# Temperature thresholds associated with increased mortality in ten major population centres in rural Victoria, Australia

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# Contents

Monash Climate identified for the Department of Human Services (DHS) threshold temperatures above which Melbourne daily mortality increased in December 2006. Following on from this work the DHS has requested that Monash Climate examine whether similar thresholds exist for the rest of Victoria, including the major population centres of Bendigo, Wodonga, Latrobe Valley, Horsham, Hamilton, Ballarat, Shepparton, Lakes Entrance, Mildura and the Geelong region. These centres are part of the DHS Climate Change and Adaptation Program which is currently being developed and implemented in rural and regional Victoria.

## *Introduction.*

The high mortality associated with the European heatwave of 2003 [1-4] and recent heat waves in the USA[5,6], and predicted increases in summer temperature associated with climate change [7], has led to an increased awareness of hot weather as an environmental hazard. Exposure to extreme heat is already a significant public health problem and a major cause of weather-related mortality in the U.S.A. [8,9]. Many large cities around the world have now implemented heat alert systems [10,11] including Melbourne, Australia [12]. However, heat alerts for smaller regional cities or large towns do not feature prominently in the literature. The research described here examines whether similar mortality-temperature thresholds to those found for Melbourne also apply to rural Victorian population centres. The Melbourne heat alert system is based on the identification of this mortality-temperature threshold [12] and relies on readily available temperature forecasts from the Bureau of Meteorology (BoM). If temperature thresholds, above which excess deaths occur, can be found for rural population centres, then daily weather forecasts could be used to develop an operational heat alert system for most population centres in the State.

## *Data and Methods*

Data for daily observed maximum and minimum temperature were purchased from the BoM for Mildura, Horsham, Hamilton, Geelong, Ballarat, Bendigo, Shepparton, Wodonga, Morwell, and Lakes Entrance, for the study period 1990 to 2006. This provided two weather stations with data covering the study period for each of the five rural Victorian health regions defined by the Department of Human Services Victoria (DHS). Figure 1 in Appendix A shows the locations of the weather stations and health regions.

## Mortality data

Daily mortality data were purchased from the Australian Bureau of Statistics (ABS) for the study period. The ABS data were provided for Statistical Districts (SDs). Each DHS health region comprised two of the ABS Statistical Districts the locations of which are also shown in Figure 1. Table 1 (Appendix A) lists the two SDs in each health region, and the weather station used for that SD. The ABS is restricted from publishing information in situations where less than five deaths occur; therefore daily data at a high spatial resolution in rural areas, where fewer than five deaths might occur, could not be obtained. Due to low numbers of daily deaths in rural areas the mortality numbers were summed every two days, thereby representing deaths over a 48 hour period, with the exception of the Geelong (Barwon) region where numbers of deaths were sufficient to allow daily analyses. Despite this accumulation, data were not available from the ABS for some regions and days, because of the "fewer than five deaths" restriction on the ABS data. Days missing from the dataset because of this restriction accounted for 1.3 - 2.5 % of the data in each region.

The elderly are more vulnerable during heat wave events and therefore it is also important to understand the demography of the rural SDs and the major population centres examined in this study. The percentage of the population aged 65 years and older in each SD, and the percentage of the population in each of the major population centres aged 65 years and older, was calculated. The results are shown in Table 1.

## Temperature data

The relationships of maximum (Tmax), minimum (Tmin), and average temperature (MeanT) with total 2-day mortality and anomalous mortality (ie, total mortality after long term trends and annual cycles have been removed) were investigated. Temperature variables were fitted to the 2-

day mortality data by selecting the maximum value of daily maximum (Tmax), daily minimum (Tmin) and daily average (MeanT, the average of Tmax and Tmin over the 9am-9pm period) temperature observed over the 48 hour period. Thus 2-day total mortality was related to the highest temperature (Tmax, Tmin, and MeanT) observed during the 2-day period. This method was considered appropriate as heat related mortality typically peaks either on the day of extreme heat or the day following the heat event. Examination of the French heat wave in 2003 [13-16] and mortality heat relationships in Melbourne [17] have demonstrated that the effects of hot weather are immediate and there is little or no mortality displacement.

Box plots were prepared for bins of maximum, minimum and average temperature and 48 hour mortality. Temperature bins in 2°C increments were used. The results for Tmax, Tmin and MeanT in each of the ten SDs are presented in Table 2 and the box plots exhibiting the clearest threshold temperatures (ie where an increase in mortality is clearest when temperatures exceed this threshold) for each SD are shown in Figures 2-11. In all cases except Wodonga, MeanT exhibited a clear threshold above which excess deaths occurred. In the case of Wodonga, Tmax exhibited a clearer threshold, so Figure 3 uses Tmax rather than MeanT (which is used for all the other locations). In the case of Geelong, where data were available to undertake the analysis using daily data rather than 2-day accumulations, the best relationship was with temperatures from the day before the mortality data.

