Heatwave defined as a heat impact event for all community and emergency sectors in Australia.

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Abstract

Lack of agreement over a heatwave definition has impeded spatial and temporal analysis of events within Australia and with comparable locations internationally. Given that heatwaves impact all natural and human engineered systems in a similar manner it seems logical to derive a measure that permits this form of analysis so that heatwave mitigation best practices may be shared.

As Australia is yet to develop a national heatwave warning system, features that have shaped heatwave warning systems in Europe and the USA are examined to inform how a domestic system may evolve.

A heatwave definition that can serve an Australian heatwave warning system has been created through considering how systems respond under heat load. Systems susceptible to failure under thermal stress have natural or engineered design limitations. These limits are an adaptive response to commonly experienced rates of heat accumulation found over both the long (climate scale) and short (acclimatisation) term. When these limits are exceeded, systems begin to fail. The larger the thermal load, the greater is the impact and scale of failure. Short and long term heat anomalies are factored together to derive a measure of heatwave intensity. This heatwave intensity measure has been shown to be useful for charting Australia's heatwave climate history, forecasts, warnings and assessment of risk arising from climate change.

A statistical interpretation of the climatology of heatwave intensity has then been developed to provide guidance on heatwave severity in chart form providing guidance on the level of impact anticipated due to the intensity of the heatwave (Nairn and Fawcett, 2013).

Introduction

Historically, heatwaves have been responsible for more deaths in Australia than any other natural hazard, including bushfires, storms, tropical cyclones and floods (Coates, 1996). McMichael et al. (2003) has estimated that extreme temperatures contributed to the deaths of over 1000 people aged over 65 each year across Australia.

Health authorities across Australia have recently recognised heatwaves as a serious and increasingly hazardous threat to our communities. This threat was realised in 2009 when over 400 people died across southeast Australia during the

January/February extreme heatwave (Mason et al., 2010; Victorian Department of Health, 2009), immediately preceding the 173 deaths arising from the Victorian Black Saturday fires (Teague et al., 2010). In subsequent seasons Australian communities have continued to experience impacts from intense heatwaves. This is consistent with expected increases in heatwave duration, frequency and intensity under projected climate change (Alexander et al., 2007).

State authorities have engaged the Australian Bureau of Meteorology (the Bureau) to explore effective mitigation and response strategies. The Bureau has responded by developing a national heatwave intensity measure that enables tracking and alerting for severe and extreme impacts (Nairn and Fawcett, 2013).

Creation of a heatwave intensity measure is only one of many ingredients required to implement and operate an effective Heat Health Warning System (HHWS). Analysis of existing HHWSs deployed across Europe and North America has recently been undertaken by the author with the support of the Bureau and a Churchill Fellowship (Nairn, 2013) to understand how the differing heatwave services have evolved, and what lessons may apply to the creation of a national heatwave warning system in Australia.

This investigation also considered the scientific methodologies employed to identify and alert for heatwave severity. International comment was invited on Australia's new heatwave intensity measure. UK and USA contacts expressed great interest in the Australian heatwave methodology leading to offers for collaborative studies to investigate impact sensitivity.

International Heatwave Lessons

There is significant heatwave service diversity around the world. The unitary states of the UK, France and Macedonia operate high profile services supported by very effective partnerships across government and non-government organisations. By comparison other nations with federated jurisdictions had lower profile services that were less effective unless central government explicitly deployed compensation measures (Nairn, 2013).

The central government in Italy provides payment incentives to clinic doctors to register patients at risk of heat stress thereby improving access to medical help during heatwaves. Another example of effective central government intervention occurs in the USA where leadership across a partnership of federal agencies guides a program of research, training and development designed to establish best practices for health and environment practitioners at state and regional levels. This whole-of-government partnership has led to a large number of federal agencies building internal business targets for the delivery of health and environment outcomes, strengthening community resilience through a range of programs delivered by different arms of the federal government. Apart from national health agencies, other federal government agencies have come to recognise and prioritise how they can contribute to public health and environment outcomes.

