12.7 ON SEASONAL DIFFERENCES IN WEATHER-RELATED MORTALITY TRENDS IN THE UNITED STATES

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1. INTRODUCTION

In most mid-latitude industrialized nations, there is a pronounced seasonality to human mortality rates, with significantly more deaths occurring in winter than in summer. This seemingly runs counter to the established observation that mortality increases during heat waves, particularly in cities where extreme heat and humidity are relatively less common. Any forecasts of the impact of climate change on future mortality rates must incorporate the observed mortality seasonality into the model. Further complicating the issue is the observation that most of the observed surface warming since World War II has occurred over higher-latitude land areas in winter (Michaels et al., 2000). Winter warming, coupled with the inherent seasonality in mortality, has led some researchers to predict that "global warming" could reduce overall mortality rates, since additional summer deaths would be more than offset by fewer winter deaths (e.g., Moore, 1998). Our goal is to attempt to understand how the seasonality in mortality is related to both weather and climate in the United States.

2. DATA

We acquired daily mortality data from the National Center for Health Statistics archives. These records include information for every individual who died in the United States from 1964–1994. Since the date of death was not recorded from 1967–1972, our data set includes 25 non-consecutive years of information.

We computed daily mortality totals for the 27 largest Metropolitan Statistical Areas (MSAs) in the United States based on the county-level MSA classifications from 1990 (Figure 1). Because mortality rates vary with demographic changes between MSAs as well as within a given MSA over time, we performed an age standardization procedure based on accepted epidemiological practices (Anderson and Rosenberg, 1998). The resulting standardized daily death rates (per 1,000,000) are thus comparable over time and between cities.

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Surface airways observations were extracted from appropriate stations for each MSA. In our summer analyses, 4 p.m. LST apparent temperature (AT)—a combination of temperature and humidity— is used as our independent variable (Steadman, 1979). We examined the data for possible lag relationships and determined that a one-day lag (with deaths following the offending weather event) provided the best fit in almost all cities. In winter, we used 7 a.m. LST temperature as the independent variable.

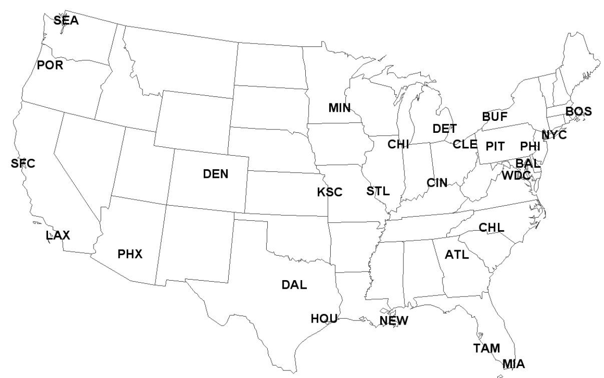

Figure 1. Locations of the 27 cities used in this analysis.

3. GENERAL DAILY WEATHER/MORTALITY RELATIONSHIPS

Plots of standardized daily mortality versus AT in most northern and interior U.S. cities have a subtle U-shape. In Detroit MI, for example (Figure 2a), mortality increases on some warm and humid days. The mortality increase at low daily temperatures is far less pronounced, even though winter death rates are markedly higher overall than summer death rates.

Other studies have indicated that early season heat has a greater impact on mortality than heat waves that occur later in the season after the susceptible population has had an opportunity to acclimate (e.g., Marmor, 1975; Kalkstein, 1993). To remove this potential bias, we de-seasoned the mortality data by subtracting the median monthly mortality from each day's mortality count (Figure 2b). Mortality is still elevated when ATs are high, but there is little evidence of a comparable response in winter. This simple standardization suggests that summertime deaths are linked to specific weather events whereas winter deaths are elevated in general but the mortality response to low temperatures is either muted or nonexistent. Given this seasonal disparity in weather/mortality relationships, it is necessary to examine summer and winter mortality using different approaches.

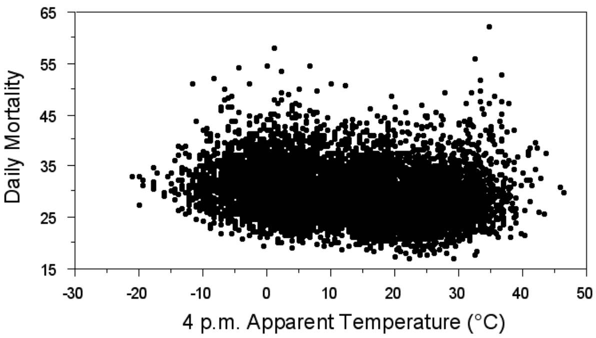

Figure 2a. Total daily mortality vs. daily 4 p.m. apparent temperature in Detroit, Mi.