## *Results*

The results of the threshold temperature analysis for all the major centres are summarised in Table 2. Figures 2-11 show the median, upper and lower quartiles and range of 2-day total mortality anomalies (ie, with the long-term trend and seasonal cycles removed) for persons aged 65 years and older versus the maximum value of the selected temperature variable (MaxT, MinT, or MeanT) over the same 48hr period as the mortality anomaly. The results presented for the Geelong/Barwon region used daily data rather than 48 hour periods.

## Bendigo

Figure 2 represents the threshold temperatures for Bendigo/Loddon. There is a small increase in mortality when the minimum temperature is 22°C (18 episodes) or warmer and when the maximum temperature is over 40°C (14 episodes). There is a marked increase in mortality when the MeanT (9am-9am) is 32°C or greater (23 episodes).

*Recommendations*

That a MeanT of 32°C be used as the basis for heat alerts in this region. Days with temperature above this threshold are associated with a median mortality increase of 18%.

## Wodonga

Figure 3 shows the threshold temperature for Wodonga/Hume region. There is a small increase in mortality when the minimum temperature is greater than or equal to 28°C (four episodes), There is no clearly identifiable increase in mortally for MeanT in this region. There is a notable increase in mortality when the maximum temperature exceeds 40°C (16 episodes). This trend towards greater mortality continues as temperatures increase to 42°C or more.

*Recommendations*

The clearest increase in mortality is for maximum temperature with a consistent median mortality increase of 20% on days exceeding 40°C.

## Latrobe Valley

Figure 4 demonstrates the threshold temperature for the Latrobe Valley/Gippsland region. There is a marked increase in mortality when the MeanT is above 30°C (25 episodes), when minimum temperatures exceed 22-24°C (eight episodes) and when maximum temperatures exceed 36°C (41 episodes).

*Recommendations*

The minimum temperature threshold for Latrobe Valley of 22°C is associated with a 20 - 30% increase in mortality. However, this threshold is not exceeded very often, only eight times in 17 years. Alerts may also be included for days when maximum temperature and MeanT thresholds are exceeded. On these days there is a median mortality increase of 18% and these occurrences are more frequent.

## Horsham

Figure 5 represents the threshold temperatures for Horsham/Grampians region. The results indicate that mortality increases when the maximum temperature rises above 38°C (103 episodes) and MeanT exceeds 32°C 33 episodes). There is an increase in mortality in the 26-28°C temperature band; this may be a statistical artefact of the frequency of occurrence of this event (115 episodes during the study period) or due to activity levels in the elderly cohort at this temperature. There was no discernable effect of minimum temperature in this region.

*Recommendations*

A MeanT threshold of 32°C results in a median mortality increase of 10%. A similar increase in mortality is noted for days when maximum temperature exceeds 38°C and these events occur three times more often than days exceeding the MeanT threshold.

## Westernport region

Threshold temperatures were unable to be determined for the Westernport region because the mortality data were unavailable due to low numbers of deaths in such a small geographical region. However, as Westernport is part of both the Melbourne Statistical division and the Gippsland Statistical Division (represented here by Latrobe Valley) it may be possible to infer a threshold from these two adjacent regions. As both Melbourne and Latrobe Valley demonstrate an increase in mortality when the MeanTemperature is 30°C or above, this is most likely the case for the Westernport region also.

## Hamilton region

Figure 6 shows the threshold temperatures for the Hamilton region. The data suggest that mortality increases when the maximum temperature exceeds 42°C. This is an infrequent occurrence; there were only six episodes during the study period. The effect of high minimum temperature is more notable with an increase in mortality above 24°C; there were 10 episodes during the study period. The increases in mortality when MeanT equals or exceeds 34°C is quite notable, however this only occurred on two occasions during the study period. As with Horsham there is a small but consistent increase in mortality when the MeanT is between 26 and 32°C; there were 206 occurrences during the study period. This may be related to activity levels in this elderly cohort, i.e. mild weather associated with increased physical activity, or the seasonal timing of temperature within this band as increased temperature occurring early in the season has a greater impact on mortality [9,18].

