Killer Summer Heat: Projected Death Toll from Rising Temperatures in America Due to Climate Change

This report was written by Peter Altman, with help from Dan Lashof, Kim Knowlton, Ed Chen, Laurie Johnson and Dr. Larry Kalkstein.

This report analyzes the results of independent peer-reviewed scientific papers and presents the findings of increasing heat-related mortality due to global warming for the 40 largest U.S. cities. The conclusions were reached by determining the sensitivity of the populations of each city to extreme heat events and then applying that sensitivity to a projection for midcentury and end-of-century climate conditions.

  Our findings indicate that rising temperatures driven by unabated climate change will increase the number of life-threatening excessive heat events, resulting in thousands of additional heat-related premature deaths each year, with a cumulative toll of approximately 33,000 additional heat-related deaths by midcentury in these cities, and more than 150,000 additional heat-related deaths by the century's end.

About NRDC

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More than 150,000 Americans may die by the end of this century as a result of a growing number of excessive heat events caused by climate change, according to an analysis of peer-reviewed scientific literature conducted by experts at the Natural Resources Defense Council.

With global warming projected to raise North America's average temperatures another 4°F -11°F this century, according to the U.S. Global Change Research Program, excessive heat events are expected to increase in frequency.

INTRODUCTION

March 2012 was the warmest March on record for the 48 contiguous United States,[1] with more than 15,000 warm-temperature records broken. January through March was the warmest first quarter since record-keeping began in 1895.[2] At least 42 states saw record daytime highs in the summer of 2011 and 49 states saw record high nighttime temperatures.[3]

Warmer temperatures during winter and spring can seem welcome, but as spring turns to summer, warmth can turn to deadly heat. According to the National Oceanic and Atmospheric Administration (NOAA), during the past ten years, heat has been the number one weather-related killer in the United States, resulting in hundreds of fatalities each year. In fact, on average, excessive heat claims more lives each year than floods, lightning, tornadoes and hurricanes combined."[4]

In the United States, hundreds of heat-related deaths occur per year due to direct impacts and the indirect effects of heat exacerbating life-threatening illnesses, such as heat exhaustion, heat stroke, cardiovascular disease, and kidney disease.[5]

Excessive heat can result in a range of adverse health impacts, including cramps, edema (swelling), syncope (fainting), in addition to heat exhaustion, and heat stroke. High humidity presents an additional threat by hindering the evaporation of sweat, a natural cooling mechanism, which can cause body temperature to rise and further increase the risk of health problems.

Extreme heat waves can cause the most harm among elderly people and young children. City dwellers are also at particular risk because of elevated temperatures in cities (the urban heat island effect) brought about by the heat-magnifying effect of paved surfaces and the lack of tree cover.

The risks to public health are greatest when high temperatures and certain weather conditions combine to cause Excessive Heat Events. EHE *days* occur when a location's temperature, dew point temperature cloud cover, wind speed and surface atmospheric pressure throughout the day combine to cause or contribute to heat-related deaths in that location.

Health impacts spike during these excessive heat events. For example, when deadly heat waves swept across most of the nation in 2006, California was hit the hardest. During a two-week period, 655 deaths, 1,620 excess hospitalizations, and more than 16,000 additional emergency room visits occurred, resulting in nearly $5.4 billion in costs.[6]

EHE days vary by region and location, since non-weather factors including geography, green space, local warning and preventive measures and the resiliency of the local residents affect how much impact the weather will actually have on health. For example, a temperature of of 102° would create a negative health outcome in Cleveland, but those same temperatures would have little additional effect on people in Phoenix.

WHAT IS THE OUTLOOK FOR THE NEXT SEVERAL DECADES?

As global temperatures inexorably rise, scientists expect that average temperatures in North America will rise by another 4°F -11°F this century.[7] As the number of dangerously hot days and heat waves increases, people—especially heat-vulnerable children and the elderly—will face higher risk for more deadly and dangerous health outcomes.

