JUNE 2017
IP: I7-06-B

ISSUE PAPER

KILLER SUMMER HEAT:

PARIS AGREEMENT COMPLIANCE COULD AVERT HUNDREDS OF THOUSANDS OF NEEDLESS DEATHS IN AMERICA'S CITIES

Juanita Constible, ***Natural Resources Defense Council***

Climate change, propelled by pollution from the production and use of fossil fuels, is driving global temperatures higher and higher. This heat comes with consequences that often can be deadly. A new analysis commissioned by NRDC shows that the number of dangerously hot summer days will increase drastically in our largest urban areas. This increase could potentially lead summertime deaths to jump by almost 2,100 percent by the 2090s compared to the 1975 to 2010 average.

If we continue to emit climate-changing pollution at our current rate, our largest urban areas like New York, Philadelphia, and St. Louis will see many more summertime deaths. Across 45 of the largest urban areas in the United States, excess deaths on dangerously hot summer days could climb from a historical annual average of about 1,360 from 1975 to 2010 to 13,860 by the mid-2040s. That's the equivalent of about 150 deaths per summer day. By the 2090s, the number of excess deaths on dangerous summer days could shoot up to an annual average of 29,850; or nearly 325 deaths per day. That's comparable to the number of all U.S. deaths from prostate cancer in 2014 (28,344), and nearly double the number of homicides (15,872) in that same year.[1] New York, Philadelphia, Chicago, Boston, and Baltimore could see the largest increases.

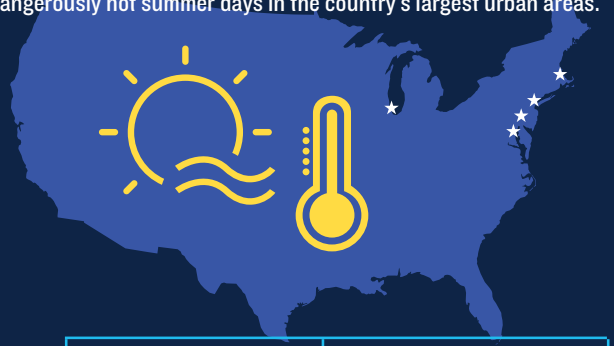
The United States can limit this damage by fully honoring its international promises to address climate change. The groundbreaking 2015 Paris Agreement is the first international agreement to include commitments from both developed and developing countries to tackle climate change.[2] If the world limits global warming as described in the Paris Agreement, the largest urban areas in the United States could reduce the annual number of excess deaths on summer days. To be specific, they could see about 2,480 fewer deaths in the 2040s and about 12,820 fewer in the 2090s. However, the Paris Agreement alone is not enough to fully protect human health from dangerous heat. To most effectively minimize our health risks, the United States and the world should make even steeper cuts to climate-changing pollution.

Acknowledgements: This report uses original analysis done in 2016 by Laurence S. Kalkstein and J. Scott Greene.

The author also would like to thank the following contributors and reviewers (in alphabetical order): Pete Altman, Han Chen, Juan Declet-Barreto, David Goldston, Mary Heglar, Kim Knowlton, Alex Krefetz, Tim Lau, Lauren Reiser, Linda Rudolph, Christina Swanson, and Jake Thompson.

AMERICA FACES MANY MORE HOT, DEADLY SUMMER DAYS UNDER CLIMATE CHANGE

Complying with the groundbreaking 2015 Paris Agreement, however, can help limit global warming and reduce deaths on dangerously hot summer days in the country's largest urban areas.



	WITHOUT ACTION*	WITH THE PARIS AGREEMENT
NEW YORK	**67** more dangerous summer days and **7,080** more deaths per year in the 2090s	**3,110** LIVES SAVED per year in the 2090s
PHILADELPHIA	**75** more dangerous summer days and **4,960** more deaths per year in the 2090s	**1,660** LIVES SAVED per year in the 2090s
CHICAGO	**69** more dangerous summer days and **2,330** more deaths per year in the 2090s	**1,630** LIVES SAVED per year in the 2090s
BOSTON	**67** more dangerous summer days and **1,270** more deaths per year in the 2090s	**710** LIVES SAVED per year in the 2090s
BALTIMORE	**78** more dangerous summer days and **980** more deaths per year in the 2090s	**420** LIVES SAVED per year in the 2090s

Within 45 of the U.S. urban areas with a population of one million or more, implementation of the Paris Agreement could **reduce total summertime deaths by about 12,820 per year** from 2091 to 2100, amounting to more than **128,000 fewer excess deaths** over the period.

*Compared to the historical average (1975 to 2010)

DANGEROUS HEAT: THE DEADLY SIDE OF SUMMER

Summer is a time for backyard parties, beach trips, and lazy naps in the shade. But it also can bring extreme heat, which kills an average of 1,300 Americans annually and sends more than 65,000 to emergency rooms with heat-related illnesses.[3] Although children, pregnant women, older adults, and people with chronic diseases are most vulnerable, anyone who exerts themselves (whether through work or play) can fall victim to heat-related health problems when temperatures soar to dangerous levels.

And summer, as we know it, is getting hotter because of man-made climate change, which is largely driven by carbon pollution from the production and use of fossil fuels.[4] The year 2016 was the world's hottest on record, falling in line behind 2014 and 2015 as the third record-breaking year in a row (Table 1).[5] Last year was also the second hottest in the continental United States, and the summer of 2016 was record-hot for California and Connecticut and above average in every other state except Hawaii.[6]

TABLE 1: GLOBALLY, 11 OF THE 12 HOTTEST YEARS ON RECORD HAVE OCCURRED SINCE 2003. DATA: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION.[7]

RANK (1 = HOTTEST YEAR ON RECORD, 1880-2016)	YEAR
1	2016
2	2015
3	2014
4	2010
5	2013
6	2005
7	2009
8	1998
9	2012
10 (tie)	2003
10 (tie)	2006
10 (tie)	2007

Even small rises in average temperature can greatly increase the threat of heat-related illnesses and deaths.[8] One national study of extreme heat from 1987 to 2005 found the risk of death climbed nearly 2.5 percent for every one degree Fahrenheit increase in average heatwave intensity.[9] Furthermore, heatwaves often bring unsafe air days with high levels of smog and other unhealthy air pollution, compounding the health threat.[10]

Estimates of future heat-related deaths as the climate changes vary widely between studies, depending on the climate model, heatwave definition, analytical technique,

EXTREME HEAT IS BAD FOR OUR HEALTH

Periodic heat disasters are stark reminders that heat-related health threats should be taken seriously. For example, the record-breaking 2006 heatwave in California accounted for an estimated $5.3 billion in lost lives and health costs.[13] Excess mortality was widespread across the state during this event, across every gender, age group, race, and ethnicity.[14]

Excessive heat puts stress on our hearts and lungs and can cause health outcomes ranging from minor skin rashes to deadly heatstrokes. The more serious conditions directly caused by heat include:[15]

- painful heat cramps, which can require medical attention if they don't resolve after an hour of rest and rehydration in a cool place.
- heat exhaustion, which can cause weakness, anxiety, dizziness, headaches, and even fainting. Heat exhaustion can be a sign of impending heatstroke.
- heatstroke, which is a medical emergency caused by a rapid rise in body temperature above 104 degrees Fahrenheit. Heatstroke injures the central nervous system and is deadly if left untreated.

