ESTIMATING THE MORTALITY EFFECT OF THE JULY 2006 CALIFORNIA HEAT WAVE

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Prepared By:
Bart D. Ostro, Lindsey A. Roth, Rochelle S. Green, and Rupa Basu

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DISCLAIMER

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

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Abstract

Several epidemiological studies have reported elevated mortality following a heat wave. Immediately after the California heat wave in July 2006, county coroners reported that the high temperatures caused approximately 147 deaths. However, heat wave-related deaths are likely to be underreported due to a lack of a clear case definition and the multifactorial nature of heat-related mortality. Public health policy suggests a need for a careful assessment of mortality following a heat wave. In addition, it is useful to provide a comparison of the mortality impact per degree during heat waves versus high temperatures observed during non heat-wave periods. For this study, daily data were collected for mortality and weather in seven California counties known to be affected by the July 2006 heat wave. The association between apparent temperature and daily mortality was assessed using a Poisson regression model and combined across counties in a meta-analysis. The results were then used to estimate the increases in the number of deaths during the heat wave. The analysis indicated a 9 percent (95 percent CI = 1.6, 16.3) increase in daily mortality per 10 degrees Fahrenheit change in apparent temperature for all counties combined. This estimate is almost 3 times larger than the effect estimated for the full warm season and 1.3 times that found for July in previous years (non heat wave years 1999 to 2003). The estimates indicate that actual mortality during the July 2006 heat wave was 2 or 3 times greater than coroner estimates. This multi-county analysis provides additional evidence that the risk of mortality increases with prolonged exposure to high apparent temperatures, as is common during a heat wave. In addition, the mortality effect per degree F was found to be several times higher than that reported during non-heat wave periods.

Keywords: Mortality, heat wave, apparent temperature, meta-analysis, time series

1.0 Introduction

Heat waves are widely publicized because of their effects on entire communities. Previous heat waves in the United States (CDC 1995, 1996, 2002; Kaiser et al. 2001; Naughton et al. 2002), as well as the 2003 heat wave in Europe (Canoui-Poitrine et al. 2006; Conti et al. 2006; Conti et al. 2005; Grize et al. 2005; Le Tertre et al. 2006; Pirard et al. 2005; Simon et al. 2005) have gained widespread attention. While there is no universal definition for a heat wave, any prolonged period of high temperatures usually lasting at least three consecutive days, especially accompanied by high nighttime temperatures, is deemed a heat wave (Kaiser et al. 2001). The number of heat-related deaths is often tabulated by county coroners during and after a heat wave. However, for several reasons, these counts are likely to underestimate the full impact of the heat wave. Heat-related deaths are typically certified as death from heat stroke or hyperthermia, typically when the core body temperature is found to be greater than 105 degrees Fahrenheit (°F). Therefore, deaths from other causes, such as cardiovascular and respiratory diseases that can be exacerbated by heat, may not be classified as heat related (Conti et al. 2006; Haines et al. 2006; McGeehin and Mirabelli 2001). Second, as recommended by the National Association of Medical Examiners, the heat-wave diagnosis: "may be established from the circumstances surrounding the death, investigative reports concerning environmental temperature, and/or measured antemortem body temperature at the time of collapse." Thus there will be some judgment on the part of the county coroner and the diagnoses may be inconsistently applied (Bouchama and Knochel 2002; CDC 1995, 1996; Kaiser et al. 2001). Third, in the absence of an "officially" declared heat wave, coroners may not be alerted to consider heat-related or exacerbated deaths (Shen et al. 1998). Therefore, the actual number of deaths from the heat wave is likely to be much higher than the number confirmed, not only during a heat wave, but especially during a non heat wave period (Basu et al. 2008; Basu and Samet 2002; Saez et al. 1995).

In this study, we examined data from the heat wave that struck California in July 2006 in an attempt to statistically determine the likely number of excess deaths that occurred during this period. Beginning around July 14 and experienced over a large part of the state, the heat wave was characterized by nearly triple-digit daytime temperatures, higher than normal humidity, and very high nighttime temperatures. Coroners' reports indicated that 147 (127 in the nine counties under study) people were killed by the heat wave, but state officials reported at the time that this number was almost certainly underreported (Thompson 2007).

In our analysis, we used a conventional time-series analysis to first empirically estimate the association between daily temperature and daily mortality counts in the counties that were most affected by the heat wave. Then we used these empirical associations to calculate the increased number of deaths due to the heat wave in each county and compared these numbers with estimates based on coroner reports. We also compared our empirical relationships, in terms of % change in mortality per degree F, with those developed from California data during non-heat wave periods from earlier years. Such comparisons highlight the important effects that are likely to occur as heat waves increase in frequency over time due to climate change.

