Union of Concerned Scientists

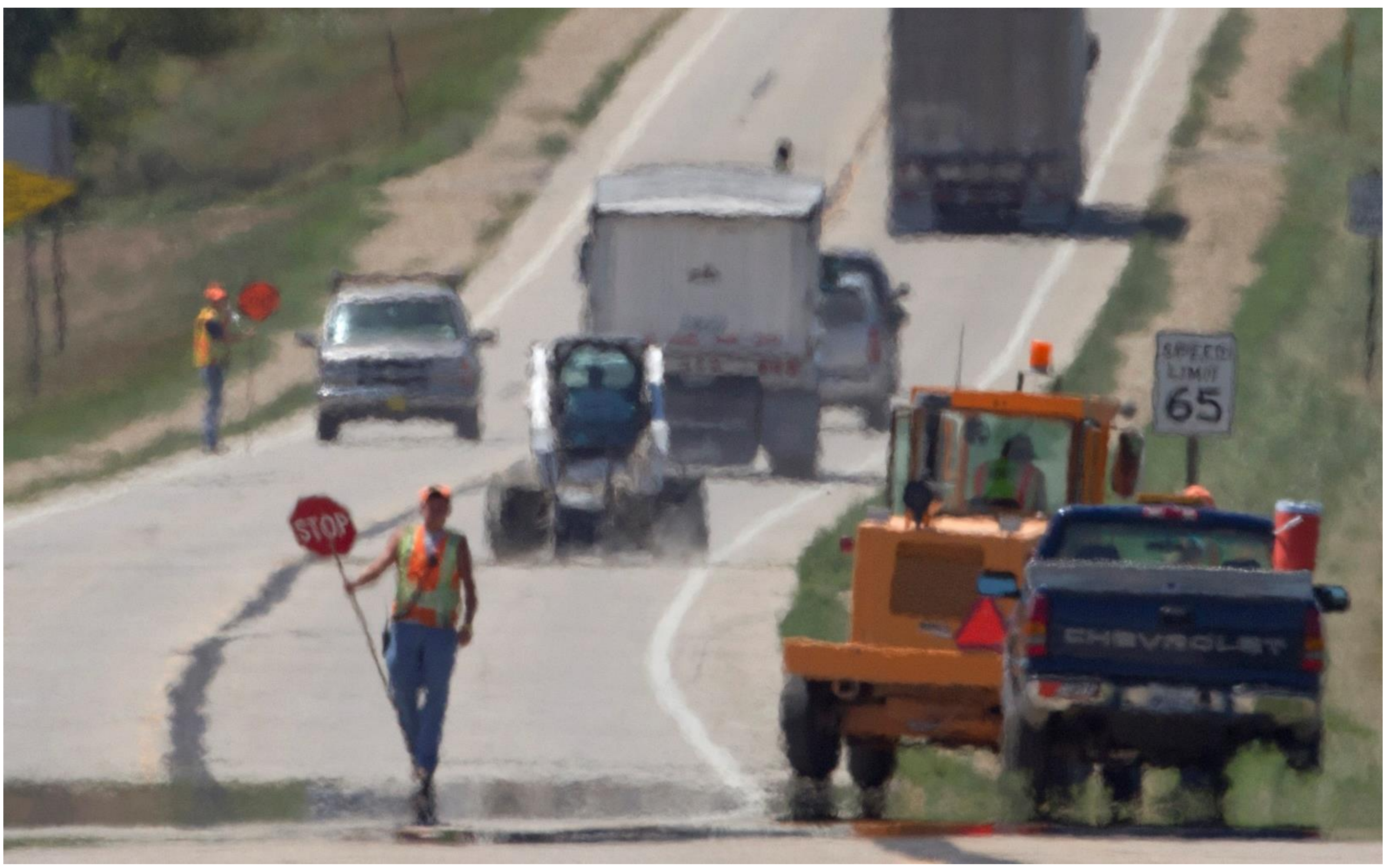
FACT SHEET

Heat Waves and Climate Change

What the Science Tells Us about Extreme Heat Events

Heat waves are a familiar phenomenon to many of us in the United States. But as climate change makes these heat waves more routine, and more severe, they are likely to become increasingly disruptive and dangerous to our daily lives. When temperatures rise to extreme levels, calls to emergency medical services increase, schools without air conditioning cancel classes, energy use increases to keep indoor spaces cool and electricity grids are strained to meet that demand, and heat-related illness—or even death—threatens the elderly, the very young, those who work outdoors, and those unable to afford or access cooling.

