Family Foundation. Online at *www.kff.org/medicaid/report/migrant-and-seasonal-farmworkers-health-insurance-coverage*.

Rosenzweig, C., W.D. Solecki, L. Parshall, M. Chopping, G. Pope, and R. Goldberg. 2005. Characterizing the urban heat island in current and future climates in New Jersey. *Global Environmental Change Part B: Environmental Hazards* 6(1):51–62. Online at *https://doi.org/10.1016/j.hazards.2004.12.001*.

Rosman, J. 2017. What happens to our bodies when it's hot out? Oregon Public Broadcasting, August 3. Online at *www.opb.org/news/article/hot-tempatures-portland-body-heat-what-happens*.

Rowan, E., C. Evans, M. Riley-Gilbert, R. Hyman, R. Kafalenos, B. Beucler, B. Rodehorst, A. Choate, and P. Schultz. 2013. Assessing the sensitivity of transportation assets to extreme weather events and climate change. *Transportation Research Record* 2326(1):16–23. Online at *https://doi.org/10.3141/2326-03*.

Rowland, T. 2008. Thermoregulation during exercise in the heat in children: Old concepts revisited. *Journal of Applied Physiology* 105:718–724. Online at *https://doi.org/10.1152/japplphysiol.01196.2007*.

Salamanca, F., M. Georgescu, A. Mahalov, M. Moustaoui, and M. Wang. 2014. Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres* 119(10):5949–5965. Online at *https://doi.org/10.1002/2013JD021225*.

Schinasi, L.H., and G.B. Hamra. 2017. A time series analysis of associations between daily temperature and crime events in Philadelphia, Pennsylvania. *Journal of Urban Health: Bulletin of the New York Academy of Medicine* 94(6):892–900. Online at *https://doi.org/10.1007/s11524-017-0181-y*.

Schmeltz, M.T., and J.L. Gamble. 2017. Risk Characterization of hospitalizations for mental illness and/or behavioral disorders with concurrent heat-related illness. *PlOS One* 12(10):e0186509. Online at *https://doi.org/10.1371/journal.pone.0186509*.

Schmeltz, M.T., E.P. Petkova, and J.L. Gamble. 2016. Economic burden of hospitalizations for heat-related illnesses in the United States, 2001–2010. *International Journal of Environmental Research and Public Health* 13:894. Online at https:/*/doi:10.3390/ijerph13090894*.

Schmeltz, M.T., G. Sembajwe, P.J. Marcotullio, J.A. Grassman, D.U. Himmelstein, and S. Woolhandler. 2015. Identifying individual risk factors and documenting the pattern of heat-related illness through analyses of hospitalization and patterns of household cooling. *PloS One* 10(3):e0118958. Online at *https://doi.org/10.1371/journal.pone.0118958*.

Seltenrich, N. 2015. Between extremes: Health effects of heat and cold. *Environmental Health Perspectives* 123(11):A275-A280. Online at *https://doi.org/10.1289/ehp.123-A275*.

Semenza, J.C., J.E. McCullough, W.D. Flanders, M.A. McGeehin, and J.R. Lumpkin. 1999. Excess hospital admissions during the July 1995 heat wave in Chicago. *American Journal of Preventive Medicine* 16(4):269–277. Online at *https://doi.org/10.1016/S0749-3797(99)00025-2*.

Sheridan, S.C., and S. Lin. 2014. Assessing variability in the impacts of heat on health outcomes in New York City over time, season, and heat-wave duration. *EcoHealth* 11(4):512–525. Online at *https://doi.org/10.1007/s10393-014-0970-7*.

Solecki, W.D., C. Rosenzweig, L. Parshall, G. Pope, M. Clark, J. Cox, and M. Wiencke. 2005. Mitigation of the heat island effect in urban New Jersey. *Global Environmental Change Part B: Environmental Hazards* 6(1):39–49. Online at *https://doi.org/10.1016/j.hazards.2004.12.002*.

Spanger-Siegfried, E., J. Funk, R. Cleetus, M. Deas, and J. Christian-Smith. 2016. *Toward climate resilience: A framework and principles for science-based adaptation*. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/global-warming/science-and-impacts/impacts/climate-resilience-framework-and-principles*.

