2B.2 SPATIAL PATTERNS OF HUMAN MORTALITY SEASONALITY IN U.S. CITIES SINCE 1964

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1. CONTEXT

Concerns over climate change impacts in the United States include the proposition that human death rates will increase (NAST, 2000). Projections of longer, more intense heat waves, more frequent or more intense isolated hot days, or changes in air mass frequency or character that would enhance heat stress in humans serve as the bases of these predictions. Thus, the research focus primarily has been on the warm season, when daily deaths rates in certain areas spike in direct response to hot days or prolonged heat waves. Despite these incidents of high warm season deaths, total mortality is significantly greater in winter in all major U.S. cities. Because observed temperatures since World War II have predominantly increased in the cold season (Michaels et al., 2000), one might hypothesize that mortality reductions from warmer winters could offset or even supersede any heat-related excess summer mortality. In this paper, we examine the variability in the seasonality of temperature and human mortality in 28 U.S. cities.

Plots of standardized daily mortality versus afternoon apparent temperature (AT) in most northern and interior U.S. cities exhibit a weak U-shaped relationship with higher mortality at the extremes of the distribution. In Kansas City, MO, for example (Figure 1a), mortality increases on some warm and humid days whereas the mortality increase when daily temperatures are low is less evident. Superimposed on this relationship is a statistically significant trend of higher daily mortality in cold season and lower warm season death rates. To allow for intermonthly mortality comparisons, we de-seasoned the mortality data by subtracting the median monthly mortality from each day's mortality count (Figure 1b). These new mortality anomalies remain high when ATs are elevated, but the weak winter relationship that was evident prior to deseasoning is no longer present. Results from this standardization indicate that summertime deaths seem related to specific weather events (Davis et al., 2002b) whereas winter death rates are generally higher but are not clearly related to daily temperatures.

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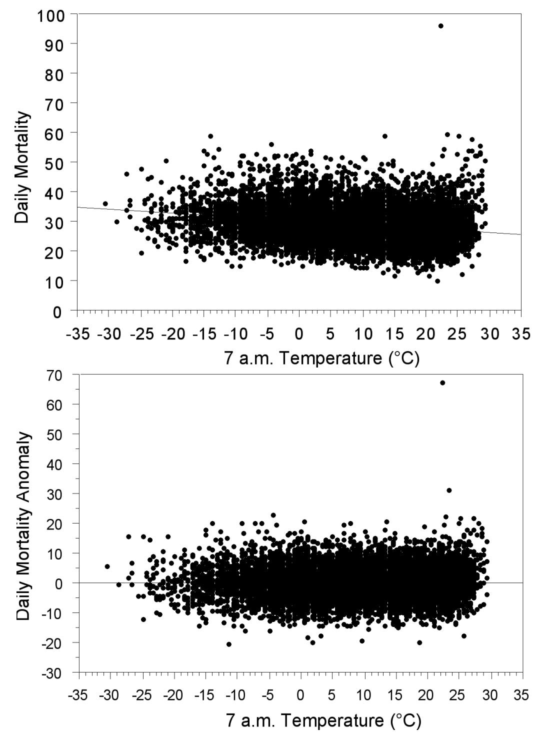


Figure 1a (top). Daily population-adjusted mortality vs. daily 7 a.m. temperature in the Kansas City, Missouri Metropolitan Statistical Area.
Figure 1b (bottom). Same as above, except that daily mortality has been "deseasoned" to produce daily mortality anomalies.

Why mortality rates in winter are higher than in summer remains unknown. Influenza has a major influence in winter, and increased deaths from some other diseases are correlated with influenza epidemics. However, influenza is not obviously related to specific weather or climate conditions, nor is it understood why influenza is a winter disease. Many of the primary causes of death exhibit a winter peak (e.g., Donaldson and Keatinge, 1997; Pell and Cobb, 1999; Lanska and Hoffman, 1999; McGregor, 2001). In light of the lack of a clear relationship between daily weather conditions and cold-season mortality, we might propose the axiom that "people are dying because it is winter, not because it is cold." Since there is no clear relationship between *daily* weather and deaths in winter, we focus our study on the relationships between monthly climate and monthly variations in mortality rates.

