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An evaluation of the progress in reducing heat-related human mortality in major U.S. cities

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Abstract This study estimates the excess mortality attributable to excessive heat events (EHEs) for forty major U.S. cities during 1975–1995 and 1975–2004. We calculate these results using the spatial synoptic classification method to identify EHE days. Step-wise regressions are then used to estimate the location-specific mortality algorithms that can account for the impact of the EHEs' duration, severity, and timing. Our excess mortality results are expressed both as lives lost and associated mortality rates (excess deaths per 100,000 residents) using 2000 Census population estimates. Our results generally show a reduction in EHE-attributable mortality rates since 1996. Adjusting our results to account for changes in the average number of EHE days per year in each period does not affect this general conclusion. However, this adjustment has a considerable impact on a measure of the cities' relative performance in terms of reducing this EHE-attributable excess

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mortality. Our results indicate there is promise for further reductions in EHE-attributable mortality from the approximately 1300 excess deaths per summer we identify using data from the 1975–2004 period. However, the magnitude of this result highlights the significant health burden of EHEs relative to other extreme weather events in the United States and suggests it is worthy of additional attention. Our results also raise important questions with respect to evaluating the performance of EHE notification and response programs and how EHE-attributable mortality should be estimated for future scenarios, notably for climate change projections.

Keywords Climate and human health · Excessive heat event programs · Excess mortality

1 Introduction

In many ways, 1995 was a watershed year in the United States in terms of increasing awareness of the public health risks of excessive heat events (EHEs). Two EHE-related events in particular helped bring about this change.

First, in mid-July, an extremely severe EHE developed over the Midwestern United States. While a large region was affected, Chicago became the event's reference point, as the heat was found responsible for over 700 excess deaths (i.e., deaths not otherwise expected based on historical averages) (Kaiser et al. 2007). This loss of life clearly demonstrated the potential health risks and impacts of EHEs.

Second, as the July 1995 EHE developed, the City of Philadelphia announced its Hot Weather-Health Watch Warning System (HHWS). This system featured a spatial synoptic classification (SSC)-based model that allowed the city to estimate potential excess heat-attributable mortality based on forecast weather conditions. Philadelphia's health department used the model's excess mortality estimates as an additional input in deciding whether to activate their heat notification and response program. As the July EHE moved East, Philadelphia's HHWS was activated in part because of the model's mortality estimates (Kalkstein et al. 1996).

Philadelphia's excess mortality from the July 1995 EHE contrasted sharply with the city's recent experience as well as with other cities like Chicago. For example, when the Philadelphia's coroner identified 105 heat-related deaths during a July 1993 EHE, the media dubbed the city the "Heat Death Capital of the World" (U.S. EPA 2006). The reduced health impacts in Philadelphia also drew significant attention because of their contrast with Chicago's experience. This contrast suggested that an integrated and aggressive EHE notification and response program could produce significant public health benefits. In fact, over a three-summer period in the 1990's, Philadelphia's program was estimated to have saved over 115 lives (Ebi et al. 2004).

As a result of these factors, many public health and elected officials, along with private groups and industry, began efforts to develop and implement EHE notification and response programs. Notably, the National Weather Service (NWS), cities, utilities, and others began a program of increasing the number of U.S. cities covered by SSC-based systems like Philadelphia's system. A number of SSC-based HHWS have been established in the US and internationally (see http://www.as.miami.edu/geography/research/climatology/OtherWWS.html for a list).

This paper's primary goal is to evaluate whether progress has been made in reducing mortality attributable to EHEs since 1995 by developing estimates of EHE-attributable excess mortality in major U.S. metropolitan areas for the period from 1975 to 1995 and the period from 1975 through 2004. A second goal is to evaluate the EHE-attributable mortality trends in these data in the context of climate trends (i.e., changes in the number of EHE days over time) and adaptation efforts such as heat warning, intervention, and response programs. Several studies have noted reductions in EHE-induced mortality over the past several decades (Davis et al. 2002, 2003). A recent study suggests that this decline may have begun to stabilize in the late 1990s (Sheridan et al. 2009). An important aspect of this research is to examine these results with additional data while trying to determine whether, and to what extent, EHE notification and response programs have contributed to any trend changes.

2 Data

This study estimates EHE-attributable excess mortality in terms of average annual excess deaths in the resident population and mortality rates for the 40 U.S. cities listed in Table 1.

The cities in Table 1 were selected by having a resident population of at least 100,000 in the 2000 U.S. Census (U.S. Census Bureau 2009) and because they were the focus of similar research in the past (Kalkstein and Greene 1997).

For each city in Table 1, we obtained electronic records from the National Center for Health Statistics consisting of the daily count of all-age, all-cause deaths from June 1 through August 31 for the years 1975 through 2004.

Meteorological data were extracted for each city for the period 1948–2007 from the information available through the National Climatic Data Center. These data include the daily values for temperature, dew point temperature, cloud cover, surface atmospheric pressure, and wind speed at 4 a.m., 10 a.m., 4 p.m., and 10 p.m.