During the spring and summer of 2012, much of the contiguous United States—particularly the eastern half—experienced a catastrophic, prolonged heat wave (Figure 1; Cattiaux and Yiou 2013). The extreme heat directly caused 123 deaths and contributed to an additional—though unquantified—number of fatalities by, for example, exacerbating pre-existing health conditions (NCEI 2018; Berko et al. 2014). Extreme temperatures and the associated drought resulted in $33 billion in losses to individuals, businesses, and public assets (NCEI 2018). Corn production dropped by more than 10 percent compared to the previous year, sending global crop prices



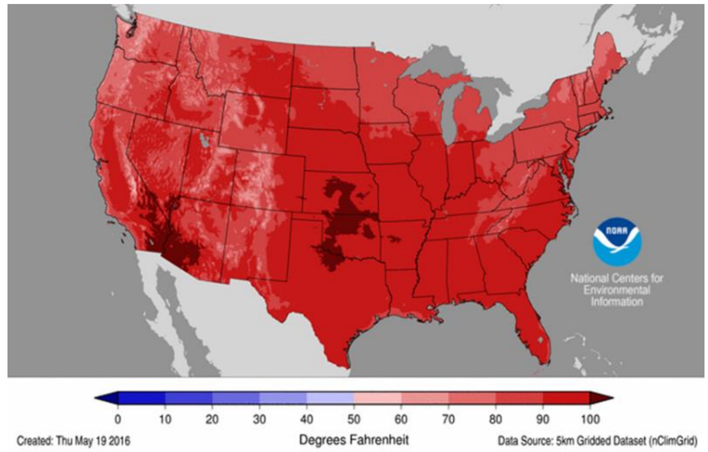
The frequency and intensity of heat waves have grown across the United States over the last five decades, increasing heat-related health risks for many US residents. Construction workers are disproportionately exposed to heat-stress conditions, such as this crew working on a section of highway US 59 in Norton, Kansas, amidst the 2012 heat wave. Source: Orlin Wagner/AP.

soaring to record levels (USDA 2013; Plume and Zabarenko 2012) and causing losses to the US beef industry with high feed prices (Stewart 2012). The heat and drought set the stage for expansive, destructive wildfires with more than 9 million acres burning across the country (NCEI 2013).

With record-breaking heat waves becoming increasingly common (Habeeb, Vargo, and Stone 2015) and changes in temperature extremes already palpable, we find ourselves questioning with each heat wave whether this is the new normal. The number of dangerously hot summer days has increased over large and small Midwestern cities like Cincinnati, Ohio, and Peoria, Illinois, since the 1940s and 1950s (Martin Perera et al. 2012). Climate change has made the extreme heat waves we are already experiencing more likely to happen and is projected to make heat waves even hotter and more frequent in the future (Vose et al. 2017; Diffenbaugh and Scherer 2013; Knutson, Zeng, and Wittenberg 2013).

This fact sheet summarizes the latest science on how (and where) extreme heat events have increased and are likely to keep increasing as global temperatures rise. It also outlines how those changes could be curtailed if we take action to reduce heat-trapping emissions. See the companion fact sheet for an exploration of the current and potential impacts of extreme heat on people at *www.ucsusa.org/extremeheat*.

FIGURE 1. Average Daily High Temperatures During the July 2012 Heat Wave



Average daily maximum temperatures (°F) for July 2012 across the contiguous United States exceeded 90°F in most parts of the country.

SOURCE: NOAA 2016.

Extreme Heat Basics

"Heat wave," "excessive heat event," "heat advisory," "hot spell"—extreme heat has many different names. For the purposes of this fact sheet, extreme heat refers to temperatures that are either exceptionally high relative to typical local conditions or reach levels that may be harmful to human health or infrastructure.

Temperature typically follows a daily cycle. Temperatures increase after sunrise, peak during the afternoon hours, continue to decline after sunset, and typically reach the daily low point during the night. When extreme daytime temperatures persist over a prolonged period (usually at least two days), it is often referred to as a heat wave (NWS n.d. a).

The impacts of temperature extremes on human health and wellbeing are generally considered in concert with humidity to measure heat stress conditions: those in which the human body has difficulty cooling itself (CDC 2017). When exposed to high temperatures, the human body sweats to release heat. When exposed to high humidity as well, that sweat does not evaporate as quickly and the body's ability to cool itself is compromised. Heat stress can result and, if not addressed, can lead to heat-related illnesses like heat exhaustion and heat stroke.

