**J8.4** CHANGING HEAT WAVE MORTALITY IN U.S. CITIES


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## 1. INTRODUCTION

Increasing atmospheric temperatures and/or humidity over time have been hypothetically linked to higher future mortality rates in U.S. urban centers in summer. These various prognostications utilize historical relationships between mortality (adjusted for demographic changes) and weather based upon the demonstrable relationship between heat and daily mortality in many cities in the Northeast and Midwest.

Previous research by the authors has demonstrated that these mortality forecasts are likely biased because they fail to account for temporal changes in heat-mortality relationships (Davis et al, 2002; Davis et al., 2003a, 2003b). We have proposed that a full suite of adaptations, from increased air conditioning usage to biophysical changes, have resulted in individuals and populations that have become less sensitive to high and humidity than they were thirty years ago.

However, our previous work treated each day individually—we did not investigate decadal-scale changes in mortality linked to multiple-day heat events (heat waves). In this preliminary analysis, we pose several questions:

1) Have mortality rates changed on a decadal basis in conjunction with heat waves?

2) Given the evidence for significant adaptations over time, is there a relationship between relatively hot, humid days and mortality?

3) Is there evidence for temporal changes in the weather associated with high mortality events?


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There is no industry-standard, quantitative definition for a "heat wave." With respect to human mortality, the human response to heat is known to vary significantly over both time and space (Davis et al., 2003a, 2003b). Therefore, we examine this issue using two approaches. In the first case, we identify hot, humid periods and then calculate mortality during these events. In the second approach, we identify high mortality events and examine the related weather to determine if the average weather conditions associated with high death rate events have changed over time.

## 2. DATA AND METHODS

In this preliminary analysis, we examine daily mortality data for Philadelphia, Pennsylvania. Daily total mortality counts for the Philadelphia Metropolitan Statistical Area (MSA) were gathered from National Center for Health Statistics archives from 1964–1998. Data from 1967–1972 were not used because the date of death was not systematically recorded during this period of time. To allow for the examination of decadal-scale changes, the data were organized into three "decades" of approximately ten years each: the "1960s–70s" (1964–66 and 1973–79), the "1980s" (1980–89) and the "1990s" (1990–98). To facilitate interdecadal (and ultimately inter-MSA) comparisons, daily death totals were age-standardized using commonly-accepted epidemiological practices (Anderson and Rosenberg, 1998). The basis for standardization was the age distribution of the entire U.S. population in the year 2000.

Mortality exhibits a very clear cold-season peak (Davis et al., 2003c). To eliminate potential biases associated with the intra-year timing of heat waves, age-adjusted mortality is standardized by subtracting the median mortality of each month from the daily mortality count. The resulting mortality anomalies exhibit neither seasonal nor temporal trends.

Hourly weather data were gathered from the weather station at Philadelphia International Airport. Apparent temperature (Steadman, 1979) was calculated from the hourly air temperature and dew point temperature data at 0700 LST based on prior research demonstrating the importance of consistently high morning temperatures associated with elevated heat wave mortality (e.g., Smoyer et al., 2000).

As our analyses are event based, it is necessary to first convert our daily data into event data. We define two types of events, mortality events and apparent temperature (AT) events. We define an event of either type as two or more consecutive days in which the variable of interest is either above or below a baseline value. In the case of mortality, the baseline is defined as the median mortality for each year-month. In the case of AT, the baseline is defined as the average 0700 LST AT of the preceding 21 days exclusive of the days within the event. Events may be a collection of either positive or negative anomalies (differences from the baseline). Within each event, we tally the total mortality anomaly, the average 0700 LST AT, the maximum 0700 LST AT, and the difference between the maximum 0700 LST AT and the average of the 0700 LST AT during the previous 21 days excluding the days within the event. This latter quantity, which we refer to as the maximum 0700 LST AT anomaly, is a measure of how unusual the temperatures during the event were in comparison with the temperatures that the population had been recently experiencing.

To determine the relationship between mortality and temperature within events, we create a series of 2x2 contingency tables (one for each "decade") with each cell containing the number of co-occurrences of specific mortality and AT situations. Within AT-defined events, we divide our data into those events that have a maximum 0700 LST AT anomaly in the upper one standard deviation above the mean for the period defined by the months of June, July and August and those events with a maximum 0700 LST AT anomaly less than or equal to one standard deviation above the mean. We also divide the total mortality anomaly within each AT-defined event in the June, July and August period into two subsamples: those events with a total mortality anomaly greater than one standard deviation above the mean, and those events with a total mortality anomaly less than or equal to one standard deviation above the June, July, and August mean for each "decade."