3 Methods

We developed two time series using the meteorological and mortality data. The first series covers the period 1975–1995. This represents our “control” period before the widespread increase in EHE awareness, when subsequent notification and response activity commenced because of the very hot summer of 1995. The second series covers the years 1975-2004. Results from this longer period can be compared with the earlier period to estimate the direction and nature of change in EHE-attributable excess mortality in the 10 years

Table 1 Cities in the study

Atlanta	Denver	Memphis	Providence
Baltimore	Detroit	Miami	Salt Lake City
Birmingham	Greensboro	Minneapolis	San Antonio
Boston	Hartford	Newark	San Diego
Buffalo	Houston	New Orleans	San Francisco
Chicago	Indianapolis	New York City	San Jose
Cincinnati	Jacksonville	Philadelphia	Seattle
Cleveland	Kansas City	Phoenix	St. Louis
Columbus	Los Angeles	Pittsburgh	Tampa
Dallas	Louisville	Portland, OR	Washington, DC

following the 1995 EHE. To facilitate comparisons across time periods and locations, our results are expressed in terms of EHE-attributable excess mortality rates per 100,000 city residents using 2000 as a base year. We developed these results using the following multi-step process.

First, for each study day at each location, we assigned an air mass category based on the available meteorological data (see Sheridan and Kalkstein 2004).

The air mass categories available through the SSC method included:

- *Dry moderate (DM)*: A warm, comfortable air mass that frequently occurs in the eastern half of the United States in the summertime.
- *Dry polar (DP)*: Cooler than DM, but still warm in the summertime. Usually occurs after the passage of a cold front.
- *Dry tropical (DT)*: The hottest air mass in the summer, with temperatures usually exceeding 95°F and sometimes topping 100°F. Little cloud cover and low humidity lead to potentially rapid dehydration.
- *Moist moderate (MM)*: A cloudy, mild air mass that may sometimes be associated with fog and light rain.
- *Moist polar (MP)*: Usually a winter, rather than summer, air mass; this is often associated when storms move up the East Coast.
- *Moist tropical (MT)*: Very warm and humid air mass, sometimes associated with summer thunderstorms. Sticky and uncomfortable, and quite common in summer.
- *Moist tropical plus (MT +)* and *Moist tropical plus plus (MT ++)*: These are particularly hot and humid subsets of the MT air mass. Dewpoint temperatures are very high, temperatures are in the 90°s, and overnight temperatures are the warmest of any air masses. Both have temperatures and dewpoints that are at least 1 standard deviation above the MT mean.
- *Transition (T)*: Associated with a frontal passage, when temperature, dewpoint, and other meteorological factors change rapidly.

Second, for each study day, we calculated the difference in the observed daily mortality from the daily standardized summertime average for that year. The daily standardized value was computed by adjusting for trends (if any) in population or intra-seasonal variability in mortality not attributed to meteorology (for a complete description of mortality standardization, refer to Sheridan and Kalkstein 2004). For example, assume that, on average, in City A 30 people died per day during the summer of 2000. If 50 deaths were observed in City A on July 1, 2000, this calculation would return a value of +20 (50–30 = 20) (negative values in this approach reflect days where observed mortality is less than the summertime average for the year).

Third, we identified offensive air masses. To do this, we characterized the distribution of the daily mortality differences for the study period for each air mass. Offensive air masses are those whose mean daily-standardized mortality difference, as calculated above, is statistically significantly greater than 0.

Based on the results of previous studies (e.g., Kalkstein et al. 2008a, b), it is clear that the dry tropical (DT) and a particularly oppressive moist tropical (MT +) air mass are offensive. Given the relatively high-heat conditions and elevated mortality in these air masses, study days in the DT or MT + air masses are considered EHE days.

Fourth, city-specific EHE-attributable excess mortality algorithms are developed for each time period. These algorithms provide a quantitative relationship between the observed mortality differences across all EHE day in the study period while considering a series of meteorological and non-meteorological variables that include:

3.1 Meteorological variables

- *tmin*: minimum temperature
- *tmax*: maximum temperature
- *tdmax*: maximum dewpoint temperature
- *tdmin*: minimum dewpoint temperature

3.2 Non-meteorological measures

- *Julian*: Numerical value for each day in the summer season. Values progress without interruption from the start of the season to the end (e.g., June 1 = 1, July 1 = 31, August 31 = 92)
- *DIS*: Day in sequence within an offensive air mass. Values start at 1 for the first EHE day after a non-EHE day and continue as long as EHE days continue without interruption.

The mortality algorithms are developed using an iterative stepwise regression analysis program that considers different combinations of the meteorological and non-meteorological variables to explain the variation in the daily mortality difference estimates. The stepwise procedure also checks for collinearity (e.g., tolerance and variance inflation factor scores) among the independent variables. If collinearity significantly altered the results of the model, the variable in question was eliminated. This is not the case in the vast majority of city models. The final mortality algorithm for a given time period in a city is the regression equation that explains the greatest extent of the observed variation in the mortality difference values (i.e., the equation that maximizes the R^2 value).

