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Using the Excess Heat Factor (EHF) to predict the risk of heat related deaths

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ABSTRACT

Extremes of climate are not uncommon in Australia and heatwaves are not infrequent. Periods of high ambient temperature may result in clusters of heat related deaths, which may place strain on forensic facilities. This paper describes the formulation of the Excess Heat Factor using meteorological data to provide a means of predicting death resulting from periods of extreme heat stress. The 2009 South Australian heatwave had the highest ranked Excess Heat Factor in Adelaide's records. There were 58 heat related deaths, with the bulk of the heat related deaths following the peak Excess Heat Factor value (144 °C^2). The 2008 heatwave had a lower peak Excess Heat Factor value (36 °C^2); there was only one heat related death, which followed the peak in the Excess Heat Factor. It is proposed that calculation of the Excess Heat Factor from meteorological data could provide a means to predict and identify heat related deaths resulting from extreme weather conditions.

1. Introduction

Heat related deaths may occur in isolation related to individual circumstances (for example, resulting from exertion)[1,2] or in clusters associated with unusually high and persistent environmental temperatures, commonly known as "heatwaves". Heatwaves are declared when temperatures exceed a predetermined level over a set number of days. However, there is no 'gold standard' to predict or define a heatwave. In Adelaide, South Australia consists of five consecutive days with temperatures of 35 °C or more, or three consecutive days with temperatures of 40 °C or more.[3]

Heat related fatality clusters can cause considerable strain on the resources of medical facilities, including forensic mortuaries, in terms of having to provide adequate staffing levels and resources to deal with markedly increased workloads. Heat related deaths would be expected when daily average and maximum temperatures remain elevated for protracted periods. However, there is not a simple relationship between temperatures and mortality.[4] Exposure to heat can result in acclimatisation and adaptation,[5] but sudden and sustained substantial elevations of ambient temperature above baseline levels have the potential to result in clusters of heat related deaths. The authors propose the use of the Excess Heat Factor, which can be calculated from meteorological data, to predict when there is a high risk of heat related mortality and morbidity.

2. Materials and methods

The means for calculating The Excess Heat Factor, which provides a numeric value for the environmental temperature load, is described below.[6] Analysis of meteorological data for South Australia for the 30-year period 1971–2000 provided the 95th percentile of the upper limit of the average daily temperature (DT_{95}) as a climate reference value. The Significance Excess Heat Index (EHI_{sig}) is defined as unusually high heat that is not sufficiently discharged overnight due to high overnight temperature. Maximum and

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subsequent minimum temperatures averaged over a three-day period (DT_{3days}) are compared against the climate reference value (DT_{95}).

$$EHI_{sig} = \text{Average}\left(DT_{3days}\right) - DT_{95}$$

Thus the Significance Excess Heat Index provides a measure of how much the average daily temperature over three days exceeds the 95th percentile of the average daily temperature over the reference 30-year period.

The Acclimatisation Excess Heat Index (EHI_{accl}) is defined as a period of heat that is warmer, on average, than the recent past. Maximum and subsequent minimum temperatures averaged over a three-day period (DT_{3days}) are compared to the average temperature over the preceding 30 days (DT_{30days}):

$$EHI_{accl} = \text{Average}\left(DT_{3days}\right) - \text{Average}\left(DT_{30days}\right)$$

Thus, the Acclimatisation Excess Heat Index makes an allowance for expected acclimatization to the variation in temperature.

The Excess Heat Factor (EHF) is calculated by multiplying the Significance Excess Heat Index by the absolute value of the Acclimatisation Excess Heat Index:

$$EHF = \left(EHI_{sig}\right) \times \left|\left(EHI_{accl}\right)\right|$$

Thus the Excess Heat Factor is an expression of the long term temperature anomaly, amplified by the short term temperature anomaly.[6] Any Excess Heat Factor value above zero indicates heatwave conditions and the higher the value the more extreme the conditions. A severe heatwave is an event where the Excess Heat Factor values exceed a threshold for severity that is specific to the climatology of each location. A severity threshold for Excess Heat Factor has been proposed utilising Probability of Exceedance theory. Rare and relatively common heatwave events are separated by sampling the 85th percentile of a site's positive Excess Heat Factor cumulative distribution function.

