Climate Change and Human Health:
Assessing the Effectiveness of Adaptation to Heat Waves

by

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Abstract.

Conservative estimates of excess mortality during heat waves can be obtained by counting the cases where death is attributed directly to heat stresses. Recent epidemiologic studies, however, have uncovered much more pronounced increases in deaths, especially for cardiovascular, cerebrovascular, and respiratory causes and especially among the elderly, on hot days.

In this paper, we wish to find out whether heat alerts issued to the population by the National Weather Service (NWS) can offset such excess mortality. To answer this question, we use a panel of daily mortality and weather data covering 86 US counties—the 50 major MSAs, plus cities where the local NWS Weather adopted an additional forecasting system that predicts excess mortality due to the heat—from 1985 to 2005. The study period covers years before and after the implementation of the heat alert policy by the NWS in Summer 1993. The NWS heat alert policy applies under specific heat index and nighttime lows conditions, allowing us to apply a regression discontinuity design.

We find that—unconditionally on heat alerts—in extremely hot days cardiovascular and respiratory mortality increases among the elderly. The effect is mitigated considerably by the presence of air conditioning in homes, and varies appreciably across regions of the country. When we include NWS alerts in our regressions, we find that their effectiveness is the highest in the Midwest, Northeast and Mid-Atlantic. Neither heat nor heat alert have much of an effect on mortality in the South, presumably because of acclimatization and behaviors. These are potentially important results for assessing adaptation options to reduce the adverse health effects of climate change.

Keywords: heat waves, health, mortality, extreme weather alerts, regression discontinuity

JEL Classification: I12, I18, J14, Q54.

1. Background and Motivation

The 2001 Intergovernmental Panel on Climate Change (IPPC) report warns that an increase in the frequency and/or intensity of heat waves will raise heat-related premature mortality, primarily among the elderly and the urban poor, with the largest increases in thermal stresses occurring in cities in temperate regions. This has resulted in adoption or at least consideration of public programs that help curb the mortality and morbidity effects of extremely hot weather.

Conservative estimates of the mortality effects of excessive heat can be obtained by counting cases where the death certificate lists heat exposure as a primary or contributing cause of death—typically when core body temperature exceeds 105° F or the body is found in an environment with a high ambient temperature and without cooling devices (EPA, 2006). But epidemiological investigations based on the statistical analysis of death counts have found that all-cause mortality increases—sometimes very sharply—over the long-term average during excessive heat episodes. Such excess mortality is about an order of magnitude larger than directly observed heat mortality (≈1800 and 180 deaths per Summer in the US, respectively) (EPA, 2006).

Historically, cardiovascular diseases have accounted for 13-90% of the increase in overall mortality during and following a heat wave, while cerebrovascular disease accounted for 6-52%, and respiratory diseases for 0-14% (Kilbourne, 1997; Curriero et al., 2001; O’Neill et al., 2003). The adverse health effects of heat waves are compounded by the poor air quality that sometimes accompanies them (O’Neill et al., 2003).

Sheridan and Kalkstein (2004) and McGeehin and Mirabelli (2001) describe the human body’s physiological response to heat and discuss reasons why certain population groups are particularly sensitive to excessive heat, depending on age, urbanization patterns, and other factors. The strongest mortality effects are seen when heat waves hit early in the season, presumably because acclimatization takes place and because the early hot weather episodes wipe out the weakest in the pool of individuals at risk (Sheridan and Kalkstein, 2004). Populations living in areas with relatively little variability in temperature appear to be more sensitive. Protections include staying in climate-controlled environments, behavioral changes, and community-wide planning and warning systems.

In the US, excess mortality was observed in the Midwest in 1980 (McGeehan and Mirabelli, 2001). Over 100 deaths were attributed to the heat in Philadelphia in 1993. The July 1995 Chicago heat wave is estimated to have claimed over 700 lives (Semenza et al., 1996), the one in California in 2006 about 400. Much alarm about the health impacts of heat waves was caused by the Summer 2003 heat wave which affected the European Region during Summer 2003. This heat wave was accompanied by an increase in mortality that started early, rose quickly, and affected primarily the elderly (75 years-old and older), but was also severe within the 45-74 year-old age group. Most of the premature deaths were attributed to cardio- and peripheral vascular, cerebrovascular, and respiratory causes. Individuals at risk during heat waves include infants, the elderly, those with existing cardio-, cerebrovascular and respiratory conditions conditions, and individuals on certain medications.

Heat/Health Warning Systems (HHWSs) are considered a promising public health tool to reduce the adverse impacts of excessive heat on human health. Briefly, they consist of (i) preparations before the onset of excessive heat; (ii) meteorology-based warning systems; (iii) rapid and coordinated actions during heat waves; (iv) criteria and procedures for deactivating the plan, and (v) evaluations following the response activities and outcomes (McGeehin and Mirabelli, 2001; Kovats and Ebi, 2007).

In the US, component (ii) is the responsibility of the National Weather Service, which has developed criteria for criteria for declaring excessive heat advisories, watches and warnings, and a set of procedures for communicating heat alerts to the public and to users of their forecast products. Excessive heat alerts are issued by dedicated Weather Forecast Offices (WFOs), which are spread throughout the country. For example, Washington, DC and Baltimore, MD, are covered by the WFO in Sterling, VA, and the Mt. Holly, NJ, WFO covers Philadelphia, eastern Pennsylvania, Delaware and parts of New Jersey. The excessive heat alert policy was established in 1992, took effect in Summer 1993, and underwent minor amendments in 2003.

At the time of this writing, the WFOs for 21 US cities have adopted an additional forecasting system based on synoptic air masses developed at the University of Delaware under the direction of Dr. Laurence Kalkstein. This latter system places the incoming air mass into one of a predetermined number of classes (e.g., moist tropical, dry tropical, and others), and issues a prediction for excess mortality based on city-specific and time-of-the-year specific thresholds (US EPA, 2006).

If this additional system—henceforth referred to as the Kalkstein HHWS—predicts a significant increase in the occurrence of adverse health effects for a particular day, the NWS WFO may or may not incorporate this prediction in its final decision to issue an advisory, watch or warning. Ultimately, the decision to issue an alert remains at the discretion of the WFO Meterologist in Charge, and indeed we are aware of many days and locales where the final NWS alert was at odds with the recommendations of the Kalkstein HHWS (Ebi et al., 2004).

The earliest adopter of the Kalkstein HHWS was the Mt. Holly WFO, which adopted it for Philadelphia in 1995. The Washington, DC-Baltimore, MD WFO in Sterling, VA, adopted it in 1996, a handful of southern WFOs adopted it in 2001-02, and Chicago and St. Louis in 2003. Other cities followed suit in later years (see Appendix A for the list of cities that adopted the system by 2006). The National Weather Service and the US EPA are considering adoption of the Kalkstein system on a national scale, i.e., for all municipalities with population exceeding 500,000, for a total of 60-70 cities (Tew et al., 2004).

Components (i), (ii) and (iii) are addressed by local governments, mostly cities, counties and states. A number of cities have developed and implemented detailed response plans. Actions taken to limit the adverse effects of excessive heat on human health include opening and operating cooling centers, extending public swimming pool hours, distributing fans or air conditioners, offering nursing and medical advice over the phone, personally visiting susceptible individuals (the elderly and those with mobility impairments), and others. These are the key features of the heat emergency response plans in Milwaukee, St. Louis, Chicago, Kansas City and Philadelphia, all of which were established after these cities experienced large heat-related mortality and morbidity increases during severe heat waves. In some cases, these plans pre-date the NWS heat alert system and/or use lower temperature thresholds to trigger response. Other cities (e.g., Phoenix) have been less proactive and do not have any particular response plans in place. Cities and states can also avail themselves of federal funding that helps the poor pay their utility bills.

To our knowledge, despite much recent attention to watch/warning policies (Sheridan and Kalkstein, 2004; Ebi and Kovats, 2007), their effect on heat-related excess mortality has not been quantitatively established. This is exactly what we wish to do in this research project. In this paper, we ask three related research questions. First, what is the effect of extremely hot weather on mortality? Second, can we disentangle the offsetting effect of warning policies? Third, does the latter effect (if any) vary across regions and with observable characteristics of the population, housing, and economic circumstances?

To answer these questions, we use daily death counts for all non-trauma and for specific causes (e.g., cardiovascular illnesses) and for specific subpopulations (e.g., the elderly) in a broad sample of US cities, and take advantage of the fact that the National Weather Service initiates alert procedures under specific forecast conditions to implement a regression discontinuity design study.

We find that heat stresses do result in an appreciable increase in mortality, primarily for cardiovascular and respiratory causes and among the elderly. The effects of the heat do vary across geographic regions, and are mitigated considerably by the presence of air conditioning in homes. NWS advisories, watches and warnings do seem to reduce the impacts of heat stresses, and these effects are different across regions. NWS heat alerts are most effective in the Midwest, Northeast, and Midatlantic, where we estimate they are capable of reducing the excess mortality induced by heat stresses among the elderly by 25% or more. Neither heat or heat alerts seem to be have much of an effect in the South, presumably because of acclimatization and behaviors. These are potentially important findings for the development of adaptation programs meant to offset the adverse health effects of climate change.

The remainder of this paper is organized as follows. Section 2 briefly discusses the relevant literature. Section 3 presents the NWS alert policy. Section 4 lays out the econometric model, identification and strategy, and the data. Section 5 presents the estimation results, and section 6 concludes.