Fifth, the mortality algorithms are used to calculate EHE-attributable excess mortality on each EHE day in each time period using the observed values for the relevant explanatory variables. This process produces daily city-specific EHE-attributable excess mortality estimates.

Table 2 provides examples of average daily EHE-attributable excess mortality for the offensive air masses for selected cities around the world.

Table 2 Average daily excess heat-attributable mortality for offensive air mass days

City	Average excess heat-attributable daily mortality on air mass day		Percentage increase from longer-term summertime baseline daily mortality	
	DT days	MT + days	DT days	MT + days
Seoul	6.9	6.7	7	7
Chicago	5.2	7.4	5	7
Washington	0.9	1.7	4	7
New Orleans	n/a[a]	3.7	n/a[a]	9
Rome	6.2	5.0	14	12
Shanghai	n/a[a]	42.4	n/a[a]	16
Toronto	4.2	4.0	11	10

[a] Indicates that air mass is not offensive in that particular city

Source Kalkstein et al. (2008b)

Table 2 shows average daily mortality increases of roughly 5–15% during EHE days, with international cities tending toward the higher numbers. However, in U.S. cities with highly variable summer climates, increases of 7–9% are common. Since the Table 2 values reflect averages, much higher increases on specific days with particularly oppressive conditions are observed.

Sixth, city-specific annual summertime excess mortality values are calculated for each year from each time series. These represent the sum of the daily algorithm-based EHE-attributable excess mortality results.

Seventh, because our EHE-attributable excess mortality values for each city are calculated relative to a year 2000 population, consideration must be given to adjusting results to account for factors, such as population growth, which could be affecting results. A simple linear regression is calculated through a plot of total summertime deaths (*Y* axis values) by year (*X* axis). If the slope of this line, calculated with an intercept, is significantly different from 0, the slope coefficient is used to create an annual adjustment factor for the summertime EHE-attributable excess mortality totals. For example, if City A has a statistically significant slope coefficient of 0.014, the adjustment factor for the daily mortality totals in the year 2003 would equal an increase of 4.2% [$0.042 = 0.014 \times (2003–2000)$]. This process is also used for totals in the years before 2000, but the resulting adjustments will have the opposite sign from those for the 2001–2004 period. For example, using the assumptions above, the adjustment for the 1995 value would be–7.0% [$-0.070 = 0.014 \times (1995–2000)$]. This adjustment process produces trend-adjusted mortality totals. Although inter-seasonal adjustments were also examined, they were not incorporated because U.S. cities do not experience the types of systematic population shifts during the summertime that would have an independent effect on daily mortality totals (e.g., large population shifts out of the city for vacations as is common in August in many European cities).

Finally, the adjusted summertime values for EHE-attributable excess mortality in each year calculated for each time series were divided by the estimate of the year 2000 resident population in each city. The year-specific EHE-attributable mortality rates for each series were then averaged to produce a single EHE-attributable excess mortality rate for each time series that is anchored on the year 2000 population.

4 Results

Table 3 presents the 2000 Census estimate of each city's resident population estimate as well as the results from applying the method for the number of EHE days and EHE-attributable excess mortality rates calculated for the 1975–1995 and 1975–2004 periods. Results in Table 3 are presented in descending order based on the results for the EHE-attributable excess mortality rate per 100,000 residents for the 1975–1995 period.

The striking result in Table 3 is the heterogeneity in the EHE-attributable excess mortality rate results. These results span nearly two orders of magnitude in each time period. The generally lower rate values for the 1975–2004 period compared to 1975–1995 also suggest that EHE-attributable excess mortality rates have declined starting since at least 1996. This is especially true in the cities in the northeastern quadrant of the country, where reductions of 15% or greater are observed for some locations.

Consistent with other multi-location studies of EHE impacts, including SSC-based and non-SSC-based studies (e.g., Anderson and Bell 2009; Medina-Ramon and Schwartz 2007; Sheridan et al. 2009), Table 3 results display a generally strong regional pattern with

Table 3 City populations in year 2000 and EHE-attributable excess mortality rate estimates for different time periods