Unfortunately, it is notoriously difficult for researchers and health professionals to assess and effectively communicate the full health burden of extreme heat.[16] This is in part because heat is often a contributing factor to death, rather than a direct cause, and therefore might not be mentioned on a death certificate.[17] For example, heat can:[18]

- dangerously dehydrate people who take diuretics for high blood pressure, glaucoma, or other conditions;
- trigger hyperventilation for people with chronic obstructive pulmonary disease, leading to respiratory failure; and
- increase the risk of heart attacks and strokes in people with atherosclerosis or other cardiovascular disease.[19]

and underlying assumptions. In general, however, the U.S. Global Change Research Program has concluded with high confidence that, "A warmer future is projected to lead to increases in future mortality on the order of thousands to tens of thousands of additional premature deaths per year across the United States by the end of this century."[11]

Note that cold-related illnesses and deaths are expected to decline as the world warms. Most national-scale studies of the United States, however, find that the increase in heat-related deaths will outweigh that decrease.[12]

THE PARIS AGREEMENT: CREATING A HEALTHIER CLIMATE FUTURE

In December 2015, representatives from more than 190 countries gathered in Paris for the 21st session of the Conference of the Parties, under an international treaty called the United Nations Framework Convention on Climate Change (UNFCCC).[20] The result was the historic Paris Agreement, the first international agreement to include commitments from both developed and developing countries to tackle climate change.[21]

The Paris Agreement entered into force on November 4, 2016, less than a year after it was adopted.[22] As Patricia Espinosa, the executive secretary of the UNFCCC remarked at the time, "The speed at which countries have made the Paris Agreement's entry into force possible is unprecedented in recent experience of international agreements and is a powerful confirmation of the importance nations attach to combating climate change and realizing the multitude of opportunities inherent in the Paris Agreement."

The Paris Agreement aims to keep global warming from crossing a dangerous threshold of 2 degrees Celsius (3.6 degrees Fahrenheit) above pre-industrial levels, and to pursue efforts to achieve a safer limit of 1.5 degrees Celsius (2.7 degrees Fahrenheit).[23] To reach the 2 degree Celsius goal, countries will need to expand their current commitments through regularly updated climate action plans.[24] And because greenhouse gases stay in the atmosphere for decades to millennia, the world is already locked into some warming.[25] Even if we stopped emitting climate-changing pollution immediately, the world would continue to warm another 0.25 to 0.5 degrees Celsius (0.45 to 0.9 degrees Fahrenheit) over a 10-year period, intensifying climate-related threats to our health.[26]

On June 1, 2017, President Trump announced that the United States would withdraw from the Paris Agreement —against the wishes of 69 percent of American voters and more than 1,100 companies with major operations in the United States.

However, the Trump administration is leading the United States in entirely the wrong direction when it comes to climate action. The administration has vowed to expand the extraction and use of coal and other dirty fossil fuels and threatened to slash clean energy and energy-

efficiency programs.[27] On June 1, 2017, President Trump announced that the United States would withdraw from the Paris Agreement—against the wishes of 69 percent of American voters and more than 1,100 companies with major operations in the United States.[28] These actions jeopardize global climate action and the health and well-being of people around the world. According to one 2017 study, delaying U.S. implementation of the Paris Agreement by just eight years could render it impossible for the world to meet the 2 degree Celsius goal.[29]

Our study shows that full implementation of the Paris Agreement will help limit global warming and could reduce excess American deaths each summer. Even with full compliance, however, deaths during dangerous summer days will increase. Our results, therefore, also affirm that the world must go much further than the Paris Agreement to fully protect human health. Meanwhile, cities and states need to continue to strengthen their heat protection and response capabilities in anticipation of more dangerous summer days, regardless of how the Paris Agreement progresses.

PROJECTING SUMMERTIME DEATHS IN A WARMING WORLD

Our analysis relies on a weather classification system called Spatial Synoptic Classification, which researchers have used since at least 1996 to study relationships between dangerous weather and human health.[30]

We first used Spatial Synoptic Classification to estimate the historical number of dangerous June, July, and August days in the country's 51 largest urban areas—those with metropolitan area populations greater than one million.[31] (The U.S. Census Bureau defines a metropolitan area as a large principal city and adjacent communities with a "high degree of economic and social integration."[32]) We define "dangerous summer days" as the location-specific number of days with weather most commonly associated with negative health outcomes.

For each urban area, we analyzed the relationship between dangerous summer days and "excess deaths"—the total number of deaths above the daily standardized summertime average for that area. We then used that relationship and climate model simulations to project the number of future deaths under two scenarios:

- A no-action scenario, which assumes continued heavy dependence on fossil fuels.[33] Under this scenario, the world would be approximately 4.1 to 4.8 degrees Celsius (7.4 to 8.6 degrees Fahrenheit) warmer in 2100 than it was in the late 19th century (1850 to 1900).[34]
- An intermediate scenario, which assumes expansion of clean energy and would result in the world being approximately 2.3 to 2.9 degrees Celsius (4.1 to 5.2 degrees Fahrenheit) warmer in 2100 compared with the late 19th century.[35] We call this the Paris Agreement scenario, because it is roughly equivalent to that resulting from full implementation of current national commitments under the agreement.[36]

This analysis is only intended to examine the health threats associated with the direct and indirect ways heat affects the human body. It does not include health threats associated with the effects of rising temperatures on extreme weather and wildfire patterns, plants that produce allergenic pollen, disease-carrying mosquitos and ticks, or other environmental hazards.[37]

Please see the Appendix for more details about our methods, including study limitations.

DEFINING DANGEROUS HEAT

The National Weather Service defines a "heatwave" as, "A period of abnormally and uncomfortably hot and unusually humid weather."[38] But what does that mean in terms of actual temperature? Well, it depends.

Human sensitivity to heat varies with geography, social and economic factors, and even local cultural norms.[39] A 100-degree day in the Northern United States can have more severe health consequences than a 100-degree day in the Southeast, where people are accustomed to hot days and air-conditioning is common.[40] In Chicago 911 calls for heat-related emergencies tend to increase when the temperature gets above 95 degrees Fahrenheit, but in Phoenix the threshold is 113 degrees Fahrenheit.[41]

For the purposes of this study, we define "dangerous summer days" as the sum of two weather types in the Spatial Synoptic Classification: dry tropical days and moist tropical days.[42] Dry tropical days are usually the hottest and driest days at a given locale. Moist tropical days are hot and humid, often with high nighttime temperatures. The exact characteristics of these two weather types vary by location.[43] For example, average dry tropical days in Phoenix are hotter, drier, and slightly less cloudy than average dry tropical days in Cincinnati. Across locations, however, both dry and moist tropical days are consistently more dangerous to human health than other weather types.[44]

SUMMERS WILL GET HOTTER—AND DEADLIER—IN AMERICA'S LARGEST URBAN AREAS

Our findings suggest that all 51 of America's urban areas with populations of more than one million will experience considerably more dangerous summer days in the 2090s than they did from 1975 to 2010 (Table 2). Historically, dangerous summer days make up less than 25 percent of summers in 47 of these urban areas. The urban areas with more than 25 percent dangerous days per summer, historically, are all in the Western United States: Salt Lake City, UT; Las Vegas, NV; Phoenix, AZ; and Riverside, CA. Without action to curb climate-changing pollution, however, dangerous summer days could make up more than 75 percent of summers in 43 of the 51 urban areas by the 2090s. In 12 of the urban areas we studied, dangerous summer days could make up 98 percent of each summer in the 2090s.