2. Previous Literature

The topic of this paper fits within three strands of the literature. The first is the public health and economics literature about the relationship between temperature and mortality. The public health literature has examined the daily fluctuations in mortality accompanying hot weather episodes, and has found a positive association between temperature and excess mortality, at least when temperature exceeds specified thresholds.

The simplest approach to examining such an association is to compare the average daily death county in the period (usually, one or two weeks) preceding a heat wave, during the heat wave, and after a heat wave (Michelozzi et al., DATE). A more sophisticated approach is to conduct a regression-based ecological study where daily death counts are regressed on temperature, other weather variables, seasonal terms, and other covariates, including potential confounders (e.g., O'Neill et al., 2003). One key question in these studies is whether hot weather causes short-term mortality displacement ("harvesting"), a phenomenon that can be investigated by including lagged temperature terms (or lagged death counts) in the right-hand side of the regression equation.

Earlier analyses (O'Neill et al., 2003; Ramon-Medina and Schwartz, 2007; and Ramon-Medina et al., 2006) have emphasized heterogeneity in the effect of heat on excess mortality. Evidence of heterogeneity has been found by fitting mortality regression equations separately to the data from different cities and studying the distribution of the city-specific heat slopes in a random-effects meta-analysis or second-stage regressions that relate these slopes to characteristics of the city.

While much of the epidemiological literature has focused on daily death counts (or even on individual death certificates, see Medina-Ramon and Schwartz, 2007, and Medina-Ramon et al., 2006), aggregate annual death counts were used in a recent paper by Deschênes and Greenstone (2007), who conclude that excess mortality due to extremely hot weather is negligible and, using information about energy consumption at the state level, surmise that adaptation to hotter weather over the rest of the century would absorb only a modest amount of resources.[1] Deschênes and Moretti (2007) examine the relationship between temperature and mortality using daily mortality counts by county in the US until 1988, and conclude that cold weather has long-term effects on mortality, whereas hot weather results in a large but mostly immediate spike in mortality, most of which appears to be mortality displacement.

None of these studies, however, has investigated the role of warning and response systems, and virtually all of them have used data from well before any of these warning and response programs were implemented. We are aware of only one study that assesses the life-saving effectiveness of the Kalkstein HHWS system during the early years of its implementation in Philadelphia: Ebi et al. (2004) ascribe it an estimated 117 lives saved over 1995-98. These authors also conduct a simple benefit-cost analysis, and conclude that the HHWS's benefits greatly exceed its costs.

In this paper, we also investigate how the effects of heat are reduced by the opportunity to use air conditioning. In this sense, we wish to explore in depth the assertions by Davis et al.

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[1] Deschênes and Greenstone (2007) use county-level annual mortality rates, which they relate to the number of days temperature has falled in specified intervals in a year. They concluded that the mortality effects of temperature are small and generally associated with low, rather than high, temperature. They predict the excess mortality outcomes associated with the weather patterns forecast by the Hadley and CCSM3 models under the A1fi and A2 storylines, which they conclude to be small. They run a companion regression where the dependent variable is energy expenditure by state in relation to the number of days when the temperature falls in specified ranges, and surmise that only small fractions of GDP (0.1-0.3%) would be spent to mitigate the adverse human health effects of very high and very low temperatures.

(2003) who ascribe a strong reduction in mortality outcomes due to heat to the presence—which does not mean actual *use* of—of air conditioning.[2]

This paper also contributes to another strand of the literature—that on individuals' behavioral responses to warnings and annoucements about environmental quality. Neidell (2004) examines children's hospital admissions for asthma-related symptoms in California, exploiting the geographic variation in pollution levels. He also controls for the number of pollution advisories issued in each month, finding support for the notion that people respond to information about pollution with avoidance behavior.

Yi Jiang (2008) examines whether people cut down on driving—an activity that generates the precursors to ground-level ozone—on "code-red" days in Baltimore, finding support for modest effects on inbound morning traffic. Cutter and Neidell ask a similar question in the San Francisco Bay area, finding that people increase the use of public transit and decrease slightly private driving. The effect on ozone levels, however, is insignificant.

How people respond to public announcement on environmental quality and extreme weather is of great important for assessing adaptation options to climate change. Ebi et al. (2004) argue that that people cease to be be responsive to repeated warnings about extremely hot weather, much like they have been noticed to fail to respond rationally to warnings or information about other uncertain natural hazards.[3] For these reasons, and because alerts and

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[2] Davis et al. argue that mortality due to heat and humidity has in fact declined in the US over time, and warn that using "old" heat-mortality relationships with climate change scenarios will overestimate the mortality impacts. They suggest that this decline is due to the almost complete air conditioning saturation of homes and building in the US, and possibly to physiological adaptation. Medina-Ramon and Schwartz (2007) control for dwellings with air conditioning in their analysis.

[3] Risk perceptions and various types of biases and myopic behavior affect hazard preparedness. Meyer (2006) reports that people tend to focus on short-term feeback and learn more from the mistake they make, rather than from narrow escapes—the mistake that they *almost* make. Brown and Hoyt (2000) offer evidence that a significant predictor of individuals' decisions to purchase federal flood insurance is simply whether flood losses are incurred in the previous year. This effect is significant even after controlling for the price of insurance, income and whether the homeowner had already undertaken other types of risk mitigation. This may be considered an example of what

warnings to the population are the most obvious adaptation option to hot weather spells, it is important to examine whether mortality endpoints are affected by alerts and risk communication.

Finally, this papers fits within the literature that examines adaptation options to climate change, an issue that has received considerable attention among researchers and in policy circles as of late (Intergovernmental Panel on Climate Change [IPCC], 2001). Adaptation policies may be adopted in addition to seeking greenhouse gases emissions reductions, and whether or not a country or region is assumed to engage in adaptation has been shown to affect considerably the predicted damages of carbon emissions (Tol, 2005). Klein (1998, 2003) presents a taxonomy of adaptation, distinguishing for proactive and reactive adaptation (depending on the time when the adaptation takes place), and private and public adaptation. Kirch et al. (2005) and Menne et al. (2006) presents surveys of possible approaches and original studies that cast light on adaptation options to reduce the adverse effects on human health of climate change.

3. NWS Warnings, Watches and Advisories

The National Weather Service alerts the population about excessive heat using four main concepts: Excessive Heat Outlooks, Watches, Warnings and Advisories. These concepts are

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Kahneman and Tversky (1973) dub availability bias—"the tendency for people to construct perceptions of likelihoods based on the mental availability of instances" (Meyer, 2006). Kahn and Luce (2005) discuss how the sense of false security influences decisions to use safety equipment, such as bicycle helmet. Due to their infrequency, natural disasters offer little feedback about the appropriateness of undertaking risk-reducing investments and behaviors, leading people into putting off or cancelling investment in risk mitigation. This tendency may reduce the effectiveness of warning systems—while they are essential in protecting lives and property, repeated warnings discourage the marginal propensity to comply when warnings are issued. Repeated exposure to false alarms diminishes over beliefs in the reliability of warnings, and undermines the perceived relationship between mitigation acts and safety (Meyer, 2006). Kahneman and Tversky (1973) discuss representativeness heuristics—people's tendency to believe that the statistical properties of large samples (and of long periods of time) should be observed in small samples (or short periods of time) as well. This tendency leads people to ignore long-term trend and to rely only on recent history as a guide to the likelihood of natural hazards or adverse events. Another factor that hinders preparedness to extreme weather events is the so-called *projection bias*—a tendency for subjective forecasts about the future to be biased towards what is experienced and felt in the presence. People may refrain from making preparations for adverse events because they cannot imagine an environment vastly different from the one they are in now.

classified and archived under the broader category of Non-precipitation Warnings, Watches, and Advisories, which also covers high winds, dense fog, etc., i.e., non-precipitation weather events that impact public safety, transportation and/or commerce.

Excessive heat outlooks provide 3-7 day advance notice of an excessive heat event that has the potential to threaten life or property. Since we only found one such announcement for the counties studied in this paper during the entire history of the program (from 1993 to the present), our analysis focuses on the other three types of alert. An Excessive Heat Watch designation indicates that conditions are favorable for the development of an excessive heat event severe enough to warrant an Excessive Heat Warning within the next 12 to 38 hours.

From 1992 to 2002 (effective in the Summer 1993), an Excessive Heat Warning was issued when the heat index value forecast met or exceeded the following two criteria: 1) maximum daytime heat index ≥ 105° F for at least two consecutive days, and 2) minimum nighttime temperature ≥ 75° F (Tew et al., 2004). As of 2003, the NWS guidance was modified to accommodate the sensitivity of the local population. Specifically, the heat index threshold was set to, and still is, 105° F for northern areas and 110° F for southern areas. The locally applicable threshold must be met or exceeded for at least two consecutive days, and the minimum nighttime lows (criterion 2) must still be at least 75° F (NWS Service Instruction, 2005). The heat index (see formula in Appendix C) combines air temperature and relative humidity to produce an estimate of perceived temperature. For example, at 50% relative humidity, 90 degrees F feel like 96° F.

A Heat Advisory (or Excessive Heat Advisory) is issued when 1) heat index values are forecast to exceed 100° F in northern areas (105° F in southern areas) for one to two days, and 2) nighttime lows are forecast to be 75° F or higher (NWS Service Instruction, 2005). As with

Excessive Heat Warnings, until 2002 the NWS applied a single threshold for the entire country (100° F).

