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ORIGINAL PAPER

A simple heat alert system for Melbourne, Australia

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Abstract A simple heat alert system, based solely on predicted maximum and minimum daily temperatures, has been developed for the city of Melbourne in southeast Australia. The system is based upon a demonstration that, when mean daily temperature exceeds a threshold of 30°C (mean of today's maximum temperature and tonight's minimum temperature), the average daily mortality of people aged 65 years or more is about 15–17% greater than usual. Similar numbers of excess deaths also occur when daily minimum temperatures exceed 24°C (increases of 19–21% over expected death rate), so a heat alert system based solely on this widely available weather forecast variable is also feasible. No strong signal of excess heat-related deaths appears when the data are stratified using daily maximum temperatures. This may be because in Melbourne some days with very high maximum temperatures will be affected by the passage of cool changes and cold fronts in the afternoon, leading to a rapid drop in temperature (i.e., some days with high maximum temperatures will not continue to be hot throughout the day and into the evening). A single day with temperatures exceeding the thresholds noted above is sufficient to cause this increase in mortality, rather than requiring an extended heat wave. The increased daily mortality does not appear to represent a short-term advancement of mortality.

Keywords Australia · Heatwave · Human health · Mortality · Climate change

Introduction

Although there have been previous studies relating excess mortality to high temperatures in Australia (e.g., Rankin 1959; Guest et al. 1999; Tong et al., submitted) and elsewhere (e.g., Semenza et al. 1996; Rooney et al. 1998; Curriero et al. 2000; Hajat et al. 2002), the high mortality associated with the European heatwave of August 2003 has led to an increased focus on this subject (e.g., Filleul et al. 2006; Fouillet et al. 2006; Le Tertre et al. 2006; Kovats and Ebi 2006). In various places, heat wave alert systems have been developed, either based on studies prior to the European heatwave (e.g., Kalkstein et al. 1996), or subsequently (Pascal et al. 2006; Kovats and Ebi 2006). No such system is available for Melbourne, Australia. The intention of this study was to determine if it was possible to prepare a simple system that uses only publicly available forecasts of daily maximum and minimum temperatures to determine whether a heat alert should be issued for a specific day. The system derived by Pascal et al. (2006) for France also uses maximum and minimum temperatures.

Although it is common knowledge that there is a tendency for increased mortality and morbidity on hot days, especially amongst the elderly (e.g., Ashcroft 2001; Flynn et al. 2005; Brücker 2005; Kosatsky 2005; Nogueira et al. 2005; Pirard et al. 2005; Simón et al. 2005; Michelozzi et al. 2005; Garssen et al. 2005; Johnson et al. 2005), there have been few studies examining whether there is a threshold temperature above which mortality increases rapidly, rather than a gradual increase as temperature increases. Such a threshold phenomenon, if it were

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shown to exist in a specific location, would presumably make the development of a threshold-based alert system both simpler to develop and more readily explained. Thus, this study examines if such a threshold does exist for Melbourne.

There has been some question about whether heat waves (or other meteorological conditions) produce a short-term advancement of mortality, rather than additional mortality. No short-term advancement of mortality was found in the August 2003 heat wave in France (Pirard et al. 2005; Fouillet et al. 2006) or Spain (Simón et al. 2005), nor in the Brisbane heat wave of February 2004 (Tong et al., submitted). On the other hand, there was evidence that this occurred in England and Wales in 2003 (Johnson et al. 2005). If hot conditions were linked to mortality primarily through advancing deaths by a few days, this would presumably lessen the utility of introducing an operational heat alert system. Thus, this study also examines the question whether hot days and nights in Melbourne lead to a short-term advancement of mortality.