HOW MUCH MORE DEADLY WILL HOT DAYS AND NIGHTS BECOME?

A recent study published in *Weather, Climate and Society (WCS)*,[8] the Journal of the American Meteorological Society, examined this question closely. This brief portrays the study's findings to make them more accessible to a general audience. The data presented here have been reviewed by one of the WCS paper's authors, Dr. Larry Kalkstein, Senior Professor of Geography and Regional Studies, at the University of Miami, to confirm that the original paper's findings are accurately reflected. A summary of the methodology underlying the WCS study has also been provided by Dr, Kalkstein and can be found as an appendix to this brief.

The study's authors examined the historical relationships among heat, weather conditions, and mortality for 40 U.S. cities and applied those relationships to the conditions that rising temperatures can be projected to produce in the coming decades. In doing so, the authors made several choices that are key to understanding the results presented later in this brief.

First, they used a sophisticated climate model from the National Center for Atmospheric Research to develop two scenarios of future temperatures. One scenario assumes that carbon and other greenhouse gas pollution will continue to rise unfettered by policy or other interventions (business-as-usual); the other scenario assumes some policy intervention has taken place sufficient to stabilize carbon dioxide concentrations at levels higher than today's but not as high as they would be without policy intervention.

Two, the authors developed two sets of algorithms to describe the relationships between temperature, weather conditions and mortality. One set is based on data from 1975-1995, and the other is based on a longer period spanning from 1975-2004. The principal difference between the two is that the longer period includes nearly a decade when cities took greater steps to anticipate excessive heat events, warn the public about them, and provide preventive measures to reduce the health toll of such events. Projections of future mortality based on this longer baseline produce lower estimates of mortality and assume some degree of adaptation to heat events.

Three, in addition, the authors made no adjustments for population growth in the cities studied. Estimation of population growth as well as the relative proportion of vulnerable individuals that may make up a city's population through the end of the century was not undertaken as part of this analysis. Holding population levels constant (while the per capita risk of mortality increases) likely understates future mortality that would be attributable to excessive heat events.

An important factor that may result in underestimation of heat-related premature mortality is the maturing of the baby boomer generation. As the Intergovernmental Panel on Climate Change stated in its 2007 report on the impacts of climate change on the United States, "Across North America, the population over the age of 65 will increase slowly to 2010, and then grow dramatically as the Baby Boomers join the ranks of the elderly—the segment of the population most at risk of dying in heat waves." The study did not adjust for this aging of the U.S. population.

The study also leans toward conservative results because it assumes a relatively steady increase in temperatures over the period of study. Actual warming will possibly be much more variable over the next several decades, with potentially larger and more intense deviations from normal meteorological conditions. Humans respond worse to higher-variability climates, since they tend to accentuate extremes in temperature that are most harmful to human health. The climate projections for this analysis may not fully reflect the potential of these sudden temperature swings, which create more intense health effects compared with gradual changes.[9] Thus, the cities in this study may experience sudden intense heatwaves that go significantly beyond the "thresholds" developed for this analysis. This could result in more heat-related mortality than the analysis projects.

The study does not take into account potential acclimatization of individuals because it is difficult to determine the exact degree to which individual behavior will change or how much change can realistically be made. If individuals continue to respond to heat exposure by purchasing air conditioners or avoiding the outdoors during heatwaves, mortality will be lower than the estimates produced here. However, there are limits to the extent of behavioral response. Those people living in poverty, who are among the most vulnerable to heat-waves, are constrained in their ability to find access to air conditioning. Likewise, many individuals are required by their job to spend time outside, so their options for reducing exposure may be limited.

This brief presents the findings from the WCS study produced using the "business-as-usual" (A1F1) pollution scenario and the more conservative mortality projections based on the longer baseline period.