*Recommendations*

A minimum temperature threshold of 24°C demonstrates a clear increase in mortality in the elderly. There is a very small increase in mortality when MeanT thresholds above 26°C are exceeded but an increase in mortality is not noted until MeanT exceeds 34°C. This has only occurred twice in 17 years.

## Lakes Entrance

Figure 7 represents the threshold temperature for the Lakes Entrance region. Days with maximum temperature over 38°C (21 episodes) are associated with increased mortality. Minimum temperature over 23°C (24 episodes) are also associated with increased mortality. Increased mortality is also noted for episodes when MeanT exceeds 30°C (10 episodes).

*Recommendations*

There is a mortality increase of 15% on days exceeding the Tmax threshold of 38°C. A MeanT threshold of 30°C is associated with a mortality increase of approximately 7%. This threshold is consistent with MeanT thresholds in neighbouring areas; this may be important as this area is a popular holiday destination and experiences a substantial increase in population over the summer holiday period. If the majority of these vacationers are from eastern Victoria then the similarity of this threshold to thresholds in these regions would be expected. Visitors from more northern regions where MeanT thresholds are higher may not be affected. Any threshold will be moderated by exposure and activity; this is of relevance to people holidaying in this region.

## Geelong

Figure 8 demonstrates the threshold temperature for the Geelong region. Mortality data for the Geelong region were sufficient in number to allow daily analysis. A relationship between daily maximum temperature and daily mortality was not demonstrated. However there was a clear relationship between daily minimum temperature (20$^{o}$C, and 11 episodes) and daily MeanT 28$^{o}$C (39 episodes) during the study period. Further analysis of mortality and daily maximum temperature lagged one day demonstrated a clear relationship when daily maximum temperature exceeded 40$^{o}$C (19 episodes). This suggests that elderly residents in this region respond to the previous day's maximum temperature, hence their capture in the MeanT analysis. This response may be multi-factorial but possible explanations may be related to the daytime urban heat island (UHI) or late afternoon peaks in temperature. This relationship cannot be clarified using the data available for this study.

*Recommendations*

A MeanT of 28$^{o}$C provides a good threshold for this region. Maximum temperature threshold of 38$^{o}$C also provides the clear threshold for this region. On the day following a day when temperature exceeded this threshold the median mortality anomaly is between approximately 15 – 30%. Authorities should be notified that mortality is likely to peak on the day following a day that exceeds the maximum temperature threshold. Public health interventions may modify this response.

## Shepparton region

Figure 9 demonstrates the threshold temperatures for the Shepparton region. Mortality is substantially increased when maximum temperature exceeds 43$^{o}$C (three episodes), and when minimum temperature exceeds 26$^{o}$C (eight episodes) and when MeanT is between 30 – 32$^{o}$C, but does not increase further when MeanT temperature increases beyond 32$^{o}$C (overall 23 episodes). The results for Shepparton are a little inconsistent. For both MeanT and minimum temperature initial increases are not sustained at higher temperatures. This may reflect temporal influences such as the seasonal timing of episodes, spatial factors such as heat islands or dwelling locations, environmental influences such as dwelling structure and population health status including co-morbidities, or social influences such as family structure and ethnicity. These factors cannot be examined using this data set.

*Recommendations*

There is a clear increase in mortality when MeanT exceeds 30°C in this region. Although the percentage increase does not increase with further increases in MeanT the median mortality for each temperature band is greater than expected. There is a similar effect for minimum temperatures above the 26°C threshold.

## Ballarat region

Figure 10 demonstrates the threshold temperatures for the Ballarat region. The thresholds for maximum and minimum temperature are 32°C (13 episodes) and 18°C (65 episodes) respectively. The strongest effect is noted for a MeanT exceeding 30°C (16 episodes).

*Recommendations*

Days with MeanT exceeding 30°C show an 18% increase in median mortality. The low minimum temperature threshold of 18°C and high number of episodes is surprising. There is a small but consistent increase in mortality when the minimum temperature threshold is exceeded; this should be taken into account when alerts are issued.

## Mildura region

Figure 11 shows the threshold temperatures for the Mildura region. Maximum temperature shows a small increase in mortality when temperatures exceed 42°C (35 episodes). The increase in mortality continues to rise when temperatures exceed 44°C (seven episodes) and 46°C (two episodes) exhibiting a clear increase in mortality with increasing temperature. Minimum temperature thresholds demonstrate an increase in mortality at temperatures above 27°C (16 episodes); however there is an unexplained decrease in mortality in the elderly when temperatures are between 25 and 27°C. There are a large number of episodes in this temperature band and the decrease may represent the thermal tolerance or the level at which residents use air-conditioning overnight. The increased mortality at higher overnight temperatures of 27 to 29°C and over 29°C may show that air-conditioning becomes ineffective at these thresholds and mortality increases. The threshold for MeanT is also quite high at 35°C (20 episodes). There is a similar pattern within the MeanT analysis showing that there is a decrease in mortality when MeanT is between 31 and 32°C. Thereafter there is an increase in mortality. Again this may reflect thermal tolerance and the use of air-conditioners.