Despite Australia’s investment in climate adaptation research (NCCARF, 2008-2013) there are comparatively weak heatwave mitigation partnerships across federal government agencies. Building effective heatwave knowledge and response systems centred on research, training and development in Australia requires multi-agency partnerships, heatwave mitigation role acquisition and community resilience policies that extend responsibility for improved health and environmental outcomes to the wider community and across federal government agencies.

Stakeholder management has been quite straightforward in France and some neighbouring countries following the 2003 extreme heatwave in which 15,000 people died in Paris alone (Robine, et al 2008). Political demand has maintained a steady stream of research and policy initiatives in countries strongly impacted by this event. Australia’s extreme heatwave impacts are yet to gain political attention, particularly as these very high impact events frequently occur in close proximity to catastrophic bushfires. The fundamental difference between these hazardous events is the rate at which impact intelligence is acquired and shared.
Rapid sharing of health impact data has become standard practice in the UK and USA, where situational awareness from shared Syndromic Surveillance Systems[1] data has empowered partner agencies to commit to mitigation strategies and respond more effectively.

Well communicated peer reviewed science has also been instrumental in governing the pattern of heatwave services supplied to the community. The UK has enshrined this approach within the Cabinet Office by assigning a Civil Contingencies Secretariat to oversee agency collaborations to ensure that hazards listed on the National Risk Register (NRR) (Gov.UK, 2013) have appropriate treatment options. Executive government ownership of NRR treatments for reduction of risk creates an environment where empowered government agencies plan and act with authority and communicate readily with the Cabinet.

International Heat Health Warning Systems are triggered by thresholds set against a range of temperature indices. The diversity of temperature thresholds employed is accompanied by difficulty in verifying their suitability for accurately identifying impact thresholds. Despite the strength of UK and USA health and weather service partnerships their use of threshold methodologies limits their ability to resolve heatwave events at resolutions requested by stakeholders (Health Protection Agency, 2007). Threshold methodologies also limit their ability to build heatwave climatologies suited to mitigation and education purposes. By comparison Australia’s candidate heatwave service compares heatwave intensity against the record of past heatwaves to assign a level of severity for each locality. The identification of heatwave intensity and its relative severity can be resolved at a local resolution which relates well to impact and permits statistically driven mitigation plans.

The unitary and federated state structures of countries in Europe and North America have required service development strategies that are sensitive to sovereign

[1] Where data is systematically collated and reported from health sector records. ie. clinic, hospital and ambulance records

divisions of power. Effective health and environment agency partnership structures are sensitive to these divisions of power. Rapid impact data gathering and sharing mechanisms support partner agencies and executive government in the delivery of effective heatwave services. An underlying principle for service development is the presence of well communicated peer reviewed science. The science of heatwave measurement and attribution of impact is still under development across Europe and the USA. Australia's heatwave methodology was considered to be a strong candidate for future heatwave services.

Heatwave Intensity

Heatwave terminology constructed by Nairn and Fawcett (2013) permits the understanding and calculation of heatwave intensity. Heatwave intensity is derived from factoring together long-term temperature (Excess Heat) and short-term temperature anomaly (Heat Stress) indices.

Excess Heat: *This is unusually high heat arising from a high daytime temperature that is not sufficiently discharged overnight due to unusually high overnight temperature. Maximum and subsequent minimum temperatures averaged over a three-day period are compared against a climate reference value to characterise this unusually high heat in an excess heat index. This is expressed as a long-term (climate-scale) temperature anomaly.*

Heat Stress: *This arises from a period where temperature is warmer, on average, than the recent past. Maximum and subsequent minimum temperatures averaged over a three-day period and the previous 30 days are compared to characterise this heat stress in a second index. This is expressed as a short-term (acclimatisation) temperature anomaly.*

Heatwave Intensity (Excess Heat Factor): *The combined effect of Excess Heat and Heat Stress calculated as an index provides a comparative measure of intensity, load (accumulated excess heat), duration and spatial distribution of a heatwave event. Heatwave conditions exist when the EHF is positive.*

EHF = Excess Heat x (1, Heat Stress)

Heatwave severity

Heatwave severity thresholds are derived from the 85th percentile of the Cumulative Distribution Function (CDF) of daily heatwave intensity (figure 1). This threshold intensity value marks the transition from frequently observed low intensity heatwaves to rarer, high intensity heatwaves.