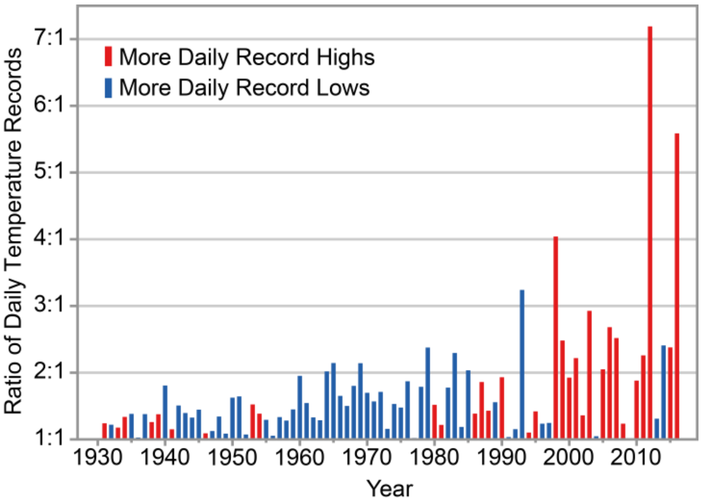
To warn people of anticipated or ongoing heat stress conditions, the National Weather Service combines heat and relative humidity to produce its heat index, or the "feels like" temperature (NWS n.d. b), used to issue heat advisories and warnings across the country. Heat advisories can therefore cite heat index values much higher than the air temperature in humid locations, such as coastal North Carolina, and several degrees cooler than the air temperature in arid locations such as Arizona.

The frequency and intensity of heat waves have increased in the last several decades in many regions of the United States.

Extreme Heat Now and in the Recent Past

Extreme heat events can be measured in a few different ways: the maximum temperatures hit (intensity), how often the

FIGURE 2. Ratio of the Number of Record Highs to Lows by Year in the United States



The ratio of the number of daily record highs and daily record lows set per year in the contiguous United States between 1930 and 2016. Red indicates a year in which there were more record highs, and blue indicates a year in which there were more record lows.

SOURCE: VOSE ET AL. 2017.

events occur (frequency), or how long they last (duration). The Dust Bowl era of the 1930s holds the record for peak frequency, intensity, and duration of heat waves across much of the United States to this day—but the frequency and intensity of heat waves have increased in the last several decades in many regions (Vose et al. 2017).

OBSERVED CHANGES IN EXTREME TEMPERATURE

With respect to intensity, the number of days with record highs in the United States has increased since the late 1970s, with more days of record-breaking hot temperatures than record-breaking cold temperatures (Figure 2; Vose et al. 2017). Overall, the frequency of heat waves has been on the rise across much of the country since the mid-1960s (Vose et al. 2017). The US Southeast has experienced the largest increase in the frequency of days with heat wave conditions since the late 1970s (Smith, Zaitchik, and Gohlke 2013), and, with the exception of the Midwest and Great Plains, the frequency of intense heat waves lasting at least four days has also increased across most of the United States since the 1960s (Vose et al. 2017). A study of heat wave characteristics in 50 large US cities (including Detroit, Philadelphia, Birmingham, Fort Worth, and Salt Lake City) found that the frequency, duration, and intensity of heat waves increased since the mid-1960s, and the duration of the heat wave season for those cities has grown longer (Habeeb, Vargo, and Stone 2015).

The area of the country experiencing unusually hot summer nights has also been on the rise, outpacing the increase in the portion of the country with unusually hot summer days (Figure 3; EPA 2016). For more information on the health-risks associated with hot summer nights, please visit *www.ucsusa.org/extremeheat*.