THE URBAN HEAT ISLAND EFFECT

City dwellers are particularly vulnerable to heat-related deaths and illnesses because of the heat island effect.[45] Urban areas tend to be hotter than surrounding suburban and rural areas because they are mostly covered in dry, heat-absorbing building materials like pavement and roofing. Daytime surface temperatures can be 18 to 27 degrees Fahrenheit higher in urban areas than in rural areas. The height and spacing of buildings (known as "urban geometry") also can contribute to the heat island effect by blocking the release of heat.

The heat island effect amplifies the risk of rising temperatures associated with climate change. One recent study of heatwaves from 1961 to 2010 found that U.S. urban areas are experiencing increasingly long, more intense, and more frequent heatwaves.[46] In more than half of the urban areas studied, heatwave trends were worsening faster than the national average.

The health burden of the heat island effect does not fall equally across neighborhoods or socioeconomic groups. An analysis of a 22-year data set of more than 2.1 million death records from seven U.S. cities showed that significant increases in deaths on extremely hot days occurred in just 12 to 44 percent of postal codes in each city.[47] Zip codes with higher risk tended to have more children and older adults, more people of color, and more people of lower socioeconomic status.

In New York City, for example, poverty, poor housing quality, and lower rates of access to air-conditioning were associated with more heat-related deaths from 1997 to 2016.[48] Even in warmer regions, lifesaving air-conditioning may not be widely available. One 2015 study, for instance, found that less than 50 percent of households in Los Angeles County have air-conditioning.[49] Furthermore, only 3 percent of households in Los Angeles County are within a 15-minute walk of an official cooling center, putting residents with neither vehicles nor air-conditioning at higher risk. Commercial establishments are more widely available (accessible by walking for 80 percent of households), but generally have limited operating hours and lack services to deal with people who are already suffering from heat-related illnesses.

TABLE 2: HISTORICAL AND PROJECTED ANNUAL NUMBERS OF DANGEROUS SUMMER DAYS (JUNE, JULY, AND AUGUST) AND EXCESS DEATHS ON DANGEROUS SUMMER DAYS IN THE 51 LARGEST URBAN AREAS IN THE UNITED STATES. MORTALITY NUMBERS REPRESENT RAW COUNTS OF DEATHS RATHER THAN DEATH RATES. PROJECTIONS MADE UNDER THE NO-ACTION SCENARIO ARE ROUNDED TO THE NEAREST 10 DEATHS. FOR SIMPLICITY, WE REFER TO EACH METROPOLITAN STATISTICAL AREA BY THE FIRST CITY IN ITS OFFICIAL NAME.[50] SIX URBAN AREAS DID NOT HAVE A STATISTICALLY SIGNIFICANT RELATIONSHIP BETWEEN THE HISTORICAL NUMBER OF DANGEROUS SUMMER DAYS AND EXCESS DEATHS: CHARLOTTE, NC; COLUMBUS, OH; HOUSTON, TX; MIAMI, FL; SAN DIEGO, CA; AND TAMPA, FL. THEY WERE THEREFORE EXCLUDED FROM FURTHER ANALYSIS. SEE APPENDIX FOR MORE DETAILS.

	PER-SUMMER AVERAGE NUMBER OF DANGEROUS SUMMER DAYS			PER-SUMMER AVERAGE NUMBER OF EXCESS DEATHS ON DANGEROUS SUMMER DAYS		
METROPOLITAN STATISTICAL AREA	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)
Atlanta, GA	9	60	80	16	250	400
Austin, TX	20	60	60	4	40	40
Baltimore, MD	12	50	90	29	520	1,010
Birmingham, AL	11	70	80	9	240	320
Boston, MA	13	50	80	67	610	1,340
Buffalo, NY	5	50	80	12	410	620
Charlotte, NC	15	80	80	No statistically significant relationship		
Chicago, IL	11	40	80	107	750	2,440

TABLE 2: HISTORICAL AND PROJECTED ANNUAL NUMBERS OF DANGEROUS SUMMER DAYS (JUNE, JULY, AND AUGUST) AND EXCESS DEATHS ON DANGEROUS SUMMER DAYS IN THE 51 LARGEST URBAN AREAS IN THE UNITED STATES. MORTALITY NUMBERS REPRESENT RAW COUNTS OF DEATHS RATHER THAN DEATH RATES. PROJECTIONS MADE UNDER THE NO-ACTION SCENARIO ARE ROUNDED TO THE NEAREST 10 DEATHS. FOR SIMPLICITY, WE REFER TO EACH METROPOLITAN STATISTICAL AREA BY THE FIRST CITY IN ITS OFFICIAL NAME.[50] SIX URBAN AREAS DID NOT HAVE A STATISTICALLY SIGNIFICANT RELATIONSHIP BETWEEN THE HISTORICAL NUMBER OF DANGEROUS SUMMER DAYS AND EXCESS DEATHS: CHARLOTTE, NC; COLUMBUS, OH; HOUSTON, TX; MIAMI, FL; SAN DIEGO, CA; AND TAMPA, FL. THEY WERE THEREFORE EXCLUDED FROM FURTHER ANALYSIS. SEE APPENDIX FOR MORE DETAILS.

	PER-SUMMER AVERAGE NUMBER OF DANGEROUS SUMMER DAYS			PER-SUMMER AVERAGE NUMBER OF EXCESS DEATHS ON DANGEROUS SUMMER DAYS		
METROPOLITAN STATISTICAL AREA	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)
Cincinnati, OH	5	50	80	13	280	580
Cleveland, OH	7	50	80	27	290	570
Columbus, OH	6	50	80	No statistically significant relationship		
Dallas, TX	20	60	70	36	320	420
Denver, CO	17	10	70	16	20	90
Detroit, MI	9	50	80	65	760	870
Hartford, CT	9	40	80	20	90	260
Houston, TX	18	80	90	No statistically significant relationship		
Indianapolis, IN	8	50	80	7	50	190
Jacksonville, FL	10	80	90	4	100	120
Kansas City, MO/KS	13	40	80	23	190	490
Las Vegas, NV	63	50	80	14	40	70
Los Angeles, CA	9	10	30	118	220	540
Louisville, KY	15	70	80	18	340	530
Memphis, TN	15	60	70	19	220	390
Miami, FL	20	80	80	No statistically significant relationship		
Milwaukee, WI	10	50	80	19	170	410
Minneapolis, MN	11	50	80	17	100	340
Nashville, TN	9	70	80	6	150	210
New Orleans, LA	10	50	90	15	70	130
New York, NY	13	60	80	288	4,500	7,370
Oklahoma City, OK	18	60	80	8	40	130
Orlando, FL	10	90	90	4	120	120
Philadelphia, PA	15	60	90	78	720	5,040
Phoenix, AZ	71	90	90	23	110	220
Pittsburgh, PA	6	60	80	16	400	530
Portland, OR	6	10	20	5	40	140
Providence, RI	12	10	70	37	110	670
Raleigh, NC	16	60	90	4	10	70
Richmond, VA	15	50	90	6	20	100
Riverside, CA	39	60	70	29	50	80