Heatwave severity is a function of each location's climatology of heatwave intensity. Statistical evaluation of the frequency distribution of heatwave intensity provides an objective severity threshold that is unique for each location.

Severe Heatwave: *An event where EHF values exceed a threshold for severity that is specific to the climatology of each location.*

Extreme Heatwave: *An event where EHF values are well in excess of the severity threshold, resulting in widespread adverse outcomes. This has been empirically determined to be where EHF values are greater than two times the severity threshold.*

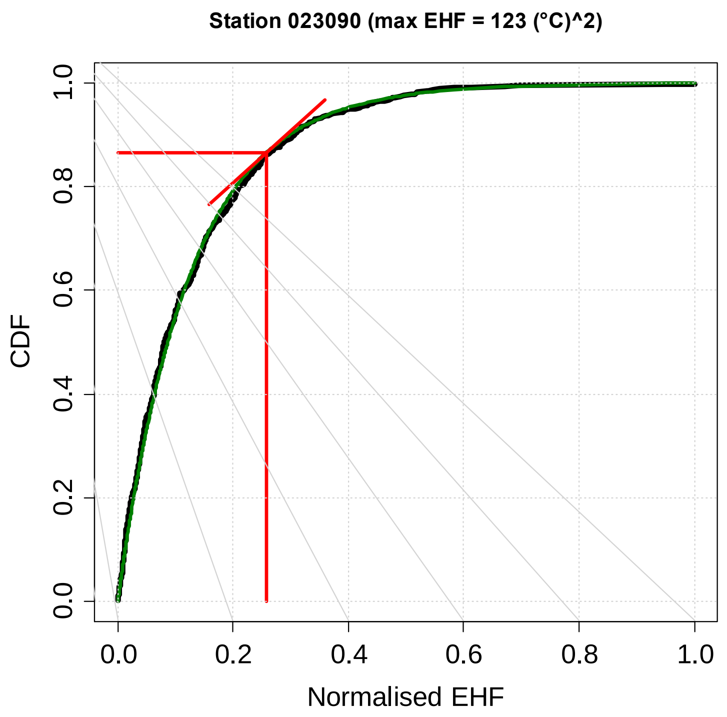

Figure 1 : Adelaide cumulative distribution function (CDF) of positive EHF (black line under the green line) normalised with respect to the maximum observed EHF, modelled generalised Pareto distribution (green line), and showing the turning-point method for determining the severe EHF threshold (red lines).

When each location's climatology has been processed as shown in figure 1 the map of Australia's heatwave intensity threshold for severity can be mapped, figure 2.