OBSERVED CHANGES IN HEAT STRESS CONDITIONS

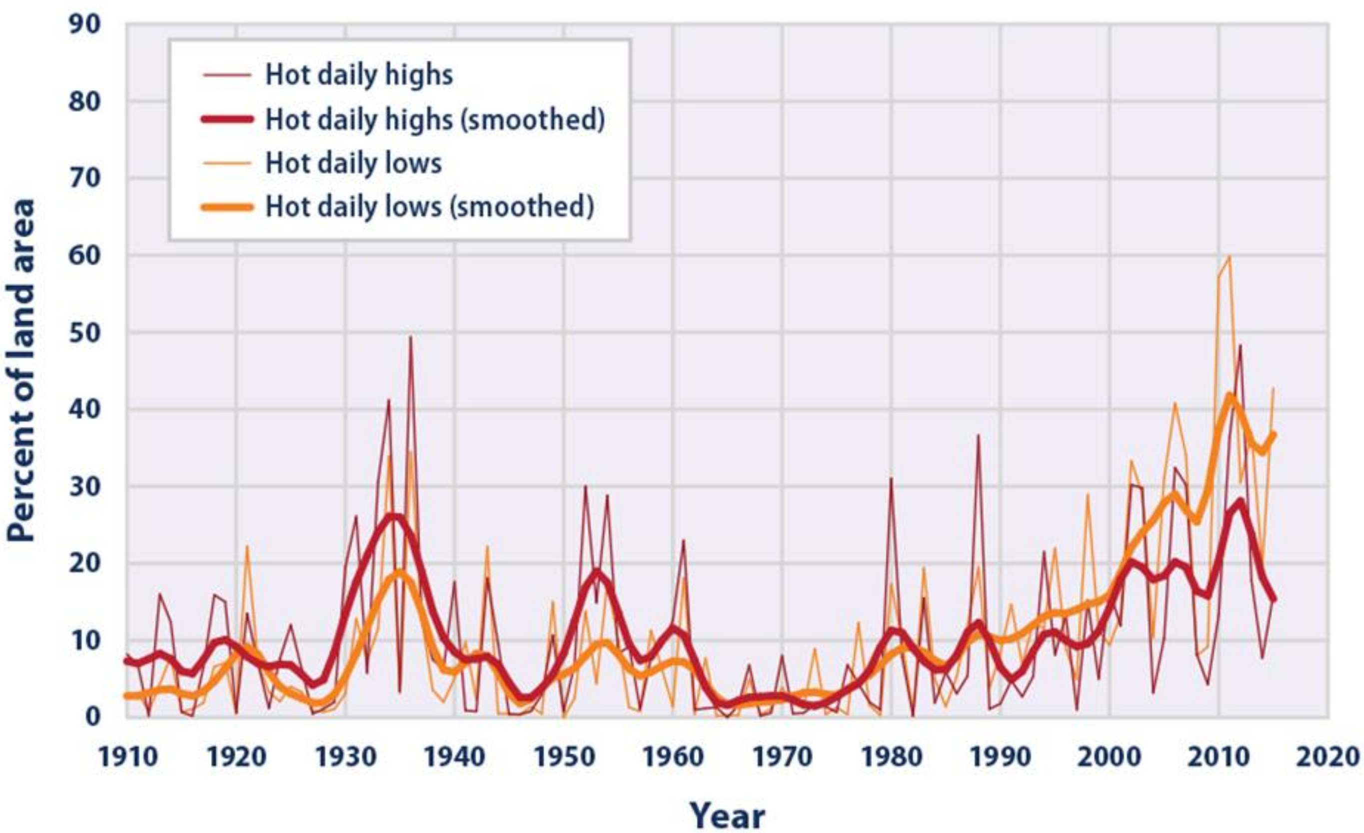
In addition to changes in extreme temperatures alone, studies of heat stress trends over the late 20th to early 21st century found increases across much of the country in the conditions that cause heat stress for humans (Knutson and Ploshay 2016; Willett and Sherwood 2010). In a study of changes in extreme heat stress conditions at 187 weather stations across the United States between 1949 and 2005, 20 percent of the stations had recorded a substantial increase in the number of one-day, extreme heat stress events—relative to local conditions between 1961 and 1990 (Grundstein and Dowd 2011). On average, these stations recorded 12 more days with extreme heat stress conditions per year in 2005 than they did in 1949.

ATTRIBUTING OBSERVED CHANGES IN EXTREME HEAT TO HUMAN-CAUSED CLIMATE CHANGE

Globally, extreme heat shows a clear, increasing trend (Zwiers, Zhang, and Feng 2011). In the United States, the extremes of the Dust Bowl era of the 1930s—which were not caused by global warming—throw off the temperature records to the point where it can be difficult for researchers to pin extreme heat over the course of the 20th century to human activity (Vose et al. 2017). Even considering this, however, the human fingerprint on the increases in extreme heat that have happened since the latter part of the 20th century is now visible (Duffy and Tebaldi 2012). Using analyses of climate records and computer simulations of a world with and without human activity, scientists are able to determine whether such observed changes would happen if humans did not produce the carbon emissions that they have since pre-industrial times. For example, a measurable, human-caused increase in summertime heat stress conditions was observed over much of the United States between 1973 to 2012 (the end of the study period) (Knutson and Ploshay 2016).

Scientists are also increasingly able to attribute the influence of human activity on individual extreme-heat events. For example, several studies of the 2012 US heat wave found that human-caused climate change increased the risk of such

FIGURE 3. Areas of the Contiguous 48 States with Unusually Hot Summer Temperatures, 1910–2015



The expanding area of the contiguous United States with unusually above-average summer temperatures (1910–2015). The temperatures of unusually hot summer nights are in orange and unusually hot summer days highs are in red. Annual values are plotted with the thin line, and a nine-year average is plotted with a thick line to more easily convey longer-term trends.

SOURCE: EPA 2016.

an event occurring: climate change likely increased the risk of the spring heat that year 12-fold (Knutson, Zeng, and Wittenberg 2013), while the extreme heat observed in July 2012 was four times more likely because of human activity than it would have been in the pre-industrial era (Diffenbaugh and Scherer 2013).