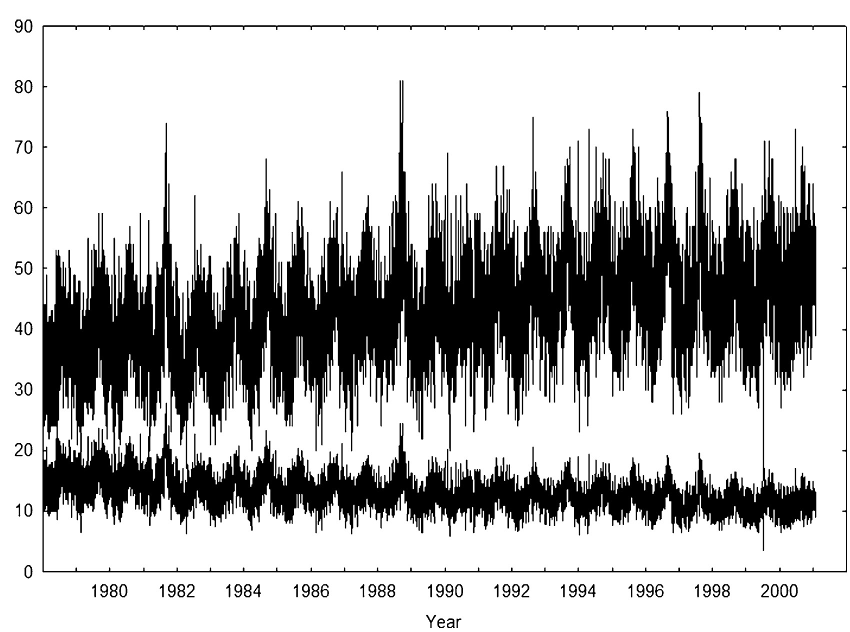
The Intergovernmental Panel on Climate Change (IPCC 2007) concluded that it is “virtually certain” that increased numbers of hot days and nights will occur through the twenty-first century, because of anthropogenic changes in atmospheric composition. McMichael et al. (2003) concluded that projected warming of Australia would lead to increased mortality through heat-related stresses. However, mortality also increases during cold conditions (Ashcroft 2001; McMichael et al. 2003) so the question arises whether increased mortality due to increased hot conditions may be offset by decreases in the numbers of cold days (also projected to occur by the IPCC). This study also considers this question in the context of Melbourne.

Materials and methods

The Bureau of Meteorology provided daily data on observed maximum and minimum temperatures for Melbourne, from 1979 to 2001. Daily mortality and population data (for the Melbourne Statistical Division) were provided by the Australian Bureau of Statistics for the same period. The investigation was focused on the population aged 65 years or older. Time series of the mortality data are shown in Fig. 1, which plots the total number of deaths each day in the over 64-year-old population (upper graph) and the death rate per 100,000 (lower graph). The upward trend in the total number of deaths is the result of the increasing population size and the increasing proportion of people aged over 64 years. The decline in the death rate per 100,000 illustrates improving health services and health of the older population, and possibly the increased use of air conditioning, and improved heating and insulation of residences. The figure also shows the strong seasonal variation in mortality, with higher numbers of deaths during winter than summer.

In order to determine the mortality anomaly it is necessary to remove the long-term trend, the seasonal variation and any shorter-term cycles which may be present in the mortality time series. One example of a short-term cycle in the mortality rate would be a winter influenza outbreak that was unusual in its timing or severity.

Fig. 1 Time series of total daily deaths in population over 64 years of age in Melbourne (*upper graph*) and death rate (per 100,000) in over 64-year-old population (lower graph)



A multiplicative decomposition model has been used to remove the trend, the seasonal variation, and any cyclic behaviour in mortality (death rate=trend × cycle × seasonal factor × anomaly). The mortality time series was decomposed using exponential smoothing, in STATISTICA 7.1. The smoothed time series obtained provided an estimate of the expected or average death rate (smoothed or expected death rate=trend × cycle × seasonal factor), for each day during the period of record. The mortality anomaly for each day over the period of record was then calculated as the deviation of the actual death rate for that day from the smoothed death rate (mortality anomaly=actual death rate/smoothed death rate).

The relationships of maximum and minimum temperatures with daily numbers of mortalities, age specific mortality rates for Melbourne, and the de-seasonalised and detrended mortality anomaly (i.e., daily mortality after adjustment for time of year and an observed long-term decline in mortality rate presumably related to improved care and infrastructure rather than climate were investigated.

Boxplot diagrams were prepared for various "bins" of maximum, minimum, and average temperatures. Preliminary investigations indicated that a good predictor of excess daily mortality was the average of the early morning minimum temperature and the previous day's maximum temperature (hereinafter referred to as the "mean temperature" or "MeanT"). Temperature "bins" 2°C wide were used to stratify the daily data to produce boxplot diagrams. Boxplots with 1°C boxes were also prepared. These showed very similar, although "noisier", results to those in the figures shown here. STATISTICA was again used to produce the boxplots.

Once this analysis had demonstrated that the mean daily temperature could provide predictions of excess heat-related deaths, separate examinations of the role of night-time minimum temperatures (MinT) and day-time maximum temperatures (MaxT) were conducted. An excess of deaths may well lag behind a period of thermal stress; obviously they cannot precede it. Because the maximum temperature in Melbourne is typically reached around 1400–1700 hours, while mortality is recorded for the 24 h commencing at midnight, many deaths may be recorded before the hottest time of day. Hence, one would expect that any effect of MaxT on daily death rate might be associated with the previous day's maximum temperature, rather than today's MaxT. So the effect of yesterday's MaxT and today's MaxT were examined separately. Since the daily minimum temperature is usually recorded around sunrise (0500–0600 hours in summer) "today's" minimum temperature seems more likely than yesterday's minimum temperature to be related to today's mortality rate. However, the possible relationship between yesterday's minimum temperature and death rates was examined.