A review of all deaths reported to the South Australian State Coroner's office from 23rd January to 10th February 2009 incorporated the period of 13 days from 26th January to 7th February where

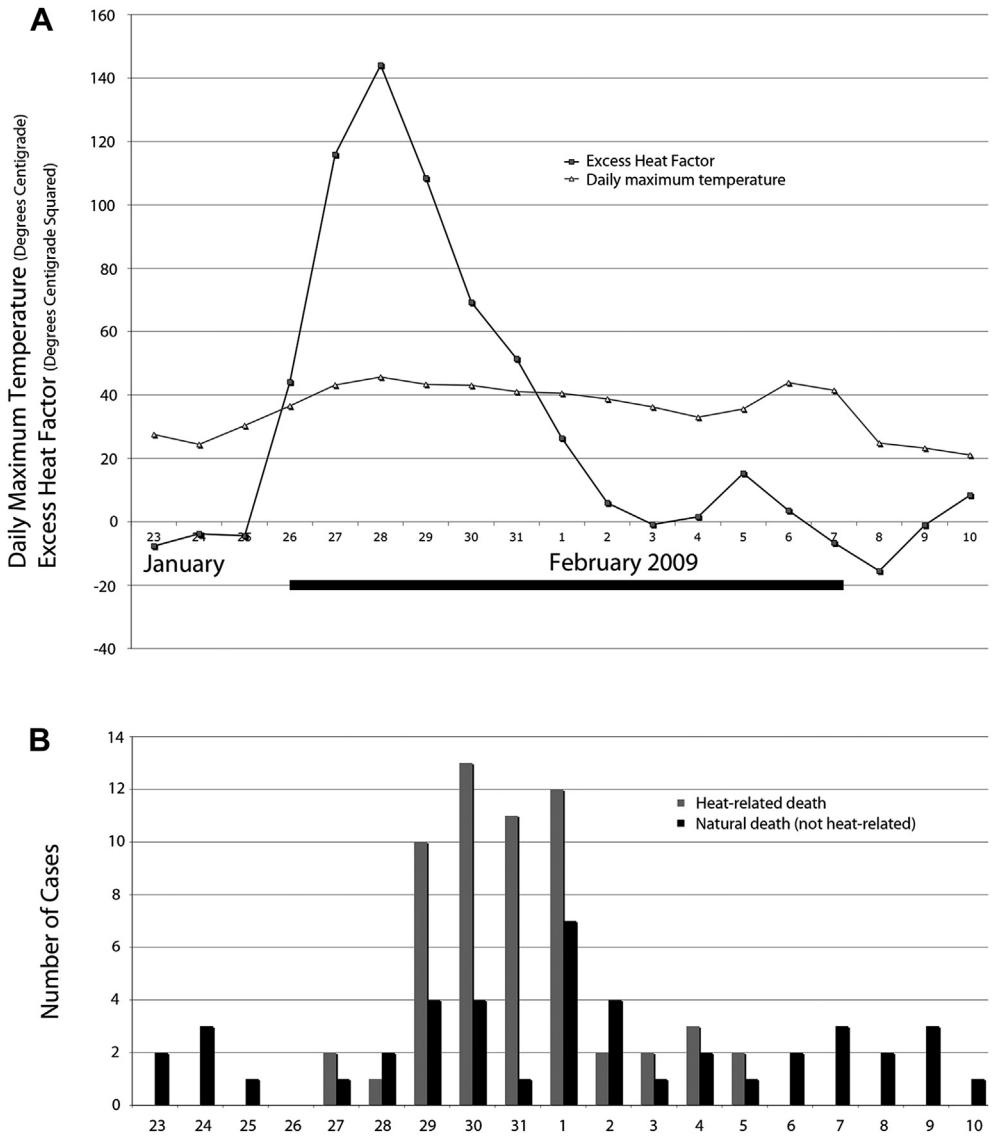

Fig. 1. 2009 Heatwave. A (top): Excess Heat Factor and maximum temperatures plotted on a daily basis. The black bar indicates the designated period of the heatwave from January 26th to February 7th 2009. B (bottom): Numbers of heat related and non-heat related natural deaths plotted against the date of death.