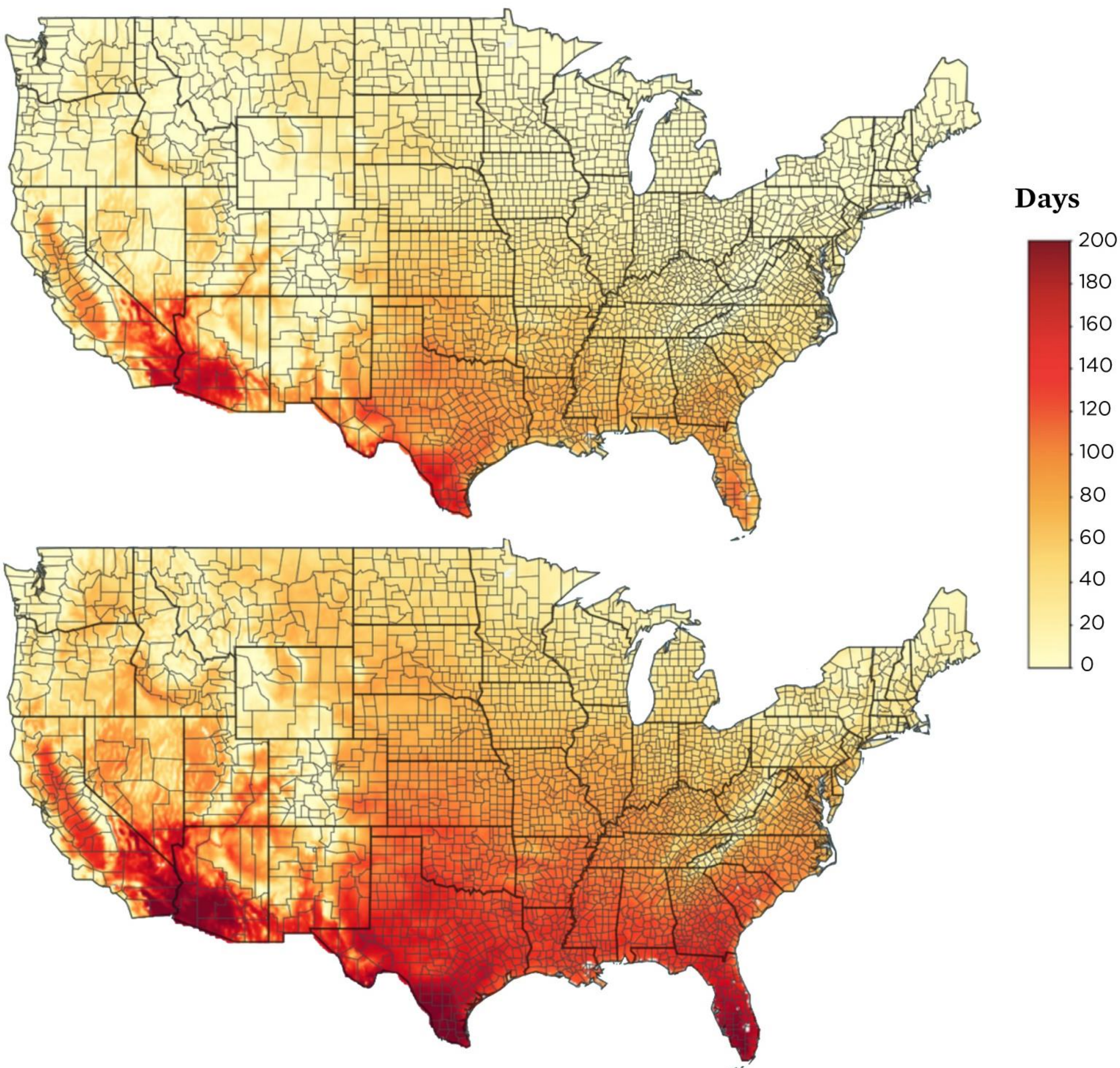
The Future of Extreme Heat

Every region of the country is projected to experience hotter temperature extremes as the 21st century unfolds (Wuebbles et al. 2014).

MID-CENTURY

We are entering the period when the occurrence of heat waves is projected to be overwhelmingly driven by human-caused climate change in some parts of the United States. Climate change is expected to be the main cause of heat waves in the western United States and Great Lakes region as early as the 2020s or 2030s and by mid-to-late century in the Great Plains region (Lopez et al. 2018). Most of the country could see 20 to 30 more days each year (relative to recent conditions between 1976 and 2005) in which daily maximum temperatures exceed 90 degrees Fahrenheit, if carbon emissions increase considerably (Figure 4; RCP8.5; Vose et al. 2017). Under these circumstances, the Southeast United States could be hit even harder, potentially enduring 40 to 50 more such days (Figure 4;

FIGURE 4. Numbers of Daily Annually with Maximum Temperatures Above 90°F



Number of days annually across the contiguous United States with maximum daily temperatures above 90°F over a historical period (1961–1990, top map) and around 2050 if emissions continue to increase significantly (RCP8.5, bottom map). Note the historical period shown is slightly earlier than that used in the respective text. By mid-century, large swaths of the country could experience on average more than three months–worth of days (100 or more) per year with maximum temperatures over 90°F.