*Recommendations*

There is a 10% increase in median mortality when the MeanT threshold of 35°C is exceeded. Similar increases in median mortality are noted when minimum temperature exceeds 29°C, and maximum temperature exceeds 44°C although these events occur less frequently.

## Discussion and conclusions

This study has demonstrated that in all major rural population centres across Victoria hot weather exceeding a specific threshold results in an increase in mortality in persons aged 65 years and older. The clearest thresholds are, in general, with daily Mean Temperature (MeanT). Calculating the average daily temperature from 9am one day to 9am the following day takes into consideration a hot day followed by a hot night. This lack of 'relief' from the heat appears to result in increased mortality in the elderly.

This research provides information about the adverse health effects of high temperatures in small regional towns in Victoria, Australia. It is interesting to note that the adverse health effects of high ambient temperatures documented in the literature for large cities in Europe [19], America [20], Sydney [21] and Melbourne Australia [12] are also found in rural communities in Victoria, Australia. This adds considerable strength to the argument that human populations are vulnerable to heat events regardless of location, and that heat stress occurs in populations living outside large cities.

The importance of this is highlighted by the number of older persons living in rural communities. Population distribution in rural centres can vary markedly (Table 1). In some SDs 25-50% of the older population live in the major centres (e.g. Ballarat, Geelong, Bendigo, Mildura and Latrobe Valley), whereas in other regions the older population is more dispersed throughout the region (eg., Western District and East Gippsland ). In both of these latter SDs the increase in median mortality on days exceeding the threshold was notably lower than in SDs where a larger percentage of the elderly population were living in the major centres. This may reflect that only healthier elderly persons live outside of major centres and away from health care support systems, or that social capital in rural areas outside the major population centres is a protective factor.

The minimum temperature thresholds are higher in the more northern regions of Mildura, Shepparton, and Wodonga The minimum temperature threshold for Wodonga was very high (28$^{o}$C). This area also showed a clearer increase in mortality (20%) related to an increased maximum temperature (above 40$^{0}$C) rather than MeanT possibly because of the very high minimum temperature threshold. The lack of a clear threshold for minimum temperature in Horsham may be due to several factors. For example, high overnight temperatures may be less common in this open plain, wheat growing and sheep grazing region, and thus the adaptive capacity of the population may be higher than other centres. The meanT thresholds were higher in the far western and northern regions of the State. In these areas the median mortality on days exceeding the thresholds varies from 7-18% with an average increase in mortality of 11.25%. The meanT thresholds in regions to the immediate northeast and east of Melbourne are lower than those in the north-western side of the State. In these eastern regions the median mortality increase also ranges from 7-18%, but the average increase in mortality on days exceeding the threshold was 16.5%. Broadly speaking it appears that older people living in the more temperate eastern side of the State are more vulnerable to heat events than those living in the warmer western regions. The reason for this difference cannot be determined from the data sets used in this study. It may be associated with socio-demographic differences, access to health care and health status, or differences in social capital.

The Victorian Government has identified the need to respond to predicted heat events and has committed to a Victorian Heatwave Plan involving communities and local government. As a part of this strategy the DHS has established a heat alert system for metropolitan Melbourne [12] and has recognised the need for similar work for regional Victoria. A series of pilot projects have been undertaken engaging local government to develop heatwave plans that could be integrated with existing local government public health and/or emergency management plans. The predictions in relation to climate change in south-eastern Australia are that extreme weather events are very likely to become more frequent and severe in the future [22 23]. By identifying threshold temperature for regional centres this study provides a scientific basis for the heatwave alert system development.

It is difficult to discuss these results in terms of the broader literature as this appears to be the first study to address the issue of developing heat thresholds for rural centres. However there is consistency over space and with known heat thresholds for the Melbourne region. One important issue that must be considered is that many of the meteorological stations used in this study are situated at airports. This provides an observation from an artificial environment that may not be directly representative of the areas from which the mortality data are derived. Actual temperatures in urban areas may be slightly hotter or cooler as a result of this measurement anomaly. As temperature forecasts from the Australian Bureau of Meteorology are based on the same weather station data as the threshold temperatures this anomaly should not be problematic, in terms of developing heat alert systems for these localities.