2. DATA AND METHODS

Our weather and mortality data sets are described in complete detail in the text of paper 9B.1 (Davis et al., 2002a) in this volume. However, since our focus in this paper is on seasonal climate rather than weather-related mortality impacts, we did not employ "Threshold Apparent Temperatures" or utilize daily lags between weather events and mortality responses as we did in 9B.1. Instead we use mean monthly 7 a.m. temperature as our climate "indicator" in these seasonal analyses.

3. CLIMATE AND MORTALITY SEASONALITY

For each of our 28 cities and for each month, we plot average mortality anomalies (monthly departures from the annual mean) vs. 7 a.m. LST mean monthly temperature. (The mortality data are standardized because, even after age-standardization, deaths rates vary between cities.) On the resulting plot, each city is designated using a different symbol and each city-month is depicted (Fig. 2).

The degree of inherent mortality seasonality is clear from the overall strength of the inverse relationship. Several interesting observations arise from this graph. First, mortality variability is much greater in the cold season than in the warm or transition seasons. The tight clustering of points in spring and autumn suggests that all cities transition from summer to winter in a similar manner (i.e., transition season death rates are similar at all locations). No city-months have below-normal mortality when the mean 7 a.m. temperature is below 0°C.

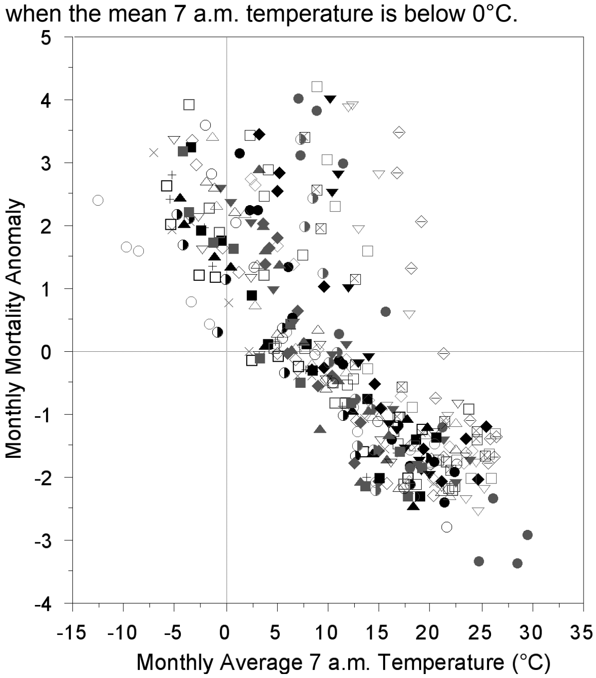


Figure 2. Average monthly mortality anomaly (from the annual mean) vs. average 7 a.m. temperature for the 28 study cities.

Least-squares linear regressions are run for each city (mean monthly mortality vs. 7 a.m. mean monthly temperature) to examine how mortality seasonality varies across the study region (Figure 3). We can loosely define climate-mortality "seasonality" as the slope of each regression line. This analysis demonstrates that this "seasonality" is related to climate and is dominated by winter mortality since the variation in summer between cities is comparatively small.