SOURCE: US CLIMATE RESILIENCE TOOLKIT CLIMATE EXPLORER N.D.

In the coming decades, residents across the United States are expected to be exposed to more intense, frequent, and longer-lasting extreme heat events. Soaring temperatures such as those endured by pedestrians in the Canoga Park section of Los Angeles in 2015, shown here, are expected to become far more common. Reducing greenhouse gas emissions can limit how extreme these conditions become. Source: Richard Vogel/AP.

Vose et al. 2017). If global carbon emissions can be stabilized in the next few decades so that carbon dioxide in our atmosphere remains below 550 parts per million by 2100 (RCP4.5), the frequency of heat waves the United States is likely to see around mid-century could be reduced by 50 percent, compared to a scenario in which carbon emissions continue to increase through to 2100 and atmospheric carbon dioxide levels reach 936 parts per million (RCP8.5; Vose et al. 2017; Sun et al. 2015). Atmospheric carbon dioxide levels are currently around 400 parts per million (Vose et al. 2017).

END OF CENTURY

By 2100, all parts of the United States are likely to experience more heat waves, with the Southeast, Southwest, and Alaska likely to see the biggest increases (Vose et al. 2017). Not only will these heat waves be more frequent, they will also be hotter than what we experience today. If carbon emissions continue to increase substantially as described above (RCP8.5), the hottest daily temperatures that occur in a given year in the United States are likely to increase by at least 10°F as compared to the end of the 20th century (Vose et al. 2017; Sillmann et al. 2013). By 2100, temperature highs that are currently rare—occurring about once every 20 years—may happen every year across the contiguous United States and Hawaii (Wuebbles et al. 2014).

The benefits of reducing carbon emissions become even more evident by 2100 (Sanderson et al. 2018). Severe temperatures would still occur four to 10 times more often by the end of the century (Wuebbles et al. 2014), requiring society to adapt to warmer conditions. But if the global community is able to meet the Paris Agreement goal of keeping global warming below 3.6°F, the hottest daily temperatures are not expected to get as hot (in many places, they will increase by approximately 3.6°F instead of 10°F as described above) (Vose et al. 2017; Sillmann et al. 2013).

What Can We Do? Preventing the Worst Consequences of Extreme Heat

Many consequences of climate change will be difficult to forestall or avoid; extreme heat is among the most straightforward. Actions we take now can help reduce the scale of the problem, bolster how prepared we are to cope with heat and help us to avoid the most severe consequences of climate change. By stabilizing global carbon emissions in the next few decades so that carbon dioxide in our atmosphere remains below 550 parts per million by 2100, the frequency of heat waves the United States is likely to see around mid-century would be reduced by approximately 50 percent, compared to a scenario in which carbon emissions continue to increase rapidly through to 2100 (Vose et al. 2017; Sun et al. 2015). And if the global community pursues aggressive emissions reductions in line with the Paris Agreement goal of keeping warming below 3.6°F, the hottest daily temperatures that occur each year in many parts of the country are likely to increase by just 3.6°F, as compared with conditions at the end of the twentieth century, instead of by 10°F.

Together with actions that would reduce carbon emissions and minimize future warming, individuals and communities need policies and infrastructure that take better account of more frequent, intense, and long-lasting extreme heat conditions. For example, while existing air-conditioning installations have helped protect the health of many vulnerable US residents, in the coming decades increased reliance on air conditioning to cope with extreme heat is likely to contribute to increased global warming emissions, worsening air quality, and an increase in air pollution–related illness and mortality unless we more aggressively invest in clean energy technology, energy conservation, and energy efficiency measures (Abel et al. 2018).

In addition to infrastructure-focused measures, existing policies need to be leveraged and new policies enacted to better help people—particularly outdoor workers, children, low-income and minority groups, elderly people, and athletes—cope with extreme heat. Policies that ensure the safety of all outdoor workers, documented or otherwise, and that expand access to and awareness of public cooling facilities are just two examples.

Heat waves have always been an aspect of summer weather in the United States. But as climate change makes heat waves more intense and more frequent, we need to be cognizant of the dangers. New and strengthened policies to protect public health and infrastructure will help us navigate a hotter near-term future more safely, while our work to reduce emissions today will have profound impacts for decades to come, helping the country to avoid the most dangerous heat increases over our long-term future.