This research has demonstrated that older people living in regional areas also experience the adverse health effects of extreme heat events despite varying degrees of acclimatisation due to regional differences in summer temperature extremes. The considerable numbers of older people living in rural areas highlights the need for heat alert systems outside capital cities. The percentage of older persons in all of the regional areas is higher than in Melbourne, indicating proportionally more people at risk in the rural centres. This work has also demonstrated that threshold temperatures can be developed for smaller regional towns as well as larger cities. The thresholds identified are different from the threshold identified for Melbourne (threshold of $30^0$C) . Whilst the meanT thresholds are higher than Melbourne in the northern regions, the meanT thresholds in the Central Highlands and Barwon regions are lower than for Melbourne. The results in this paper highlight the vulnerability of the elderly in rural areas and the need for region specific heat alert systems. Heat waves are not limited to large cities or legislative boundaries, and may affect large parts of states or countries; it is not sufficient only to provide heat alerts for large cities.

As with the heat alert system for Melbourne, heat alerts for rural regions can be issued using official Bureau of Meteorology forecasts. The DHS could issue heat alerts through local health and welfare agencies, and increase awareness of 'hot' weather as a health hazard for elderly people by providing education campaigns involving local authorities based on these simple thresholds.

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## Appendix A

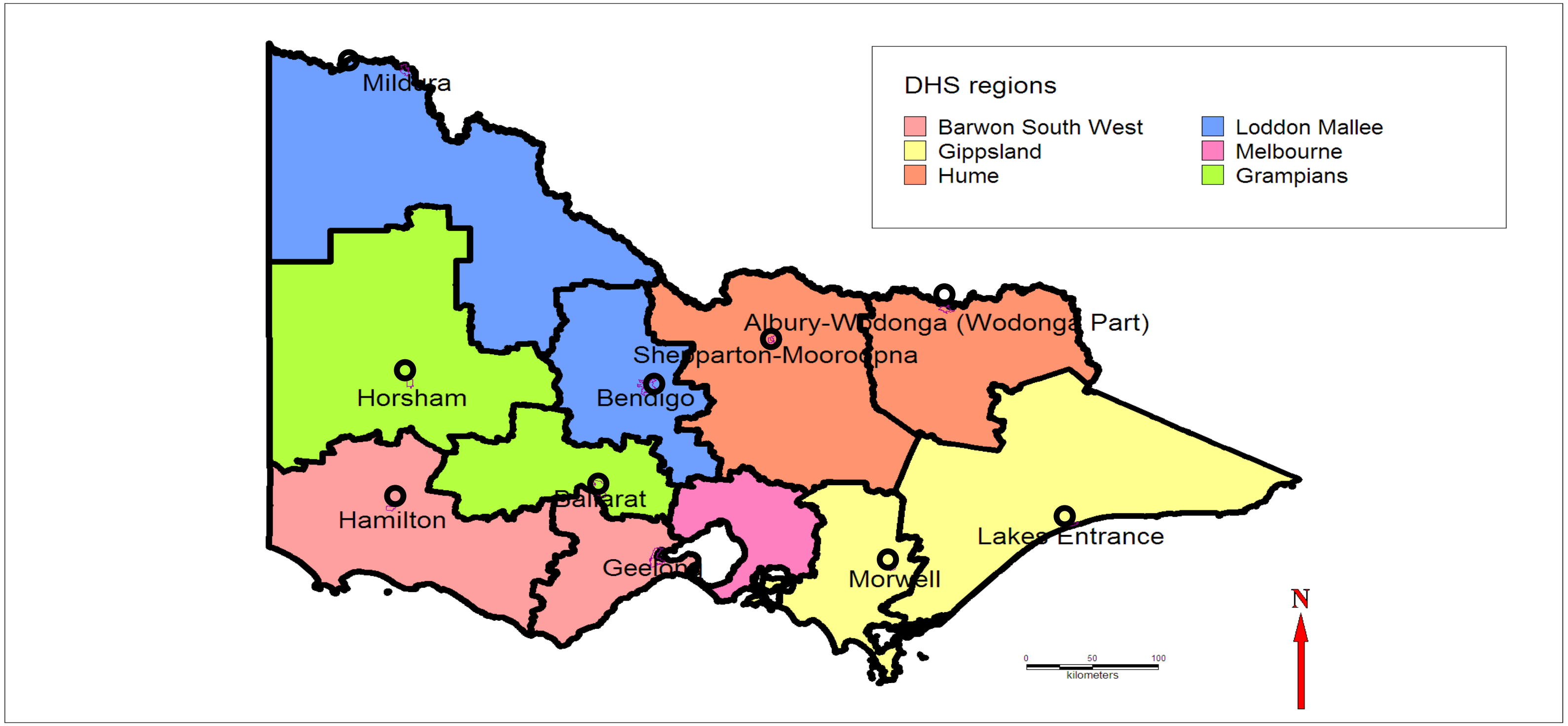



**Figure 1. The Department of Human Services delivers services through its eight health regions (three of these are in Melbourne and are omitted from the figure and from this study). Each region is comprised of two statistical districts (SD) each of which includes one major population centre. The population centres and names of the SDs in each region are listed in Table 1. The BoM weather stations are located in each of the major centres.**

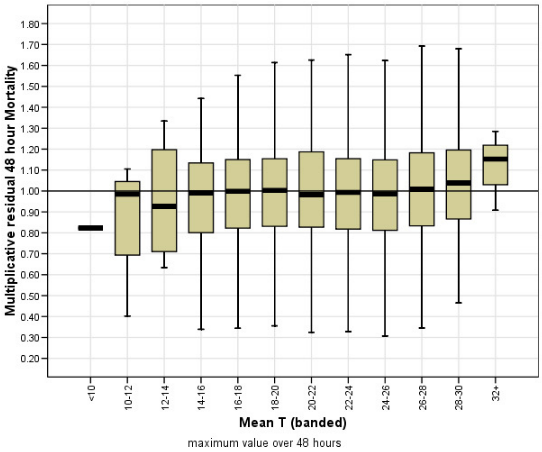



**Figure 2. Bendigo(Loddon) 48 hr MeanT and 48hr residual mortality 1990-2006**

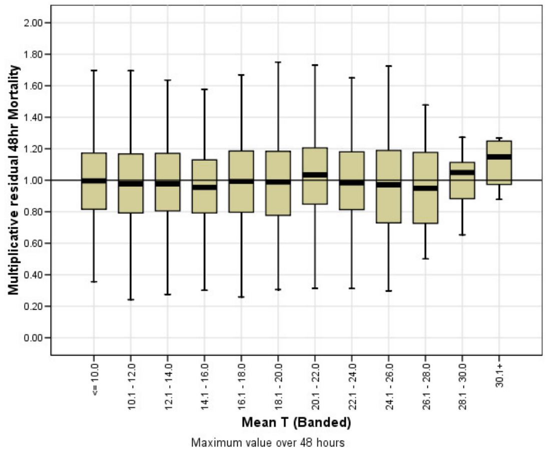



**Figure 4. Latrobe Valley (Gippsland) 48 hr MeanT and 48hr residual mortality 1990-2006.**

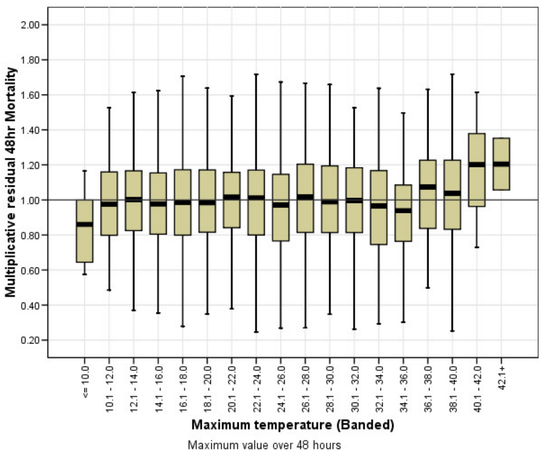



**Figure 3. Wodonga (Hume) 48 hr maximum temperature and 48hr residual mortality 1990-2006. Tmax provides a clearer threshold for Wodonga than MeanT.**