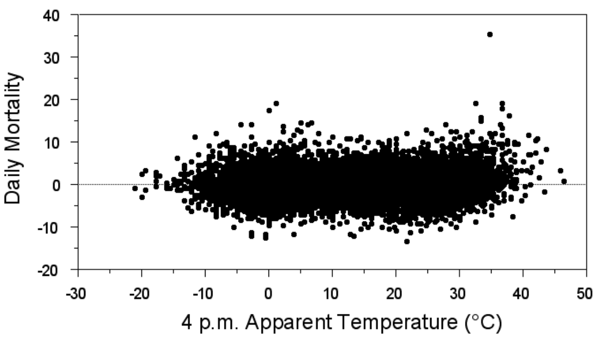

Figure 2b. Standardized daily mortality vs. 4 p.m. apparent temperature in Detroit, MI.

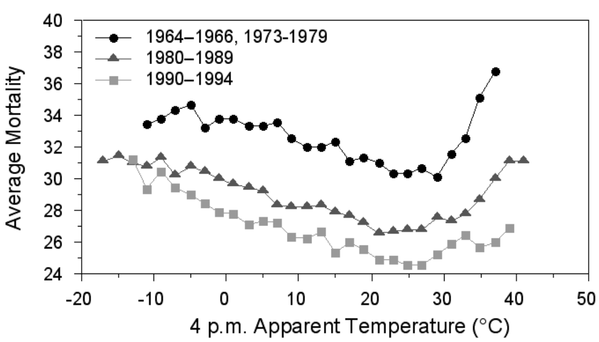

Figure 2c. Average daily mortality vs. temperature by “decade” in Detroit, MI.

4. SUMMER RESULTS

Careful examination of Figure 2b argues for the existence of a “threshold AT,” or the AT above which mortality is significantly above normal. Using a method detailed in Davis et al. (2002), we calculate a threshold AT of 30°C for Detroit. Figure 3 shows the threshold ATs determined for all cities. Overall, there are an average of 1.57 additional deaths the day after 4 p.m. ATs exceed 30°C in Detroit.

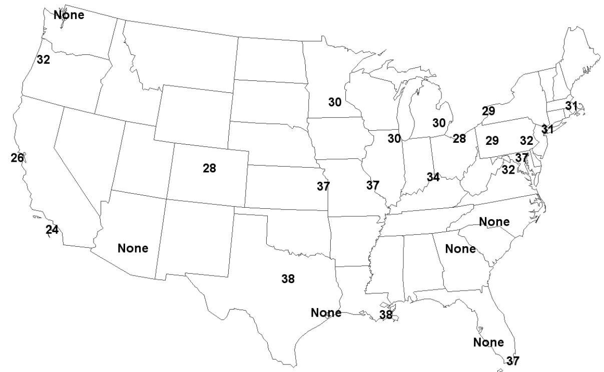

Figure 3. Threshold 4 p.m. ATs (°C) for each of the 27 cities.

Thus far, we have not considered the possibility of temporal trends in mortality responses to warm and humid conditions. Because of biophysical and infrastructural adaptations and civic responses to heat or heat forecasts, there is evidence that people react differently to heat stress now than they did in the 1960s (Davis et al., 2002). To examine decadal trends, the data are organized by “decade” into three groups, 1964–1966 and 1973–1979 (10 years), 1980–1989 (10 years) and 1990–1994 (5 years). In Detroit, mortality rates on days above the threshold AT have declined over time (Figure 2c). This behavior is common to most of the weather-sensitive cities examined.

Figure 4 shows the average daily mortality anomaly above the threshold temperature during each “decade” for all 27 cities. On Figure 4, the bars are ordered by “decade” (sixties/seventies, eighties, nineties) for each city. White bars represent a value that is not statistically different from zero, filled bars (gray and black) represent values that are statistically different from zero, and black bars are statistically different from the gray bars. Cities with no bars at all have no definable threshold temperatures (i.e., show no elevated mortality with extremely high temperatures).

There are clear spatial patterns in the decadal mortality impacts of high ATs. The areas most affected by summertime heat and humidity are the Northeast and Midwest. In many southern cities, threshold ATs do not exist, so there is no elevated mortality on the hottest days (Charlotte, Atlanta, Tampa, Houston, Phoenix). In almost every city, the death rate has dropped over time. In many cases, the decline since the 1970s has been statistically significant. This strongly suggests that air-conditioning, among other factors, has played a major role in mortality reduction in cities where air-conditioning was less common in the 1960s and 1970s.

The significantly elevated mortality in Portland, San Francisco, and Los Angeles is somewhat unexpected. One possibility is that because of the maritime climate, the populace in these cities is disproportionately affected by warm and humid conditions. However, another factor could be the true representativeness of the weather station selected for these MSAs that have such inherently variable climates. In Los Angeles, for example, the weather at LAX is probably not the best choice to represent the entire L.A. basin.