A second form of analysis used here was to prepare boxplots based on the days when minimum temperature did not fall below 24°C (the first stage of the analysis identified this temperature as the threshold above which death rates inceased). The boxplots showed the median and extremes of the anomaly death rate from the seasonal model discussed above, for up to 3 days prior to the hot nights and up to 7 days afterwards. This analysis provided a basis for determining if a hot day/night only affected death rates that day or if there was a continuing effect. It also provided some evidence on which to discuss whether excess mortality observed on the hot days/nights was the result of a short-term advance of mortality.

Results

Figure 2 shows the median, lower and upper quartile points, and range, of numbers of deaths (amongst persons aged 65 years or more) for the 2°C-wide "bins" of mean daily temperature. The median number of deaths, and the lower and upper quartiles, are shifted higher for both low temperatures (<10°C) and high temperatures (>30°C). There is a substantial increase in the numbers of deaths once the mean temperature exceeds 30°C.

Figure 3 shows the analogous diagram but plotting death rates (per 100,000 persons). Again, the median and lower and upper quartile points increase once the temperature exceeds 30°C. There were 43 days in the 1979–2001 period when the mean daily temperature equalled or exceeded 30°C. The mean death rate of the over 64-year-old population on these days was 13.99 (SD=3.39), whereas the mean death rate for the 3373 occasions when the mean daily temperature was between 16 and 28°C was 12.13 (SD=3.36). Figure 4 repeats this exercise, but plots the daily anomalies from the long-term trend and seasonal cycle of mortality rates (to avoid confounding problems caused by the trends observed in Fig. 1). In this case, once the mean temperature exceeds 28°C, the mean death rate anomaly and the quartile points increase substantially. There is also some indication in this figure (as in Figs. 2 and 3) that the anomaly in the death rate continues to increase as the mean temperature increases above this threshold temperature. The mean multiplicate death rate anomaly of the over 64-year-old population on the 43 days when the mean temperature exceeded 30°C was 1.17 (SD=0.22), i.e. an average increase of about 17% from the death rate expected for that time of year and corrected for the long term downward trend.

Similar figures were also prepared individually for each month of the year. These figures (not shown) indicated that the high temperature effects on excess mortality were most clear in December and January. There was only a weak

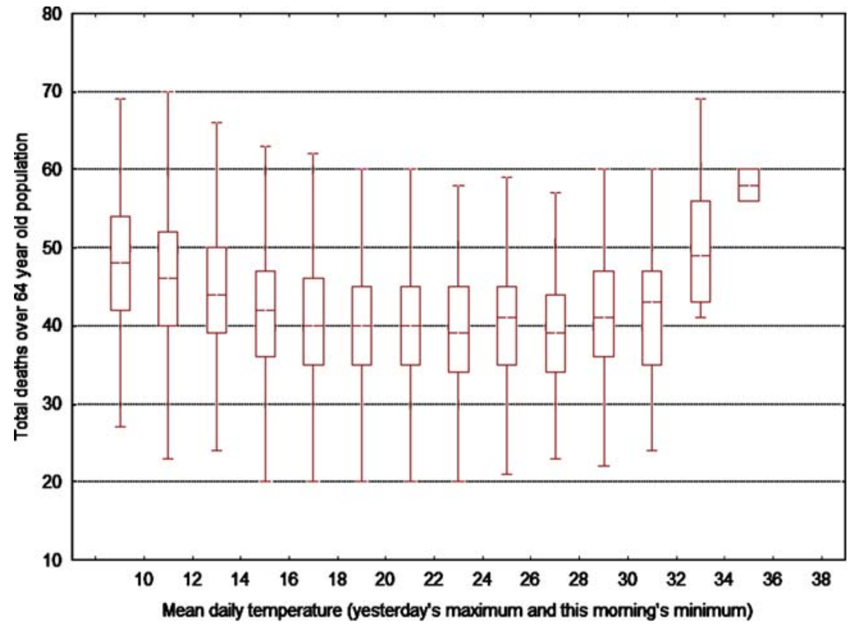


Fig. 2 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of daily deaths of over 64-year-olds in Melbourne, for 2°C ranges of mean temperature

effect in February and mean temperatures very rarely exceeded 30°C in November or March, so there were insufficient days to undertake a credible analysis for these months.