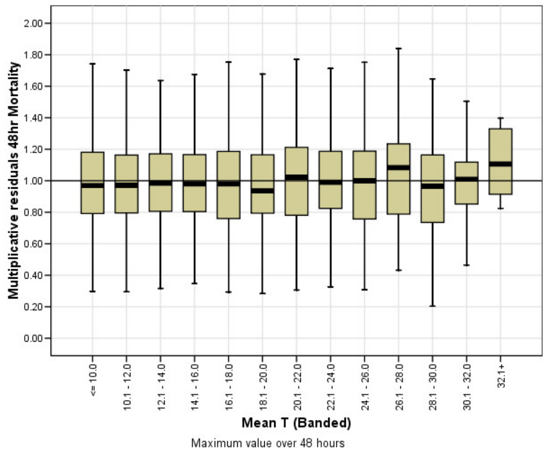
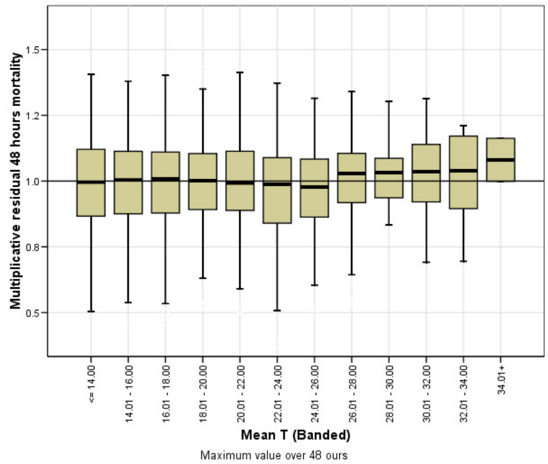



**Figure 5. Horsham (Grampians) 48 hr MeanT and 48hr residual mortality 1990-2006.**



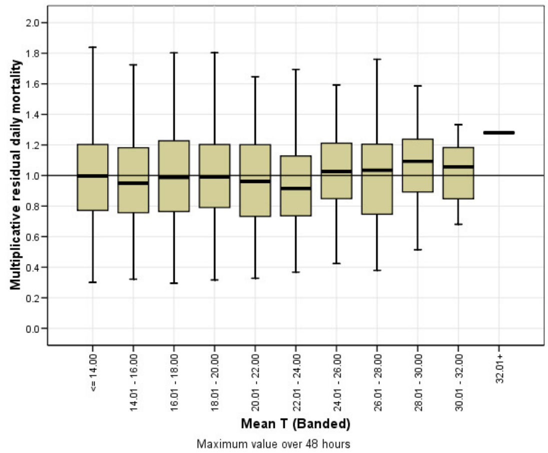
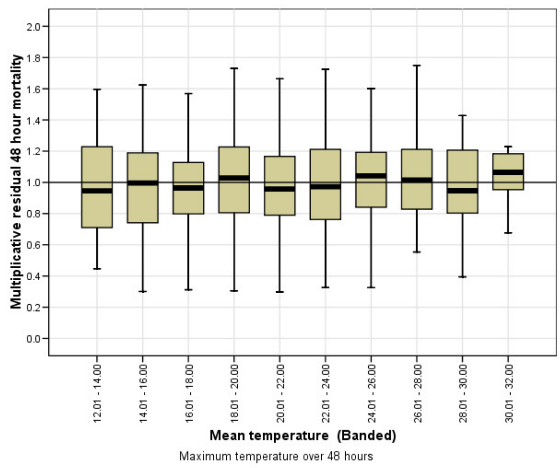




**Figure 8. Geelong (Barwon region) 48 hr MeanT and 48hr residual mortality 1990-2006.**

**Figure 6. Hamilton (Western District) 48 hr MeanT and 48hr residual mortality 1990-2006.**



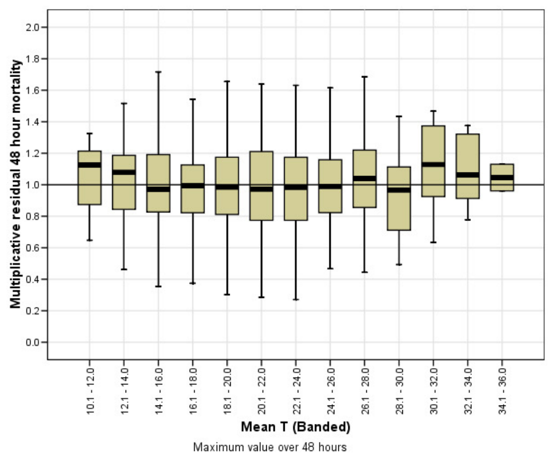




**Figure 9. Shepparton (Goulburn) 48 hour MeanT and 48 hour residual mortality 1990 – 2006.**

**Figure 7. Lakes Entrance (East Gippsland) 48 hour MeanT and 48 hour residual mortality 1990 – 2006.**

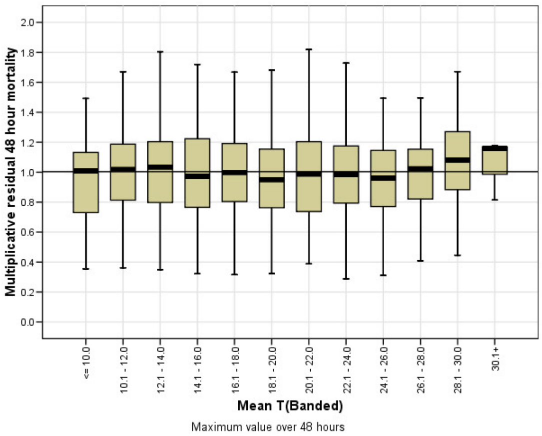



Figure 10. Ballarat (Central Highlands) 48 hour MeanT and 48 hour residual mortality 1990 – 2006.