ACKNOWLEDGEMENTS

The fact sheet team would like to express thanks to the following individuals for their invaluable review: Dr. Meredith Jennings, National Academies of Sciences, Engineering, and Medicine Gulf Research Program; Dr. Kim Knowlton, Natural Resources Defense Council; and Dr. Benjamin Sanderson, CERFACS/CNRS Laboratoire Climat, Environnement, couplage et incertitudes.

REFERENCES

Abel, D.W., T. Holloway, M. Harkey, P. Meier, D. Ahl, V.S. Limaye, and J.A. Patz. 2018. Air-quality-related health impacts from climate change and from adaptation of cooling demand for buildings in the eastern United States: An interdisciplinary modeling study. *PLOS Medicine* 15(7):1–27. doi:10.1371/journal.pmed.1002599.

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 *www.cdc.gov/nchs/data/nhsr/nhsr076.pdf*, accessed July 24, 2018.

Cattiaux, J., and P. Yiou. 2013. US heat waves of spring and summer 2012 from the flow-analogue perspective. In *Explaining extreme events of 2012 from a climate perspective*, edited by T.C. Peterson, M.P. Hoerling, P.A. Stott, and S.C. Herring, special supplement, a*Bulletin of the American Meteorological Society* 94(9):10–13. doi:10.1175/BAMS-D-13-00085.1.

Centers for Disease Control and Prevention (CDC). 2017. Tips for preventing heat-related illness. June 19. Online at *www.cdc.gov/disasters/extremeheat/heattips.html*, accessed July 24, 2018.

Climate Resilience Toolkit Climate Explorer. No date. Online at *https://climateexplorer2.nemac.org*, accessed July 31, 2018.

Diffenbaugh, N.S., and M. Scherer. 2013. Likelihood of July 2012 US temperatures in preindustrial and current forcing regimes. In *Explaining extreme events of 2012 from a climate perspective*, edited by T.C. Peterson, M.P. Hoerling, P.A. Stott, and S.C. Herring, special supplement, *Bulletin of the American Meteorological Society* 94(9):6–9. doi:10.1175/BAMS-D-13-00085.1.

Duffy, P.B., and C. Tebaldi. 2012. Increasing prevalence of extreme summer temperatures in the US. *Climatic Change* 111(2):487–495. doi:10.1007/s10584-012-0396-6.

Environmental Protection Agency (EPA). 2016. Climate change indicators: High and low temperatures. Online at *www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures*, accessed July 25, 2018.

Grundstein, A., and J. Dowd. 2011. Trends in extreme apparent temperatures over the United States, 1949-2010. *Journal of Applied Meteorology and Climatology* 50(8):1651–1653. doi:10.1175/JAMC-D-11-063.1.

Habeeb, D., J. Vargo, and B. Stone Jr. 2015. Rising heat wave trends in large US cities. *Natural Hazards* 76(3):1651–1665. doi:10.1007/s11069-014-1563-z.

Knutson, T.R., and J.J. Ploshay. 2016. Detection of anthropogenic influence on a summertime heat stress index. *Climatic Change* 138(1–2):25–39. doi:10.1007/s10584-016-1708-z.

Knutson, T.R., F. Zeng, and A.T. Wittenberg. 2013. The extreme March–May 2012 warm anomaly over the eastern United States: Global context and multimodel trend analysis. In *Explaining extreme events of 2012 from a climate perspective*, edited by T.C. Peterson, M.P. Hoerling, P.A. Stott, and S.C. Herring, special supplement, *Bulletin of the American Meteorological Society* 94(9):13–17. doi:10.1175/BAMS-D-13-00085.1.

Lopez, H., R. West, S. Dong, G. Goni, B. Kirtman, S.-K. Lee, and R. Atlas. 2018. Early emergence of anthropogenically forced heat waves in the western United States and Great Lakes. *Nature Climate Change* 8:414–420. doi:10.1038/s41558-018-0116-y.

Martin Perera, E.M., T. Sanford, J.L. White-Newsome, L.S. Kalkstein, J.K. Vanos, and K. Weir. 2012. *Heat in the heartland: 60 years of warming in the Midwest*. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/global_warming/science_and_impacts/impacts/global-warming-and-heat-waves.html*, accessed July 24, 2018.

National Centers for Environmental Information (NCEI). 2018. Billion-dollar weather and climate disasters: Table of events. Silver Spring, MD: National Oceanic and Atmospheric Administration. Online at *www.ncdc.noaa.gov/billions/events/US/1980-2018*, accessed July 25, 2018.