We repeat the steps above using mortality-defined events.

## 3. RESULTS AND DISCUSSION

### *3.1 Apparent Temperature-Defined Events*

The standard approach in this type of study is to first identify heat waves and then to determine if mortality is elevated during those events. We present the results using a 2x2 contingency table with "observations" (in this case, the number of mortality events) in columns and the "forecasts" (AT events) in rows (Table 1). Each decade is presented separately to allow for inter-decadal comparison. For example, in the 1960s-70s, out of 169 total events, there were 8 occasions when heat waves corresponded with mortality elevated above a one standard deviation threshold (Cell A), and the mean daily mortality on these events was 44.00 deaths. On 22 occasions, heat waves were not associated with excess mortality (Cell B). Furthermore, there were 6 high mortality events not linked to high heat in the 1960s-70s (Cell C), although the average death rate during these events (24.96) was lower than that during heat waves. Obviously, most events are associated with neither high mortality nor high heat (Cell D).

If the presence of a "heat wave" is used to "forecast" excess mortality, this forecast would be successful less than one-fourth of the time in the 1960s-70s (Threat Score=0.22) (Wilks, 1995). This number remains low in subsequent decades, suggesting that high mortality events are frequently not associated with heat waves, regardless of the decade.

Kuiper's skill score (KSS) provides an overall assessment of the frequency of correct forecasts relative to expectations (Wilks, 1995). A perfect forecast yields a KSS equal to one and random forecasts produce a KSS of zero. Use of heat waves alone to forecast mortality events exhibits some skill (0.43–0.54) but no clear trend over time.

The mean mortality during heat waves has declined markedly in Philadelphia from 44.0 deaths/day in the 1960s-70s to 14.67 in the 1980s to 12.65 in the 1990s. These declines occurred despite maximum 0700 LST event ATs that averaged 1.0°C higher in the 1990s compared to the 1960s (Table 3). However, the KSS value of 0.44 indicates that there remains evidence of heat-wave mortality in Philadelphia in the 1990s, but that mortality is occurring at a higher AT threshold (i.e., the temperature *anomalies* are similar), in agreement with our recent research (Davis et al., 2003a, 2003b)

### *3.2 Mortality-Defined Events*

An alternative approach is to examine periods of anomalously high mortality and then determine if these events are consistently linked to above normal ATs.

In the 1960s-70s, 10 of the 16 mortality events (63%) occurred in conjunction with heat waves (Table 2). This ratio dropped to 44% by the 1990s, and mean mortality within the events was reduced by almost 50%. However, the consistently low Threat Score (~0.25) over all three decades indicates that other factors are having a strong influence on the heat wave-mortality linkage. The KSS values (averaging about 0.26) are much lower than those using temperature-based definitions.

It is important to note that the average maximum 0700 LST AT anomalies during events remained fairly consistent over time (Table 4). Given the observed positive trend in ATs, this provides additional evidence that some degree of adaptation has occurred over our period of record. Because the long-term trend was removed in our analysis, mortality events are linked to heat waves that represent the same *relative* temperature departures in the 1990s that they did in the 1960s-70s.

## 4. CONCLUSIONS

Our previous work on decadal-scale mortality trends demonstrated that mortality rates on hot, humid days had declined significantly in Philadelphia over time but that some degree of heat response remained evident in the 1990s. This research confirms those general findings with respect to heat waves. The association between high AT events and high mortality events has essentially remained unchanged over time, and high mortality events are consistently linked to comparable AT departures over our entire period of record. These results provide support for arguments that adaptations have reduced, but have not eliminated, the linkage between high heat and mortality. Thus, those who argue for relative rather than absolute thermal thresholds are supported by our preliminary findings.

The lack of strong linkages between heat waves and mortality can be accounted for in several different ways. Mortality displacement would reduce the impact of subsequent heat waves within a year following any major mortality event. Within-season acclimatization could have a similar impact. Furthermore, the timing of any heat wave within a calendar year may influence the resulting mortality. Fortunately, many of these questions can be addressed using an approach similar to the one outlined here. Our future work will involve an expansion of this study to other major metropolitan areas in the United States.