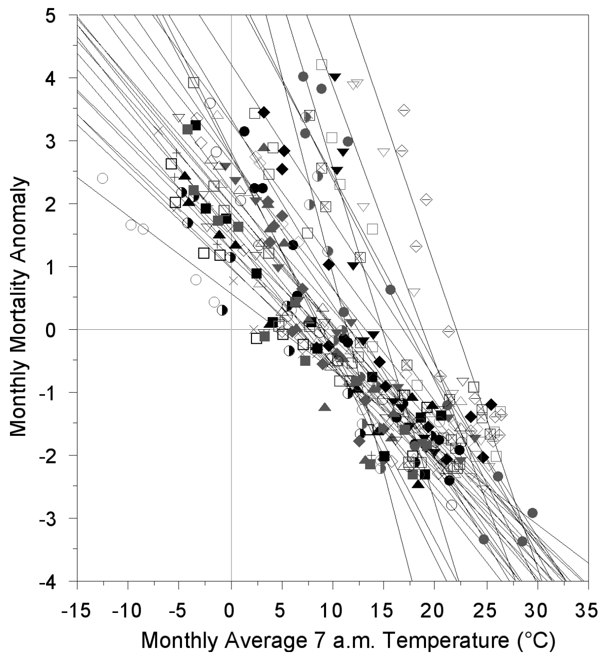


Figure 3. Linear regressions through the twelve monthly values of average monthly mortality anomaly vs. monthly average 7 a.m. temperature for each of the 28 study cities.

Another approach is to examine how mortality varies throughout the year in different locations. We identified three approximate seasonal groupings of data points (Figure 4). In winter (December–March), mortality rates vary significantly between cities. However, in summer (June–September), the tight convergence of points from different cities suggests that there might be a "mortality optimum"—a mean morning temperature at which death rates reach a minimum. Subjective analysis suggests that this condition occurs with a mean 7 a.m. temperature of about 15°C (68°F). Although we do not intend to argue for a physiological basis of this finding, it seems that there is little mortality "benefit" (or continued reductions in death rates) from increasingly warm summer months beyond this "optimum" value. During the transition seasons (April, May, and October, November) there is a strong negative mortality–temperature relationship. The lack of scatter in these months suggest that most cities transition between high and low mortality months at about the same rate. In other words, as winter approaches and mortality begins to increase, the rate of mortality increase between October and December occurs at approximately the same rate in all cities and is therefore independent of climate.

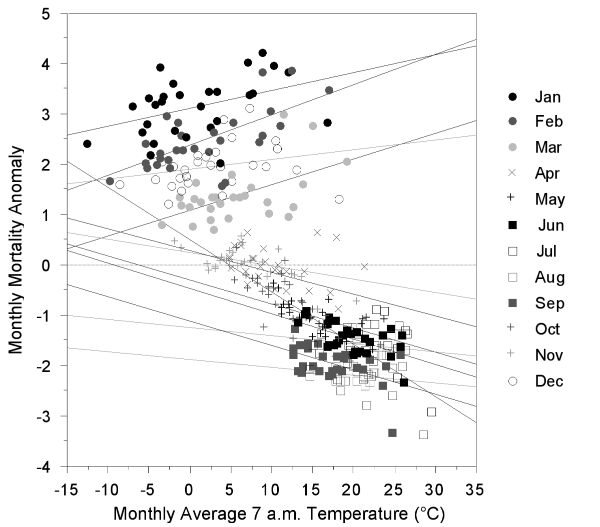


Figure 4. Linear regressions through the 28 values of average monthly mortality anomaly vs. monthly average 7 a.m. temperature for each of the 12 months of the year divided into 3 seasons (Dec.–Mar. (circles); Apr., May, Oct., Nov. (crosses); Jun.–Sep. (squares)). Black trend lines (associated with filled in monthly symbols) indicate a significant relationship (p≤0.05).

4. TEMPORAL CHANGES IN MORTALITY SEASONALITY

We next investigate how mortality seasonality has changed over time in the context of a background climate change and other societal influences. There has been a systematic decline in adjusted death rates over time across all cities that is unrelated to climate (Figure 5). Improved health care, reduced poverty, technological advances, etc. have all resulted in greater average longevity in the United States (we hereafter refer to these changes as "technological" influences). But these declines have also taken place in the context of a background warming. For the 28 cities in this study over our period of record, 7 a.m. temperatures have increased in all months, particularly from January–March and May-August (Figure 6). These trends may be related to large-scale climate variability but they also include urbanization effects which are more pronounced in early morning.