Figures 2, 3, and 4 demonstrate that there exists a simple threshold of mean daily temperatures above which substantial excess mortality of the population above 64 years of age tends to occur. But is this heat effect the result of high day-time temperatures or high night-time temperatures or a combination of both? Figure 5 repeats the analysis of Fig. 4, but using only "this morning's" minimum temperature to stratify the mortality rates. Comparison of Fig. 4 with Fig. 5 shows that, as a predictor of excess mortality, the minimum temperature appears to be of comparable strength to the mean daily temperature. There were 28 days in the 1979–2001 period when the minimum temperature equalled or exceeded 24°C. The mean death rate of the over 64-year-old population on these days was 14.44 (SD=3.42), whereas the mean death rate for the 33,46 occasions when the minimum temperature was between 12 and 22°C was 12.13 (SD=

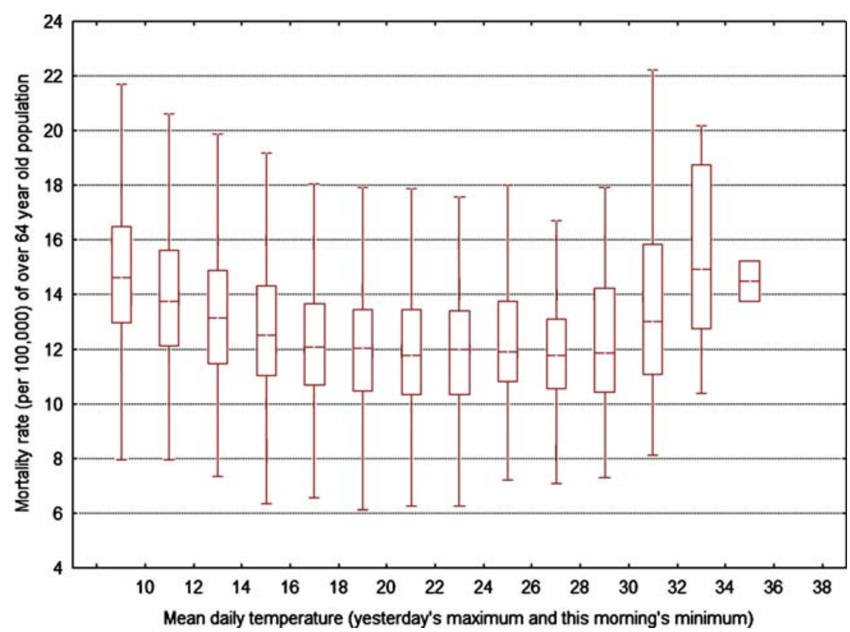


Fig. 3 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of daily death rates (per 100,000 persons) of over 64-year-olds in Melbourne, for 2°C ranges of mean temperature

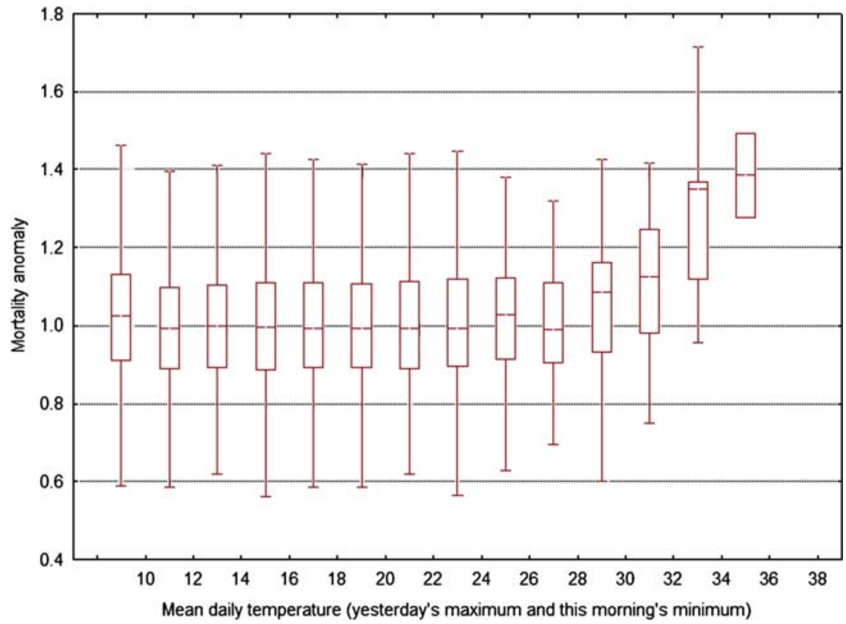


Fig. 4 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of residual of death rates (per 100,000 persons) from long-term trend and seasonal cycle, of over 64-year-olds in Melbourne, for 2°C ranges of mean temperature

2.36). The mean multiplicative residual death rate of the over 64-year-old population on these 28 days when the minimum temperature exceeded 24°C was 1.21 (SD=0.23), i.e. an average increase of about 21% from the death rate expected for that time of year and corrected for the long term downward trend. However, it should be noted that occurrences of high overnight temperature will tend to follow on from high temperatures the previous day (i.e. a night with high temperature would represent a period of relatively sustained high temperatures).