Steadman, R.G. 1979a. The assessment of sultriness: Part I: A temperature-humidity index based on human physiology and clothing science. *Journal of Applied Meteorology* 18(7):861–873. Online at *https://doi.org/10.1175/1520-0450(1979)018<0861:TAOSPI>2.0.CO;2.*

Steadman, R.G. 1979b. The assessment of sultriness. Part II: Effects of wind, extra radiation and barometric pressure on apparent temperature. *Journal of Applied Meteorology* 18(7):874–885. Online at *https://doi.org/10.1175/1520-0450(1979)018<0874:TAOSPI>2.0.CO;2.*

Stillman, J.H. 2019. Heat waves, the new normal: Summertime temperature extremes will impact animals, ecosystems, and human communities. *Physiology* 34(2):86–100. Online at *https://doi.org/10.1152/physiol.00040.2018.*

Stöllberger, C., W. Lutz, and J. Finsterer. 2009. Heat-related side-effects of neurological and non-neurological medication may increase heatwave fatalities. *European Journal of Neurology* 16(7):879–882. Online at *https://doi.org/10.1111/j.1468-1331.2009.02581.x.*

Stone, B., J.J. Hess, and H. Frumkin. 2010. Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? *Environmental Health Perspectives* 118(10):1425–1428. Online at *https://doi.org/10.1289/ehp.0901879.*

Stone, W. 2019. Phoenix tries to reverse its "silent storm" of heat deaths. NPR, July 9. Online at *www.npr.org/2018/07/09/624643780/phoenix-tries-to-reverse-its-silent-storm-of-heat-deaths.*

Talati, S. 2019. Confronting solar geoengineering: What you need to know. Cambridge, MA: Union of Concerned Scientists. Blog, April 5. Online at *https://blog.ucsusa.org/shuchi-talati/solar-geoengineering-what-you-need-to-know.*

Tree People. 2019. Los Angeles Urban Cooling Collaborative. Online at *www.treepeople.org/urbancooling.*

Union of Concerned Scientists (UCS). 2019. UCS position on solar geoengineering. Online at *www.ucsusa.org/sites/default/files/attach/2019/gw-position-Solar-Geoengineering-022019.pdf.*

Union of Concerned Scientists (UCS). 2018. Heat waves and climate change: What the science tells us about extreme heat events. Online at *www.ucsusa.org/our-work/global-warming/global-warming-impacts/heat-waves-and-climate-change-what-science-tells-us.*

Union of Concerned Scientists (UCS). 2017. What is climate engineering? Online at *www.ucsusa.org/global_warming/science_and_impacts/science/climate-engineering.*

Union of Concerned Scientists (UCS). 2016. Clean car standards resource center. Online at *www.ucsusa.org/clean-vehicles/fuel-efficiency/clean-car-standards.html.*

United Nations Framework Convention on Climate Change (UNFCCC). 2015. The Paris agreement. Online at *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.*

University Corporation for Atmospheric Research (UCAR). 2011. Urban heat islands. Online at *https://scied.ucar.edu/longcontent/urban-heat-islands.*

US Census Bureau. 2019. 2010 Census urban and rural classification and urban area criteria. Online at *www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2010-urban-rural.html.*

US Census Bureau. 2017. Maricopa County added over 222 people per day in 2016. Online at *www.census.gov/newsroom/press-releases/2017/cb17-44.html.*

US Census Bureau. 2010a. Decennial Census datasets. Online at *www.census.gov/programs-surveys/decennial-census/data/datasets.html.*

US Census Bureau. 2010b. County rurality level: 2010. Online at *www2.census.gov/geo/docs/reference/ua/County_Rural_Lookup.xlsx.*

US Energy Information Administration (USEIA). 2018. One in three U.S. households faces a challenge in meeting energy needs. Online at *www.eia.gov/todayinenergy/detail.php?id=37072.*

US Energy Information Administration (USEIA). 2017. *What's new in how we use energy at home: Results from EIA's 2015 Residential Energy Consumption Survey (RECS)*. Washington, DC: US Department of Energy. Online at *www.eia.gov/consumption/residential/reports/2015/overview/pdf/whatsnew_home_energy_use.pdf.*

US Geological Survey (USGS). No date. California's Central Valley. Online at *https://ca.water.usgs.gov/projects/central-valley/about-central-valley.html.*

US Global Change Research Program (USGCRP). 2018. *Fourth national climate assessment*: *Impacts, risks, and adaptation in the United States,* volume 2. Washington, DC. Online at *https://nca2018.globalchange.gov.*

US Global Change Research Program (USGCRP). 2017. *Climate science special report: Fourth national climate assessment,* volume 1. Washington, DC. Online at *http://doi.org/10.7930/J0J964J6.*

Vaidyanathan, A., S. Saha, A.M. Vicedo-Cabrera, A. Gasparrini, N. Abdurehman, R. Jordan, M. Hawkins, J. Hess, and A. Elixhauser. 2019. Assessment of extreme heat and hospitalizations to inform early warning systems. *Proceedings of the National Academy of Sciences* 116(12):5420–5427. Online at *https://doi.org/10.1073/pnas.1806393116.*