These alerts are in effect for a specified day, sequence of days, or portions of a day (e.g., in the afternoon). They can be issued early in the day for which they are meant to apply, or one or two days in advance. Updates on the status of warnings, watches and advisories must be issued at least every 6 to 8 hours. Watches can be converted to actual warnings or downgraded to advisories, depending on forecast updates. Advisories can be upgraded to warnings if the revised weather forecast indicates more oppressive conditions, or cancelled. Warnings can be downgraded, or cancelled altogether if the forecast conditions have changed.

We identified a total of 4055 days with NWS excessive heat event alert over 1993-2007 for the 86 counties covered in out study (see Appendix A for a list of these counties). Of these, 3121 were heat advisories (77% of the total), 648 were excessive heat warnings (16%), and 286 were excessive heat watches (7%).[4] Figure 1 shows the distribution of excessive heat alerts over time. Peaks and troughs match nicely our temperature records indicating warmer and cooler summers.

When attention is restricted to 1993-2005 to match our death counts, which are available only until 2005, we obtain a total of 3062 excessive heat events. Excluding the hot summers of 2006 and 2007 increases the prevalence of advisories and reduces the percentage of warnings: There are now a total of 2644 advisories (86% of the total count), 366 warnings (12%) and 52 watches (about 2%). When we further restrict the sample to the county-day observations for which we have the information necessary to compute the heat index, we get a total of 2809

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[4] We re-classified the one Excessive Heat Outlook as a Watch for the purposes of our analysis.

county-days with an excessive heat alert—2465 advisories (87%), 322 warnings (11%), and 52 watches (about 2%).

Table 1 shows the distribution of all excessive heat events by county. This table supports the notion that certain WFOs appear to issue primarily or exclusively one type of alert. For example, only excessive heat advisories were issued for Birmingham, AL (Jefferson County, FIPS 1073), and Little Rock, AR (Pulaski County, FIPS 5119) over 1993-2007, whereas the WFO at Mt. Holly, NJ, which covers Philadelphia, has issued primarily heat warnings for Philadelphia over the same period, even though NWS records show that the forecast heat index was usually 105-110 at all three locales. (Philadelphia is in Philadelphia County, FIPS 42101.)

Taken together with the fact that Technical Directives instruct NWS personnel to initiate alert procedures when the max daytime heat index reaches or exceeds 100° F for at least one to two consecutive days, this suggests that it is reasonable to collapse the three types of alert into a single dummy variable and to base our next analyses on the recoded "any type of excessive heat alert" indicator. The threshold for triggering any excessive heat alert is thus a forecast maximum heat index of 100 °F for one or two consecutive days, with nighttime lows of at least 75° F.[5]

4. The Model and the Data

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[5] We do not have access to the forecast heat index. What we do have is observed heat index, which should match well the forecast heat index, as temperature forecasts are generally accurate (CITE, DATE) and we observed very few cancellations, upgrades or downgrades of the heat alerts. Using the observed maximum heat index, we estimated a logit model predicting the issuance of an excessive heat alert as a function of the *observed* heat index, higher-order polynomials in the heat index, a dummy for whether the heat index equals or exceeds 100° F, minimum temperature, month dummies, and day of the week, holiday and holiday weekend dummies interacted with the 100° F and hotter dummy. This model shows that weather alone predicts correctly over 94% of the alert/no alert observations. The day of the week, holiday and holiday weekend dummies interactions do not enter significantly. When we added county population density and percentage of homes with air conditioning, both interacted with the hot day dummy, we found that they are positively associated with excessive heat alert, given the weather conditions. However, this does not necessarily mean that opportunities for protective behaviors and sensitive subpopulations weigh in heavily when MICs make their final decision: We remind the reader that our counties are not exhaustive or representative of the entire country, and at any rate we do not have information about the forecast variables used by the local WFO.

A. The Model

Using Summer daily mortality counts for 86 counties in the US—the counties with the largest metropolitan statistical areas in the country and/or where the Kalkstein HHWS programs were adopted (see Appendix A)—from 1985 to 2005, we would like to estimate the following regression equation:

$$(1) \qquad D_{i,mdy} = \alpha_{i,my} + \mathbf{w}_{i,mdy}\boldsymbol{\beta} + NWS_{i,mdy}\delta_1 + KALK_{,mdy}\delta_2 + EMGMT_{i,mdy}\lambda + \varepsilon_{it}$$

where subscript *i* denotes the county, *d* is the day, *m* the month and *y* the year (so that *dmy* is the exact date); *D* is the daily death count for selected causes of death (see Appendix B), divided by the appropriate population; $\alpha_{i,my}$ is a city-specific month-by-year effect, and **w** is a vector of weather variables. NWS is a dummy capturing whether a heat advisory, watch or warning was issued for day *mdy* by the NWS, KALK is a dummy capturing whether the supplemental Kalkstein system, where adopted, recommended issuing an alert on day *dmy*, and EMGMT is a dummy capturing whether the city activated excessive heat emergency measures on day *dmy*.

Equation (1) can be amended to allow for the effects of the weather to vary with population and city characteristics (e.g., percentage of the population aged 65 and older in the city, share of the elderly living alone, percentage of homes with air conditioners, poverty rate, etc.; see Braga et al., 2002; Davis et al., 2002, and Klinenberg, 2002, and, for heterogeneity in the effect of heat across cities, O’Neill et al., 2003; Medina-Ramon and Schwartz, 2007; and Medina- Ramon et al., 2006).[6] Likewise, interaction terms between program variables and city

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[6] Earlier research has emphasized that sociodemographics and economic circumstances are likely to play a role in heat-related mortality. This is the case, for example, for Washington, DC and Baltimore, MD, which have identical climates but different sociodemographics. Baltimore has indeed been found to have higher excess mortality outcomes during extremely hot weather (O’Neill et al., 2003).

characteristics can be entered to capture heterogeneity in the policies' ability to curb the mortality effects of heat.

We are especially interested in the coefficients on the NWS, KALK, and EMGMT dummies. The coefficient on *NWS*, δ_1, should capture the direct effects of issuing a heat alert, those that are presumably due to individuals heeding the alert and avoiding strenous activities, staying out of the heat, paying attention to susceptible individuals, etc. We would expect this coefficient to be negative.

If the coefficient on *KALK*, δ_2, is positive, this means that the Kalkstein system is capable of identifying additional days with elevated mortality, and thus opportunities for reducing mortality risks if appropriate announcements are made. Finally, the coefficient on *EMGMT* should capture the offsetting effect on mortality of city-run or city-coordinated activities.

At the time of this writing, we have gathered the complete set of dates with NWS alerts since the program was established in 1993, but, unfortunately, we have been able to gather only limited information about the Kalkstein HHWS recommendations in the cities where the NWS WFO adopted the system, and we are still compiling the exact dates when the cities undertook heat emergency activities. This means that we are forced to estimate a simplified version of equation (1)—one where *KALK* and *EMGMT* are suppressed,[7] but *NWS* is retained. The estimate of δ_1 will therefore absorb the mortality reductions due to both private and city-run activities intended to reduce the impact of excessive heat, and we will not be able to say much about δ_2 or λ.

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[7] It should be noted that EMGMT may be endogenous with mortality—knowledge of the population's vulnerability presumably prompts cities to implement such initiatives. Including city-specfic month-by-year effects may help circumvent this problem, to the extent that such effects account for city-specific factors that drive vulnerability.

B. Identification and Estimation Strategy

To identify δ_1, we rely on the fact that our study period begins in 1985, well before the NWS established and implemented the heat alert policy, and on the variation in temperature, humidity, and other weather variables across locales and from day to the next at one locale. We also exploit a regression-discontinuity design, since the NWS initiates its excessive heat alert procedure when the forecast heat index is at least 100° F for one to two days, and nighttime temperature is at least 75° F.

To estimate equation (1), we would therefore enter the forecast heat index and the forecast nighttime temperature in the model, as well as higher-order polynomials in these variables, along with all other regressors (including, of course, the *NWS* dummy; see Wooldridge, 2002, p. 613-614). We do not have the *forecast* heat index and nighttime lows, which the alert decisions are based on; we do, however, have *observed* heat index and minimum temperature, which are generally extremely close to the predicted ones. We will thus use the observed heat index and lows to estimate equation (1).[8]

In general, we expect the effect of heat to be small. With the possible exception of susceptible populations or unusually intense heat waves, heat is not expected to be a major driver of mortality. Likewise, we expect the coefficient on NWS to be relatively small. The question we wish to address in this paper is exactly what its magnitude is.

C. Coping with the Heat: Socioeconomic Status and Air Conditioning

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[8] Regardless of NWS policy, the earlier epidemiologic literature has emphasized the importance of daily apparent temperature (O'Neill et al., 2003; Hayhoe et al., 2004), which accounts for air temperature and humidity.

It is important to stay indoors in a cooled environment during heat waves, and air conditioning is indeed widespread in the United States, yet Klinenberg (2002), in his analysis of the 1995 Chicago heat wave, points out that many poor and elderly persons were not actually running their air conditioning because they could not afford to pay high utility bills. Accordingly, we wish to control for the eligibility and generosity of programs that help the poor pay their utility bills can we truly capture the reduction in mortality outcomes afforded by air conditioning.