TABLE 2: HISTORICAL AND PROJECTED ANNUAL NUMBERS OF DANGEROUS SUMMER DAYS (JUNE, JULY, AND AUGUST) AND EXCESS DEATHS ON DANGEROUS SUMMER DAYS IN THE 51 LARGEST URBAN AREAS IN THE UNITED STATES. MORTALITY NUMBERS REPRESENT RAW COUNTS OF DEATHS RATHER THAN DEATH RATES. PROJECTIONS MADE UNDER THE NO-ACTION SCENARIO ARE ROUNDED TO THE NEAREST 10 DEATHS. FOR SIMPLICITY, WE REFER TO EACH METROPOLITAN STATISTICAL AREA BY THE FIRST CITY IN ITS OFFICIAL NAME.[50] SIX URBAN AREAS DID NOT HAVE A STATISTICALLY SIGNIFICANT RELATIONSHIP BETWEEN THE HISTORICAL NUMBER OF DANGEROUS SUMMER DAYS AND EXCESS DEATHS: CHARLOTTE, NC; COLUMBUS, OH; HOUSTON, TX; MIAMI, FL; SAN DIEGO, CA; AND TAMPA, FL. THEY WERE THEREFORE EXCLUDED FROM FURTHER ANALYSIS. SEE APPENDIX FOR MORE DETAILS.

	PER-SUMMER AVERAGE NUMBER OF DANGEROUS SUMMER DAYS			PER-SUMMER AVERAGE NUMBER OF EXCESS DEATHS ON DANGEROUS SUMMER DAYS		
METROPOLITAN STATISTICAL AREA	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)	HISTORICAL (1975-2010)	NO ACTION (2046-2055)	NO ACTION (2091-2100)
Rochester, NY	6	60	80	15	260	600
Sacramento, CA	22	60	60	30	210	250
Salt Lake City, UT	36	50	70	5	30	50
San Antonio, TX	13	60	80	2	50	90
San Diego, CA	1	10	10	No statistically significant relationship		
San Francisco, CA	2	40	50	15	100	200
San Jose, CA	4	70	70	10	150	330
Seattle, WA	4	10	30	20	20	80
St. Louis, MO	18	60	90	32	290	640
Tampa, FL	8	90	90	No statistically significant relationship		
Virginia Beach, VA	18	70	90	20	170	220
Washington, DC	15	60	80	30	240	560

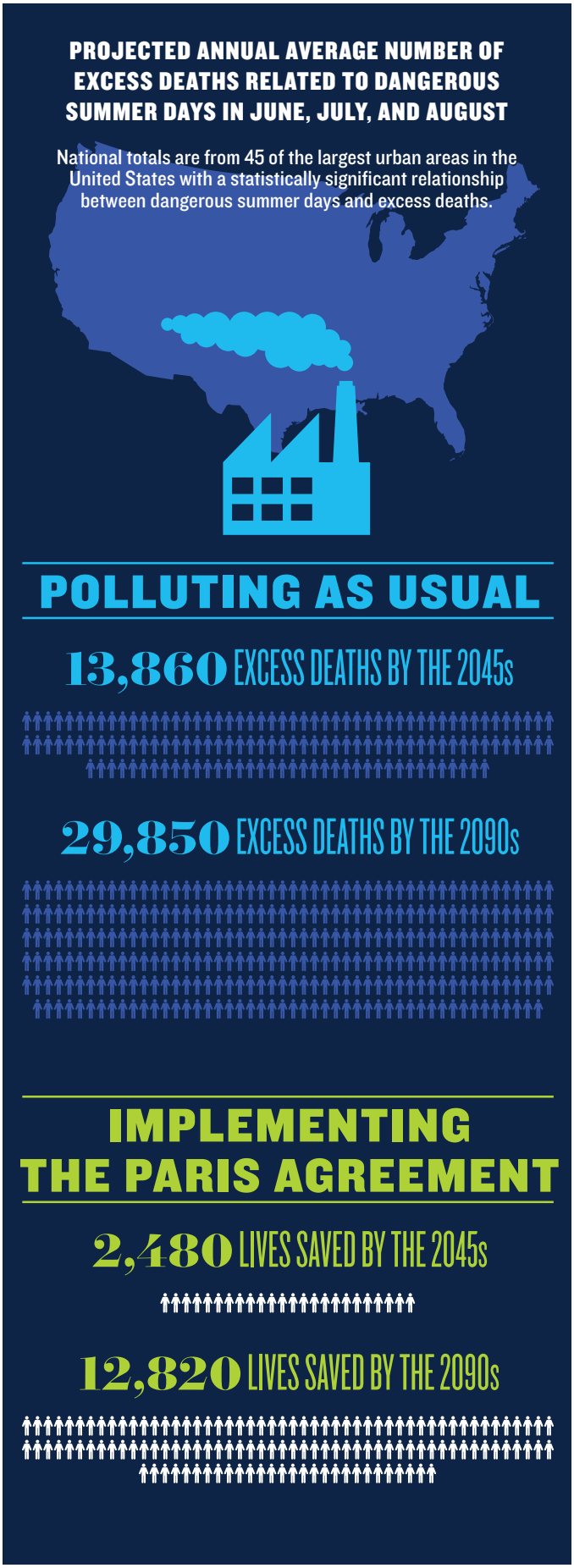
Cutting climate-changing pollution will reduce the future number of dangerous summer days and avoidable deaths in America's largest urban areas.

We also found an increase in excess deaths in all 45 of the urban areas with a statistically significant relationship between deaths and dangerous summer days (Table 2). The urban areas with the largest estimated annual increase in excess summer deaths under the no-action scenario are shown in Table 3. Nearly two-thirds of the projected increase in excess deaths in the 2090s would occur in just nine metropolitan areas.

Cutting climate-changing pollution will reduce the future number of dangerous summer days and avoidable deaths in America's largest urban areas. The intermediate-emissions scenario could save about 2,480 lives per year in the 2040s compared with the no-action scenario, and about 12,820 lives per year in the 2090s.