City	2000 population (in 100,000 s)	EHE attributable excess mortality rate for the period 1975–1995[a]	EHE attributable excess mortality rate for the period 1975–2004[a]	Average number of EHE days, 1975–1995	Average number of EHE days, 1975–2004
Hartford	1.2	26.7	22.5	5.9	5.4
Newark, NJ	2.7	24.0	20.8	8.1	7.4
Providence, RI	1.7	22.9	22.0	6.5	6.5
Boston	5.9	17.7	16.7	11.3	11.1
Greensboro	2.2	16.3	14.0	7.6	7.1
Louisville	2.6	15.3	14.9	8.0	7.9
Kansas City	4.4	10.9	9.4	7.4	7.5
Birmingham	2.4	10.0	9.8	5.1	5.1
Baltimore	6.5	9.9	8.8	8.3	7.6
Cleveland	4.8	9.4	8.3	5.2	4.8
Atlanta	4.2	8.8	8.3	5.3	4.6
Tampa	3.0	8.7	8.4	3.4	4.1
Denver	5.5	8.3	8.7	9.2	9.6
Memphis	6.5	8.3	7.1	9.4	8.8
St. Louis	3.5	8.2	6.8	11.2	10.2
Buffalo	2.9	7.7	6.3	3.3	2.8
Pittsburgh	3.3	7.5	5.7	5.4	5.2
Detroit	9.5	7.0	5.5	8.7	8.5
Minneapolis	3.8	5.4	3.7	8.2	7.8
New Orleans	4.8	5.0	4.6	4.6	6.4
Washington, DC	5.7	5.0	4.2	16.0	14.9
Philadelphia	15.2	4.6	3.5	6.0	6.6
Dallas	11.9	4.5	3.9	10.8	8.8
Jacksonville	7.4	4.0	4.1	7.0	6.4
Chicago	29.0	3.6	3.2	4.8	7.2
Cincinnati	3.3	3.5	3.5	3.5	3.6
Indianapolis	7.8	3.2	3.0	5.0	4.9
New York	80.1	3.1	2.3	10.7	11.7
Portland, OR	5.3	2.6	1.7	4.0	4.0
Phoenix	13.2	2.5	2.5	7.0	7.1
Seattle	5.6	2.3	2.0	1.6	2.7
San Antonio	11.4	1.7	1.8	4.6	4.7
San Jose	8.9	1.3	1.1	0.3	0.3
Salt Lake City	1.8	0.9	1.1	0.5	0.4
Los Angeles	36.9	0.7	0.5	1.1	0.9
Columbus	7.1	0.6	0.5	4.8	5.0
San Diego	12.2	0.5	0.0	1.0	0.7
San Francisco	7.8	0.4	0.4	1.5	1.5
Houston	19.5	0.3	0.1	1.2	1.6
Miami	3.6	0.0	0.0	0.0	0.0

[a] Rates reflect the average number of EHE-attributable summer deaths for the period based on each city's resident population in the year 2000. Summer is defined as the period from June 1 through August 31 each year

northeastern and midwestern cities having most of the highest EHE-attributable excess mortality rates. Specifically, the four cities with the highest rates are all located northeast of Philadelphia. This regional pattern is consistent with results from past studies (e.g., Chestnut et al. 1998; Sheridan et al. 2009), which concluded that the risk of EHE-attributable mortality increases with increasing inter- and intra-seasonal climate variability.

At the other extreme, a number of cities with relatively low EHE-attributable excess mortality rates in both time series are intuitive given their generally warm and stable climates (e.g., Miami, several locations in southern California and Texas). It is noteworthy that cities near the bottom of the ranking in Table 3 have generally fewer EHE days (most less than 2 per year) compared to cities near the top of the ranking (often 5 or more EHE days per year, and sometimes much more). However, Table 3 has some surprises; Columbus seems out of place in terms of its low level of observed impacts given its climate variability. Similarly, while Seattle and Portland have both shown relatively high impacts in other studies (e.g., Sheridan et al. 2009), these locations appear less impacted in this analysis.

The Table 3 results also can be distinguished, in part, based on the size of the city's population. Specifically, no city with a 2000 population exceeding 1 million falls in the top half of sensitive cities or has an EHE-attributable excess mortality rate per 100,000 residents that is greater than or equal to 5.0 for the 1975–1995 time period. Of the cities with more than a million residents in 2000, Philadelphia has the most sensitive ranking of 23rd among the 40 cities.

Underlying the mortality estimates in Table 3 are the city and period-specific mortality algorithms in Table 4.

Table 4 demonstrates the relative importance of the independent variables in explaining the calculated EHE-attributable excess mortality for each city. For the most part, explanatory variables have the anticipated sign when they are incorporated in a mortality algorithm. Specifically, the temperature-related variables have a positive sign, indicating increasing excess mortality on EHE days with higher temperatures. The exceptions occur mostly with the dewpoint temperature measures; some cities, particularly in the Northeast, show inverse relationships between minimum dewpoint temperatures and mortality. This underscores the impact of a hot, dry DT day in some of these locales (Tampa's algorithms are somewhat counterintuitive, and the relationships are quite weak). The daily maximum temperature always has the anticipated positive sign on its coefficient value. Similarly, the day in sequence variable generally has the anticipated positive sign on the coefficients, indicating that there is an expected increase in EHE-attributable excess mortality purely as a function of the duration of the event. Finally, the Julian variable almost always has a negative sign, suggesting EHEs occurring later in the summer are likely to result in fewer excess deaths relative to a similar event earlier in the season.

In both time series, the maximum temperature variable appears most frequently as an explanatory variable (21 out of 39 times in both series). The Julian and day-in-sequence (DIS) are the next in frequency, appearing roughly 15–18 times depending on the variable and series. Interestingly, only Chicago has mortality algorithms in both time series that do not incorporate any temperature-based explanatory variables, although the DIS variable is highly important. These results support a priori expectations that the level of EHE-attributable excess mortality in an event should be sensitive to the event's severity, timing, and duration.