maximum daily temperatures in Adelaide, the state capital, exceeded 35 °C, including eight days where temperatures exceeded 40 °C and included the hottest day for 70 years at 45.7 °C.[7] (Temperatures for Adelaide were obtained from the Australian Bureau of Meteorology.) A similar analysis was performed for the period 27th February–23rd March 2008, which included 12 days from 3rd to 17th March with maximum air temperatures above 35 °C and 3 days above 40 °C. For this study deaths were recorded as heat related or not heat related as indicated by the pathologist and/or Coroner. The dates of death used for formulation of the graphs are as determined by the Coroner from statements of witnesses and the pathologist.

3. Results

Calculation of the Excess Heat Factor revealed a marked peak of 144 °C^2 on day three of the 2009 heatwave. In Adelaide's 120-year climate record, the Excess Heat Factor of the 2009 heatwave is the top ranked event. Adelaide's second ranked heatwave occurred in February 1899. The maximum Excess Heat Factor of the 2009 heatwave was elevated 5-fold above the heatwave severity threshold of 32 °C^2 for Adelaide. Six of the 13 days of this heatwave had an Excess Heat Factor above the severity threshold. During the period of the 2009 heatwave (from 26th January to 7th February) there were a total of 58 deaths reported to the Coroner in which exposure to high ambient temperature was regarded to have caused or significantly contributed to the death. The first heat related death of the 2009 heatwave was recorded on 27th February, but the majority of the heat related deaths occurred from 29th January to 1st February. Fig. 1 displays the maximum daily temperature and Excess Heat Factor values above the distribution of deaths. It is apparent that the peak of heat related deaths followed immediately after the peak of the Excess Heat Factor (Fig. 1).

Calculation of the Excess Heat Factor values for the 2008 heatwave revealed a peak of 36 °C^2 on day ten of the heatwave. Two of the 15 days of this heatwave had an Excess Heat Factor above the severity threshold of 31.4 °C^2. These levels were much lower than the values for 2009. There was only one heat related death over the 2008 heatwave period; in Fig. 2 it can be seen that this occurred after the peak Excess Heat Factor value.

4. Discussion

'Heat-related death' has been proposed as a term that may be used when it is considered that death has been either caused by, or contributed to, by high environmental temperatures, but the body temperature at the time of collapse or death is not available, and no other cause of death is present.[8] This is an acknowledgement of the difficulty in fulfilling the criteria required for the clinical diagnosis of heat stroke (core temperature 40.6 °C or higher with mental confusion[9]) as records of core temperature measurement and cognitive function are usually not available unless death has followed admission to a medical facility.[10,11]

Heatwaves can be defined as a minimum number of days above a threshold temperature.[3] However, maximum temperatures may not provide a guide to the effect on human health due to factors including adaptation.[12] During the period of a heatwave it is proposed that the 'excess heat', which accumulates resulting in raised maximum (daytime) and minimum (nighttime) temperatures, is an important determinant of morbidity and mortality. The degree of heat stress generated by the heatwave depends on how much hotter the