Figure 4. The average daily mortality anomaly above the threshold temperature during each "decade" for all 27 cities. The bars are ordered by "decade" (sixties/seventies, eighties, nineties) for each city. White bars represent a value that is not statistically different from zero, filled bars (gray and black) represents values that are statistically different from zero, and black bars are statistically different from the gray bars. Cities with no bars at all have no definable threshold temperatures (i.e., show no elevated mortality with extremely high temperatures).

5. WINTER AND SEASONAL RESULTS

Using a method parallel to our summer analysis, we attempted to determine weather–mortality relationships for winter. In a large majority of cities, there is no identifiable threshold temperature, even when a wide variety of lags are examined. The flattening of the low end of the mortality curve, after deseasoning, argues for a different mortality response than in summer. Nationwide, winter mortality rates are markedly higher than summer, for reasons that remain unknown to bioclimatologists and epidemiologists. Influenza is a major mortality factor in winter, and increased deaths from other diseases are correlated with influenza epidemics. Influenza has not yet been linked to weather or climate conditions, and it is not even certain why influenza is a winter disease. Furthermore, most primary causes of death peak in winter (e.g., Donaldson and Keatinge, 1997; Pell and Cobb, 1999; Lanska and Hoffman, 1999), leading to the axiom that "people are dying because it is winter, not because it is cold."

Intercity comparisons demonstrate that death rates and seasonal (winter vs. summer) mortality amplitudes are not consistent across the United States. Therefore, we attempted to examine how climate might be related to mortality and the seasonal mortality curve.

For each of our 27 cities and for each month, we plot mortality anomalies (departures from the grand mean for each city) vs. 7 a.m. LST mean monthly temperature. (Mortality standardization is needed to adjust for different deaths rates in different cities that exist even after age standardization.) The resulting plot has several interesting features (Figure 5a). The inverse relationship demonstrates the strength of the winter–summer mortality seasonality. No city-months have below-normal mortality in months with mean 7 a.m. temperatures below freezing. There is clearly more within-season variability in winter than in summer and mortality seems to vary little in the transition between the cold and warm "seasons."

When a linear regression is run for each city (mortality vs. 7 a.m. mean monthly temperature), natural city groupings can be found based upon the slopes of the regression lines (Figure 5b). These groupings are cities with similar seasonal patterns in monthly climate-mortality relationships. For example, the slopes of the four cities with the warmest winters (thick black lines) are similar.

These locations all have warm winters relative to the other cities in the study and a large winter–summer mortality amplitude (a steep slope). The largest cluster of cities, most of which have at least one month of mean below zero morning temperatures, has less seasonal mortality variability (thin gray lines). A third group is a transition between these two extremes (dashed lines). From this figure, it becomes evident that the annual amplitude change in mortality is driven by winter mortality—the variation in summer is comparatively small.

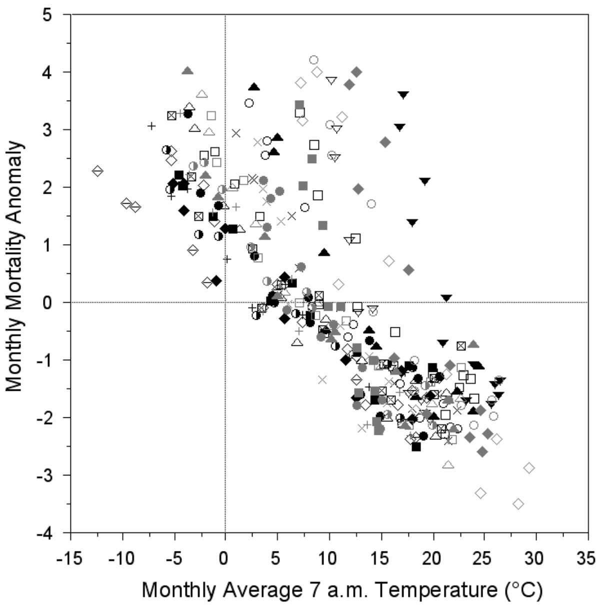

Figure 5a. Average monthly mortality anomaly (from the annual mean) vs. monthly average 7 a.m. temperature for all 27 cities.