When comparing the algorithms between the 1975–2004 and 1975–1995 periods, it is difficult to find systematic differences in the structure of the algorithms between the two time periods. In some cases, the changes are subtle and relate to the magnitude of the

Table 4 EHE-attributable excess mortality algorithms

City	1975–1995								1975–2004							
	Intercept	tmax	tmin	tdmax	tdmin	DIS	Julian	R^2	Intercept	tmax	tmin	tdmax	tdmin	DIS	Julian	R^2
Atlanta	−6.26	0.35				0.50		0.020	2.98	0.14				0.30	−0.03	0.046
Baltimore	−10.41	0.53				0.76	−0.03	0.171	−12.01	0.54				0.66		0.165
Birmingham	−39.40	0.99	0.47				−0.05	0.226	−25.05	0.63			0.44		−0.03	0.122
Boston	−95.60	2.24	1.75				−0.12	0.203	−79.73	1.90	1.38	0.75	−0.83	1.30	−0.10	0.196
Buffalo	−11.23	0.41	0.39	0.32	−0.50			0.106	−18.46	0.58	0.43		−0.44		−0.04	0.111
Chicago	0.59					3.33		0.212	1.44					3.70		0.222
Cincinnati	−6.65				0.16			0.095	−6.40				0.16	0.15	0.01	0.107
Cleveland	7.88					0.40		0.050	9.21			0.26	−0.30	0.49		0.040
Columbus	−18.26	0.39	0.26					0.165	−5.75		0.29					0.131
Dallas	−4.52					0.43		0.090	−0.72					0.33	−0.05	0.104
Denver	5.47					−0.15		0.080	5.23	0.03	−0.09		0.06			0.090
Detroit	−32.45	0.90		0.36		1.84		0.137	−38.13	1.14			0.27	1.16		0.114
Greensboro	−0.17	0.25		−0.20				0.141	7.14			−0.13				0.080
Hartford	−7.58	0.37				0.39		0.161	−11.60	0.52						0.159
Houston	−73.24			3.04				0.162	−48.33			1.97				0.132
Indianapolis	2.18				0.23		−0.04	0.173	3.05			0.18			−0.04	0.163
Jacksonville	−13.10		0.61	−0.14			−0.02	0.110	−4.57		0.38					0.077
Kansas City	−8.57		0.60			0.85	−0.03	0.293	−15.00		0.87			0.97	−0.03	0.220
Los Angeles	1.16		2.34		0.13		−0.10	0.130	−29.76	0.38	2.80		0.34		−0.18	0.191
Louisville	1.15			0.18				0.116	0.19				0.27		−0.02	0.124
Memphis	−16.25	0.56		0.35	0.26	0.63	−0.03	0.304	−13.71	0.42	0.17			0.55	−0.03	0.220
Miami	No equations								No equations							
Minneapolis	−18.58	0.67					−0.04	0.171	−16.95	0.61					−0.04	0.162
New Orleans	−9.70		0.42					0.117	−2.86			0.14		0.21		0.098

Table 4 continued

City	1975–1995								1975–2004							
	Intercept	tmax	tmin	tdmax	tdmin	DIS	Julian	R^2	Intercept	tmax	tmin	tdmax	tdmin	DIS	Julian	R^2
New York	−127.68	3.89		0.92		7.69	−0.20	0.284	−135.09	3.58	1.00			5.51	−0.23	0.161
Newark	−10.47	0.55						0.199	−10.71	0.54						0.202
Philadelphia	−82.89	2.52				1.32	−0.07	0.153	−60.09	1.88					−0.07	0.082
Phoenix	−5.15			0.12			−0.03	0.141	−8.54	0.08	0.16					0.145
Pittsburgh	−20.33	0.90		0.55	−0.81			0.105	−27.97	1.17		0.33	−0.56		−0.05	0.099
Portland, OR	−20.32	0.67		0.22			−0.04	0.182	−25.22	0.93		0.39	−0.50		−0.03	0.175
Providence	−30.63	0.99		0.37			−0.04	0.241	−24.00	0.79		0.32			−0.02	0.200
Salt Lake City	3.01				0.09			0.020	3.43			0.60				0.040
San Antonio	−6.29				0.45	0.37		0.191	−5.61				0.43	0.37		0.169
San Diego	16.97				−0.66	−2.10	0.10	0.216	No equations						0.169	
San Francisco	−2.50	0.34					−0.06	0.046	−3.57	0.31						0.081
San Jose	0.74	0.05						0.070	0.73	0.05						0.060
Seattle	−5.02				0.49	1.47		0.154	−4.34				0.49	1.61		0.140
St. Louis	−7.76	0.32					−0.03	0.115	−1.17					0.16		0.104
Tampa	40.30			1.07	−2.42			0.128	34.24		−1.46	0.46		0.65		0.080
Washington, DC	0.74	0.26		−0.15	0.18		−0.02	0.157	−3.02	0.15				0.28	−0.02	0.142

intercept. In others, the coefficients of the independent variables have changed. One consistent feature is that, for most of the cities with the highest algorithm R^2 values, the longer-running time period demonstrates lower R^2 values than the shorter-running time period.