The Federal government developed a program to assist low-income households cope with high energy prices during periods of high energy demand (cold winter and hot summer). The program—the Low Income Home Energy Assistance Program (LIHEAP), first implemented in 1981, provides resources to the States so that they can subsidize heating in the Winter and—in certain States—cooling in the Summer. Eligibility rules and program generosity vary across the States and over time, and in future research we plan to exploit this variation to disentangle the effect of these subsidy programs during heat alerts. In this paper, for simplicity we limit the analysis to the effect of federal funding for cooling (see section 5.D).

D. The Data

The National Center for Health Statistics of the Centers for Disease Control allowed us to use mortality records for persons aged 18 and older over 1985-2005. We calculated daily death counts for each county for selected causes of deaths, age groups, and gender. Our main mortality measures are (i) all death counts for all causes except incidents and poisonings, plus deaths that were attributed directly to the heat, and (ii) deaths for cardiovascular and respiratory causes, all ages and for persons aged 65 and older.[9]

The dependent variables in our regressions, however, are *rates*, i.e., daily death counts divided by the appropriate population (e.g., individuals aged 65 and older when we examine death counts for persons aged 65 and older). In practice, we found that the effects of heat are limited primarily to the elderly, and so we report and discuss primarily estimation results for this age group, without distinguishing for gender.

Descriptive statistics for the various mortality outcomes are displayed in table 2. Briefly, our main variable, *deaths* (defined in (i) above), has a daily average of 17.50. There are very few county-days observations equal to zero, and for large counties like Los Angeles County or Cook County (Chicago), daily tallies are usually around or in excess of 100.[10] Cardiorespiratory death counts are usually a little over 50% of the *deaths* tallies, and cardiorespiratory deaths among the elderly account for just about 50% of the *deaths* figures. Descriptive statistics by region are reported in table 3.

Weather data (temperature, humidity, dewpoint, windspeed, etc.) were obtained from NOAA's National Center for Data on Climate. Weather variables generally comes from airports and military installations; we occasionally found monitoring stations in city centers or at universities. When multiple monitors are available for the same county, we make sure that in constructing our weather variables (min, max, average, etc.) we use only the monitoring stations within 15 miles of the centroid of the county. For large counties with diverse terrain and climate

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[9] See Appendix B for a full list of these variables. We did not attempt to model separately the deaths attributed directly to the heat (ICD-9 codes E900.0, E900.1, E900.9), because, with the only exception of major heat waves like the one in Chicago in July 1995, they are very infrequent.

[10] The maximum value for deaths was observed in Chicago during the fateful July 1995 heat wave. Deaths in Chicago was equal to 455 on 15 July 1995. This figure was four times as large as the daily average on the week before the heat wave struck.

(e.g., San Diego), the notion of centroid of the county is suspect, and so we placed the individual monitoring stations on a map and examined them individually to determine whether they should be used or disregarded.

We calculated the heat index for each day for each county using the formula in Appendix C, which is appropriate when the temperature is at least 80° F and the relative humidity at least 40%. Table 4 shows that hot days (which we define as days when the max. heat index was at least 100° F, the threshold for activating NWS heat alerts) are abundant in the sample, especially in the South.

All other variables come from the Bureau of the Census, Human and Health Services (e.g., the American Housing Survey for air conditioning data; the annual LIHEAP reports), the National Weather Service, and the US Environmental Protection Agency Air Quality System. Descriptive statistics for these variables are reported in table 5.

As a final point, our focus on daily data from May 1 to Sept. 30 of each year is motivated by our interest in events and policies that take place only in the Summer. An advantage of restricting attention to Summer days is that we do not need to worry about seasonal mortality patterns, a possible confounder of the relationship between heat and mortality (see, among others, Deschênes and Moretti, 2007). Mortality rates have generally declined over time, although they have done at different rates in different areas (The New York Times, DATE). Long-term trends in mortality are folded into the city-specific month-by-year fixed effects.

5. Results.

A. Preliminary Analyses

Does excessive heat affect mortality? To answer this question, we begin by comparing daily mortality counts on “hot” days, which we define as those with maximum heat index greater or equal to 100° F, with counts on days when the heat index is below 100° F. We restrict attention to the years before 1993, the year when the heat advisory policy became effective for the NWS, and group the counties in our sample into six regions. The regions should capture the temperature ranges residents can be presumed to be accustomed to, and hence for acclimatization. They may also, of course, capture lifestyle, economic circumstances, urban fabric and housing types, etc.

Daily averages and t statistics of the null hypotheses that such means are not different across hot and non-hot days are displayed in table 6. Table 6 shows that cancer mortality rates are relatively insensitive to extreme heat, and that both adult non-trauma mortality rates and cardiorespiratory mortality rates among the elderly are higher during hot days in four out of the six regions examined. Southern and Southeastern counties, which experience many hot days and where most homes and buildings are air-conditioned, are relatively insensitive to the heat, as are Midwestern locations, whereas Northeastern and Pacific region counties appeared to experience higher summer mortality rates during hot days. We do not have a good explanation for why mortality rates increased during hot days in the mid-Atlantic region, given its hot summers and comparatively high prevalence of air conditioning. Philadelphia, Baltimore and Washington, DC, subsequently did experience elevated mortality outcomes during the heat wave of July and August 1993, and so it is possible that these results indicate an especially susceptible population.

Next, we fit separate regression equations for each county for two alternate dependent variables—the adult non-trauma mortality rate, and the cardiovascular and respiratory mortality rate among the elderly, respectively. The independent variables include month effects, year effects, day-of-the-week dummies, holiday and holiday weekend dummies, the heat index, and an interaction between the heat index and the hot dummy. The latter is supposed to capture any changes in the slope of the relationship between heat and mortality under extreme thermal stress. This time, we use all days and years in our study period (max. 3213 observations per county).

The results are strongest for cardiorespiratory death rates among the elderly, and this is the reason why the remainder of this discussion focuses on this dependent variable. The estimated coefficients on the heat index, summarized in panel (A) of table 7, suggest that there is a considerable degree of heterogeneity in the response of mortality to heat. Since we do not control yet for NWS events, this heterogeneity reflects the vulnerability of the local population, acclimatization to heat (or lack thereof), warnings and opportunities for mitigating actions. We note once again that mortality among the elderly is insensitive to heat in the South and Southeast, and that there is evidence of a positive relationship between the heat index and elderly mortality in the other regions. Again, the effect seems to be particularly pronounced in the Northeast. In these regressions, the coefficients on the interaction between heat index and the hot day dummy are generally insignificant.

To disentangle the effects of heat stresses from those of behaviors that might follow warnings, we re-estimate these regressions after entering the NWS announcement dummy. Panels (B1) and (B2) of table 7 summarize the coefficients on the heat index and the NWS annoucement dummy, respectively, by region. NWS announcements appeared to have reduced the effects of the heat in Midwest, Northeast, and Pacific Region counties. They have had virtually no effect in the West—a result that we attribute to the infrequency of the advisories in this region—and appear to be *positively*, rather than negatively, associated with elderly cardio-respiratory mortality rates in the mid-Atlantic region and Southern cities.

Since the NWS and EPA are interested in the enhanced use of warning systems in cities with more than 500,000 people, we examine the effect of the NWS announcements after grouping counties by population size. Panel (C) of table 7 suggests that the association between NWS advisories and mortality outcomes among the elderly does vary with county population, but not in a monotonic fashion.

B. Results for the Main Regression Model

Results for selected variants of our main model (equation (1)) for cardiorespiratory mortality rates among the elderly are displayed in table 8. Panels (A)-(D) refer to the full sample for which the conventional formula for the heat index is appropriate (230,790 day-county combinations out the total 276,318),[11] whereas in panels (E)-(F) we take further advantage of the regression discontinuity design of our study by restricting attention to the days with heat index of at least 90° F, for a total of 100,713 observations. (We remind the reader that alert procedures are activated by the NWS when the forecast index is at least 100° F and the nighttime temperature is sufficiently high.)

All regressions control for month-by-year-by-city effects, as well as day-of-the-week, holiday and holiday weekend dummies. Selected specifications further include lagged heat index (up to lag 14), lagged mortality rates in an effort to reduce serial correlation, and ozone, which is sometimes argued to be a potential confounder of the relationship between heat stress and

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[11] The heat index formula in Appendix C is appropriate when the heat index is at least 80° F and the relative humidity at least 40%.

mortality. We enter the heat index in a linear fashion and also interacted with the percentage of home with air conditioning and region dummies.[12]

All panels of table 8 show that when heat stress is more severe, mortality does increase among the elderly. The effect is significant at the 1% level in all specifications, but the magnitude of the effect changes considerably across specifications. Since NWS alerts and the ensuing activities at the city level are not entered in the specification of panel (A), the coefficient on the heat index in this panel subsumes both heat stresses and coping activities. Panel (B) shows that the effect of the heat index on the current-day elderly mortality rate becomes much stronger when one controls for the heat index on previous days. One possible reason for this result is that including lagged heat index measures rids the sample of the first two weeks of May each year, when temperatures tend to be lower.

It is also clear that air conditioning offsets effectively heat stresses, to the point that heat would have virtually no impact in a county with 100% of the homes served by air conditioning, and that there is considerable heterogeneity in the effect of heat stresses across different areas of the country. Some of the region-specific effects of heat remain in place even after we account for NWS alerts (which presumably trigger different responses at different locales).