Do maximum temperatures also have an effect on mortality? Figures 6 and 7 repeat the analysis of Fig. 5 (i.e. the relationship between temperature and the residual death rate for the over 64-year-old population) but using "yesterday's" and "today's" maximum temperature, respectively, as the stratifying variable. Neither figure shows a clear tendency for a substantial increase in death rate when maximum temperatures are very high (when compared with the strong effect evident in Fig. 5), although Fig. 7 shows a weak tendency for increases in deaths when today's

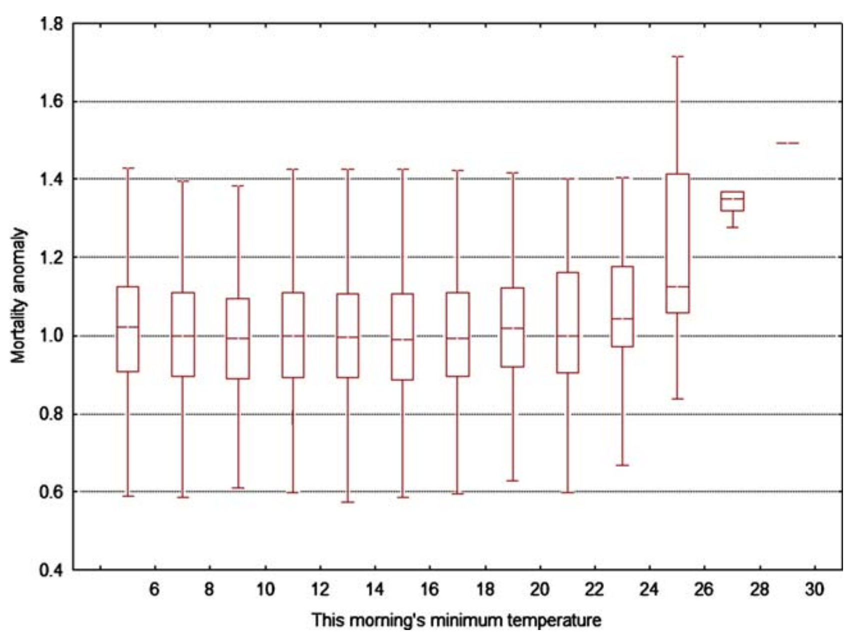


Fig. 5 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of residual of death rates (per 100,000 persons) from long-term trend and seasonal cycle, of over 64-year-olds in Melbourne, for 2°C ranges of "this morning's" minimum temperature

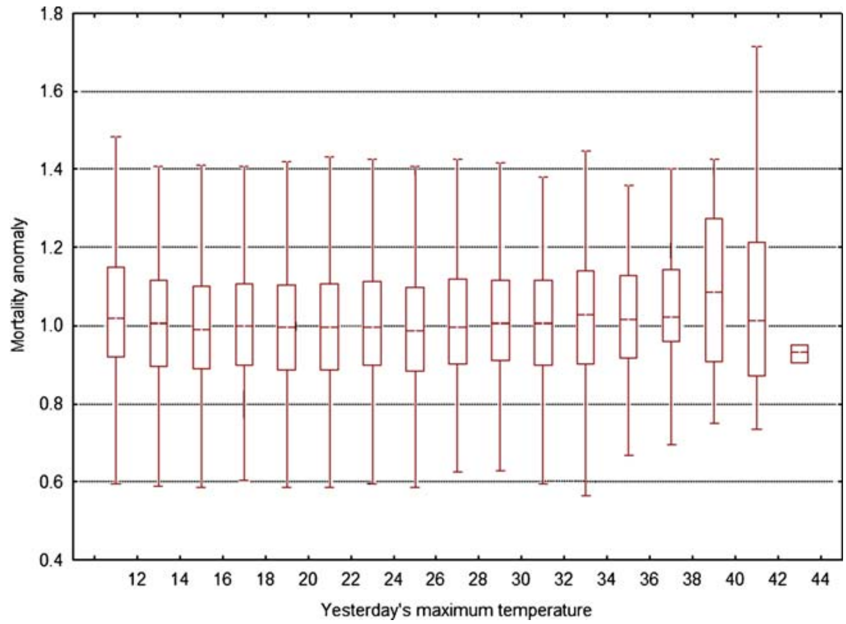


Fig. 6 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of multiplicative residuals, of over 64-year-olds in Melbourne, for 2°C ranges of "yesterday's" maximum temperature

maximum temperatures start to exceed 30°C. Other analyses (not shown) based on stratification using maximum temperatures and analogous to Figs. 2, 3, and 4 also reveal no strong tendency for excess deaths to be related to high maximum temperatures.