Vaidyanathan, A., A.M. Vicedo-Cabrera, N. Abdurehman, F. Sera, and A. Gasparrini. 2018. The relationship between extreme heat and cardiovascular mortality: Assessing effect modification by social vulnerability metrics. ISEE Conference Abstracts. Online at *https://ehp.niehs.nih.gov/doi/10.1289/isesisee.2018.O02.03.09.*

Van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S.J. Smith, and S.K. Rose. 2011. The representative concentration pathways: An overview. *Climatic Change* 109(1–2):5. Online at *https://doi.org/10.1007/s10584-011-0148-z*.

Watts, J.D., and L.S. Kalkstein. 2004. The development of a warm-weather relative stress index for environmental applications. *Journal of Applied Meteorology* 43(3):503–513. Online at *https://doi.org/10.1175/1520-0450(2004)043<0503:TDOAWR>2.0.CO;2*.

Weather Underground. 2017. Fort Lauderdale weather history. Online at *www.wunderground.com/history/daily/us/fl/fort-lauderdale/KFLL/date/2017-9-11*.

Wellenius, G.A., M.N. Eliot, K.F. Bush, D. Holt, R.A. Lincoln, A.E. Smith, and J. Gold. 2017. Heat-related morbidity and mortality in New England: Evidence for local policy. *Environmental Research* 156(July):845–853. Online at *https://doi.org/10.1016/j.envres.2017.02.005*.

Westaway, K., O. Frank, A. Husband, A. McClure, R. Shute, S. Edwards, J. Curtis, and D. Rowett. 2015. Medicines can affect thermoregulation and accentuate the risk of dehydration and heat-related illness during hot weather. *Journal of Clinical Pharmacy and Therapeutics* 40(4):363–367. Online at *https://doi.org/10.1111/jcpt.12294*.

White House. 2016. *United States mid-century strategy for deep decarbonization*. Washington, D.C. Online at *https://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf*.

Wisland, L. 2018. *Turning down the gas in California*. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/sites/default/files/attach/2018/07/Turning-Down-Natural-Gas-California-fact-sheet.pdf*.

World Health Organization (WHO). 2008. Heat–health action plans. Online at *www.euro.who.int/__data/assets/pdf_file/0006/95919/E91347.pdf*.

World Meteorological Organization and World Health Organization (WMO and WHO). 2015. *Heatwaves and health: Guidance on warning-system development*. Geneva, Switzerland.

Xu, Z., R.A. Etzel, H. Su, C. Huang, Y. Guo, and S. Tong. 2012. Impact of ambient temperature on children's health: A systematic review. *Environmental Research* 117(August):120–131. Online at *https://doi.org/10.1016/j.envres.2012.07.002*.

Zhang, K., T.-H. Chen, and C.E. Begley. 2015. Impact of the 2011 heat wave on mortality and emergency department visits in Houston, Texas. *Environmental Health* 14(1):11. Online at *https://doi.org/10.1186/1476-069X-14-11*.

Zhao, Y., A. Ducharne, B. Sultan, P. Braconnot, and R. Vautard. 2015. Estimating heat stress from climate-based indicators: Present-day biases and future spreads in the CMIP5 global climate model ensemble. *Environmental Research Letters* 10:084013. Online at *https://doi.org/10.1088/1748-9326/10/8/084013*.

Killer Heat in the United States

Climate Choices and the Future of Dangerously Hot Days

> ***We must act decisively to cut heat-trapping emissions to defend ourselves against a gravely hot future.***

Extreme heat events have killed more people in the United States over the last 30 years than cold snaps, floods, hurricanes, or tornadoes. As global temperatures rise, driven by societies' heat-trapping emissions, the health, lives, and livelihoods of people across the country will be threatened by more frequent and intense episodes of dangerous heat each year. Some heat conditions will be so extreme they will exceed the calculable "feels like" temperature range used by the National Weather Service—they'll be literally off the charts.

The Union of Concerned Scientists has projected the frequency of extremely hot days for the middle and end of this century across the contiguous United States. The analyses are based on the choices before us: to act decisively to cut emissions, to wait until midcentury to act, or to do nothing at all. Failure to act now would result in a future unrecognizably hot to today's adults—one in which swaths of the country would become too hot too often to safely go about daily life. By swiftly and aggressively reducing emissions, we can avoid the gravest consequences and ensure a future that, while warmer, is safer for today's children as they live out their lives.

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