Table 1: Increases in the Number of Excessive Heat Event Days (EHE Days) Caused by Climate Change					
		EHE Days Per Summer			
	Average Number of EHE Days per Summer (Historical Average 1975-1995)	**by Mid-Century (2045-2055)**		**by End-of-Century(2090-2099)**	
Location		**Climate Change Will Increase Per-Summer EHE Days by...**	**...Making the New Total Number of EHE Days Increase to**	**Climate Change Will Increase Per-Summer EHE Days by...**	**...Making the New Total Number of EHE Days Increase to**
Atlanta, GA	5	43	48	53	58
Baltimore, MD	8	37	45	61	69
Birmingham, AL	5	19	24	51	56
Boston, MA	11	40	51	60	71
Buffalo, NY	3	0	3	12	15
Chicago, IL	5	13	18	28	33
Cincinnati, OH	4	18	22	26	30
Cleveland, OH	5	0	5	12	17
Columbus, OH	5	-1	4	11	16
Dallas, TX	11	11	22	26	37
Denver, CO	9	79	88	68	77
Detroit, MI	9	6	15	27	36
Greensboro, NC	8	51	59	62	70
Hartford, CT	6	25	31	52	58
Houston, TX	1	4	5	12	13
Indianapolis, IN	5	17	22	27	32
Jacksonville, FL	7	17	24	36	43
Kansas City, MO	7	31	38	41	48
Los Angeles, CA	1	59	60	87	88
Louisville, KY	8	-3	5	21	29
Memphis, TN	9	9	18	31	40
Miami, FL	0	14	14	55	55
Minneapolis, MN	8	15	23	22	30
New Orleans, LA	5	3	8	49	54
New York, NY	11	44	55	64	75
Newark, NJ	8	47	55	60	68
Philadelphia, PA	6	48	54	67	73
Phoenix, AZ	7	77	84	68	75
Pittsburgh, PA	5	47	52	54	59
Portland, OR	4	38	42	47	51
Providence, RI	7	31	38	56	63
Salt Lake, UT	0	0	0	0	0
San Antonio, TX	5	18	23	25	30
San Diego, CA	1	38	39	60	61
San Francisco, CA	2	64	66	52	54
San Jose, CA	0	4	4	4	4
Seattle, WA	2	52	54	55	57
St. Louis, MO	11	24	35	34	45
Tampa, FL	3	33	36	56	59
Washington, DC	16	37	53	53	69
Current average of EHE days per year...	**233**				
Plus the additional EHE days climate change will cause annually by mid-century...		**1,109**			
Results in more than five time as many EHE days by mid-century.			**1,342**		
Plus the additional EHE days climate change will cause annually by the end of the century...				**1,685**	
And the result is more than EIGHT TIMES as many EHE days by the end of the century.					**1,918**

Note: This table shows the change to the number of EHE days projected to be caused by climate change and total projected average EHE days during 2045-2055 and 2090-2099, based on a climate model assuming the A1FI emissions scenario, which portrays a ""business-as-usual"" trend with continued significant reliance on fossil-fuels and no significant policy interventions. The figures in the ""Average Number"" column are the baseline; the figures in the ""Climate Change Will Increase . . . "" show the change in EHE days per summer as our climate warms up. Figures in the ""Resulting in Overall ... "" columns show the combination of the baseline and the additional climate-induced levels. Note: "Summer" refers to the months of June, July and August.

Source: Greene, S; Kalkstein L; Mills D; Samenow, J. 2011. "An Examination of Climate Change on Extreme Heat Events and Climate–Mortality Relationships in Large U.S. Cities." Weather, Climate and Society, October 2011, 3, 281-292."