2.0 Data and Methods

2.1. Data

The number of daily all-cause deaths for July 2006 was requested for all California counties, with more than five confirmed or presumed heat-related deaths from July 14–August 1, 2006, based on the coroners' reports. The confirmed heat-related cases were obtained from the California Office of Emergency Services Law Enforcement Branch, which contacted each county's coroner/medical examiners offices. In an attempt to complete a timely analysis of the heat wave effects, we obtained the data before they were made available from the state vital statistics records. For this reason, only "all-cause" mortality was available, and only for the period of July 2006.

Data were requested by calling the County Heath Officers, which are part of the California Center for Health Statistics (CHS). Ultimately, the counties of Fresno, Imperial, Los Angeles, Kern, Merced, Sacramento, and San Bernardino provided mortality data. San Joaquin and Stanislaus counties were also contacted, but the necessary all-cause mortality data were unavailable, so the two counties are not included in the initial empirical analysis. However, since more than five heat-related deaths occurred in these two counties, we included the counties in our estimates by extrapolating the meta-results (described below) from the other counties. Daily disease-specific mortality and demographic information about the decedents were not available at the time of our analysis.

Hourly data on relative humidity and ambient temperature were obtained for the nine affected counties from the California Irrigation Management Information System (CIMIS). The apparent temperatures, which are a function of relative humidity and ambient air temperatures and are better (Kalkstein 1986) indicators of potential heat stress than temperature alone, were calculated for each monitor and then averaged across the monitors in each county. *Apparent temperature* is defined earlier (Basu et al. 2008) and was calculated based on the 24-hour daily average of temperature, as well as on the daily countywide averages of the maximum and minimum temperatures.

2.2. Methods

2.2.1. Estimating the County-Specific Temperature-Mortality Associations

We first determined the empirical relationship between apparent temperature and daily mortality for each county for July 2006. The daily mortality counts are non-negative discrete integers that represent rare events, which typically follow the Poisson distribution. Therefore, Poisson regression was used to quantify the relationship between apparent temperature and mortality. Similar regression models have been used to examine the effects on mortality from air pollution and from temperature during non-heat waves (Medina-Ramon and Schwartz 2007; Ostro et al. 2007). We also examined the potentially confounding role of day of the week, since there is some evidence that this factor can affect mortality counts. However, during the month of July, day of week was not a confounder, so a simple univariate model was used. A Poisson model was estimated for each county, and then the results were combined in a random effects meta-analysis model using Stata (StataCorp 2003). The coefficient from the meta-analysis was then applied to the two counties for which mortality data were unavailable. All temperature effects were reported in degrees Fahrenheit. We also tested the impact of multivariate models including ozone in the sensitivity analysis, detailed below.

2.2.2. Quantifying the Mortality Impact

Once empirical relationships between apparent temperature and mortality were determined for each county, the parameter estimates were used to calculate the increases in the number of deaths from the heat wave in each county. To do so, we needed to determine the temperature difference between the non-heat wave period and the heat wave period, which we defined in two ways: (1) July 15 through July 26, and (2) July 15 through July 31. We used two definitions of the heat wave period because delineation of the heat wave was uncertain and varied by region, and because death related to heat waves could continue for a few days following the episode. Temperatures during two different non-heat wave periods were examined: (1) the average apparent county-specific temperature during the non-heat wave portion of July 2006, and (2) the average county-specific historical apparent temperatures in July from 1999–2005. Thus, if apparent temperatures in July 2006 were higher overall than an historically "average" year, this method would incorporate the real effects from the heat waves relative to a "normal" year.

The excess deaths from the heat wave were calculated separately for each county based on the difference in temperature between the heat wave period and non-heat wave period (described above) and temperature-mortality coefficient. Confidence intervals for the combined nine-county mortality affect were determined by statistically summing across all nine counties' distributions (with the temperature parameter estimate, its standard error, and assuming a normal distribution) using a Monte Carlo simulation over 100,000 trials in version 7.2.1 of Crystal Ball (Decisioneering 2006).