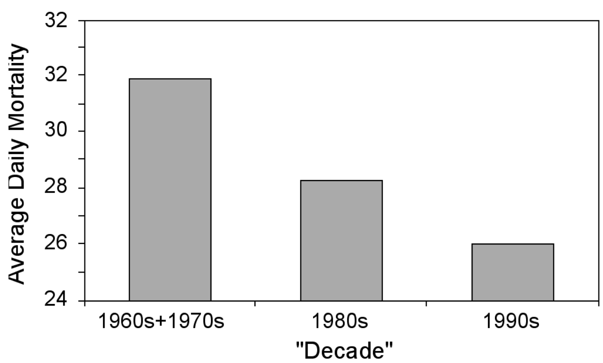


Figure 5. Average daily mortality totals across all study cities for each decade.

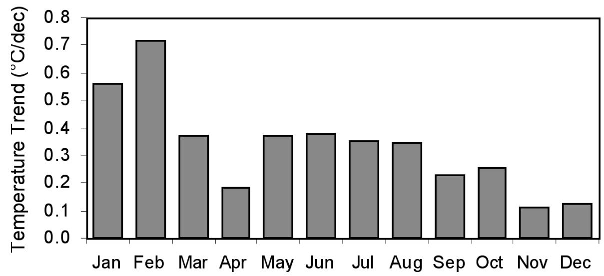


Figure 6. Trends (°C/dec) in 7 a.m. LST temperature from 1964–1998 averaged over the 28 study cities.

To predict the influence of climate change on mortality, one could use the within-month regression relationships presented in Figure 4 coupled with the observed warming trends (Figure 6). Using this approach, we would project enhanced winter mortality and reduced mortality in the shoulder seasons. However, when the within-month relationships are computed separately for each decade, we find that this prediction is invalid based on observed changes. Figure 7 shows the slope of the regression lines when the relationships in Figure 4 are calculated for each decade. The months with positive slopes have exhibited significant declines by the 1990s, whereas the months with negative slopes have seen slope increases. Thus, over time, the seasonal mortality amplitude differences between U.S. cities have become muted. In other words, there is no apparent mortality benefit, as judged by seasonal differences, in one's place of residence in the United States, at least with respect to people who live in major metropolitan areas.

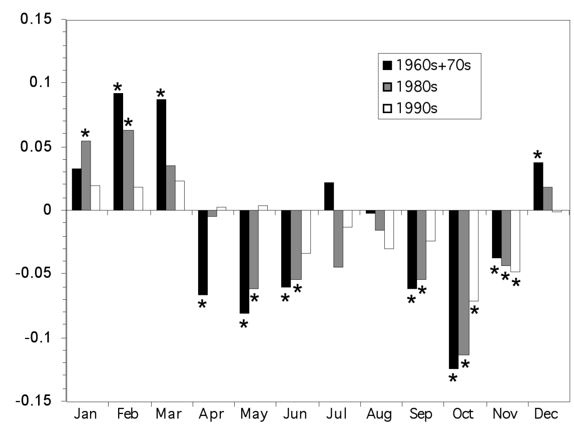
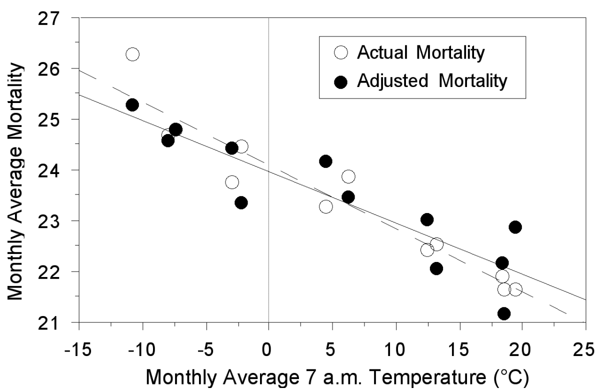


Figure 7. The slope of the best-fit least-squares regression line between the average monthly mortality anomaly and the average monthly 7 a.m. temperature across all 28 study cities for each month and decade. Asterisks indicate a statistically significant regression slope (p≤0.05).