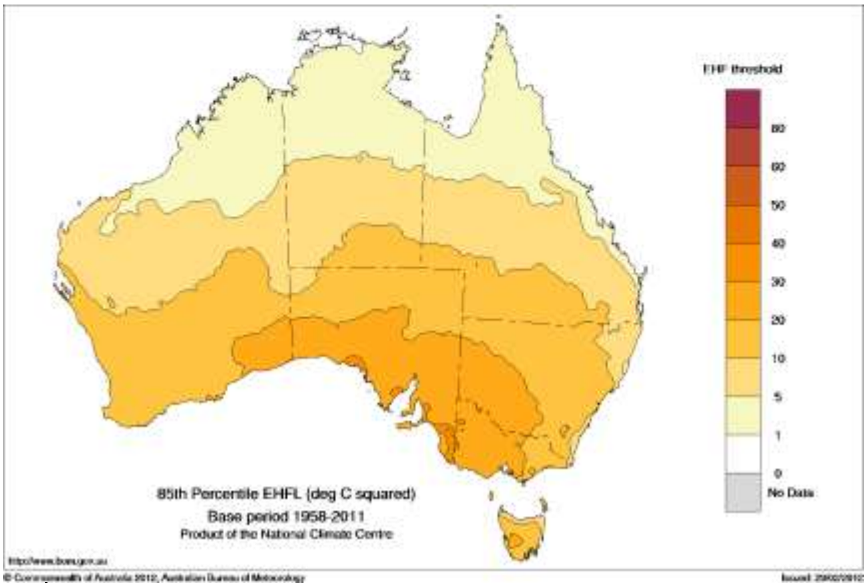

Figure 2: 85th percentile for positive EHF values (that is, EHF_{85}), calculated over the period 1958-2011, using gridded Daily Mean Temperature (DMT) analyses.

Climatologically-derived severe heatwave intensity thresholds are then mapped to charts of heatwave intensity illustrating areas of low, severe and extreme intensity, (Heatwave and Severe L1 to Severe L4 in figure 3).

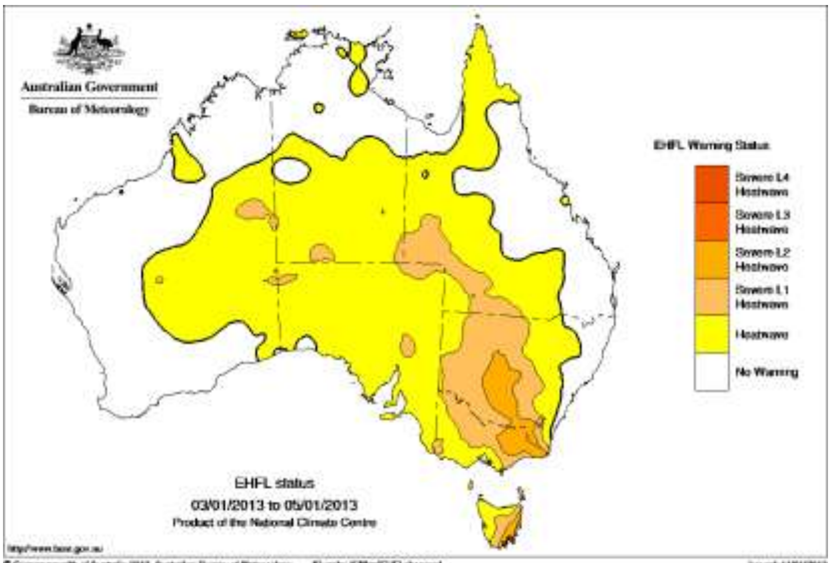

Figure 3: Areas with positive EHF for the period 03-05 January 2013, mapped for incidence of heatwave and level of severity. The contour band "Severe L1 Heatwave" indicates EHF values between one and two times the EHF severity threshold, while the contour band "Severe L2 Heatwave" indicates EHF values between two and three times the EHF severity threshold, and so on.

On 4th January 2013 several large bushfires became established across Tasmania. It is notable that figure 3 shows the eastern half of Tasmania was experiencing Severe L1 and L2 Heatwaves in a period which spans these fires. These levels denote rare and very intense heatwave conditions which were conducive to unusual bushfires as well as health challenges for vulnerable people.

2009 Extreme Heatwave and Catastrophic Fires

In January and February 2009 southeast Australia experienced an extreme heatwave sequence culminating in Black Saturday on 7th February (National Climate Centre, 2009). Figure 4 shows the accumulated heat load calculated from gridded climate data (Jones et al., 2009) across southern Australia encompassing this period.