Indeed, panel (C) shows that there is considerable regional variation in the association between NWS alerts and mortality. The effects are large and negative for the Midwest and the Northeast, less pronounced for counties in the Mid-Atlantic region, and absent altogether for the

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[12] In runs not reported, we included higher-order polynomials in the heat index (an approach recommended in Wooldridge, 2002, p. 613-614, for regression discontinuity design studies, and frequently implemented in applied work), but we found that these terms were individually and jointly insignificant, and that they did not change the coefficients on the remaining variables. We obtain similar results when these higher-order terms are interacted with population density, a possible determinant of vulnerability to heat stresses. For these reasons, these runs are omitted from table 3. We also attempted regressions with the heat index and the interaction between the heat index and the hot day dummy, but the latter never entered significantly.

Pacific Region.[13] We can conjecture possible reasons for these results. Most likely the high density of the midwestern and northeastern cities make it easier for cities to organize cooling centers and home visits for the elderly in poor health and with mobility impairments. Midwestern cities such as St. Louis, Milwaukee, Chicago and Kansas City indeed have considerable experience with coping with heat waves and have developed detailed response plans. Such activities would seem a lot more difficult to implement in sprawling cities like Los Angeles or San Diego. However, the coefficients on the NWS alert-region interactions are estimated imprecisely and are significant at the conventional levels only for the Midwest.

Finally, our results do not offer much guidance in terms of whether NWS alerts results in lower mortality among the elderly in cities with population of 500,000 or more. It is true that the coefficient on the interaction (NWS alert × population 500,000 to one million) is negative and of appreciable magnitude, but it is also statistically insignificant, and at any rate the coefficients on the interactions with other population size class dummies fail to support monotonic effects. It would be interesting to see what happens if we create interactions with only one size dummy—more or less than half a million residents. We plan to investigate this issue in the near future.

When attention is restricted to days with heat index of at least 90° F—a range of temperature closer to the threshold of 100° F at which alert procedures are initiated—the impact of the heat index on mortality is much stronger: In panels (F)-(K) the coefficients on the heat index are virtually twice as large as those for the comparable specifications based on the complete sample. The reduction in mortality afforded by the NWS alerts is also stronger in all regions, except for the Midwest, where it is slightly smaller and less statistically significant than

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[13] Interactions with the South, Southeast and West dummies are omitted from the specifications reported in this paper because of the evidence from preliminary runs that neither heat stresses or NWS alerts matter much in the South and Southeast, and because in the West alerts are very rare.

in the complete-sample runs. Even so, the Midwest appears to be the area of the country where cities appear to benefit the most from NWS alerts. Focus on the warmer days also strengthens the mortality reduction benefits of NWS alerts in sufficiently large counties, but once again the effects are non-monotonic in county population.

C. Robustness Checks

The effect of heat stress on mortality is sometimes thought to be truly caused, or at least worsened, by air pollution, and specifically by ground-level ozone. For this reason, we included the one-hour maximum ozone in the county for that day in several of the specifications of table 8.[14] We found that ozone was generally positively, but insignificantly, associated with the mortality rate for cardiovascular causes among the elderly, and that controlling for ozone did not change the effects of heat or of the heat alerts.

There remains, of course, the possibility that in cities with active ozone advisory programs people might be responding to air pollution warnings instead of heat alerts. For two cities, Washington, DC and Baltimore, we have the full history of the color-code warnings for ozone since 1993 and 1995, respectively (available at www.wmcog.org). We restrict the sample to these two cities and to 1993-2005, and run regressions where we control for the city, month, year, heat index, the NWS heat alerts, and for whether the day is a "code-red" day, which means that the ozone hourly maximum is forecast to exceed 125ppb. The coefficients on this dummy and on the NWS dummy were both insignificant, and there was no evidence of a synergy between the two advisory systems either.

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[14] A number of counties do not monitor ozone levels. To avoid losing observations to the main regressions, we created a companion missing-ozone dummy and recoded ozone to zero on days and counties with missing values. Both the missing-ozone dummy and recoded ozone were included in the model.

As mentioned, we would like to be able to include in our regression a dummy for whether the Kalkstein HHWS system recommended issuance of an alert on any given day. Unfortunately, we were able to obtain the exact dates when this system issued recommendations only for 2006 and 2007, for which mortality data are not yet available from the NCHS. Only for a handful of cities, including Chicago, St. Louis, Philadelphia, Little Rock, Phoenix, Dallas and Ft. Worth were we able to obtain the exact dates of the Kalkstein HHWS advisories for a few years within our study period. Unfortunately, the regression results are suspect. There is virtually no association between NWS announcements and Kalkstein HHWS recommendations when these are entered additively. That the coefficient on the HHWS dummy alone is insignificant suggests that this system does not, after all, identify obvious high-risk days. Yet, an interaction term between the two would appear to have a disproportionately large and negative effect on mortality. We attribute this finding to the fact that rarely do the two systems agree with one another.[15]

Interactions of the NWS alert dummy with LIHEAP funding, percentage homes with air conditioning, and percentage of elderly in the population were also attempted, but gave counterintuive results that we attribute to the collinearity between these variables and others in the model. We also found no evidence of changes in the impact of the NWS alerts after 2002, when the NWS directive became more slightly tailored to the local climate.

D. Magnitude of the Effects of Heat and Alerts

We use the results reported in column (G) of table 8 to get a sense of the magnitude of the mortality effect of heat stress, unconditional on the presence of NWS communications. We

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[15] In Chicago, for example, the NWS rarely issued advisories or warnings after 1999. The Kalkstein system made several recommendations for issuing alerts in 2003-05, but only on one of these days did the NWS actually issue an alert.

compute that in the Northeast, where in 2005 about 80% of the homes have air conditioning, an increase from in a heat index from 95° F to 110° F results in an increase in the mortality rate for cardiovascular and respiratory causes among the elderly of 0.9 in 100,000. Since in 2005 there were a total of 1,253,850 persons of age 65 and older in the Northeast counties in our sample (Suffolk County in Massachusetts, the five counties that cover New York City, and Hudson County in New Jersey), on a day with such a heat increase we would expect 11 additional deaths for the abovementioned causes in this age group.

Suppose now that we can distinguish for the presence or absence of NWS communications on such a day. If no NWS alert is issued, the model reported in column (I) of table 8 predicts that the same increase in the heat index (from 95° F to 110° F) results in 12.30 additional deaths on that day among the elderly in the 7 Northeast counties. By contrast, if a NWS alert is issued on this particular day, there would be 9.11 additional deaths. We conclude that on one such high-heat day, the alert prevents 3 fatalities. In 2005, our Northeast counties experienced 4 days with heat index equal to or greater than 110. All of these days were accompanied by NWS excessive heat warnings. The warnings would thus be credited for preventing 12 cardiovascular and respiratory-related fatalities among the elderly for the Summer of 2005 alone.

Deschênes and Moretti (2007) examine the matter of lasting effects of temperature v. short-term mortality displacement. They conclude that in the case of high temperatures, there is an immediate and large increase in mortality, but after a few days the effect is completely dissipated. We concur with their findings: For a hypothetical, and elderly, Northeast resident, the sum of the coefficients on the contemporaneous and lagged heat indices is 0.0569, a figure that appears to be slighly below the range they report, and much of this figure is accounted for by the immediate effects, since the sum of the coefficients on the 14 lagged heat terms is -0.00764. The individual coefficients on the lagged heat index terms are very small; they alternate signs, those on the two most recent ones being negative. We conclude that heat results in short-term displacement of mortality.

6. Conclusions

Are excessive heat alerts effective in reducing mortality during extremely hot days, and does their effectiveness vary across locations, depending on local circumstances, opportunities for protecting behaviors, resources, and activities organized by local governments? We have tried to answer this question using a panel of data that covers 86 US counties from 1985 to 2005. National Weather Service announcements about extremely hot weather started in 1992, so our data cover hotter and less warm summer days before and after the onset of this program.

We have found that heat stresses have an appreciable mortality effect primarily on the elderly, and primarily on cardiovascular and respiratory causes of death. This effect appears to be short-term mortality displacement. There is a meaningful degree of heterogeneity across geographic regions, and air conditioning has a strong protective protective effect. Using a regression discontinuity design based on the fact that NWS heat alerts are activated when specific heat index conditions and nighttime lows are met, we have found that alerts do reduce mortality, especially in the Midwest, Northeast and Mid-Atlantic. We estimate that heat advisories can reduce mortality by about 25% or more during extremely hot days (e.g., those when the heat index is 110° F or higher).

Neither heat stresses nor NWS alert seem to have much effect in the South, presumably because of acclimitization to the heat, use of air conditioning, and behaviors. We are unable to identify effects of alerts in the West, a result that we attribute to the fact the heat advisories, warnings and watches have been relatively rare in the West counties in our sample during our study period.

In future research, we hope to be able to explicitly control for city-run activities meant to cope with heat waves and extremely hot days. We also hope to be able to determine more conclusively whether an additional forecasting-alert system adopted by selected WFOs in different cities is capable of identifying high-risk days. For now, what we can say is that NWS alerts hold promise in terms of reducing the mortality impacts of heat stresses, whether by triggering individual behaviors or city-run coping measures.

Figure 1. NWS Heat Alerts (Excessive Heat Advisories, Watches and Warnings) by Year in the 86 Counties.