Are these changes toward more uniformity between cities a result of a warming climate or technological factors? To assess the impact of climate change on seasonality as distinct from the effect of declining death rates, we applied the observed monthly temperature changes (Figure 6) and the observed mortality declines (for each city we adjusted each month's average daily mortality by the ratio of the 1960s–70s mortality to the

1990s mortality) and compared these projections to the observed 1990s monthly mortality-temperature relationship. In Minneapolis, for example (Figure 8a), there is more seasonality than would be expected given the observed changes to climate and overall mortality rates there. Conversely, the seasonality in Miami is less than expected (Figure 8b). Here, the winter mortality is lower than expected in all cool months and higher than expected in summer. For all 28 cities in this study, however, we found no cities in which the observed mortality seasonality deviated significantly from the projections using our simple model. In other words, the observed warming has no detectable net influence on mortality seasonality after the general declines in mortality rates (technology impacts) are considered. This result is consistent with the homogenization of the seasonal mortality response over time (Figure 7).



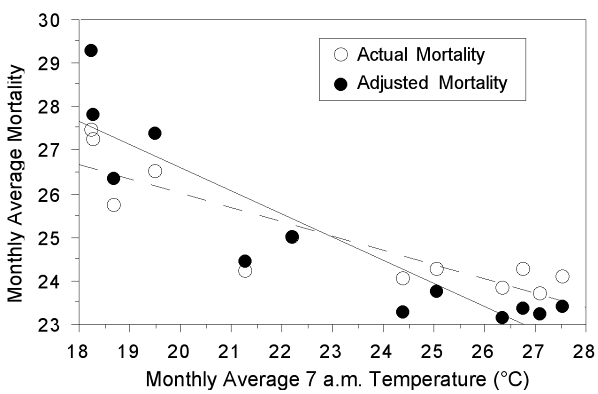


Figure 8a (top). Relationship between monthly average mortality and monthly average 7 a.m. temperature for Minneapolis, MN. The open circles (and dotted trend line) are the observed values for the period 1990–1998 while the closed circles (and solid trend line) are the values observed during the period 1964–1966 and 1973–1979 adjusted to the mortality rate and climate of the 1990s.

Figure 8b (bottom). Same as Figure 8a except for Miami, FL.

Despite the lack of statistically significant differences between the overall mortality/temperature relationships in observations and projections, there remain some interesting patterns in the monthly anomalies. When the mean projected 1990s mortality (based on climate change and technology) is compared to the monthly observed values averaged for all 28 cities (Figure 9), we note that our model overestimates mortality in June and July and underestimates it from November through January. We believe the summer errors can be accounted for by the documented decline in the weather sensitivity of the population to high temperatures and humidity (e.g., Davis et al., 2002a, b). Despite observed summer warming (Figure 6), mortality rates have declined faster than one would predict based on the mean decadal mortality rate declines. In late fall and early winter, however, death rates are greater than expected (Figure 9). It is unlikely that this is related to warmer winters, since the warming rates in November and December are the lowest of any months yet the mortality departures are comparable to those of January. One possible source of model error is our assumption that technological impacts are independent of month. If, for example, medical technology has less developed treatments for a disease that occurs primarily in winter, our model would underestimate winter mortality.

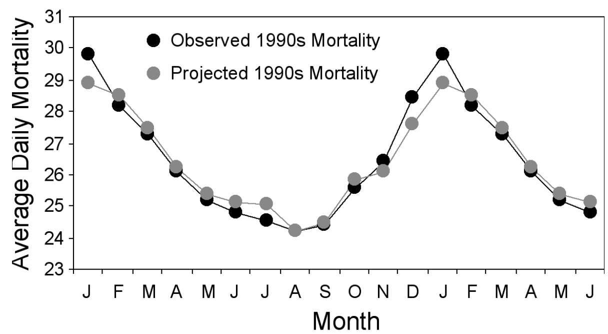


Figure 9. Observed and projected average daily mortality for each month of the year in the 1990s.