New York, USA - June 10, 2011 where the thermometer reached 80+ degrees

Table 2: Increases in EHE-Attributable Mortality Caused by Climate Change						
		Mortality Per Summer				Cumulative Additional Mortality
		By Mid-Century (2045-2055)		By End-of-Century (2090-2099)		By Mid-Century) (2050)	By End-of-Century (2099)
Location	Average Mortality per Summer (Historical Average 1975-2004)	Climate Change Will Increase Per-Summer Average Mortality by...	...Making the New Total Summertime Mortality Increase to	Climate Change Will Increase Per-Summer Average Mortality by...	...Making the New Total Summertime Mortality Increase to	Year after year of increased mortality due to climate change adds up to...
Atlanta, GA	35	-11	24	-6	29	(359)	(756)
Baltimore, MD	57	26	83	70	127	495	2,947
Birmingham, AL	24	8	32	51	75	103	1,680
Boston, MA	99	55	154	114	213	1,404	5,715
Buffalo, NY	18	33	51	74	92	479	3,190
Chicago, IL	93	49	142	157	250	1,034	6,361
Cincinnati, OH	12	9	21	16	28	245	897
Cleveland, OH	40	93	133	446	486	2,530	16,625
Columbus, OH	4	38	42	151	155	1,066	6,001
Dallas, TX	46	69	115	144	190	1,885	7,271
Denver, CO	48	46	94	35	83	1,551	3,515
Detroit, MI	52	133	185	402	454	4,109	17,877
Greensboro, NC	31	16	47	21	52	331	1,259
Hartford, CT	27	13	40	49	76	283	1,892
Houston, TX	2	14	16	25	27	406	1,391
Indianapolis, IN	23	28	51	50	73	837	2,783

Table 2: Increases in EHE-Attributable Mortality Caused by Climate Change							
		Mortality Per Summer				**Cumulative Additional Mortality**	
		By Mid-Century (2045-2055)		**By End-of-Century (2090-2099)**		**By Mid-Century) (2050)**	**By End-of-Century (2099)**
Location	**Average Mortality per Summer (Historical Average 1975-2004)**	**Climate Change Will Increase Per-Summer Average Mortality by...**	**...Making the New Total Summertime Mortality Increase to**	**Climate Change Will Increase Per-Summer Average Mortality by...**	**...Making the New Total Summertime Mortality Increase to**	**Year after year of increased mortality due to climate change adds up to...**	
Jacksonville, FL	30	81	111	169	199	1,813	8,141
Kansas City, MO	41	48	89	71	112	1,280	4,236
Los Angeles, CA	18	11	29	29	47	219	1,222
Louisville, KY	39	218	257	337	376	5,081	18,988
Memphis, TN	46	84	130	247	293	1,645	10,154
Miami, FL	0	0	0	0	0	0	0
Minneapolis, MN	14	79	93	107	121	2,892	7,516
New Orleans, LA	22	7	29	46	68	221	1,613
New York, NY	184	-2	182	65	249	(573)	1,127
Newark, NJ	56	13	69	30	86	320	1,409
Philadelphia, PA	53	4	57	25	78	(39)	714
Phoenix, AZ	33	11	44	58	91	213	2,021
Pittsburgh, PA	19	14	33	19	38	411	1,241
Portland, OR	9	8	17	12	21	237	736
Providence, RI	37	16	53	50	87	353	2,035
Salt Lake, UT	2	1	3	2	4	36	113
San Antonio, TX	21	6	27	14	35	98	631
San Diego, CA	0	4	4	7	7	119	396
San Francisco, CA	3	2	5	5	8	87	260
San Jose, CA	10	3	13	5	15	69	281
Seattle, WA	11	-2	9	1	12	(99)	(125)
St. Louis, MO	24	58	82	113	137	1,285	5,621
Tampa, FL	25	0	25	16	41	(72)	351
Washington, DC	24	33	57	49	73	942	2,994
Current annual average mortality...	1,332						
plus the additional annual mortality due to climate change by mid-century...	1,316						
results in DOUBLED total EHE-mortality by mid-century:		2,648					
By the end of the century the additional burden of climate change on EHE-mortality is even greater compared to current levels . . .			3,276				
Resulting in more than a TRIPLING of EHE-Mortality by the end of the century.				4,608			
By 2050, the additional cumulative heat-related mortality caused by the additive effect of climate change is:						32,934	
By 2099, the additional cumulative heat-related mortality caused by the additive effect of climate change is:							150,322

Note: This table shows the additional mortality caused by climate change as well as total EHE mortality by 2050 and 2099 based on a climate model assuming the A1FI emissions scenario, which portrays a "business-as-usual" trend with continued significant reliance on fossil-fuels and no significant policy interventions. It also shows the cumulative impact of the additional mortality that occurs due to the effect of climate change. The figures in the "Average Number" column are the baseline; the figures in the "Climate Change Will Increase . . . " show the change in mortality per summer as our climate warms up. Figures in the "Making a New Summertime Total" show the combination of the baseline and the additional climate-induced levels. Note: "Summer" refers to the months of June, July and August.