TABLE 3: URBAN AREAS WITH THE LARGEST ESTIMATED ANNUAL INCREASE IN EXCESS SUMMER DEATHS UNDER THE NO-ACTION SCENARIO, RELATIVE TO THE 1975 TO 2010 BASELINE. FOR SIMPLICITY, WE REFER TO EACH METROPOLITAN STATISTICAL AREA BY THE FIRST CITY IN ITS OFFICIAL NAME.[51]

2046 TO 2055	2091 TO 2100
New York (4,210 more deaths p/year)	New York (7,080 more deaths p/year)
Detroit (700 more deaths p/year)	Philadelphia (4,960 more deaths p/year)
Chicago (640 more deaths p/year)	Chicago (2,330 more deaths p/year)
Philadelphia (640 more deaths p/year)	Boston (1,270 more deaths p/year)
Boston (540 more deaths p/year)	Baltimore (980 more deaths p/year)
Baltimore (490 more deaths p/year)	Detroit (810 more deaths p/year)
Buffalo (400 more deaths p/year)	Providence (630 more deaths p/year)
Pittsburgh (380 more deaths p/year)	Buffalo (610 more deaths p/year)
Louisville (320 more deaths p/year)	St. Louis (610 more deaths p/year)
Dallas (280 more deaths p/year)	Rochester (590 more deaths p/year)



The urban areas that could see the largest health benefit in the 2090s from implementation of the Paris Agreement are:

- New York (3,110 lives saved per year)
- Philadelphia (1,660 lives saved per year)
- Chicago (1,630 lives saved per year)
- Boston (710 lives saved per year)
- Providence (570 lives saved per year)
- Buffalo (460 lives saved per year)
- Baltimore (420 lives saved per year)
- Rochester (330 lives saved per year)
- St. Louis (300 lives saved per year)

MINIMIZING NEEDLESS AMERICAN DEATHS

Our results highlight the worsening health threat of dangerous summer heat and underscore the urgent need for the United States to do its part to reduce climate-changing pollution.

Under the Paris Agreement, the United States committed to cutting 26 to 28 percent of its climate-changing pollution relative to 2005 levels by 2025.[52] This is ambitious, but achievable. Existing policies like the Clean Power Plan, energy efficiency standards, and fuel-efficiency standards for vehicles represent significant progress toward the country's current commitments and lay the groundwork for more ambitious action in the future. At the same time, these policies have spurred economic development and provided health and environmental protections.[53]

The Trump administration is unfortunately working to systematically dismantle this progress by ordering the U.S. Environmental Protection Agency (EPA) and other federal agencies to rescind or revise the very types of policies we need to strengthen, including the Clean Power Plan.[54] At the same time, the administration wants to slash the federal budget, shrinking the capacity of the Centers for Disease Control and Prevention (CDC) and other agencies to undertake scientific research essential for evidence-based decisionmaking. It also would limit the EPA's ability to enforce climate and clean-air laws.[55] Finally, the administration is trying to weaken or eliminate the Affordable Care Act, which widens access to health insurance, and programs like the Low Income Home Energy Assistance Program, which helps households pay air-conditioning bills.[56]

To minimize needless and preventable American deaths from heat-related causes, the Trump administration must cease these rollbacks of vital health and environmental protections and immediately recommit to the Paris Agreement. Although President Trump announced that he was withdrawing the United States from the agreement, the country cannot formally notify the United Nations of that intent until November 4, 2019.[57] Full withdrawal would take place one year later, right after the 2020 presidential election.

Even if the administration returns to our nation's existing course of climate action, however, the Paris Agreement is not enough to fully protect our health from dangerous heat. For instance, a 2017 study of the world's 101 largest megacities found that just 1.5 degrees Celsius of additional warming above pre-industrial levels could result in 5.7 times more global heat stress (number of days with a heat index above 40.6 degrees Celsius) than from 1979 to 2005.[58] At 2 degrees Celsius, there could be 12 times more heat stress.

Given this reality, our findings also highlight the need for city and state officials to strengthen their protections against extreme heat. It is imperative that all large urban areas proactively develop heat-health plans to address both short-term heat emergencies (e.g., with cooling centers) and longer-term warming (e.g., with energy efficiency measures in multifamily housing). The most effective plans would be responsive to regional demographic patterns.[59] For example, Philadelphia has an extensive heat plan, including a notification system, cooling centers, and educational materials about heat-related health impacts.[60] City officials recognize, however, that the threat of dangerous summers is growing as the climate warms. In collaboration with experts from academia and the private sector, the city is updating its plan to better serve the most vulnerable city residents, including older adults and low-income residents. In Michigan, health officials are learning how to motivate residents to go to cooling centers during heatwaves.[61] Surveys in Ingham County, Michigan, where more than 22 percent of the population lives below the poverty level, revealed that local food banks were the best venues for delivering cooling-center information to vulnerable residents.[62]

Finally, even though heat is a leading cause of weather-related deaths and a threat to all Americans, the United States does not have a centralized tracking and reporting system for heat-related illnesses and deaths.[63] Many state and local health departments across the country need formal guidance on how to define heat-related illnesses and effectively make use of heat-health data.[64] A system similar to the CDC's National Notifiable Diseases Surveillance System—which does not include heat-related illnesses or deaths—would help health officials respond to emergencies more rapidly, assess the efficacy of actions to improve health outcomes during extreme heat, and even help make a stronger case for heat-health interventions.[65]

Formally withdrawing from the Paris Agreement or dismantling the key underlying policies will invite significant harm to our health and our environment. Congress and the Trump administration should instead act to save Americans from needless summer deaths. They should maintain the EPA's and CDC's funding levels. And they should maintain and strengthen our international commitment to act on climate.

APPENDIX: PROJECTING THE CHANGE IN KILLER SUMMER HEAT

In each of the 51 U.S. metropolitan statistical areas (MSAs) with a population of one million or more, we used the observed relationship between all-cause mortality and dangerous summer days for the 1975 to 2010 period to estimate excess deaths. From this relationship, we projected the effect of climate change to estimate future excess deaths.[66]

We first classified every day from 1975 to 2010 in each MSA using a system called Spatial Synoptic Classification.[67] This system categorizes individual days at a given location into weather types based on observed air temperature, dew point, cloud cover, pressure, and wind velocity.

For the purposes of this study, we define "dangerous summer days" as the sum of two weather types in June, July, and August that are most commonly associated with negative health outcomes: dry tropical (DT) days and moist tropical-plus (MT+) days.[68] Dry tropical days are usually the hottest and driest days at a given locale. They are characterized by clear, sunny skies and windy conditions, which can heat buildings and human bodies to high temperatures and increase heat stress by removing moisture. The air masses associated with DT days generally originate in desert regions of the Western United States, but can travel to the East Coast under the right atmospheric conditions. Moist tropical-plus days are typically associated with the Bermuda High, which pumps hot, humid air northward from the Gulf of Mexico and the Caribbean Sea. Although MT+ days may not have the highest daytime temperatures, they often are characterized by high nighttime temperatures because humidity slows nighttime cooling. Humidity also inhibits the evaporation of sweat, which is a natural cooling mechanism in humans.