Another way to examine seasonality changes is to plot mean monthly mortality in the 1960s-70s and the 1990s vs. mean 7 a.m. temperature in the respective decade (Figure 10). In this presentation, the 1960s-70s mortality rates are adjusted to the 1990s rate using the same monthly percentage adjustment employed earlier. One interesting observation is that spring mortality exceeds autumn mortality. A possible explanation is the "mortality displacement" effect whereby early-season heat waves induce a higher mortality response than late-season events (Kunst et al., 1993; Kilbourne, 1997). Over time, however, the differences in transition season mortality have minimized. If this does represent a mortality displacement effect, then the differences between the two decades in summer is consistent with our observation that the populace has become systematically desensitized to weather and climate effects. However, at present we have no explanation for the substantial changes in late fall and winter. In the earlier decades, mortality in December was much lower than in February, but this relationship switched by the 1990s. The increase in the January death rate over time is pronounced.

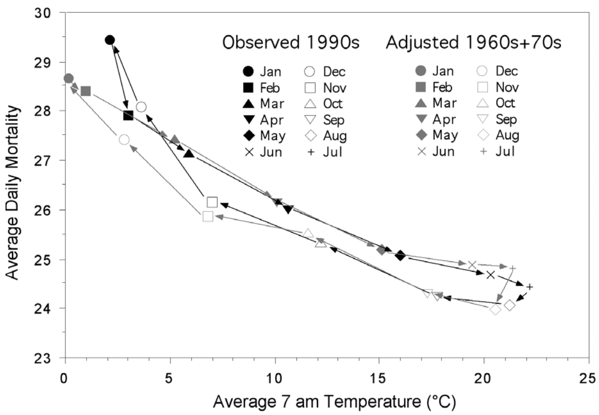


Figure 10. Average daily mortality vs. average 7 a.m. temperature in the 1990s (black symbols) and mortality-adjusted values in the 1960s-70s (gray symbols).

5. CONCLUSIONS

This examination of climate and mortality seasonality relationships in U.S. cities has revealed the following observations:

1) Despite large variations in climate between study cities, all cities exhibit essentially the same seasonal mortality amplitude. Even though actual death rates vary between cities (after age-standardization), the difference between winter and summer mortality rates is approximately the same everywhere.
2) In light of the observed warming, we adjusted the mortality rates for the "decade" of the 1960s-70s on a monthly basis to that of the 1990s and applied the observed monthly climate change. Our results show that the 1990s observations do not deviate significantly from this simple model for any city.

Our ultimate goal is to develop the ability to estimate future mortality based on climate forecasts and historical evidence. Our analysis for the United States offers two possible predictive models. In one approach, you would project future death rates by assuming that, say, a January warming will result in the people in Boston responding like the people of New York do at present (the trend lines in Figure 4 after adjusting for the changes over time presented in Figure 7). Based on the 1990s data, this model would project minimal future mortality changes. An alternative approach would be that, as Boston Januaries warm, people will react more like they do in February (e.g., along the trend lines in Figure 3). The monthly comparisons between the 1990s and the 1960s-70s (Figure 10) provides more support for the latter model. In general, this model works well for most months (February–May, August–October). The June and July differences can be accounted for by the documented desensitization of the populace to high apparent temperatures over time, which can be ascribed to adaptation in all forms, including technological impacts (Davis et al., 2002a,b,c). However, the changes in late fall and winter, particularly in January, do not fit this model. The unexpectedly high adjusted mortality rates in December and January in the 1990s remains open for discussion.

In general, a "homogenization" of weather-mortality relationships appears to be occurring in seasonal mortality rates across cities. While the scenario that mortality reductions from winter warming will offset increased summer heat deaths is not supported by observations from either season. Weather and climate are exerting consistently less influence over mortality rates and spatial mortality patterns than they did 30-40 years ago.

6. REFERENCES

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