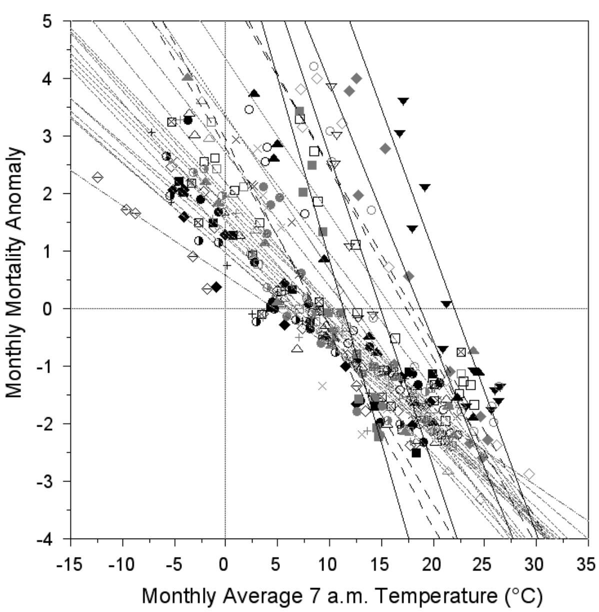

Figure 5b. Linear regressions through the twelve monthly values of average monthly mortality anomaly vs. monthly average 7 a.m. temperature for each of the 27 cities.

Next, we examine how mortality for different cities varies throughout the year. After detailed examination, we identified three approximate seasonal clusters of data points (Figure 5c). In winter (December–March), mortality rates vary highly between cities. There is a fairly weak positive relationship with temperature; that is, cities with warmer winters have slightly higher death rates than cities with colder winters. In summer (June–September), however, the within-season regression line is essentially flat. The tight convergence of points perhaps argues for the existence of a "mortality optimum," or a mean morning temperature at which death rates reach a minimum. Subjective evaluation of Figure 5c suggests that this occurs with mean 7 a.m. temperatures around 15°C (68°F). While this is little more than an interesting observation, similar hypotheses have recently been proposed by others. Finally, during the transition seasons (April, May, and October, November) there is a surprisingly tight negative mortality–temperature relationship. The lack of scatter in these months indicates that all cities transition between high and low mortality months at the same rate. In other words, mortality increases between October and December at about the same rate in all cities and is therefore independent of climate.

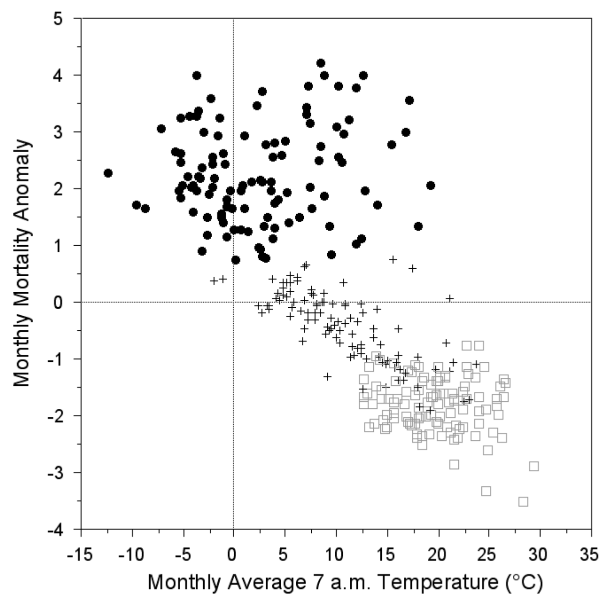

Figure 5c. Average monthly mortality anomaly (from the annual mean) vs. monthly average 7 a.m. temperature divided into three mortality seasons: December through March (black circles); June through September (gray squares); April, May, October, November (crosses).

6. SUMMARY AND CONCLUSIONS

To summarize the seasonal comparisons, cities in warm climates have a mortality advantage in summer since they reach the "mortality optimum" earlier and transition away from it later than colder cities. In winter, however, these cities experience higher mortality rates despite higher temperatures. Conversely, in cities where below-freezing winter temperatures are common, mortality rates are lower during the peak mortality season, but these individuals spend fewer days of the year at or near the "mortality optimum" so the overall yearly death rate may be comparable to that of a warmer locale.

These analyses provide support for the hypothesis that people respond to relative rather than absolute weather and climate conditions. Residents of cities in colder climates have lower relative mortality rates than those in warmer cities, perhaps because of adaptation. However, these cities show pronounced summer mortality in conjunction with hot and humid days, whereas cities where these conditions are common see little or no enhanced mortality.

Impacts of projected climate warming remain uncertain. In summer, the significantly weakening relationship over time between afternoon AT and mortality strongly suggests that adaptations, such as the increasing use of air-conditioning in the Northeast and Midwest, have substantially safeguarded these cities against current or future mortality increases. However, the weak positive relationship between mortality and mean morning temperature suggests that a warmer climate could increase, rather than decrease, winter mortality rates. But these excess winter deaths could be balanced by fewer summer deaths in locations where the "mortality optimum" is reached for a longer period of time. Whatever the ultimate impacts of climate change on mortality are in the United States, all of these analyses point to complex interrelationships that cannot be modeled simply without accounting for the fundamental seasonal, temporal, and geographic differences in how people respond to and interact with their weather and climate.

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