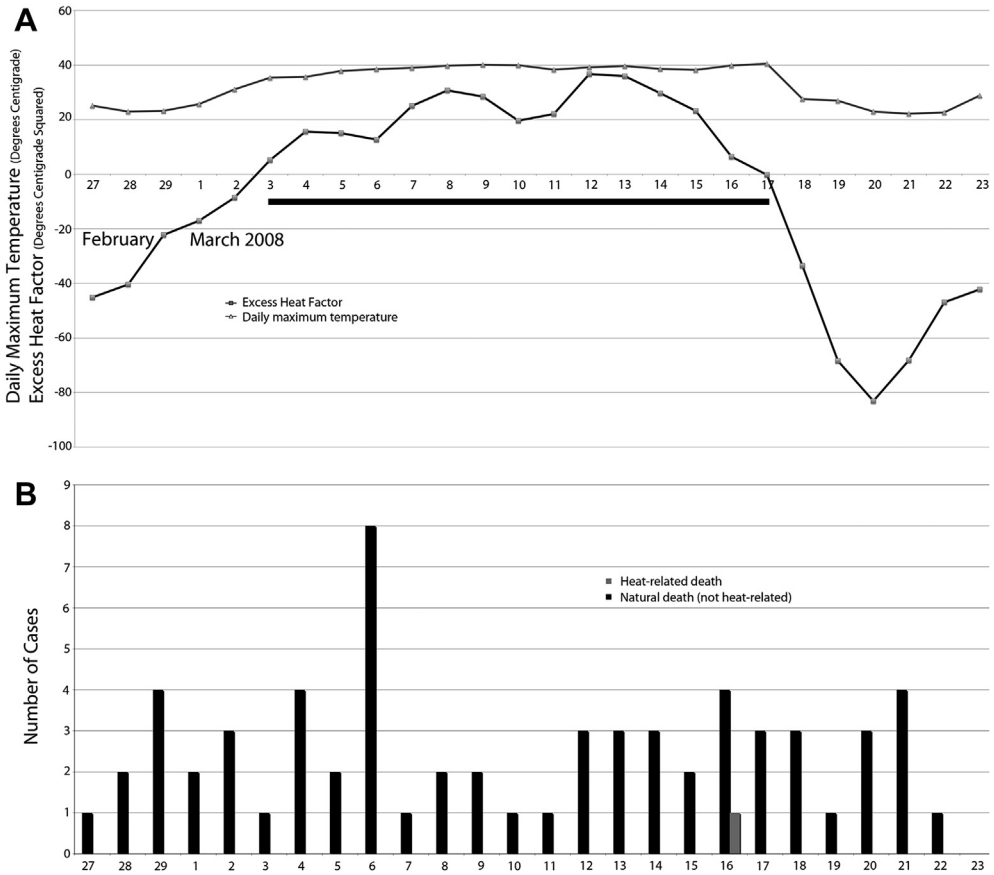

Fig. 2. 2008 Heatwave. A (top): Excess Heat Factor and maximum temperatures plotted on a daily basis. The black bar indicates the designated period of the heatwave from March 3rd to 17th, 2008. B (bottom): Numbers of heat related and non-heat related natural deaths plotted against the date of death.

temperatures are above the recent average. The Excess Heat Factor combines excess heat and heat stress to produce an indication of the severity of the heat event. There is a striking correlation between the number of deaths and the deviation from normal of the Excess Heat Factor for 2009 (Fig. 1). The data for 2008, where there was a much less significant change in the Excess Heat Factor show a corresponding low number of heat related deaths. Of note, elevation in Excess Heat Factor values preceded the increase in heat related deaths by 2–3 days and so may provide a clearer indication of the numbers of impending cases of heat related death that may be anticipated. The relationship between excess fatalities and high EHF values has been shown for other capital cities (based on EHF extracted from a variation of the algorithm using a gridded data set).[11]

Limitations of this study are that in some cases the exact date of death was uncertain, but a best estimate was used based on witness statements and the opinion of the pathologist. The findings are based on Coronial data and not death certifications for the State; this has limited the number of deaths included in the study by restricting the analysis to cases that have been reported to the State Coroner, but this should include most sudden deaths. It has to be conceded that it is difficult to make a post-mortem diagnosis of heat related death with certainty.[8] Nonetheless, the findings of this study indicate why the Excess Heat Factor has been identified as a parameter for the monitoring of temperature changes to alert health authorities dealing with non-lethal heat related illness as well as fatalities.[13] In the forensic setting, use of the Excess Heat Factor may assist with identifying when death may have occurred as a result of heat as positive values indicate heatwave conditions. The Excess Heat Factor has been proposed as means of defining a heatwave that can be adopted internationally[14] and evaluation of the Excess Heat Factor to assess its ability to predict heat related deaths is planned.

Ethical approval

Not applicable.

Funding

None.

Conflict of interest

None.

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