A boxplot was used to examine the residual death rates from up to 3 days prior to the 28 days when temperatures did not fall below 24° ("hot nights") and up to 7 days after these hot nights (Fig. 8). The figure shows the large mortality anomalies on the day immediately following such hot nights, but there is also increased mortality the following day. Otherwise, there is little evidence of any departure from the expected death rates. This suggests that the excess deaths associated with very hot nights are not simply representing a short-term advancement of mortality associated with the high temperatures (if "short-term" is defined as 7 days or less). If short-term displacement was taking place, one might expect the residual death rates several days after the hot nights to be lower than expected.

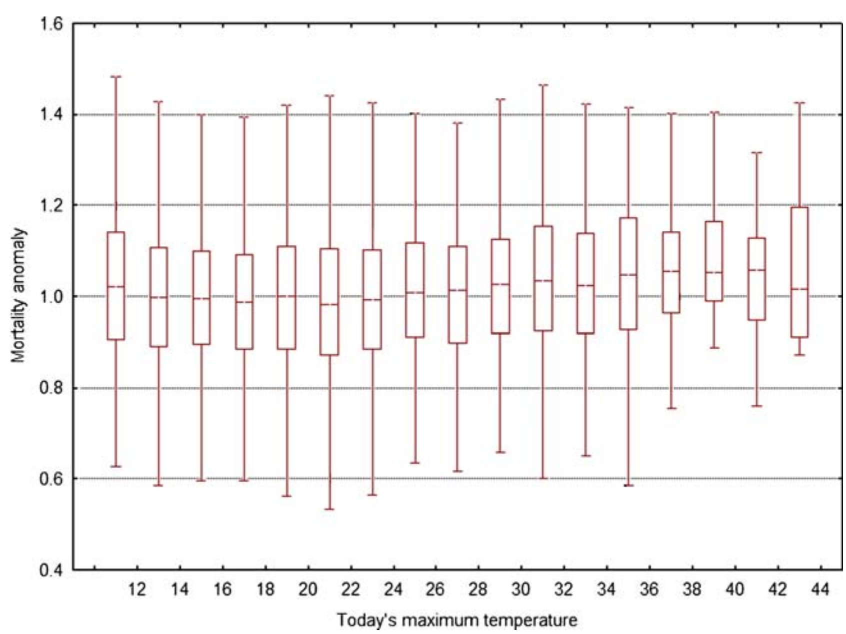


Fig. 7 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of multiplicative residual, of over 64-year-olds in Melbourne, for 2°C ranges of "today's" maximum temperature

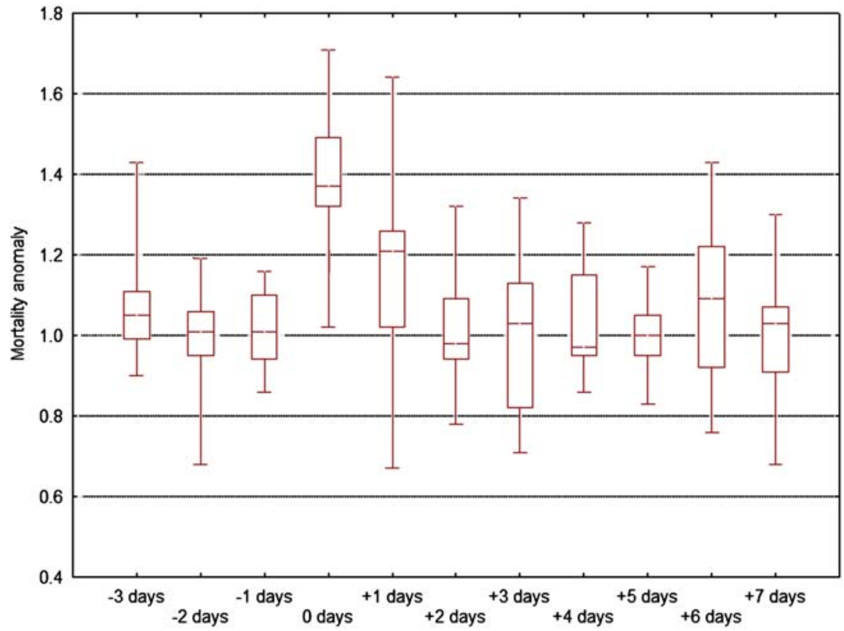


Fig. 8 Median and lower and upper quartile points (*boxes*) and ranges (*whiskers*) of multiplicative residuals of over 64-year-olds in Melbourne, from 3 days before to 7 days after nights with minimum temperatures exceeding 24°C