The characteristics of DT and MT+ days vary by location.[69] For example, average DT days in Phoenix, Arizona are hotter, drier, and slightly less cloudy than average DT days in Cincinnati, Ohio. Across locations, however, DT and MT+ days are consistently more dangerous to human health than other weather types.

Air pollution like ground-level ozone (smog) is not used to classify weather types, but conditions on DT and MT+ days can accelerate the formation of smog and small particulate matter.[70]

Once we classified summer days in each location, we used a statistical technique called stepwise multiple regression to develop city-specific equations describing the relationship from 1975 to 2010 between excess deaths and meteorological variables (day of the year, day in the sequence of the heatwave, temperature, and dew point).[71] "Excess deaths" are the total number of deaths in a given MSA (i.e., from "all causes," as defined by the International Classification of Diseases Ninth Revision [ICD-9]) above the daily standardized summertime average for that MSA. We did not find statistically significant relationships between dangerous summer days and excess deaths in six MSAs

(Charlotte, NC; Columbus, OH; Houston, TX; Miami, FL; San Diego, CA; and Tampa, FL), and omitted them from further analysis.

For the remaining 45 MSAs, we used the equations to develop midcentury (2046 to 2055) and late-century (2091 to 2100) projections of dangerous summer days and excess deaths under two emission scenarios.[72] Representative Concentration Pathway 8.5 (RCP8.5) is a high-emission scenario roughly equivalent to business-as-usual (i.e., no action), and RCP4.5 is an intermediate-emission scenario roughly equivalent to global implementation of the Paris Agreement.[73] The emission scenarios were used as inputs to the Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel ensemble.[74] We regridded the models to 0.5 degrees of latitude by 0.5 degrees of longitude, which is roughly the size of many major urban areas in the United States.

The model runs produced erratic swings in midmorning dew point values in the driest and hottest urban areas (e.g., Phoenix, Arizona), particularly under the RCP8.5 scenario. This resulted in an unrealistic number of transition days, in which one weather type is shifting to another.[75] We largely addressed this issue by using a smoothing algorithm to interpolate midmorning dew point values from the early morning and afternoon values.

This study had some limitations. First, the findings most likely reflect the combined effects of extreme heat and air pollution, which often occur together.[76] For instance, a 28-year study of 12 Canadian cities found that DT and MT+ weather types significantly increased the likelihood of extreme air pollution events and that smog particularly increased the relative risk of death during both mild and dangerous weather.[77] Second, we did not consider possible behavioral changes of local populations (e.g., increased use of air-conditioning) or physiological acclimatization to extreme heat, which could reduce the risk of death during dangerous summer days.[78] On the other hand, we also did not include future changes in population size or demographic makeup, which could have the opposite effect. One of the few heatwave studies to include a detailed investigation of future shifts in the U.S. population suggests the combination of national population growth and local and regional redistribution of people is nearly as important as climate change to human heat exposure.[79] Finally, although the location-specific application of Spatial Synoptic Classification captures the historical heat island effect in a given area, we did not attempt to analyze how heat islands might change over time. For instance, a study of large cities in the United States and Canada suggests that areas of cities with high densities of tall buildings will warm slightly faster than less dense areas.[80]

ENDNOTES

1 Kenneth D. Kochanek et al., *Deaths: Final Data for 2014*, *National Vital Statistics Reports* 65, no. 4 (Hyatsville, MD: U.S. Department of Health & Human Services, June 2016). www.cdc.gov/nchs/data/nvsr/nvsr65/nvsr65_04.pdf.

2 Natural Resources Defense Council (NRDC), *The Paris Agreement on Climate Change* (December 2015). www.nrdc.org/sites/default/files/paris-climate-agreement-IB.pdf.

3 Marcus C. Sarofim et al., Temperature-related Death and Illness, chapter 2 in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (U.S. Global Change Research Program, 2016). s3.amazonaws.com/climatehealth2016/low/ClimateHealth2016_02_Temperature_small.pdf.

4 Gerald A. Meehl et al., "US Daily Temperature Records Past, Present, and Future," *Proceedings of the National Academy of Sciences of the United States of America* 113, no. 49 (December 2016), 13977-13982. www.pnas.org/content/113/49/13977.abstract.

5 National Aeronautics and Space Administration, *NASA, NOAA Data Show 2016 Warmest Year on Record Globally* (January 18, 2017), www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-globally.

6 National Oceanic and Atmospheric Administration (NOAA), *National Overview - Annual 2016* (January 9, 2016), www.ncdc.noaa.gov/sotc/national/201613 (March 16, 2017).

7 NOAA, *Global Climate Report – Annual 2016* (January 2017), www.ncdc.noaa.gov/sotc/global/201613 (April 24, 2017).

8 Marcus C. Sarofim et al., 2016.

9 G. Brooke Anderson and Michelle L. Bell, "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 (February, 2011), 210-218, ehp.niehs.nih.gov/1002313/.

10 Marcus C. Sarofim et al., 2016.

11 In the context of the cited report, "high confidence" indicates the conclusion is supported by moderate evidence and medium scientific consensus. Marcus C. Sarofim et al., 2016.

12 Ibid.

13 Kim Knowlton et al., "Six Climate Change-Related Events in the United States Accounted for About $14 Billion In Lost Lives and Health Costs," *Health Affairs* 30, no. 11 (November 2011), 2167-2176. content.healthaffairs.org/content/30/11/2167.full?ijkey=wUzlufto4tODk&keytype=ref&siteid=healthaff.

14 Lauren Joe et al., "Mortality During a Large-Scale Heat Wave by Place, Demographic Group, Internal and External Causes of Death, and Building Climate Zone," *International Journal of Environmental Research and Public Health* 13, no. 3 (2016), 299. www.mdpi.com/1660-4601/13/3/299/htm.

15 B. Jacklitsch et al., *Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*, (National Institute for Occupational Safety and Health, 2016), www.cdc.gov/niosh/docs/2016-106/. G.R. McGregor et al., eds., *Heatwaves and Health: Guidance on Warning-System Development* (World Meteorological Organization and World Health Organization, 2015) www.wh o.int/globalchange/publications/WMO_WHO_Heat_Health_Guidance_2015.pdf. www.who.int/globalchange/publications/heatwaves-health-guidance/en/

16 NRDC, *Tracking 'The Silent Killer': Experts Track Effects of Heat on Human Health as Temperatures Rise* (May 2016). www.nrdc.org/sites/default/files/tracking-silent-killer-heat-health-fs.pdf.

17 Marcus C. Sarofim et al., 2016. Xuping Song et al., "Impact of Ambient Temperature on Morbidity and Mortality: An Overview of Reviews," *Science of the Total Environment* 586 (May 2017), 241-254. www.sciencedirect.com/science/article/pii/S0048969717302292.

18 B. Jacklitsch, et al., 2016. McGregor, et al., 2015.

19 G.C. Donaldson et al., "Cardiovascular Responses to Heat Stress and the Consequences in Healthy and Vulnerable Humans," *International Journal of Hyperthermia* 19, no. 3 (2003), 225-235. www.tandfonline.com/doi/abs/10.1080/0265673021000058357.