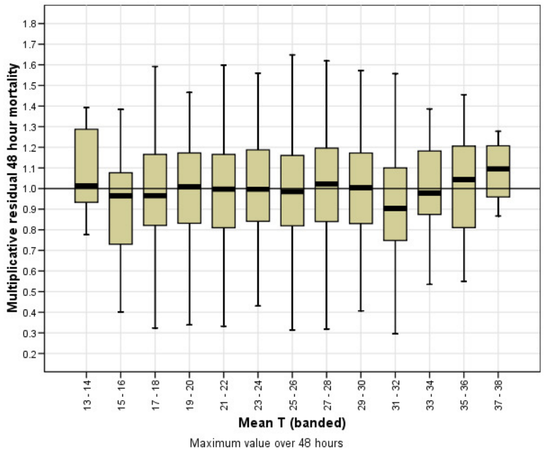



**Figure 11. Mildura (Mallee) 48 hour MeanT and 48 hour residual mortality 1990 – 2006.**

**Table 1. Population demography of persons aged 65 years and older living in the SD and major centres in the five rural DHS health regions in Victoria.**

| DHS Region | SD | Major centre | Percentage of persons living in each major centre aged 65 years or older. Number of persons 65 years and older in parentheses. | Percentage of persons in the SD aged 65 years or older living in a major centre. Number of persons aged 65 years and older living in each SD are shown in parentheses |
|---|---|---|---|---|
| Grampians | Central Highlands | Ballarat | 14% (12,020) | 57% (21,099) |
| Barwon South West | Barwon | Geelong | 15% (22,509) | 55% (40,989) |
| Loddon Mallee | Loddon | Bendigo | 15% (11,665) | 45% (25,708) |
| Loddon Mallee | Mallee | Mildura | 16% (4,705) | 32.4% (14,516) |
| Gippsland | Gippsland | Latrobe Valley | 16% (8,081) | 31% (26,107) |
| Grampians | Wimmera | Horsham | 19% (2,615) | 27% (9,463) |
| Hume | Ovens Murray | Wodonga | 14% (3,363) | 24.4% (13,732) |
| Hume | Goulburn | Shepparton | 15% (5,612) | 18.40% (30,488) |
| Barwon South West | Western District | Hamilton | 16% (1,886) | 11% (16,166) |
| Gippsland | East Gippsland | Lakes Entrance | 18% (1,407) | 10% (14,627) |

**Table 2 Threshold temperatures (˚C) for rural Victorian centres. Numbers of episodes exceeding thresholds during the study period are listed in parentheses. The percentage increase in mortality on days exceeding the threshold is also shown for each threshold.**

| Major centre (SD) | Threshold temperature | | | | | |
|---|---|---|---|---|---|---|
| | Tmax | | Tmin | | MeanT | |
| Bendigo (Loddon) | 40 (14 ) | 8% | 22 ( 18 ) | 5% | 32 ( 23 ) | 18% |
| Wodonga (Hume) | 40 ( 16) | 20% | 28 (4) | 5% | 30 (28) | None identified |
| Latrobe Valley (Gippsland) | 36 (41) | 16% | 22 (8) | 22% | 30 ( 25) | 18% |
| Horsham (Grampians) | 38 (103) | 10% | None identified | None identified | 32 (33) | 10% |
| Hamilton (Western District) | 42 (6) | 5% | 24 (10) | 7% | 34 (2) | 7% |
| Lakes Entrance (East Gippsland) | 38 (21) | 15% | 23 (24) | 7% | 30 (10) | 7% |
| Geelong (Barwon) | 40 (19) 1 day lag | 10% | 20 (11) | 4% | 28 (39) | 15% |
| Shepparton (Goulburn) | 43 (3) | 36% | 26 (8) | 15% | 30 (23) | 15% |
| Ballarat (Central highlands) | 32 (13) | 5% | 18 (65) | 10% | 28 (16) | 18% |
| Mildura (Mallee) | 44 (7) | 18% | 27 (16) | 10% | 35 (20) | 10% |