Discussion

Figures 2, 3, and 4 illustrate that mean daily temperatures exceeding about 30°C lead to an increased likelihood of excess mortality amongst the population over 64 years of age. The shift is quite considerable, especially if the long-term decline in mortality and the seasonal and other cycles in mortality are taken into account (Fig. 4). A mean temperature of 30°C would appear, therefore, to provide a useful threshold for issuing heat alerts for Melbourne. The increased mortality does not appear to represent a short-term advancement of mortality (Fig. 8). In France in 2003, the evidence suggests also that there was no short-term mortality displacement (Le Tertre et al. 2006; Kovats and Ebi 2006), and Tong et al. (submitted) found no evidence of a short-term mortality displacement in the severe Brisbane heat wave of early 2004. On the other hand, some studies have found short-term mortality displacement (Hajat et al. 2006; Johnson et al. 2005).

The results described above lead to a simple method for a public heat alert system that can be implemented by anyone with access to forecast daily maximum and minimum temperatures. The Bureau of Meteorology provides forecasts of these through the media and on the internet. If at any time during the forecast period the average of the predicted maximum temperature on one day and the predicted minimum temperature for the following morning exceeds 30°C, a heat alert could be issued to the public and/or local authorities, ambulance services and other health and welfare organizations. The heat alert would indicate likely increases in mortality in the 24-h period following the high temperatures. The number of alerts issued each year would likely be quite small (typically about two per year), since the threshold has only been exceeded 42 times in the 1979–2001 period. One advantage of the simplicity of this system is that a heat alert could be triggered some days ahead of the hot conditions, when official forecasts of daily mean temperature exceed the threshold. Diaz et al. (2006a) note that such early alerts should be a feature of a heat alert system if the system is to be effective in reducing heat-related circulatory illness. Keatinge (2003) also notes the necessity for a successful heat alert system to trigger responses prior to the onset of hot weather.

An even simpler system would be to use predicted minimum temperatures of above 24°C as the threshold to initiate a heat alert system. The Bureau of Meteorology widely disseminates forecasts of minimum temperatures so this would provide a simple means to prepare and disseminate heat alerts.

Of course, we have related actual temperatures to death rates. Forecasts of temperature several days in advance are not perfectly accurate, and it would be interesting to examine whether the results presented here were less clear if predicted temperatures were used to stratify the data on deaths.

It is intriguing that maximum temperatures do not appear to have a strong effect on death rates. This may be because in many very hot days in Melbourne the very hot temperatures are reached by early afternoon, and the temperature can then drop dramatically following the arrival of a pre-frontal trough (cool change) or a cold front. So, for at least some days with very high maximum temperatures, the temperature has fallen to more moderate levels well before the end of the day. This reasoning suggests that a more sophisticated analysis based on changes in temperature through the day could lead to a more discriminating heat alert system, by identifying those days when very high maximum temperatures were maintained through the day. The data examined in this study do not allow such an extended study to be pursued. A more sophisticated approach, along the lines used by Kalkstein et al. (1996), might also lead to a system that more readily identifies days when high heat-related mortality might be expected. On the other hand, such sophisticated systems require more sophisticated systems for their operational implementation and use, compared to the system described herein.

This study has used only total deaths in the age group above 64 years of age to determine the response to high temperatures in Melbourne, without examining the possible causes of the increased mortality in these situations. It seems reasonable that similar risk factors as have been found elsewhere would apply in Melbourne. Thus, people with "psychiatric disorders, depression, cardiovascular and cerebrovascular conditions, and diabetes are at high risk during a heat wave" (Kovats 2006). The elderly can be especially at risk because perception of ambient temperature is poorer, so they do not always recognise that they are over heating (Kovats 2006). Flynn et al. (2005) discuss other physiological changes that occur with advancing age and that could contribute to higher heat-related mortality in the elderly, as well as outlining approaches to reduce heat-related mortality. Passive dissemination of ways to avoid heat stress does not seem sufficient to reduce vulnerability, and vulnerable people need to be identified and cared for. The heatwave plan implemented in England after the European heat wave of 2003 includes a call for additional support involving at least daily contact for at-risk individuals living at home. Simple responses to a heat alert, such as opening a window, using a fan, light and loose-fitting clothing, avoiding unnecessary exertion and if necessary sprinkling water on clothing, can prevent heat stress (Keatinge 2003), and maintaining hydration is obviously important. Hot conditions also tend to lead to increased hospitalisation, separate to the increased mortality (e.g., Mastrangelo et al. 2006; Kovats and Ebi 2006). So an effective heat alert system would also include responses to assign increased ambulance and hospital resources during hot conditions. It appears that people dying in heatwaves die quickly, often before they reach hospital, and this should be reflected in any heat alert system design (Kovats and Ebi 2006).