Table 5 provides an alternative summary and analysis of some of the study data and results. The table first quantifies the change in EHE-attributable excess mortality rates in each city by subtracting the calculated 1975–2004 rate from the 1975–1995 rate. This absolute change is then given perspective by expressing the reduction as a percentage of the original 1975–1995 rate.

Similarly, Table 5 presents the change in the average number of EHE days per summer from 1975–1995 compared to 1975–2004 as a percentage of the 1975–1995 value. The result summarizes the direction and relative magnitude of the change (negative values indicate an increase in the average number of EHE days). This information is important because, all else equal, more EHE days in a period would be expected to increase EHE-attributable excess mortality.

Finally, the percent reduction in average EHE days is subtracted from the calculated percent reduction in the EHE-attributable excess mortality rate. The resulting value, a crude "index of risk" that appears in the last column of Table 5, attempts to put apparent changes in the mortality rates in perspective while accounting for any change in risk associated with the change in EHE days between the two time periods. In this "index of risk" calculation, cities in locations where there was an increase in average EHE days are effectively given additional credit in terms of a result where the percentage value increases compared to the originally calculated reduction in EHE-attributable excess mortality.

Table 5 shows that during 1996–2004, only 4 of the 40 locations experienced absolute increases in their EHE-attributable excess mortality rate, while 35 experienced reductions (Miami, with no indication of EHE-attributable excess mortality in either period, is removed from consideration). In a number of cities, the EHE-attributable excess mortality rate fell dramatically in absolute terms with the incorporation of data and results from the 1996–2004 period. This group was led by Hartford whose EHE-attributable excess mortality rate fell by 4.26 deaths per summer per 100,000 residents.

However, the potential magnitude of any absolute rate reduction is constrained by the initial EHE-attributable excess mortality rate calculated for the 1975–1995 period. As a result, the absolute rate reduction is a potentially less appropriate measure for evaluating a city's progress in addressing EHE-attributable health risks and impacts. To account for this, we calculated how the mortality rate reductions compare to the initial rate estimates for the 1975–1995 period as a percentage to provide a relative measure of each city's improvement. In this perspective, over 60% of the locations (24 of 39 cities–again eliminating Miami from consideration) experienced at least a 10% reduction in the EHE-attributable excess mortality rates based on reductions experienced from 1996–2004. This group of cities is led by Houston, which experienced a 69% reduction in its EHE-attributable excess mortality rate from the 1975–1995 to the 1975–2004 period.

However, this measure does not account for how the rates may have changed because of changes in the average number and severity of EHE days in the longer time period. This is especially important since most of the cities (24 of the 39 cities) show a decline in the average number of EHE days per summer comparing the 1975–2004 period to the 1975–1995 period. All else equal, it is reasonable to assume that cities where the average number of EHE days per summer declined would also experience a lower EHE-attributable excess mortality rate with the average risk reduction.

Table 5 Changes in EHE-attributable excess mortality rates and EHE days

City	Reduction in EHE-attributable excess mortality rates per 100,000 (1975–1995 rate—1975–2004 rate)	Reduction in mortality rate as a percentage of 1975–1995 baseline rate	Reduction in average number of EHE days per year as a percentage of 1975–1995 baseline rate	Percentage reduction in mortality rate Minus percentage reduction in the average number of EHE days
Houston	0.22	69	−29	98
Seattle	0.30	13	−67	80
Chicago	0.37	10	−52	62
New Orleans	0.41	8	−41	49
Portland, OR	0.92	35	−1	36
New York	0.77	25	−10	35
Philadelphia	1.03	23	−11	33
Minneapolis	1.74	32	5	27
San Jose	0.12	10	−17	26
Tampa	0.25	3	−20	23
Pittsburgh	1.88	25	3	21
Columbus	0.08	15	−4	19
Detroit	1.47	21	3	18
Los Angeles	0.24	34	18	16
Kansas City	1.49	14	−1	15
Washington, DC	0.81	16	7	10
St. Louis	1.38	17	9	8
Memphis	1.19	14	7	8
Greensboro	2.31	14	7	7
Hartford	4.26	16	9	7
Indianapolis	0.22	7	1	5
Newark, NJ	3.16	13	9	4
Boston	0.98	6	2	4
Providence, RI	0.95	4	1	3
Cleveland	1.15	12	9	3
Cincinnati	0.03	1	−2	3
Buffalo	1.43	18	16	2
San Antonio	(0.02)	−1	−2	1
Baltimore	1.02	10	9	1
San Diego	0.15	31	30	1
Phoenix	0.01	0	−1	1
Louisville	0.39	3	2	1
Birmingham	0.15	1	1	0
Denver	(0.37)	−4	−4	0
San Francisco	0.01	3	4	−1
Dallas	0.68	15	18	−3
Atlanta	0.51	6	12	−7
Jacksonville	(0.15)	−4	8	−12
Salt Lake City	(0.20)	−23	16	−39
Miami	0.00	n/a	n/a	n/a