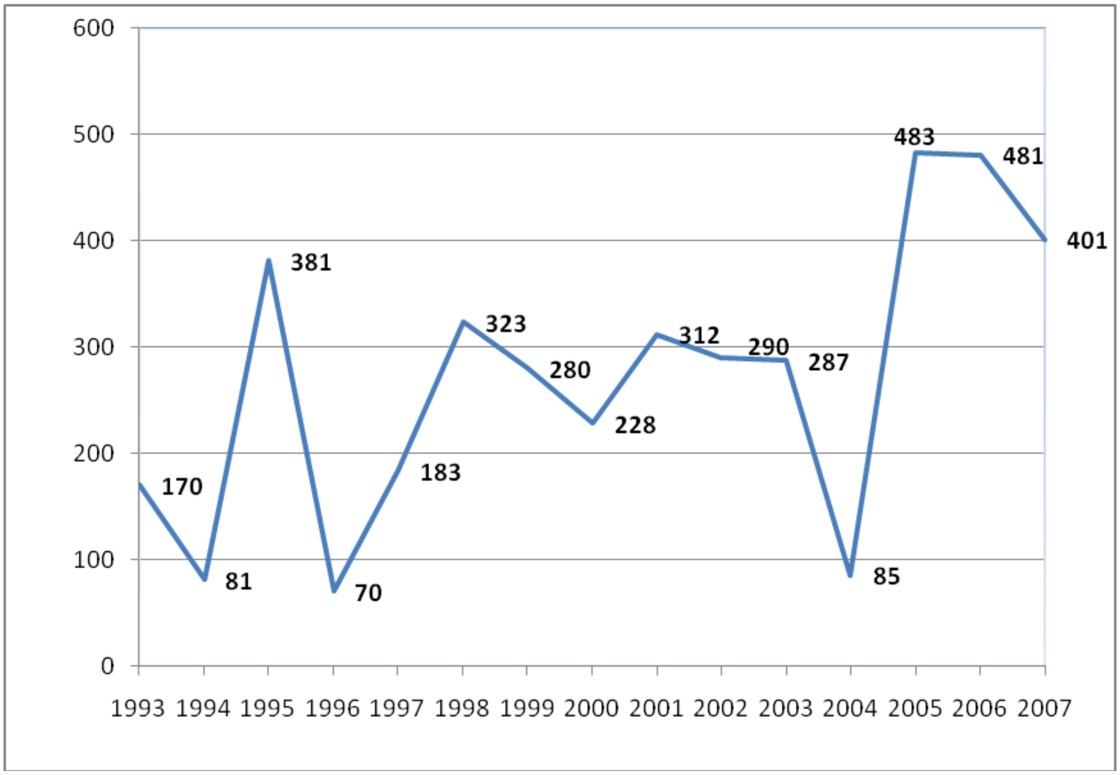

Table 1. Frequency of NWS Heat Alerts, 1993-2007

Fips	Excessive Heat Advisory	Excessive Heat Warning	Excessive Heat Watch	TOTAL
1073	35	0	0	35
4013	40	10	1	51
4027	9	16	0	25
5119	201	0	0	201
6037	14	11	6	31
6067	11	0	0	11
6073	32	16	6	54
6075	15	0	0	15
9009	7	4	1	12
11001	104	14	1	119
12057	2	0	0	2
12086	8	1	0	9
13121	34	2	0	36
17031	12	15	17	44
17119	37	11	23	71
17133	35	10	16	61
17163	36	11	23	70
18167	14	3	0	17
20091	84	38	0	122
20103	83	38	0	121
20209	83	38	0	121
22017	81	0	1	82
22019	45	0	1	46
22033	23	0	0	23
22071	30	0	3	33
22073	83	0	1	84
22079	38	0	1	39
24510	103	13	1	117
25025	8	1	6	15
26163	16	1	0	17
27053	11	0	7	18
27123	9	0	7	16
28075	51	0	2	53
29037	78	33	0	111
29047	21	0	0	21
29071	36	10	15	61
29095	56	32	0	88
29099	35	10	15	60

Fips	Excessive Heat Advisory	Excessive Heat Warning	Excessive Heat Watch	TOTAL
29113	35	10	15	60
29165	21	0	0	21
29177	67	32	0	99
29183	36	8	23	67
29189	40	11	23	74
29510	42	11	23	76
34017	75	9	3	87
36005	73	11	1	85
36047	73	11	1	85
36061	73	11	1	85
36081	73	11	1	85
36085	73	11	1	85
37081	28	8	3	39
37119	17	1	0	18
39035	19	5	2	26
39049	0	4	0	4
39061	2	7	0	9
39099	12	3	2	17
39151	12	3	2	17
40109	29	8	0	37
40143	67	30	0	97
41051	3	3	4	10
42003	10	2	0	12
42101	34	92	20	146
47037	15	0	0	15
47157	64	5	0	69
48113	184	0	0	184
48201	79	1	0	80
48439	174	0	0	174
48453	27	0	0	27
49035	15	0	0	15
49049	13	0	0	13
53033	1	2	7	10
55079	15	0	0	15

Table 2

Descriptive statistics--Mortality outcomes						
Variable	**Label**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
deaths	total non-trauma death plus death caused by heat	276318	17.50128	22.33818	0	455
TotDeath	total non-trauma death	276318	17.49353	22.32606	0	437
TotDeath2	no trauma, no ill-def	276318	17.26863	22.14483	0	435
TotDeath3	cardioresp	276318	11.28652	15.40095	0	379
TotDeath4	no trauma, lt 65	276318	4.469112	6.209455	0	117
TotDeath5	no trauma or ill-def, lt 65	276318	4.368651	6.108085	0	115
TotDeath6	cardioresp, lt 65	276318	2.304638	3.588725	0	93
TotDeath7	no trauma, 65+	276318	13.02442	16.61367	0	320
TotDeath8	no trauma or ill-def, 65+	276318	12.89998	16.52758	0	320
TotDeath9	cardioresp, 65+	276318	8.981883	12.23344	0	286
TotDeath10	no trauma, M lt 65	276318	2.744519	3.983057	0	81
TotDeath11	no trauma or ill-def, M lt 65	276318	2.677162	3.914126	0	80
TotDeath12	cardioresp, M lt 65	276318	1.412217	2.2888	0	65
TotDeath13	no trauma, M 65+	276318	5.858543	7.718865	0	137
TotDeath14	no trauma or ill-def, M 65+	276318	5.801808	7.673845	0	137
TotDeath15	cardioresp, M 65+	276318	4.026936	5.707218	0	123
TotDeath16	no trauma, F lt 65	276318	1.724593	2.58877	0	36
TotDeath17	no trauma or ill-def, F lt 65	276318	1.69149	2.553629	0	35
TotDeath18	cardioresp, F lt 65	276318	0.892421	1.612799	0	28
TotDeath19	no trauma, F 65+	276318	7.165878	9.292552	0	183
TotDeath20	no trauma or ill-def, F 65+	276318	7.098173	9.249518	0	183
TotDeath21	no trauma or ill-def, F 65+	276318	4.954947	6.898689	0	163
Totdeath22	neoplasms, all ages, both genders	276318	3.05654	5.392611	0	63
Totdeath23	trauma, all ages, both genders	276318	1.490583	2.741427	0	451
heatdeaths	deaths directly attributed to heat	276318	0.007745	0.121803	0	18
mortrate	Deaths divided by population	252,218	1.99	0.98	0	27.42
cardiorespraté	Totdeath3 divided by population	252,218	1.29	0.81	0	19.32
cancerrate	Totdeath22 divided by population	252,218	0.36	0.44	0	14.49
cardiorespraté65	Totdeath9 divided by population aged 65 and older	252,218	8.65	5.47	0	143.73

Table 3

Descriptive Statistics--Daily Mortality Outcomes by Region					
Mid-Atlantic	**N**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
mortrate	12852	2.845189	0.621417	0.343614	6.769807
cardioresprate	12852	1.731367	0.623538	0	5.526373
cancerrate	12852	0.513273	0.426089	0	2.175496
cardioresprate65	12852	9.336272	3.40856	0	34.00169
Midwest					
mortrate	80827	2.132589	1.2355	0	19.32367
cardioresprate	80827	1.414844	1.034567	0	19.32367
cancerrate	80827	0.384604	0.547133	0	14.49275
cardioresprate65	80827	8.960503	7.097552	0	143.7298
Northeast					
mortrate	25702	2.145559	0.585014	0	5.626588
cardioresprate	25702	1.403198	0.539841	0	4.382031
cancerrate	25702	0.377152	0.33872	0	2.364911
cardioresprate65	25702	9.154829	3.616383	0	29.76958
Pacific Coast and Hawaii					
mortrate	36282	1.727548	0.636842	0	9.025882
cardioresprate	36282	1.097944	0.528049	0	6.602258
cancerrate	36282	0.302095	0.314149	0	2.25647
cardioresprate65	36282	8.162613	3.939509	0	57.88154
South					
mortrate	45541	1.930301	0.996988	0	27.42331
cardioresprate	45541	1.219885	0.797023	0	17.02899
cancerrate	45541	0.340965	0.426585	0	5.144827
cardioresprate65	45541	8.797318	5.472614	0	112.2612
Southeast					
mortrate	22468	2.011034	0.6254	0	5.763392
cardioresprate	22468	1.288377	0.583138	0	4.550046
cancerrate	22468	0.371603	0.35055	0	2.113188
cardioresprate65	22468	8.478167	3.678743	0	29.69635
West					
mortrate	28546	1.511608	0.779351	0	8.24156
cardioresprate	28546	0.956982	0.639412	0	5.899208
cancerrate	28546	0.271081	0.358587	0	4.315414
cardioresprate65	28546	7.515198	4.955846	0	43.31254