2.2.3. Sensitivity Analyses

We conducted several sensitivity analyses to explore how our assumptions would affect the mortality account. First, we used the meta-estimate of the effect of temperature on mortality for the seven counties and applied it to all nine counties in the analysis. This method assumes that, given the statistical and random variation that might occur in any single county regression, the meta-estimate might provide a more robust estimate of the overall effect. As a second sensitivity analysis, we estimated a model that included a term for ozone, since this pollutant is often highly correlated with temperature. The meta-estimate from this model was then used to calculate mortality effects. In our final sensitivity analysis, we calculated mortality after subtracting off the potential effects of ambient ozone, since several studies have reported effects on mortality (Bell et al. 2004). Specifically, an analysis of the 95 largest cities in the United States generated a pooled estimate of a 0.25% increase in mortality (95% CI = 0.12% - 0.39%) per 10 parts per billion (ppb) change in 24-hour average ozone. Subtracting off a potential ozone effect would thus provide a more conservative estimate of the independent effect of apparent temperature. Each of these sensitivity analyses was conducted using the two definitions of the heat wave period.

2.2.4. Comparison of Parameter Estimates to Companion Non-Heat Wave Analysis

Finally, we compared the estimated mortality effect per degree Fahrenheit apparent temperature increase using data during the heat wave compared to data during non-heat wave periods (i.e., May to September, 1999–2003) to determine the shape of the functional relationship between temperature and mortality. Such a comparison tests for the likelihood of a non-linear association between temperature and mortality; a functional relationship not observed during the non-heat wave years of (May to September) 1999 to 2003 in California (Basu et al. 2008) but observed in many cities that tend to have higher apparent temperatures than those observed in California (Armstrong 2006; Stafoggia et al. 2008).

3.0 Results

Table 1 shows the descriptive statistics about each county's weather and all-cause mortality data. The table summarizes the number of monitors; average, minimum, and maximum apparent temperatures; the average and range of daily mortality counts; and the number of confirmed/presumed heat-related deaths based on the coroners' reports. The number of temperature monitors used in the analysis ranges from two in Sacramento County to nine in Imperial County. The latter also has the highest temperatures (average, minimum, and maximum) and the lowest average daily deaths (only two) during July 2006, whereas Los Angeles had 163 deaths. Fresno and Stanislaus counties had the highest confirmed/presumed heat-related deaths based on the coroners' reports.

Figure 1 shows the average apparent temperatures for each county during the study period and highlights the pattern of the heat wave, where the highest temperatures vary by county and occurred from July 13–28. Imperial County had the highest temperatures overall, and Los Angeles County temperature peaked early. The remaining counties have generally similar distributions of apparent temperatures; San Bernardino has the mildest average apparent temperature during the peak of the heat wave.

Table 2 summarizes the county-specific regression coefficients and the combined meta-analysis indicating the increased risk of mortality for a 10°F (5.6°C) in apparent temperature. Positive associations between apparent temperature and mortality were observed in each of the counties, with several being statistically significant. Imperial County had the highest coefficient (51%), while Los Angeles County had the lowest (4.3%). The combined result from a random effects meta-analysis of the seven counties indicates a statistically significant 9% (95% CI = 1.6, 16.3) change in daily mortality per 10°F (5.6°C) change in apparent temperature.

Table 1. Average daily temperature and mortality data and county statistics, July 1, 2006 through July 31, 2006

	Fresno	Imperial	Kern	Los Angeles	Merced	Sacra-mento	San Bernardino	San Joaquin	Stanislaus
Number of Temperature Monitors	8	9	5	7	3	2	4	3	4
Average Apparent Temperature (^oF)	83.5	101.3	84.4	81.4	80.1	77.7	77.1	78	78.1
Minimum Apparent Temperature (^oF)	71.7	92.2	74.4	73.6	67	67.3	69	66.6	65.6
Maximum Apparent Temperature (^oF)	97.2	108.6	95.8	93	97.1	96.5	83.5	92.8	94.6
Average of Daily Deaths	17.5	2.2	13	162.5	3.2	24.6	33.2	-	-
Range of Daily Deaths	(10–32)	(0–6)	(5–21)	(138–193)	(1–7)	(13–34)	(18–48)	–	–
Total Heat-related Deaths[#]	26	11	15	5	6	13	10	17	24
2006 Estimated Population (1000s)*	892	160	780	9,948	246	1,375	1,999	673	512

[#]Confirmed or presumed heat-related between July 14–August 1 by the County Coroner/Medical Examiners Office as reported by the California Office of Emergency Services.