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**1964-66, 1973-79**

| Maximum 0700 AT Anomaly > 1 St. Dev. | Mortality > 1 St. Dev.: Yes | Mortality > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 8 (44.00) | B 22 (1.01) | 30 (10.90) |
| No | C 6 (24.96) | D 133 (-2.85) | 139 (-1.08) |
| | 14 (33.31) | 155 (-1.86) | 169 (1.05) |

Threat Score = .22
Kuiper's Skill Score = .43

**1980-89**

| Maximum 0700 AT Anomaly > 1 St. Dev. | Mortality > 1 St. Dev.: Yes | Mortality > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 16 (14.67) | B 20 (1.21) | 36 (8.48) |
| No | C 8 (11.54) | D 143 (-1.57) | 151 (-1.13) |
| | 24 (17.24) | 163 (-1.71) | 187 (0.72) |

Threat Score = .36
Kuiper's Skill Score = .54

**1990-98**

| Maximum 0700 AT Anomaly > 1 St. Dev. | Mortality > 1 St. Dev.: Yes | Mortality > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 11 (12.65) | B 19 (1.07) | 30 (4.97) |
| No | C 8 (9.42) | D 118 (-0.88) | 126 (-0.87) |
| | 19 (13.80) | 137 (-1.63) | 156 (0.25) |

Threat Score = .29
Kuiper's Skill Score = .44

Table 1. Contingency tables, by "decade," of mortality associated with high and low AT events. Event frequencies are presented in each cell with the mean mortality in parentheses. The Threat Score and Kuiper's Skill Score are presented for each "decade" below the table.

**1964-66, 1973-79**

| Mortality > 1 St. Dev. | Maximum 0700 AT Anomaly > 1 St. Dev.: Yes | Maximum 0700 AT Anomaly > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 10 (30.13) | B 6 (37.55) | 16 (32.91) |
| No | C 24 (3.91) | D 177 (-2.82) | 183 (-1.49) |
| | 34 (11.62) | 201 (-2.02) | 217 (0.56) |

Threat Score = .25
Kuiper's Skill Score = .26

**1980-89**

| Mortality > 1 St. Dev. | Maximum 0700 AT Anomaly > 1 St. Dev.: Yes | Maximum 0700 AT Anomaly > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 13 (18.09) | B 14 (15.53) | 27 (16.76) |
| No | C 25 (0.80) | D 188 (-2.06) | 202 (-0.84) |
| | 38 (6.72) | 213 (-1.72) | 240 (0.36) |

Threat Score = .25
Kuiper's Skill Score = .27

**1990-98**

| Mortality > 1 St. Dev. | Maximum 0700 AT Anomaly > 1 St. Dev.: Yes | Maximum 0700 AT Anomaly > 1 St. Dev.: No | |
|---|---|---|---|
| Yes | A 12 (16.04) | B 15 (10.71) | 27 (13.08) |
| No | C 24 (-1.44) | D 161 (-1.66) | 176 (-0.61) |
| | 36 (4.37) | 185 (-1.63) | 212 (0.24) |

Threat Score = .24
Kuiper's Skill Score = .25

Table 2. Same as in Table 1 for mortality-defined events.

| Variable | Mean | Std. Dev. | Count |
|---|---|---|---|
| AT 1960s+70s | 21.42 | 3.57 | 169 |
| AT 1980s | 21.63 | 3.53 | 187 |
| AT 1990s | 22.55 | 3.73 | 156 |
| Max AT 1960s+70s | 23.29 | 3.93 | 169 |
| Max AT 1980s | 23.26 | 3.87 | 187 |
| Max AT 1990s | 24.27 | 4.12 | 156 |
| Max AT Anom 60s+70s | 2.21 | 4.07 | 169 |
| Max AT Anom 1980s | 1.78 | 4.01 | 187 |
| Max AT Anom 1990s | 2.10 | 4.27 | 156 |

Table 3. Summary statistics, by “decade” for apparent temperature-defined events during the months of June, July and August; 0700 LST average apparent temperature, ºC, (AT), average maximum 0700 LST AT within each event, ºC, (Max AT), and the average difference between the maximum AT within each event and the average 0700 AT during the preceding 21 days exclusive of the days within the event, ºC, (Max AT Anom).

| Variable | Mean | Std. Dev. | Count |
|---|---|---|---|
| AT 1960s+70s | 21.58 | 3.30 | 217 |
| AT 1980s | 21.86 | 3.40 | 240 |
| AT 1990s | 22.85 | 3.60 | 212 |
| Max AT 1960s+70s | 23.58 | 3.49 | 217 |
| Max AT 1980s | 23.76 | 3.69 | 240 |
| Max AT 1990s | 24.78 | 3.99 | 212 |
| Max AT Anom 60s+70s | 2.45 | 3.44 | 217 |
| Max AT Anom 1980s | 2.21 | 3.23 | 240 |
| Max AT Anom 1990s | 2.66 | 3.59 | 212 |

Table 4. Same as Table 3 for mortality-defined events.