Table 4

Frequency of days with Heat Index ge 100 by month by region							
	Midatlantic	Midwest	Northeast	Pacific	South	Southeast	West
May	19	83	24	19	447	230	175
Jun	124	962	168	83	2816	1083	747
Jul	438	3597	575	304	5998	2087	1248
Aug	273	2758	387	341	5627	2089	1247
Sep	31	421	45	168	2033	1219	753
total hot days	885	7821	1199	915	16921	6708	4170
Total days in the sample	12852	96390	25704	41769	48195	22491	28917

Table 5. Descriptive Statistics for the Covariates

Variable	N	Mean	Std Deviation	Minimum	Maximum
avgtemp	252,218	72.58	9.46	22	107.2
avgdewpoint	249,693	59.22	11.04	0.9	84.3
maxmaxtemp	252,206	84.83	9.84	27.1	124
minmintemp	245,784	60.89	10.22	-11	90.9
countypopulation	252,218	961,292.09	1,256,576.31	20,700	9,941,197
age65plus	252,218	110,628.02	134,163.41	2,783	998,314
pcapinc	252,218	24,930.15	9,101.49	9,199	93,377
pcapincadjusted	252,218	16,215.38	4,288.65	6,572.96	49,840.88
liheapcooling	252,218	10,459.94	35,180.06	0	310,146
liheapnetallotment	252,218	46,010,706.49	47,012,915.02	948,765	263,290,800
pctpeople_in_poverty	193,065	14.25	5.50	3.90	37.90
density	252,218	3,787.47	8,452.40	15.84	58,969.68
pctwithAC	245,165	0.79	0.25	0.06	1.00
onehrmaxo3 (one-hour max. ozone reading)	276,318	0.05	0.04	0	1
relhumidity	249,681	44.11	13.11	3.37	100
heatindex	249,681	88.49	9.71	55.68	193.16
ozonemissing1	276,318	0.18	0.38	0	1
Hot day (heat index ge 100° F)	276,318	0.14	0.35	0	1
midwest	276,318	0.35	0.48	0	1
northeast	276,318	0.09	0.29	0	1
south	276,318	0.17	0.38	0	1
pacific	276,318	0.15	0.36	0	1
southeast	276,318	0.08	0.27	0	1
midatlantic	276,318	0.05	0.21	0	1
west	276,318	0.10	0.31	0	1
Medium size county (0.25 to 0.5 million)	276,318	0.20	0.40	0	1
Large county (0.5-1 million)	276,318	0.31	0.46	0	1
Very large county (1-3 million)	276,318	0.22	0.41	0	1
Ex. Large county (more than 3 million)	276,318	0.05	0.21	0	1

Table 8. Regression results.

Dep variable: cardiorespraterate65	all days with acceptable HI (N=230,790)									
	(A)		(B)		(C)		(D)		(E)	
	coeff.	**t stat.**	**coeff.**	**t stat.**	**coeff.**	**t stat.**	**coeff.**	**t stat.**	**coeff.**	**t stat.**
Heatindex	0.036126	3.52	0.060676	5.47	0.051929	4.71	0.051355	4.65	0.051296	4.64
heatindex*pctwithAC	-0.03175	-2.78	-0.05078	-4.24	-0.04176	-3.51	-0.04188	-3.52	-0.04178	-3.51
heatindex*midwest	0.005024	0.86	0.003485	0.56	0.002512	0.41	0.002463	0.4	0.002425	0.39
heatindex*midatlanti	0.018648	2.09	0.011094	1.2	0.0109	1.15	0.010479	1.1	0.010439	1.1
heatindex*northeast	0.028875	3.94	0.020638	2.68	0.020665	2.63	0.019946	2.54	0.019939	2.54
heatindex*pacific	0.003701	0.41	-0.00822	-0.87	-0.0039	-0.41	-0.00464	-0.49	-0.00462	-0.49
heatindex*south	-0.00106	-0.16	-0.00049	-0.07	-0.00248	-0.35	-0.00213	-0.3	-0.00215	-0.31
NWSannounc					0.179138	1	0.175145	0.98	0.20599	0.66
midwest*NWSannounc					-0.58173	-2.18	-0.5772	-2.16	-0.58452	-2.04
midatlant*NWSannounc					-0.18997	-0.53	-0.18748	-0.52	-0.14866	-0.37
northeast*NWSannounc					-0.33622	-1.07	-0.33449	-1.07	-0.33892	-1.01
pacific*NWSannounc					-0.05219	-0.08	-0.0502	-0.08	-0.05994	-0.09
NWSannounc*medium-sized popul.									-0.03568	-0.1
NWSannounc*large population									-0.11551	-0.3
NWSannounc*very large population									0.003367	0.01
NWSannounc*v very large popul.									-0.03476	-0.07
city*month*year fixed effects	yes		yes		yes		yes		yes	
heat index lags	no		yes		yes		yes		yes	
mort. Outcome lags	no		no		yes		yes		yes	
ozone	no		no		no		yes		yes	

Dep variable: cardiorespate65	only days with heat index of at least 90F (N=100,713)											
	(F)		(G)		(H)		(I)		(J)		(K)	
	coeff.	t stat.	coeff.	t stat.	coeff.	t stat.	coeff.	t stat.	coeff.	t stat.	coeff.	t stat.
heatindex	0.08871	3.02	0.10261	3.65	0.10123	3.41	0.08502	2.88	0.08504	2.88	0.08471	2.87
heatindex*pctwithAC	-0.0792	-2.53	-0.0965	-3.18	-0.0911	-2.88	-0.0754	-2.4	-0.0754	-2.39	-0.0749	-2.38
heatindex*midwest	-0.0105	-0.92	-0.0088	-0.78	-0.0075	-0.66	-0.0068	-0.59	-0.0068	-0.59	-0.0069	-0.6
heatindex*midatlanti	0.03419	1.62	0.03039	1.45	0.03337	1.57	0.04035	1.79	0.0404	1.8	0.04012	1.78
heatindex*northeast	0.03404	1.85	0.03461	1.9	0.03627	1.95	0.04073	2.05	0.04084	2.05	0.0408	2.05
heatindex*pacific	-0.0027	-0.12	-0.0144	-0.64	-0.01	-0.44	-0.0018	-0.08	-0.0017	-0.07	-0.0016	-0.07
heatindex*south	0.01389	1.22	0.01101	0.98	0.01474	1.28	0.01311	1.15	0.01308	1.15	0.01292	1.13
NWSannounc							0.11581	0.61	0.11652	0.62	0.09777	0.29
midwest*NWSannounc							-0.5339	-1.82	-0.5344	-1.83	-0.5233	-1.66
midatlant*NWSannounc							-0.3884	-0.94	-0.3885	-0.94	-0.2974	-0.66
northeast*NWSannounc							-0.3704	-1.02	-0.3702	-1.02	-0.3806	-0.99
pacific*NWSannounc							0.02856	0.04	0.02843	0.04	0.05278	0.07
NWSannounc*medium-sized popul.											0.11766	0.31
NWSannounc*large population											-0.1507	-0.37
NWSannounc*very large population											0.06412	0.17
NWSannounc*v very large popul.											-0.0974	-0.18
city*month*year fixed effects	yes		yes		yes		yes		yes		yes	
heat index lags	yes		no		yes		yes		yes		yes	
mort. Outcome lags	yes		no		no		yes		yes		yes	
ozone	no		no		no		no		yes		yes	

Table 6. Comparison of mortality rates across hot (heat index ≥ 100° F) and non-hot days, 1985-1992

	Mid-Atlantic region			Midwest			Northeast			Pacific region		
label	daily mean hot=0	daily mean hot=1	t test	daily mean hot=0	daily mean hot=1	t test	daily mean hot=0	daily mean hot=1	t test	daily mean hot=0	daily mean hot=1	t test
mortrate	2.9173	3.1374	-5.83	2.2285	2.2058	0.8	2.3923	2.6184	-6.79	1.8059	1.7974	0.3
cardioresprate	1.8417	1.8148	0.79	1.5461	1.4683	3.35	1.5749	1.6707	-3.52	1.2068	1.2264	-0.83
cancerrate	0.7681	0.7841	-0.97	0.5705	0.5547	1.3	0.5810	0.5640	1.27	0.4826	0.4752	0.59
cardioresprate65	9.7273	10.1463	-2.01	9.7974	9.7094	0.53	9.8006	10.7868	-5.22	8.7619	9.3464	-3.22
deaths	31.8955	29.3638	3.15	14.4476	12.4749	4.71	28.4744	29.9910	-1.61	22.8410	53.5962	-14.43
totdeath3	20.3772	16.9245	6.6	9.8995	8.1889	6.18	18.7541	19.1685	0.65	15.6056	37.4808	-9.62
totdeath22	8.4855	7.3477	4.8	3.7864	3.2269	5.21	6.6949	6.2697	1.92	5.9815	13.6891	-14.54
totdeath9	15.8473	12.9164	6.9	7.7754	6.4888	5.96	14.7455	15.0966	-0.7	12.4662	29.8910	-9.74

	South			Southeast			West		
label	daily mean hot=0	daily mean hot=1	t test	daily mean hot=0	daily mean hot=1	t test	daily mean hot=0	daily mean hot=1	t test
mortrate	1.9902	1.9132	5.1	2.1434	2.1261	1.13	1.5254	1.8359	-11.35
cardioresprate	1.3242	1.2837	3.22	1.4209	1.4422	-1.59	1.0229	1.2121	-8.25
cancerrate	0.5161	0.4950	3.09	0.5647	0.5674	-0.4	0.3911	0.5197	-8.84
cardioresprate65	9.4814	9.6823	-2.27	9.0108	9.0344	-0.27	8.2591	7.3644	5.77
deaths	11.5435	13.3197	-10.05	18.2370	23.1817	-14.02	7.6846	17.9266	-22.47
totdeath3	7.6072	8.7870	-9.59	12.2477	15.8939	-13.92	5.1730	12.0767	-20.81
totdeath22	3.0171	3.5124	-9.36	4.7902	6.0836	-12.69	1.9836	4.9868	-21.99
totdeath9	5.7288	6.4575	-8.22	9.8579	12.7462	-13.13	4.1913	9.7057	-20.45

Table 7. Summary statistics of estimated slopes from county-by-county regressions.