*U.S. census: http://quickfacts.census.gov/qfd/states/06/06099.html

Figure 1. The average apparent temperature for the month of July 2006, by county

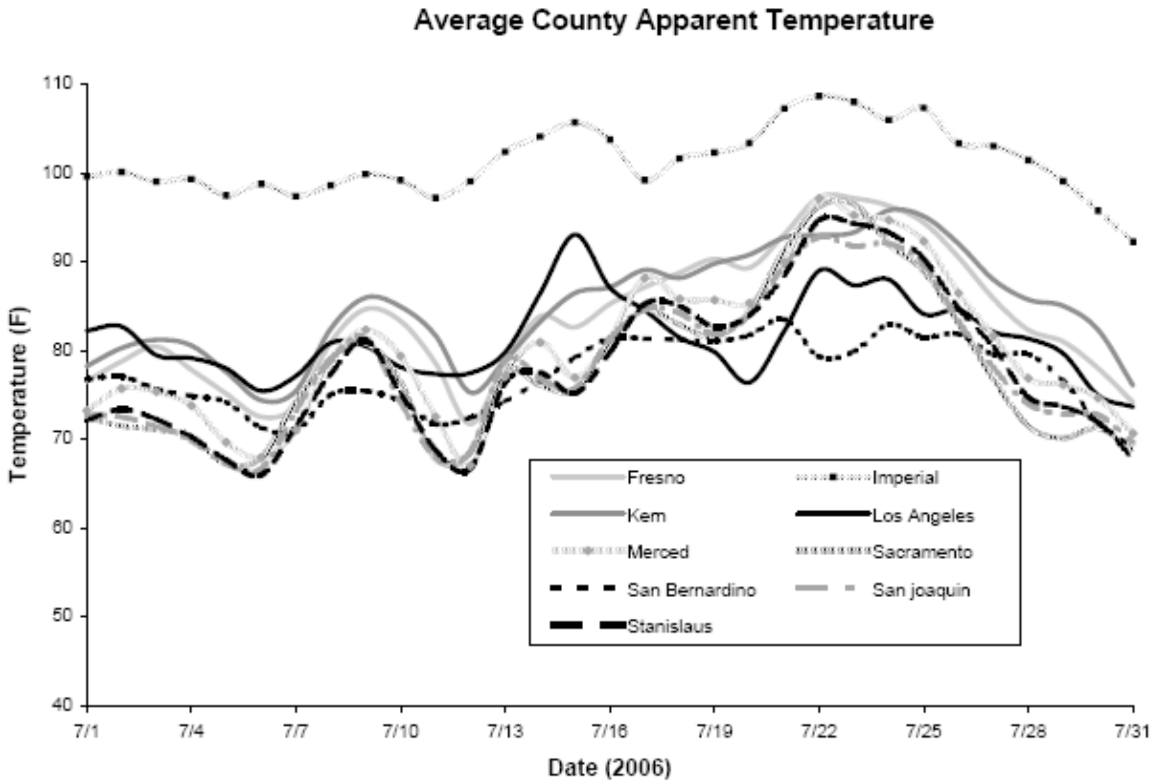

Table 2. Basic results of Poisson regression estimating number of deaths per 10°F change in apparent temperature

County	Percent change in mortality per 10^oF	95% CI
Fresno	19.4	8.6, 30.2
Imperial	51.3	-11.3, 113.8
Kern	7.0	-8.3, 22.4
Los Angeles	4.3	-1.9, 10.4
Merced	11.8	-11.1, 34.7
Sacramento	6.1	-2.1, 14.3
San Bernardino	11.4	-2.7, 25.4
Meta-analysis	9.0	1.6, 16.3

Table 3 summarizes the results for the estimated mortality impacts during the heat wave, for the two heat wave definitions. In the basic model, we applied the pooled estimated regression effect and 95% CI based on a Monte Carlo summation of the quantitative temperature-mortality estimates summarized in Table 2. Comparing county-specific temperatures during heat wave days of July 2006 with the average temperatures during non-heat wave days for the same month in 2006, we obtained a central estimate of 188 for the heat wave defined as July 15–26 (95% CI = 119, 257) and 209 (95% CI = 132, 284) for the heat wave defined as July 15–31, versus 127 for the same nine counties based on the coroners' reports.

Using the average temperatures for July 1999–2005 as a contrast period, we obtained an estimate of 243 deaths (95% CI = 106, 381) and 260 deaths (95% CI = 97, 425), respectively.