The system outlined above is very simple. It is likely that more discrimination could be achieved between moderate and excess mortality days if an index of atmospheric moisture was included in the system, or if forecasts of temperature at specific times of the day were available. The use of a synoptic classification system might also enhance predictability of excess deaths by identifying oppressive weather patterns. The operational implementation of such a system, however, would require more direct involvement from the Bureau of Meteorology (in terms of providing more detailed forecasts) than the simple system outlined here. Investigation of other age groups may also provide more useful information (e.g., Diaz et al. 2006b found an effect of hot periods on mortality of males aged 45–64 in Madrid), as would work to investigate the effect of high temperatures on the specific causes of death. This study has not investigated whether an extended period of hot days would further increase mortality. Hajat et al. (2006) found a small increase in mortality during heat waves, over and above the mortality arising from hot days in general. They concluded that the largest "burden of heat deaths did not occur during heat waves but during isolated hot days or other periods when temperatures were perhaps more moderate but occurred with greater frequency". Our study only examined mortality for the city as a whole, rather than examining the geographical distribution of deaths. Smoyer (1998) demonstrated that there are spatial differences in heat-related mortality, with higher mortality rates in warmer and more disadvantaged areas (in St. Louis, USA). A more complex analysis of Melbourne, focussing on spatial distributions of mortality might lead to a more effective heat alert system. Recent work in Melbourne on the spatial variability of urban climate in relation to urban structure (e.g., Coutts et al. 2007a, b) could provide a context for that work. Finally, this short investigation has not examined the possible confounding effects of air pollution on mortality. Fischer et al. (2004) and Stedman (2004) provide evidence that air pollution contributed to the deaths during the 2003 heat wave in Europe. Brücker (2005), Filleul et al. (2006) and Dear et al. (2005) report that ozone and high temperatures both contributed to excess mortality in France during the 2003 heatwave, although Le Tertre et al. (2006) did not find evidence that air pollution was confounding estimates of heat-related deaths. Tong et al. (submitted) found that air pollution played a role secondary to heat stress in causing excess deaths in a heat wave in Brisbane in 2004.

Figures 4 and 5 provide a basis for determining whether, in Melbourne, projected warming (IPCC 2007) would lead to increased mortality, or whether increases in mortality associated with hot days could be offset by decreases in mortality from cold days or spells. Figure 4 shows the mortality rate for the 2°C-wide temperature "bins" expressed as deviations from the seasonal cycle. There is still a clear increase in mortality on hot days, even when the seasonality is taken into account. However, at the other end of the temperature scale there is little evidence of an increase in mortality on cold days, once the seasonality is taken into account. The deviation in average daily mortality from the seasonal cycle of mortality on days in the coldest bin is little different to the days of moderate temperatures. This suggests that an individual cold day in winter does not, of itself, lead to increased mortality in Melbourne. The relationship between cold temperatures and mortality seen in Figs. 2 and 3 arises, then, from the obvious relationship between winter and increased mortality—a very cold day in winter does not tend to increase mortality above that experienced generally through winter. To summarise, an individual hot day leads to increased mortality, but an individual cold day appears to be associated with increased mortality only because such days occur preferentially during winter and factors other than cold snaps lead to higher winter mortality. This suggests that future warming in Melbourne may lead to increased mortality due to increased numbers of hot days and that this may not be offset by decreased mortality associated with decreases in the frequency of cold days (although warmer winters overall would presumably lead to fewer winter deaths). However, Keatinge et al. (2000) pointed out that European regions with hot summers did not have significantly higher annual heat related mortality rates than cold regions, and that heat-related deaths occurred above higher temperature thresholds in hotter cities. This suggests that populations are capable of adjusting to very different mean summer temperatures, and Keatinge et al. (2000) suggest that populations could continue to adjust to future increases in temperatures due to the enhanced greenhouse effect. Donaldson et al. (2003) reported that heat-related mortality in several widely separated places had fallen since 1971, even though mean temperatures had not fallen. This suggests, also, that adaptations are reducing the impact of hot conditions. Donaldson et al. suggest that such adaptations include increased prevalence of air conditioning, at least in one region studied (North Carolina). However, Kovats and Ebi (2006) point out that complete adaptation is unlikely, since all European populations studied thus far have shown mortality increases at extreme high temperatures.

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