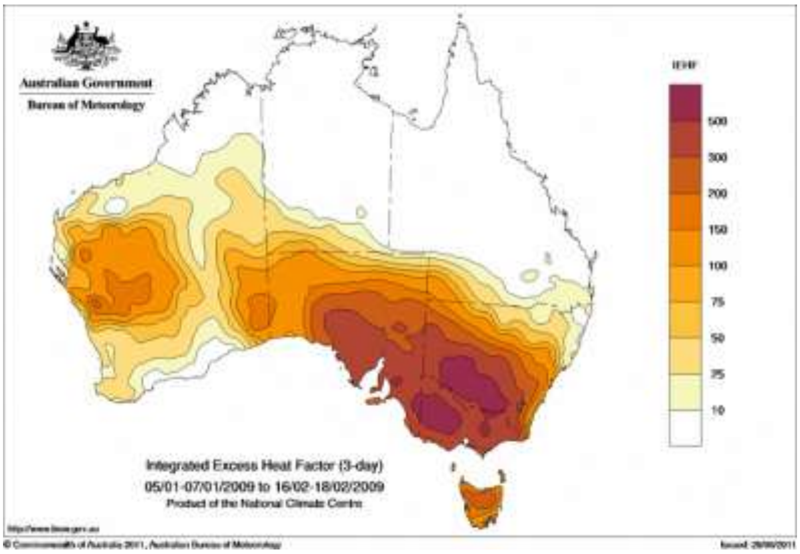

Figure 4. Accumulated Excess Heat Factor (EHF) from 5 January to 16 February 2009.

Catastrophic bushfires in the state of Victoria at the end of the heatwave resulted in the death of 173 people (Teague et al., 2010). Prior to this bushfire over 400 excess deaths occurred in the states of South Australia and Victoria (Mason et al., 2010; Victorian Department of Health, 2009, Langlois et al., 2013). Accumulated EHF over 400°C^2 in these two states is broadly indicative of the area impacted (figure 4).

Adelaide's time sequence for EHF and day of heat attributed mortality shown in Figure 5 shows the peak heatwave intensity leading the mortality peak by two days. It is also notable that the first day of severe heatwave intensity led the first record of heat mortality by one day. Each EHF value on the chart is an expression of the average heat load over a three day period, inclusive of the current and following two days. Calculated in this manner EHF shows a predictive capacity for the heat mortality response.

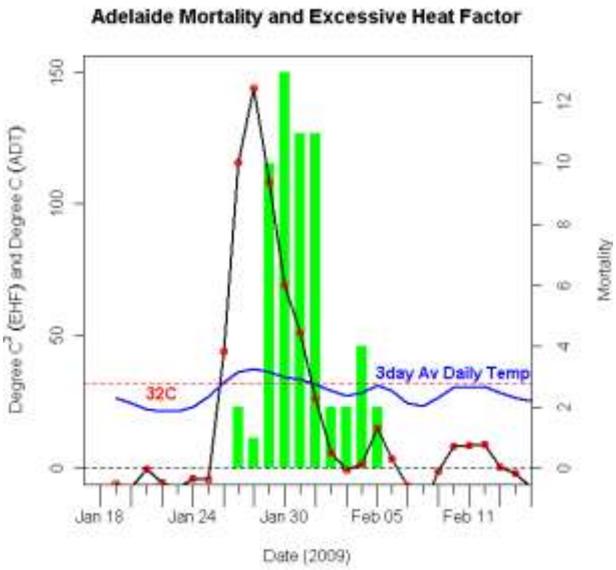

Figure 5. Mortality and EHF for 2009 extreme heatwave in Adelaide, South Australia. Heat related mortality (green bars), Excess Heat Factor (black lines with red dots) and three day average daily temperature (blue line). Severe EHF threshold of 32°C^2 (---)

In Adelaide's 120 year climate record the 2009 EHF peak amplitude of 144°C^2 shown in figure 5 is the top ranked event which is over four times the severe threshold value of 32°C^2. Values of EHF greater than twice the severe threshold value have been found to align with extreme heatwave impacts in Australia, USA and Europe (Nairn and Fawcett, 2013).