The last column in Table 5, the “index of risk,” attempts to reconcile changes in the EHE-attributable excess mortality rates with changes in the number of EHE days by subtracting the estimated percent reduction in EHE days from the estimated percent reduction in the EHE-attributable excess mortality rate. The result of this calculation can be thought of as the change in EHE-attributable excess mortality rates adjusted for changes in EHE days. In practice, initial mortality rate reductions are reduced in locations where there was a decrease in EHE days while the rate is increased in locations where more EHE days were experienced (i.e., negative values for EHE day reductions). Using this measure, Houston emerges as the city where arguably the greatest strides in reducing EHE-attributable excess mortality have occurred since 1995, given that the city experienced a 69% reduction in its EHE-attributable excess mortality rates (comparing the 1975–2004 value to the 1975–1995 value), while the average number of EHE days per summer increased by 29%. This yields an index of risk of 98%. The next two cities, Seattle and Chicago, have had ongoing sophisticated heat intervention programs, as well as a sophisticated warning system, for most if not all of the period from 1996 to 2004, so their appearance near the top of the table is not surprising. The next four cities, New Orleans, Portland, New York, and Philadelphia, appear near the top for different reasons. The NWS Office in New Orleans has been particularly cooperative in working with the local utility company, Entergy, in the issuance of excessive heat warnings since the late 1990s. In fact, Entergy funded the New Orleans HHWS in 1999 and has been a leading utility in the suspension of service cutoffs during excessive heat warning days. Portland, along with nearby Seattle, has been a leader in stakeholder collaboration during EHEs. New York City’s Department of Public Health and Mental Hygiene has collaborated closely with the local NWS office for a number of years. And of course, after 1995, Philadelphia became a model of what to do correctly during EHE periods–stakeholder collaboration, use of a sophisticated HHWS, and community involvement have been at a maximum in this city.

Cities near the bottom of the list, those with an index of risk value of 2% or less, are generally in the South or Southwest and can be further separated into two groups. In the first group, roughly for the cities listed between San Antonio and Atlanta, the story is of locations where changes in mortality rates generally mirror the changes in the number of EHE days. This suggests that EHE notification and response programs, where present, are not making the types of improvements that other locations are realizing. The second group consists of Jacksonville and Salt Lake City where increases in heat-attributable deaths occurred while the number of EHE days declined. These results should be evaluated further as they suggest either the lack of a program or a public failure to recognize and accept the health risks of EHEs.

The appeal of the index of risk measure used in Table 5 is revealed considering a special case city like Denver. Denver experienced a 4% increase in its EHE-attributable excess mortality using the comparison described above. At the same time, the city also experienced 4% more EHE days. Combining the results indicates that no progress (a 0% result) was made in reducing EHE-attributable excess deaths once changes in the number of EHE days were included. Denver has a variable summer climate and a moderately high level of EHE-attributable excess mortality, as indicated in Table 3. Relative to some of the other cities in this list, Denver has a fairly passive EHE notification and response program. Thus, this is a city where potentially significant health improvements could be realized with respect to EHEs with a more active EHE program. In 2010, the NWS will institute a new synoptic-based HHWS in this city. Future studies might reveal if there is, as one might expect, a significant decrease in Denver’s EHE-attributable excess mortality in future years if the HHWS leads to improvements in identifying EHE days and results in a more integrated and active EHE notification and response program.

It is possible to use the information from our analysis to construct other measures of the possible impact of HHWS since 1995. The purpose of our index of risk measure is not to provide an absolute measure of the possible impact of the growth of HHWS but to account for some of the key factors that may influence measures of progress, specifically differences in the number of EHE days.

5 Discussion

This paper's goal was to estimate current EHE-attributable excess heat mortality rates in 40 major U.S. cities and to determine whether room for improvement still exists in terms of reducing future EHE health impacts.

We addressed this question using a SSC-based method that identifies the relevant days for consideration and provides a means of estimating the actual burden of these events in terms of excess mortality. While there are other more traditional epidemiological approaches that could be used to quantify the impact of EHEs, it is important to note how and why the SSC-based method is appropriate for this specific task.

EHEs have a number of important characteristics that need to be accounted for in efforts to quantify their impact. Specifically, EHEs are discrete weather events defined primarily by an exceedence of site-specific criteria that are used to define "normal" conditions at that time of year (U.S. EPA 2006). With air mass criteria that vary by location, the SSC-based method addresses this concern by providing a local benchmarking for exceptional conditions. In addition, the SSC method clearly identifies EHE days based on an observable historical association with elevated mortality. More fundamentally, the SSC explicitly recognizes that EHEs are meteorological phenomena by using air mass categories to identify EHE days for evaluation. Finally, the algorithms that are developed and used to calculate EHE-attributable excess mortality provide an opportunity for capturing important and well-recognized features of the health risks of EHEs, including the sensitivity of the risk/impacts to the severity and duration of the EHE as well as its timing.