Sources: Column 2: Kalkstein L., Greene S., Mills D., Samenow S. "An evaluation of the progress in reducing heat-related human mortality in major U.S. cities," 2010, Natural Hazards. DOI 10.1007/s11069-010-9552-3.

Columns 4 and 6: Greene, S; Kalkstein L; Mills D; Samenow, J. 2011. "An Examination of Climate Change on Extreme Heat Events and Climate–Mortality Relationships in Large U.S. Cities." Weather, Climate and Society, October 2011, 3, 281-292.

RESULTS

Excessive Heat Events

The *WCS* study projects that rising temperatures projected due to heat-trapping pollution may cause more than a five-fold increase in the number of excessive heat event days (EHE days) across the cities by mid-century and more than an eight-fold increase by the end of the century.

Combined, the 40 cities studied[10] experience an average of 233 EHE days per year currently (over a 1975-1995 reference period). By mid-century, 35 of the 40 cities are projected to experience more EHE days. As a result, by mid-century the number of EHE days for all cities will have increased by 1,109, bringing the total number of EHE days by mid-century up to 1,342, more than a five-fold increase.

By the end of the century, 39 cities are projected to experience more EHE days. As a result, by the end of the century the number of EHE days for all cities will have increased by 1,685, bringing the total number of EHE days by century's end up to 1,918, an increase of more than eight times the baseline level.

In most cases, the increase in EHE days leads to an increase in EHE mortality. The WCS study projects that 37 of the 40 cities studied will experience an increase in EHE mortality by the end of the century.

Combined, the 40 cities in the study currently experience an average of 1,332 EHE deaths per year in the 1975-2004 reference period. Climate change drives that figure up by 1,316 by mid-century to 2,648 deaths per year, effectively doubling EHE deaths by that time. Climate change is estimated to cause an even greater increase over the course of the century, increasing by the end of century the annual EHE deaths by 3,276 to reach 4,608 EHE deaths total in the 40 cities, per year.

The cumulative impact of climate change on EHE deaths is substantial. Combined, the 40 cities studied are expected to experience 32,934 more deaths by mid-century than they would in the absence of climate change, and 150,322 more deaths by century's end than they would in the absence of climate change.

Those cities experiencing the greatest increase in EHE deaths by mid-century are: Louisville, Kentucky (5,081); Detroit, Michigan (4,109); Minneapolis, Minnesota (2,892); Cleveland, Ohio (2,530); Dallas, Texas (1,885); Jacksonville, Florida (1,813); Memphis, Tennessee (1,645); Denver, Colorado (1,551); Boston, Massachusetts (1,404); and Kansas City, Missouri (1280).

Those cities experiencing the greatest increase in EHE deaths by end-of-century are Louisville, Kentucky (18,988); Detroit, Michigan (17,877); Cleveland, Ohio (16,625); Memphis, Tennessee (10,154); Jacksonville, Florida (8,141); Minneapolis, Minnesota (7,516); Dallas, Texas (7,271); Chicago, Illinois (6,361); Columbus, Ohio (6,001); Boston, Massachusetts (5,715); and St. Louis, Missouri (5,621).

CONCLUSION

Rising global temperatures pose a wide range of threats to public health, including increased mortality driven by excessive heat events. While the preventive and protective measures adopted by cities in recent years can be expected to offset some of the impacts of climate change, which includes contributing to worsening heat waves, it is clear that if temperatures continue to rise, this will likely expose the populations in our biggest cities to greater risks of heat-related deaths.