The corresponding chart of heatwave severity shown in figure 6 conveys the spatial spread of this extreme heatwave at the time of peak EHF in Adelaide, providing a ready assessment of the stress systems were enduring across the south and southeast of Australia at this stage of the heatwave.

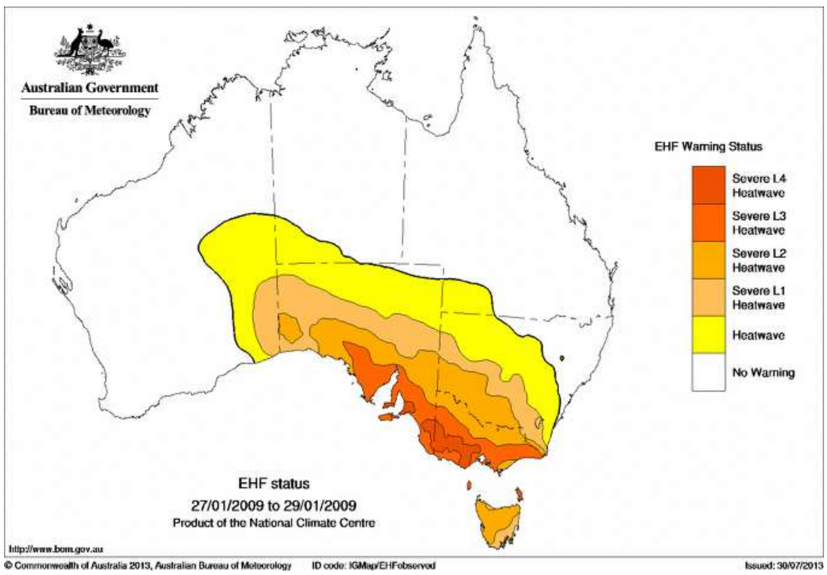

Figure 6. Heatwave severity for 27 January 2009 (three day period).

The accumulated EHF for this event was 586°C^2 which is also the top ranked event in Adelaide's 120 year climatology. Adelaide's second ranked heatwave occurred in January 1939. The 1939 extreme heatwave also coincided with devastating bushfires, with 438 heatwave deaths reported in South Australia, Victoria and New South Wales (EMA, 2007).

Potential Heatwave Services

The Bureau's capacity to develop and provide a heatwave service is predicated on capacity building;

(i) in developing a well-understood and scientifically defensible heatwave definition;

(ii) in acquiring stable systems for the examination of the climate record; and

(iii) the provision of reliable and robust forecast and warning services.

The Bureau of Meteorology's roll out of the Next Generation Forecast and Warning System (NexGenFWS, Hart and Jacobs) by the end of 2014 will provide a gridded data set on which a potential heatwave service could be based. Gridded climate data already permits studies into past heatwaves allowing examination of the sensitivity of EHF to impact on other business sectors such as agriculture losses, bushfire severity or power distribution system efficiency and reliability.

Conclusions

Bureau of Meteorology research has established a heatwave intensity methodology which is suitable for identifying and tracking severe and extreme impact heatwaves.

Established Heat Health Warning Systems in the UK and USA rely upon strong partnerships between health and environment agencies which are supported by impact data sharing systems underpinned by peer reviewed research. Best international practices are marked by policy initiatives that are sensitive to jurisdictional divisions of power. Establishment of a national heatwave warning system in Australia would benefit a whole-of-government strategy that treats heatwaves as a national public health threat. A Bureau of Meteorology heatwave warning system needs to be one of many federal government initiatives aimed at improving the effectiveness of state and local government and non-government agencies mitigation strategies.

There is a clear link between extreme heatwaves and catastrophic bushfires resulting in high loss of life. Differentiating between heatwave and bushfire impacts can be achieved through the rapid acquisition and sharing of impact data across the government. New partnerships across the federal government are required to achieve this outcome, particularly with health agencies.

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