DepVar: cardiorespirate65	N	mean coefficient	% coefficients significant
Mid-Atlantic	4	0.023265	50
Midwest	27	0.012615	22
Northeast	8	0.036353	100
Pacific	13	0.026382	54
South	15	-0.00594	6.67
Southeast	7	0.008559	42.85
West	9	0.015948	22.22

A: Summary of estimated coefficients on heat index from separate regressions for each county. Regressions control for month-year effects, heat index, heatindex*hot, day of the week, holiday and holiday weekend.

Mid-Atlantic	4	0.0748	100
Midwest	27	0.029492	29.62
Northeast	8	0.092888	87.5
Pacific	13	0.065667	53.84
South	15	0.007969	6.67
Southeast	7	0.019285	14.28
West	9	0.026044	33.33

B1: Summary of estimated coefficients on heat index from separate regressions for each county. Regressions control for month-year effects, heat index, heatindex*hot, day of the week, holiday, holiday weekend, and NWS announcement.

Mid-Atlantic	4	0.152493
Midwest	27	-0.12971
Northeast	8	-0.27024
Pacific	13	-0.0932
South	15	0.216373
Southeast	7	-0.17772
West	9	-0.03314

B2: Summary of estimated coefficients on NWS advisory from separate regressions for each county. Regressions control for month-year effects, heat index, heatindex*hot, day of the week, holiday, holiday weekend, and NWS announcement.

size=pop 1-3 million	19	-0.37044
size=pop 100-250,000	7	-0.11684
size=pop 250-500,000	17	-0.09955
size=pop 3 million and over	4	0.040838
size=pop 500k-1	27	0.032136
size=pop < 100k	9	0.439449

C: Summary of estimated coefficients on NWS advisory from separate regressions for each county. Regressions control for month-year effects, heat index, heatindex*hot, day of the week, holiday, holiday weekend, and NWS announcement.

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Appendix A. List of principal cities/counties in the sample.

county name	City	Kalkstein HHWS adopted?	state	county fips
Hennepin	Minneapolis-St. Paul	Yes	MN	27053
Ramsey	Minneapolis-St. Paul		MN	27123
Milwaukee	Milwaukee		WI	55079
Cook	Chicago	Yes	IL	17031
Wyandotte	Kansas City		KS	20209
Vigo	Terre Haute		IN	18167
Stark	Canton		OH	39151
Boulder	Boulder		CO	8013
El Paso	Colorado Springs		CO	8041
Denver	Denver		CO	8031
Wayne	Detroit		MI	26163
Mahoning	Youngstown		OH	39099
Cuyahoga	Cleveland		OH	39035
Franklin	Columbus		OH	39049
Allegheny	Pittsburgh		PA	42003
St. Louis City	St. Louis	Yes	MO	29510
Hamilton	Cincinnati	Yes	OH	39061
New Haven	New Haven		CT	9009
Spokane	Spokane		WA	53063
Suffolk	Boston		MA	25025
Burlington	Jersey City		NJ	34017
The Bronx/Bronx Co. Manhattan/New York Co. Queens/Queens Co. Brooklyn/Kings Co. Staten Island/Richmond Co.	New York City		NY	36005 36061 36081 36047 36085
Philadelphia	Philadelphia	Yes	PA	42101
Utah	Provo		UT	40049
Salt Lake	Salt Lake City		UT	49035
Baltimore City	Baltimore		MD	24510
Tulsa	Tulsa		OK	40143
Oklahoma	Oklahoma City		OK	40109
Davidson	Nashville		TN	47037
District of Columbia	Washington	Yes	DC	11001
Guilford	Greensboro		NC	37081
Bernalillo	Albuquerque		NM	35001
Mecklenburg	Charlotte		NC	37119
Dallas	Dallas	Yes	TX	48113
Multnomah	Portland	Yes	OR	41051
Fulton	Atlanta		GA	13121
Shelby	Birmingham		AL	1073

Kings	Seattle	Yes	WA	53033
Travis	Austin		TX	48453
Houston	Houston		TX	48201
Sacramento	Sacramento		CA	6067
Orleans Parish	New Orleans	Yes	LA	22071
San Francisco	San Francisco		CA	6075
Los Angeles	Los Angeles		CA	6037
Orange	Orlando		FL	12095
San Diego	San Diego		CA	6073
Hillsborough	Tampa		FL	12057
Broward	Ft. Lauderdale		FL	12011
Dade	Miami		FL	12086
Honolulu	Honolulu		HI	15003
Maricopa	Phoenix	Yes	AZ	04013
Yuma	Yuma	Yes	AZ	04027
Pulaski	Little Rock	Yes	AR	05119
East Baton Rouge Parish	Baton Rouge	Yes	LA	22033
Calcasieu Parish	Lake Charles	Yes	LA	22019
Ouachita Parish	Monroe	Yes	LA	22073
Caddo Parish	Shreveport	Yes	LA	22017
Hinds	Jackson	Yes	MS	28049
Lauderdale	Meridian	Yes	MS	28075
Montgomery	Dayton	Yes	OH	39113
Shelby	Memphis	Yes	TN	47157
Tarrant	Fort Worth	Yes	TX	48439

Appendix B.

<u>Daily</u> death <u>counts</u> for the period from May 1 to Sept 30 from 1986 to 2005 available to us:

1. all, excluded ICD-9 800-999 (injury and poisoning) and ICD-9 e800-e999 (external causes, such as transportation accidents, etc.)*
2. all, excluded ICD-9 800-999 (injury and poisoning), ICD-9 e800-e999 (external causes, such as transportation accidents, etc.), and ICD-9 780-799 (Symptoms, Signs and Ill-defined Conditions)**
3. cardiovascular (ICD-9 codes 390-459) and respiratory (ICD-9 codes 460-519)***
4. persons of age less than 65, all causes excluded ICD-9 800-999 and ICD-9 e800-e999*
5. persons of age less than 65, all causes excluded ICD-9 800-999, ICD-9 e800-e999 and ICD-9 780-799**
6. persons of age less than 65, cardiovascular and respiratory causes, ICD-9 codes 390-519***
7. persons of age greater than 65, all causes excluded ICD-9 800-999 and ICD-9 e800-e999*
8. persons of age greater than 65, all causes excluded ICD-9 800-999, ICD-9 e800-e999 and ICD-9 780-799**
9. persons of age greater than 65, cardiovascular and resp causes, ICD-9 codes 390-519***
10. males of age less than 65, all causes excluded ICD-9 800-999 and e800-e999*
11. males of age less than 65, all causes excluded ICD-9 800-999, e800-e999 and 780-799**
12. males of age less than 65, cardiovascular and resp causes, ICD-9 codes 390-519***
13. males of age more than 65, all causes excluded ICD-9 800-999 and e800-e999*
14. males of age more than 65, all causes excluded ICD-9 800-999, e800-e999 and 780-799**
15. males of age more than 65, cardiovascular and resp causes, ICD-9 codes 390-519***
16. females of age less than 65, all causes excluded ICD-9 codes 800-999 and e800-e999*
17. females of age less than 65, all causes excluded ICD-9 codes 800-999, e800-e999 and 780-799**
18. females of age less than 65, cardiovascular and resp causes, ICD-9 codes 390-519***
19. females of age more than 65, all causes excluded ICD-9 codes 800-999 and e800-e999*
20. females of age more than 65, all causes excluded ICD-9 800-999, e800-e999 and 780-799**
21. females of age more than 65, cardiovascular and resp causes, ICD-9 codes 390-519***

* When ICD-10 is used, replace with ICD-10 codes S00-T98 and V01-Y98

** When ICD-10 is used, replace with ICD-10 codes S00-T98, V01-Y98 and R00-R99

*** When ICD-10 is used, replace with ICD-10 I00-I99 and J00-J99.

Appendix C. Calculation of Heat Index.

The National Weather Service calculates the Heat Index (HI) as follows:

(C1) $HI=-42.379+2.04901523\cdot T+10.14333127\cdot RH-0.22475541\cdot RH\cdot T-0.00683783\cdot T^2-0.05481717\cdot RH^2+0.00122874\cdot T^2\cdot RH+0.00085282\cdot T\cdot RH^2-0.0000199\ T^2\cdot RH^2$

where T is air temperature in Farenheit and RH is relative humidity expressed in percent. Adjustments must be made to general formula (C1) when the humidity is low and the air temperature high, and when the air temperature is mild but the humidity is high.