In the second analysis, we used the meta-estimate of the effect of temperature on mortality for all counties in the Monte Carlo summation. In this case, the mortality count estimates are 206 (95% CI = 141, 273) and 330 (95% CI = 173, 488) using the two alternative contrast time periods and the heat wave definition of July 15–26. In the third analysis, we used county-specific regression models that included ozone. In several of these models, the parameter for temperature effects increased, while ozone was usually not statistically different from zero. Using these models, the mortality estimates increased to 248 (95% CI = 147, 350) and 397 (95% CI = 203, 591) respectively. The larger effect was mostly due to the higher apparent temperature coefficient in Los Angeles County, with ozone in the model.

In all the above analyses the mortality count estimates were higher for the July 15–31 definition of the heat wave versus the July 15–26 definition (see Table 3). However, we did not find an ozone effect in our analysis of July 2006, probably due to the low statistical power in the 30-day analysis. In addition, ozone was not found to be a confounder or an effect modifier during non heat wave periods in California in previous analysis. There are many recent multi-city studies that report mortality effects of ozone (Bell et al. 2004). Therefore, for the final analysis and to ensure that no ozone-related mortality is attributed to temperature, we used a coefficient, relating ozone to mortality, based on a meta-analysis of the 95 largest U.S. cities (Bell et al. 2004). This coefficient was applied to county-specific daily ozone data and the resulting mortality estimates were subtracted from the total mortality derived in the base case. As displayed in Table 3, the estimates decrease to 160 (95% CI = 105, 213) and 215 (95% CI = 92, 337) for the two comparison time periods of July 2006 and July 1999–2005, respectively.

Table 3. Increases in deaths from all causes associated with the July 2006 heat wave, in nine California counties (central estimate with 95% confidence interval in parenthesis)

	Heat-wave defined as July 15–26		Heat-wave defined as July 15–31	
Model	Versus July 2006 non-heat wave days	Versus average for July 1999–2005	Versus July 2006 non-heat wave days	Versus average for July 1999–2005
1. Base model using county-specific regressions	188 (119, 257)	243 (106, 381)	209 (132, 284)	260 (97, 425)
2. Temperature-mortality meta estimate used for every county	206 (141, 273)	330 (173, 488)	223 (155, 292)	370 (181, 558)
3. Model 1 with ozone	248 (147, 350)	397 (203, 591)	333 (212, 455)	505 (269, 739)
4. Model 1 minus ozone effect estimated from NMMAPS study *	160 (105, 213)	215 (92, 337)	181 (118, 240)	232 (83, 381)

* based on the National Morbidity, Mortality, and Air Pollution Study of 95 U.S. urban communities (Bell et al. 2004)

3.1. Comparison of Parameter Estimates to Companion Non-Heat Wave Analysis

In our final analysis, we compared the regression coefficients for temperature during the July 2006 heat wave period versus that during the non-heat wave years of 1999–2005, based on Basu et al. (2008). There were four counties (Fresno, Kern, Los Angeles, and Sacramento) that were common to both studies. The heat wave analysis also included empirical estimates from the counties of Imperial, Merced, and San Bernardino, while the non-heat wave analysis of the earlier years also included the counties of Contra Costa, Orange, Riverside, San Diego, and Santa Clara. Therefore, Table 4 presents results for the four common counties as well as the full set of counties in each analysis. For the earlier years, we present results for both the full period of analysis (May through September) as well as for July only.

Table 4. Comparison of mortality effects in heat wave versus non-heat wave periods

County	Heat Wave Period, 2006			Non-Heat Wave Period, 1999–2003				
	July			May–September			July	
	Percent change per 10°F	95% CI		Percent change per 10°F	95% CI		Percent change per 10°F	95% CI
Fresno	19.4	8.6, 30.2		1.3	-1.4, 4.1		7.7	0.3, 15.1
Kern	7.0	-8.5, 22.5		3.5	0.4, 6.7		8.4	0.4, 16.4
Los Angeles	4.3	-1.9, 10.4		4.4	2.9, 6.0		6.4	2.7, 10.1
Sacramento	6.1*	-2.1, 14.3		2.6	0.4, 4.7		5.6	0.3, 10.9
Meta Analysis (4 similar counties)	8.4	1.9, 14.9		3.2	1.9, 4.6		6.6	3.8, 9.3
Meta-Analysis (all counties)#	9.0	1.6, 16.3		2.3	1.0, 3.6		4.1	2.6, 6.1

#Analysis based on data from 7 counties from heat wave (Fresno, Imperial, Kern, Los Angeles, Merced, Sacramento, San Bernardino) and 9 counties during non-heat wave years (Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara)

The mortality effect reported in Table 4, expressed as the percent increase in mortality per 10°F change in apparent temperature, obtained for the four common counties is 8.4% for the heat wave versus 3.2% for the analysis of May through September, 1999–2003 and 6.6% for July 1999–2003. For the effect estimates for the four common counties, most of this difference is due to the results for Fresno. For all available counties (seven for the July 2006 heat wave and nine for the 1999–2003 non-heat wave periods) the heat wave effect is 9.0%, versus 2.3% and 4.1% for May–September, 1999–2003, and July, 1999–2003, respectively, of non-heat wave years. Thus, for both the four common counties and all county analyses, the temperature effect during the heat wave appears to be roughly two to three times greater than that during the general non-heat wave period.