Under the Clean Air Act, the United States Environmental Protection Agency (EPA) is charged with protecting public health from dangerous air pollution; one way to do this is by setting standards to limit carbon and other global warming pollutants. In late March 2012, the agency took its first steps to limit carbon pollution from industrial sources by proposing the Carbon Pollution Standard for New Power Plants. Carbon pollution from existing power plants, refineries and other sources must follow, and other sectors will need to be addressed as well. Citizens may express their support for EPA's proposed carbon pollution standard for new power plants by submitting a public comment to the Agency by June 25, 2012.

APPENDIX

Summary of the methodology used in the October 2011 *Weather, Climate and Society*-published study "An Examination of Climate Change on Extreme Heat Events and Climate–Mortality Relationships in Large U.S. Cities." (Greene S, Kalkstein LS, Mills, DM, Samenow J, DOI:10.1175/WCAS-D-11-00055; 2011;3:281-291)

We developed relationships between climate and excessive heat event mortality for 40 cities around the United States; all cities had metropolitan-area populations exceeding 1,000,000 people. We looked at deaths from all causes and summed them for each day in each of the cities.

Our studies suggest that, rather than responding in isolation to individual weather elements such as maximum temperature, human health is affected by the simultaneous interactions from a combination of meteorological variables, such as temperature, humidity, cloud cover, and wind speed. Therefore, we identified weather situations, or "oppressive air masses" that increase the incidence of hot-weather mortality. We found two air masses are particularly hot and uncomfortable, the dry tropical (DT), which is the hottest and driest air mass, and the moist tropical (MT+), which is very hot and humid. Human mortality increases significantly in many cities when these air masses are present.

During the summer period of June 1 through August 31, each day in each city is assigned an air mass category to determine if DT and MT+ show statistically significantly higher daily mortality. In those cities where this is the case (the vast majority), a mortality algorithm is developed that relates the variation in mortality on all oppressive air-mass days within a city to meteorological and environmental variables. The meteorological variables considered are maximum and minimum air temperature and maximum and minimum dewpoint temperature. The environmental variables considered include consecutive days of offensive air mass conditions and the time of the season when the offensive air mass occurs (the authors' research shows that heat waves early in the summer season generally are more dangerous to human health than heat waves late in the summer season). For example, the following algorithm was developed for the DT air mass in St. Louis, based upon relationships between historical weather and mortality data in that city during DT days:

$MORT = 0.32T_{max} - 0.03TOS$, where MORT is excessive mortality during DT days, T_{max} is the maximum temperature in degrees C, and TOS is time of season, where June 1 receives a value of 1 and August 31 is given a value of 92.

For this study, the Parallel Climate Model (PCM) was used to complete climate simulations with the results then downscaled to each city. The PCM is a global coupled atmosphere-ocean general circulation model developed at the National Center for Atmospheric Research that provides state-of-the-art simulations of the earth's past, present, and future climate states. This incorporates observed historical emissions of carbon dioxide, methane, and other greenhouse gases, as well as projections into the 21st century. Two scenarios were used: the higher-emissions A1FI scenario, and the lower-emissions B1 scenario. The A1FI is a "business-as-usual" scenario and assumes carbon dioxide concentrations of approximately 1,000 parts per million (ppm) by the end of this century. The B1 values assume that we will stabilize carbon dioxide levels at 550 ppm by the end of the century.

These scenarios were applied to three decadal periods: 2020-2029, 2045-2054, and 2090-2099, and six-hourly meteorological simulations were developed for all summer days within these decades. These numbers were compared with results during the reference period, beginning in 1975.

Finally, two sets of historical weather/mortality algorithms were developed: one covering the period 1975-1995, when there was little awareness of the dangers of heat on human health, and for the longer period of 1975-2004, which includes a later period when the establishment of advanced heat-health warning systems was becoming widespread and local health departments were developing sophisticated heat-intervention measures for the vulnerable population. Thus, the latter values assume some level of adaptation to heat and will likely produce smaller numbers of excess deaths during offensive air mass days.