National Oceanic and Atmospheric Administration (NOAA). 2016. National temperature and precipitation maps. Online at *www.ncdc.noaa.gov/temp-and-precip/us-maps/*, accessed July 25, 2018.

National Weather Service (NWS). No date a. Glossary. Online at *https://w1.weather.gov/glossary/index.php*, accessed July 25, 2018.

National Weather Service (NWS). No date b. Heat Index. Online at *www.weather.gov/safety/heat-index*, accessed July 29, 2018.

Plume, K., and D. Zabarenko. 2012. Grain prices set records as US drought, food worries spread. *Reuters*, July 19. Online at *www.reuters.com/article/us-usa-drought/grain-prices-set-records-as-drought-food-worries-spread-idUSBRE86F1D420120720*, accessed July 25, 2018.

Sanderson, B.M., K.W. Oleson, W.G. Strand, Flavio Lehner, and B.C. O'Neill. 2018. A new ensemble of GCM simulations to assess avoided impacts in a climate mitigation scenario. *Climatic Change* 146(3-4):303-318. doi:10.1007/s10584-015-1567-z.

Sillmann, J., V.V. Kharin, F.W. Zwiers, X. Zhang, and D. Bronaugh. 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *Journal of Geophysical Research* 118(6):2473–2493. doi:10.1002/jgrd.50188.

Smith, T.T., B.J. Zaitchik, and J.M. Gohlke. 2013. Heat waves in the United States: Definitions, patterns and trends. *Climatic Change* 118(3–4):811–825. doi:10.1007/s10584-012-0659-2.

Stewart, J. 2012. Hurt: Drought devastating to beef industry; herd numbers dropping. *Purdue University*, October 25. Online at *www.purdue.edu/newsroom/releases/2012/Q4/hurt-drought-devastating-to-beef-industry-herd-numbers-dropping.html*, accessed July 25, 2018.

Sun, L., K.E. Kunkel, L.E. Stevens, A. Buddenberg, J.G. Dobson, and D.R. Easterling. 2015. *Regional surface climate conditions in CMIP3 and CMIP5 for the United States: Differences, similarities, and implications for the US National Climate Assessment*. NOAA Technical Report NESDIS 144. Washington, DC: National Environmental Satellite, Data, and Information Service; National Oceanic and Atmospheric Administration. doi:10.7289/V5RB72KG.

US Department of Agriculture (USDA). 2013. *Crop production: 2012 summary*. Online at *http://usda.mannlib.cornell.edu/usda/nass/CropProdSu/2010s/2013/CropProdSu-01-11-2013.pdf*, accessed July 25, 2018.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner. 2017. *Temperature changes in the United States*. In: *Climate science special report: Fourth national climate assessment, volume I*, edited by D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock. Washington, DC: US Global Change Research Program. doi: 10.7930/J0N29V45.

Willett, K.M., and S. Sherwood. 2010. Exceedance of heat index thresholds for 15 regions under a warming climate using the wet-bulb globe temperature. *International Journal of Climatology* 32(2):161–177. doi:10.1002/joc.2257.

Wuebbles, D., G. Meehl, K. Hayhoe, T.R. Karl, K. Kunkel, B. Santer, M. Wehner, B. Colle, E.M. Fischer, R. Fu, A. Goodman, E. Janssen, V. Kharin, H. Lee, W. Li, L.N. Long, S.C. Olsen, Z. Pan, A. Seth, J. Sheffield, and L. Sun. 2014. CMIP5 climate model analyses: Climate extremes in the United States. *Bulletin of the American Meteorological Society* 95(4):571–583. doi:10.1175/BAMS-D-12-00172.1.

Zwiers, F.W., X. Zhang, and Y. Feng. 2011. Anthropogenic influence on long return period daily temperature extremes at regional scales. *Journal of Climate* 24(3):881–892. doi:10.1175/2010JCLI3908.1.

Union of Concerned Scientists

FIND THIS DOCUMENT ONLINE: www.ucsusa.org/extremeheat

NATIONAL HEADQUARTERS
Two Brattle Square
Cambridge, MA 02138-3780
Phone: (617) 547-5552
Fax: (617) 864-9405

WASHINGTON, DC, OFFICE
1825 K St. NW, Suite 800
Washington, DC 20006-1232
Phone: (202) 223-6133
Fax: (202) 223-6162

WEST COAST OFFICE
500 12th St., Suite 340
Oakland, CA 94607-4087
Phone: (510) 843-1872
Fax: (510) 451-3785

MIDWEST OFFICE
One N. LaSalle St., Suite 1904
Chicago, IL 60602-4064
Phone: (312) 578-1750
Fax: (312) 578-1751

WEB: www.ucsusa.org

PRINTED ON RECYCLED PAPER USING VEGETABLE-BASED INKS