4.0 Discussion

The relationship between high temperatures and mortality is well established (CDC 1994; Faunt et al. 1995; Mackenbach et al. 1997). The findings presented here provide evidence that the overall mortality impact of the heat wave is greater than those described as "heat-related" deaths in the coroners' reports. These reports suggest 127 deaths during the July 2006 heat wave in California for the nine counties examined. Our results, however, suggest that the true effect may be 1.25 to 3 times that estimate, depending on the assumptions used. Compared to the non-heat wave days of July 2006 as a reference period, the central estimates of excess mortality during the heat wave ranged from 160 to 333 deaths, depending on the regression model used and the definition of heat wave days. However, 2006 was warmer than previous years, so if July (1999–2005) is used for the baseline temperature the central estimates ranged from 215 to 505 heat wave deaths. Our results support the hypothesis that coroner reports are likely to understate the true effect of a heat wave.

Our results also suggest that the mortality effects per degree Fahrenheit apparent temperature may be approximately two to three times higher during heat wave versus non-heat wave periods. This finding is supported by evidence for non-linear temperature dose-response functions generated from the many studies that included higher apparent temperature than those typically observed in California (Diaz et al. 2006; Medina-Ramon and Schwartz 2007). In the latter, where the humidity is generally very low in the areas with high temperature (and hence, the low apparent temperatures relative to the U.S. East Coast and Europe), we have observed evidence of fairly linear dose-response functions between temperature and mortality (Basu et al. 2008). Evidence of stronger effects during the heat wave days are provided by several recent studies. For example, when mean daily apparent temperatures were limited to above 75°F, the effect estimates were higher than those that were observed for the entire distribution of data distribution (Basu et al. 2008). In an analysis of 50 U.S. cities, Medina-Ramon and Schwartz (2007) reported an estimated mortality effect of extreme heat of 3.9% per degree of minimum temperature versus 0.7% during the less extreme days. They also report larger effects among cities with cooler average temperatures and less air conditioning. In an analysis of three European cities, Hajat et al. (2006) reported stronger effects per degree for the heat wave periods (defined as the ninety-ninth percentile of temperatures) relative to general summer temperatures. Specifically, for London, Budapest, and Milan, the impact of same day temperature during the heat waves was 1.2, 3.4, and 3.2 times that of general summertime effects, respectively. In addition to mortality, existing studies suggest greater effects on morbidity during heat waves as well (Ebi et al. 2006; Haines et al. 2006; Patz and Olson 2006; Schwartz et al. 2004).

There are several limitations of our analysis. First, regarding the mortality data, each county's office obtained the data individually, and only data for July 2006 were available. Different methods of extracting the data might affect the overall results. Second, counties were selected for the heat wave study if they had five or more confirmed heat-related deaths. Because of the lack of a clear case definition, some of the county's inclusion (or exclusion) may have been a direct result of the coroners' interpretation for that county. Third, the delineation of the heat wave period is uncertain and varies by region, as shown in Figure 1. Therefore, to test the sensitivity of our assumptions, we used two definitions of the heat wave period in this study. Finally, the appropriate contrast period for the heat wave is uncertain, as are the potential effects of concurrent ozone. As a result, we conducted several sensitivity analyses to suggest the likely range of estimates. We also chose not to conduct an analysis that compared observed versus expected mortality, since that method is heavily dependent on the selection of a reference period and also since it would be more difficult to factor out the pollution effects.

As opposed to the coroner reports of 127 heat wave deaths in the nine counties that we examined, our analysis suggests that total mortality was as much as a twice that estimate relative to a baseline of the non-heat wave period of July 2006, and as much as a triple that estimate relative to July temperatures from earlier, cooler years. In addition, our analysis and those of others indicate that, absent substantial efforts in mitigation and adaptation, significant direct effects on health, in terms of both mortality and morbidity, will result from both increases in general temperatures and more frequent heat waves expected from global climate change.

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