Additional Analysis by NRDC

The Greene, et al. paper on which this report is based was geared toward a scientific rather than a lay audience. NRDC, with review and approval by Dr. Kalkstein, applied some simple analytical tools to the findings in the original paper in order to make them more accessible.

Table 1 "Excessive Heat Events" in this report is based upon Table 2 from the original paper. Our table reports the baseline average number of EHE days for each city, taken directly from Table 2 in the original. The original tables also provided the total number of EHE days projected in future years, where the total includes the baseline number of days plus the additional EHE days that would be caused by climate change. We chose to report the change to the average number of EHE days caused by cilmate change in order to make the effects of rising temperatures more clear. We did this by subtracting from the future EHE values the baseline values, leaving the difference caused by climate change. For example, the original paper reported a baseline average of 16 EHE days for Washington, D.C. and projected an average of 53 EHE days per summer during the period 2045-2055. To show just the impact of climate change, we subtracted the baseline (16) from the future value (53) to show the difference (37).

We also include in our table values for the total and average numbers of EHE days.

Table 2 "Additional Heat-Related Deaths" in this report is based on Table 4 in the original report and on unpublished data the authors used to generate Table 4 but did not report in the table itself. Table 4 in the original report provides estimates of future heat-related deaths under two global warming scenarios. This table is based on the author's more conservative approach of setting the baseline number of

heat-related deaths based on the years 1975-2004. The authors reported the baseline values used in a separate study[11], and we used those baselines to produce estimates of the change in heat-related deaths attributable to warming temperatures. We used the same approach as for our Table 1, by subtracting from the future average mortality values the baseline values for each city.

Table 2 builds on the original papers Table 4 in another way, by providing an estimate of the cumulative number of additional heat-related deaths attributable to climate change. We calculated the cumulative total by adding the average additional heat-related deaths for the three periods in the original study (2020-2029, 2045-2055, 2090-2099); we then estimated the additional heat-related deaths for the years in between those periods by assuming a linear increase in average annual heat-related deaths between the last year of each period and the first year of the next, taking care to remove overlapped years.

Endnotes

1   National Oceanic and Atmospheric Administration *State of the Climate National Overview*, March 2012. http://www.ncdc.noaa.gov/sotc/national/2012/3.

2   Ibid.

3   http://www.nrdc.org/health/extremeweather/.

4   http://www.nws.noaa.gov/om/hazstats.shtml.

5   US Environmental Protection Agency, National Oceanographic and Atmospheric Administration and Centers for Disease Control, *Excessive Heat Events Guidebook*, June 2006 (http://www.epa.gov/hiri/about/pdf/EHEguide_final.pdf).

6   Knowlton, K., Rotkin-Ellman, M., et al., 2011: "Six Climate Change–Related Events in the United States Accounted for About $14 Billion in Lost Lives and Health Costs." *Health Affairs*, November 2011, vol. 30, no. 11, 2167-2176.

7   Global Climate Change Impacts in the United States", page 29. Accessed on May 18, 2012 from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

8   Greene, S; Kalkstein L; Mills D; Samenow, J. 2011. "An Examination of Climate Change on Extreme Heat Events and Climate–Mortality Relationships in Large U.S. Cities." *Weather, Climate and Society*, October 2011, 3, 281-292.

9   Zanobetti A., O'Neill M., Gronlund C., Schwartz D., Summer temperature variability and long-term survival among elderly people with chronic disease. PNAS 2012 109 (17) 6608-6613; published ahead of print April 9, 2012, doi:10.1073/pnas.1113070109.

10 The forty cities studied are those shown by the 2000 Census to have populations over 1 million. The 2000 Census was the most recent information available at the time the research began.

11 Kalkstein L., Greene S., Mills D., Samenow S. "An evaluation of the progress in reducing heat-related human mortality in major U.S. cities," 2010, *Natural Hazards*. DOI 10.1007/s11069-010-9552-3.