20 United Nations Framework on Climate Change (UNFCCC), *UNFCCC – 20 Years of Effort and Achievement*, unfccc.int/timeline/ (March 8, 2017).

21 NRDC, *The Paris Agreement on Climate Change* (December, 2015). www.nrdc.org/sites/default/files/paris-climate-agreement-IB.pdf.

22 UNFCCC, *Over 55 Parties Covering More Than 55 per cent of Global Greenhouse Gas Emissions Ratify the Paris Climate Change Agreement* (October 5, 2016), newsroom.unfccc.int/unfccc-newsroom/landmark-climate-change-agreement-to-enter-into-force/.

23 UNFCCC, *Paris Agreement* (2015). unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

24 Glen P. Peters et al., "Key Indicators to Track Current Progress and Future Ambition of the Paris Agreement," *Nature Climate Change* 7 (2017), 118-12. www.nature.com/nclimate/journal/v7/n2/full/nclimate3202.html.

25 J.M. Melillo et al., eds., *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment* (U.S. Global Change Research Program, 2014). nca2014.globalchange.gov/highlights.

26 H. Damon Matthews and Kirsten Zickfeld, "Climate Response to Zeroed Emissions of Greenhouse Gases and Aerosols," *Nature Climate Change* 2 (2012), 338-341. www.nature.com/nclimate/journal/v2/n5/full/nclimate1424.html. A. Crimmins et al., eds. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (U.S. Global Change Research Program, 2016), health2016.globalchange.gov/downloads.

27 The White House, *Presidential Executive Order on Promoting Energy Independence and Economic Growth* (March 28, 2017), www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1. Office of Management and Budget, *Budget of the U.S. Government: A New Foundation for American Greatness, Fiscal Year 2018* (May 2017). www.whitehouse.gov/sites/whitehouse.gov/files/omb/budget/fy2018/budget.pdf.

28 Jake Schmidt, *Trump Recklessly Pulls U.S. out of the Paris Agreement*, (NRDC, June 1, 2017), www.nrdc.org/experts/trump-recklessly-pulls-us-out-paris-agreement.

29 Benjamin M. Sanderson and Reto Knutti, "Delays in US Mitigation Could Rule Out Paris Targets," *Nature Climate Change* 7 (February 2017), 92-94. www.nature.com/nclimate/journal/v7/n2/full/nclimate3193.html.

30 D.M. Hondula et al., "The SCC: A Decade of Climate-Health Research and Future Directions," *International Journal of Biometeorology* 58 (2014), 109. P. Grady Dixon et al., "Perspectives on the Synoptic Climate Classification and its Role in Interdisciplinary Research," *Geography Compass* 10/4 (2016), 147-164. onlinelibrary.wiley.com/doi/10.1111/gec3.12264/abstract.

31 Scott C. Sheridan, "The Redevelopment of a Weather-Type Classification Scheme for North America," *International Journal of Climatology* 22 (2002), 51-68. onlinelibrary.wiley.com/doi/10.1002/joc.709/full.

32 U.S. Census Bureau, *Metropolitan and Micropolitan*, www.census.gov/programs-surveys/metro-micro/about.html (June 4, 2017).

33 Detlef P. van Vuuren et al., "The Representative Concentration Pathways: An Overview," *Climatic Change* 109 (2011), 5-31. link.springer.com/article/10.1007%2Fs10584-011-0148-z.

34 O. Edenhofer et al., eds., "IPCC, 2014: Summary for Policymakers," in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014. www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf.

35 Detlef P. van Vuuren et al., 2011. O. Edenhofer et al., eds., 2014.

36 Climate Action Tracker, *Effect of Current Pledges and Policies on Global Temperature*, climateactiontracker.org/global.html (February 22, 2017).

37 A. Crimmins et al., 2016.

38 National Weather Service, *Glossary*, w1.weather.gov/glossary/index.php?letter=h (June 4, 2017).

39 McGregor et al., 2015.

40 Jeremy E. Diem et al., "Heat in the Southeastern United States: Characteristics, Trends, and Potential Health Impact," *PLoS ONE* 12, no. 5 (May 2017). e0177937, doi.org/10.1371/journal.pone.0177937.

41 Wen-Ching Chuang et al., "Sensitivity to Heat: A Comparative Study of Phoenix, Arizona and Chicago, Illinois (2003–2006)," *Urban Climate* 5 (2013), 1-18. www.sciencedirect.com/science/article/pii/S2212095513000291.

42 Scott C. Sheridan and Laurence S. Kalkstein, "Progress in Heat Watch Warning System Technology," *Bulletin of the American Meteorological Society* 85 (December 2004), 1931-1941. journals.ametsoc.org/doi/pdf/10.1175/BAMS-85-12-1931.

43 Ibid.

44 Ibid.

45 U.S. Environmental Protection Agency, *Reducing Urban Heat Islands: Compendium of Strategies: Draft*, (2008), www.epa.gov/heat-islands/heat-island-compendium.

46 Dana Habeeb et al., "Rising Heat Wave Trends in Large US Cities," *Natural Hazards*, 76, no. 3 (April 2015), 1651-1665. link.springer.com/article/10.1007%2Fs11069-014-1563-z.

47 David M. Hondula et al., "Geographic Dimensions of Heat-Related Mortality in Seven U.S. Cities," *Environmental Research* 1308 (April 2015), 439-452. www.sciencedirect.com/science/article/pii/S0013935115000687.

48 Joyce Klein Rosenthal et al., "Intra-Urban Vulnerability to Heat-Related Mortality in New York City, 1997–2006," *Health & Place* 30 (November 2014), 45-60. www.sciencedirect.com/science/article/pii/S1353829214001087.

49 Andrew M. Fraser et al., "Household Accessibility to Heat Refuges: Residential Air Conditioning, Public Cooled Space, and Walkability," *Environment and Planning B: Planning and Design*, first published July 2016. journals.sagepub.com/doi/abs/10.1177/0265813516657342.

50 U.S. Census Bureau, *Population Change for Metropolitan and Micropolitan Statistical Areas in the United States and Puerto Rico (February 2013 Delineations): 2000 to 2010 (CPH-T-5)*, www.census.gov/population/www/cen2010/cph-t/cph-t-5.html (January 23, 2017).

51 Ibid.

52 NRDC, *The Road from Paris: The United States Progress Toward its Climate Pledge* (November 2016), www.nrdc.org/sites/default/files/paris-climate-conference-US-IB.pdf.

53 For example, Environmental Entrepreneurs (E2) and E4TheFuture, *Energy Efficiency Jobs in America* (December 2016). www.e2.org/wp-content/uploads/2016/12/EnergyEfficiencyJobsInAmerica_FINAL.pdf. California Environmental Protection Agency Air Resources Board, *California's Advanced Clean Cars Midterm Review: Summary Report for the Technical Analysis of the Light Duty Vehicle Standards* (January 2017). www.arb.ca.gov/msprog/acc/mtr/acc_mtr_finalreport_full.pdf.