This study reveals that most of the studied major U.S. metropolitan cities with a year 2000 resident population of at least 100,000 have experienced reductions in EHE-attributable excess mortality during the 1996–2004 period. This result holds when improvements are measured as either a reduction in EHE-attributable excess mortality rates or a combined assessment of these rate reductions with an adjustment in the change in average number of EHE days, although the method of measurement can significantly change how improvements in specific cities are viewed.

We hypothesize that these reductions are attributable to improvements in EHE forecasting/recognition combined with an increased interest and commitment of public and private resources to EHE education, notification, and response measures, including the development of SSC-based heat health warning systems in a number of the study cities. Recent studies have shown that the public is generally aware of NWS excessive heat warnings and advisories (Sheridan 2007). Thus, there is evidence that the EHE message is getting out to the general public in addition to EHE program managers and partners.

While our results are consistent with this hypothesis, and with 1995 being a year that spurred interest, development, and implementation of EHE notification and response programs, our results cannot be used to attribute these improvements solely to these programs or to definitively state that the improvements began only in 1996. However, it is likely that the reductions in EHE-attributable excess mortality rates would be observed using different years to define the split in the time periods.

The data required to consider alternative explanations for the observed reductions were not available or developed for this assessment. For example, one could speculate that much of the improvement could be attributable to the increasing prevalence of air conditioning, especially central air conditioning, throughout much of this period (U.S. Energy Information Administration 2000). However, while increased prevalence of air conditioning may reasonably be assumed to have increased EHE mitigation/protection opportunities during this time for a large percentage of the U.S. population, it is not clear that those at greatest risk who disproportionately account for EHE-attributable mortality either have experienced increased access to air conditioning or have substantially increased their use of personal air conditioning during EHEs. In contrast, there is still considerable evidence to suggest that those at greatest risk during EHEs may restrict their use of available personal air conditioning units out of concern for the associated electrical charges (NWS 2004; Sheridan 2007; Luber and McGeehin 2008).

It is clear that cities that take the heat/health issue seriously have tended to experience dramatic improvements based on the results in Table 5. Philadelphia's efforts, highlighted specifically in a recent EPA heat events guidebook (U.S. EPA 2006), now serve as an international model. Chicago's recent strides in heat/health mitigation issues are explained fully in the new Chicago Climate Action Plan (Hayhoe and Wuebbles 2008). The NWS now considers it a prime mission of theirs to accurately call heat warnings to save lives and property. To support this mission, the NWS has a goal of developing HHWS for roughly 50 more U.S. cities with populations of 500,000 or more (NOAA 2009).

The number of potential lives saved by instituting EHE notification and response plans is significant. Multiplying the average EHE-attributable excess mortality rates for each period by the 2000 Census resident population estimate for each city, this improvement is consistent with over 200 lives being saved per year based on reductions achieved during the 1996–2004 period (1,556 lives using the 1975–1995 rates vs. 1,339 lives using the 1975–2004 rates). This result helps clarify the final response with respect to the paper's second goal. Specifically, while this reduction reflects considerable progress, it also reflects that a considerable challenge and opportunity remain with respect to effectively notifying and helping the U.S. public respond to EHE conditions. The loss of roughly 1,300 lives per year in the studied locations alone would clearly make EHEs the single largest source of loss of life in the United States among extreme weather events in a typical year (NWS 2009). This finding is especially important considering the public health consensus is that all EHE-attributable mortality is preventable (e.g., CDC 2004; Luber and McGeehin 2008). It is also worth noting the potential for this estimate to considerably understate the true average health impact of EHEs in the United States as the cities in this assessment only account for roughly 38 million of the approximately 281 million U.S. residents as of 2000 (U.S. Census Bureau 2009)

Moving forward, our results also raise a number of additional questions and opportunities for future EHE-related research including:

- How can, or should, future mortality impacts of EHEs be quantified?
- Is there some critical relationship between EHE-attributable excess mortality rates and the size of a city's population? For example, is size an indicator of the nature, type, and extent of resources that are typically committed to an EHE notification and response program?

- What would the results be for estimates of potential future EHE-attributable excess mortality in these locations using the SSC method developed in this paper with meteorological data from climate change simulations?
- Can critical elements from EHE notification and response programs, or best practices from cities that have demonstrated significant improvements over time, be identified in the hope that dissemination of this information can reduce the rate of EHE-attributable health impact s everywhere?

The health risks and impacts attributable to EHEs are expected to vary with the specifics of the events. This research has developed estimates of the current impact of EHEs in a group of major U.S. cities using available mortality and meteorological data. Our results and analysis also show that significant, and perhaps surprising, improvements have been made in reducing the health impact of EHEs over time in major U.S. cities. However, these same results highlight the significant public health impact these events still have in the United States and clarify that there is considerable room for continued progress and a likely need for future aggressive efforts while contemplating a generally hotter world with more frequent and severe EHEs.

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