54 The White House, *Presidential Executive Order on Promoting Energy Independence and Economic Growth* (March 28, 2017), www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1.

55 Jonathan M. Samet et al., "The Trump Administration and the Environment—Heed the Science," *The New England Journal of Medicine* 376, no. 12 (March 2017). 1182-1188. www.nejm.org/doi/full/10.1056/NEJMms1615242#t=article. Lissa Lynch and Juanita Constible, *Trump Budget Cuts Climate Science & Action Across the Board* (NRDC, March 17, 2017), www.nrdc.org/experts/lissa-lynch/trump-budget-cuts-climate-science-action-across-board.

56 Deron Lovaas, *Trump Budget Would Pile Bigger Energy Burden Onto the Poor* (NRDC, May 30, 2017), www.nrdc.org/experts/deron-lovaas/trump-budget-would-pile-bigger-energy-burden-poor. Alaska Wilderness League et al., to the U.S. Congress (March 22, 2017). www.sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/Environmental%20NGO%20Letter%20Supporting%20Healthcare%20Access.pdf.

57 Jake Schmidt, 2017.

58 Tom K.R. Matthews et al., "Communicating the Deadly Consequences of Global Warming for Human Heat Stress," *Proceedings of the National Academy of Sciences of the United States of America*, Online Before Print (March 27, 2017). www.pnas.org/content/early/2017/03/21/1617526114.abstract.

59 Jason Vargo et al., "The Social and Spatial Distribution of Temperature-Related Health Impacts from Urban Heat Island Reduction Policies," *Environmental Science and Policy* 66 (December 2016), 366-374. www.sciencedirect.com/science/article/pii/S1462901116305627.

60 City of Philadelphia, *Safety & Emergency Preparedness: Excessive Heat*, beta.phila.gov/services/safety-emergency-preparedness/natural-hazards/excessive-heat/ (March 16, 2017).

61 American Public Health Association and Centers for Disease Control and Prevention (CDC), *Adaptation in Action: Grantee Success Stories from CDC's Climate and Health Program* (March 2015). www.cdc.gov/climateandhealth/pubs/adaptation-in-action.pdf.

62 Ibid. and U.S. Census Bureau, *American Fact Finder: Ingham County, Michigan*, factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml?src=bkmk (June 9, 2017).

63 Kim Knowlton, *Tracking 'The Silent Killer': Experts Track Effects of Heat on Human Health as Temperatures Rise* (NRDC, May 24, 2016), www.nrdc.org/resources/tracking-silent-killer.

64 Council of State and Territorial Epidemiologists, *Heat-Related Illness Syndrome Query: A Guidance Document for Implementing Heat-Related Illness Syndromic Surveillance in Public Health Practice* (September 2016). c.ymcdn.com/sites/www.cste.org/resource/resmgr/pdfs/pdfs2/CSTE_Heat_Syndrome_Case_Defi.pdf.

65 CDC, *National Notifiable Diseases Surveillance System (NNDSS)*, wwwn.cdc.gov/nndss/ (May 17, 2017). Kim Knowlton, *Tracking 'The Silent Killer': Experts Track Effects of Heat on Human Health as Temperatures Rise* (NRDC, May 2016). www.nrdc.org/sites/default/files/tracking-silent-killer-heat-health-fs.pdf.

66 For the sake of simplicity, we refer to Metropolitan Statistical Areas by the first place in their full name. For example, we shorten "Philadelphia-Camden-Wilmington, PA-NJ-DE-MD" to "Philadelphia, PA." U.S. Census Bureau, *Population Change for Metropolitan and Micropolitan Statistical Areas in the United States and Puerto Rico (February 2013 Delineations): 2000 to 2010 (CPH-T-5)*, www.census.gov/population/www/cen2010/cph-t/cph-t-5.html (January 23, 2017).

67 Scott C. Sheridan, "The Redevelopment of a Weather-Type Classification Scheme for North America," *International Journal of Climatology* 22 (2002), 51-68. onlinelibrary.wiley.com/doi/10.1002/joc.709/full.

68 Scott C. Sheridan and Laurence S. Kalkstein, "Progress in Heat Watch Warning System Technology," *Bulletin of the American Meteorological Society* 85 (December 2004), 1931-1941. journals.ametsoc.org/doi/pdf/10.1175/BAMS-85-12-1931.

69 Ibid.

70 P. Grady Dixon et al., "Perspectives on the Synoptic Climate Classification and its Role in Interdisciplinary Research," *Geography Compass* 10/4 (2016), 147-164. onlinelibrary.wiley.com/doi/10.1111/gec3.12264/abstract. Ying Liu et al., "Effects of Synoptic Weather on Ground-Level PM2.5 Concentrations in the United States," *Atmospheric Environment* 148 (January 2017), 297-305. www.sciencedirect.com/science/article/pii/S1352231016308597.

71 The mortality database, unlike the synoptic database, only extends to 2010. For more methodological details, see Laurence S. Kalkstein et al., "An Evaluation of the Progress in Reducing Heat-Related Human Mortality in Major U.S. Cities," *Natural Hazards* 56, no. 1 (January 2011), 113-129. link.springer.com/article/10.1007%2Fs11069-010-9552-3.

72 Detlef P. van Vuuren et al., "The Representative Concentration Pathways: An Overview," *Climatic Change* 109 (2011), 5-31. link.springer.com/article/10.1007%2Fs10584-011-0148-z.

73 Climate Action Tracker, *Effect of Current Pledges and Policies on Global Temperature*, climateactiontracker.org/global.html (February 22, 2017).

74 Karl E. Taylor et al., "An Overview of CMIP5 and the Experiment Design," *Bulletin of the American Meteorological Society* 93 (April 2012), 484-498. journals.ametsoc.org/doi/citedby/10.1175/BAMS-D-11-00094.1.

75 Scott C. Sheridan, "The Redevelopment of a Weather-Type Classification Scheme for North America," *International Journal of Climatology* 22 (2002), 51-68. onlinelibrary.wiley.com/doi/10.1002/joc.709/full.

76 Jordan L. Schnell and Michael J. Prather, "Co-Occurrence of Extremes in Surface Ozone, Particulate Matter, and Temperature Over Eastern North America," *Proceedings of the National Academy of Sciences of the United States of America* 114, no. 11: 2854-2859. www.pnas.org/content/114/11/2854.abstract.

77 J. K. Vanos et al., "Association of Weather and Air Pollution Interactions on Daily Mortality in 12 Canadian Cities," *Air Quality, Atmosphere, and Health* 8 (June 2015), 307-320. link.springer.com/article/10.1007%2Fs11869-014-0266-7.

78 P. Grady Dixon et al., 2016.

79 Bryan Jones et al., "Future Population Exposure to U.S. Heat Extremes," *Nature Climate Change* 5 (2015), 652-655. www.nature.com/nclimate/journal/v5/n7/full/nclimate2631.html.

80 K.W. Oleson et al., "Interactions Between Urbanization, Heat Stress, and Climate Change," *Climatic Change* 129 (2015), 525-541. link.springer.com/article/10.1007/s10584-013-0936-8.