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THE HEATWAVES OF THE 2013/2014 AUSTRALIAN SUMMER

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ABSTRACT

Heatwaves represent a significant natural hazard in Australia, arguably more hazardous to life than bushfires, tropical cyclones and floods. In the 2008/2009 summer, for example, many more lives were lost to heatwaves than to that summer's bushfires which were among the worst in the history of the Australian nation. Yet for many years, these other forms of natural disaster have received much greater public attention than heatwaves. This might be changing in Australia however, as health and emergency services increasingly use weather forecast information to become proactive in providing advice to the community on how to mitigate the effects of heatwaves. Significant community engagement took place during the 2013/2014 Australian summer, a summer which generated some significant heatwaves, comparable to those of 2009, 2004, 1939 and 1908.

In January 2014, the Australian Bureau of Meteorology introduced a pilot national heatwave forecasting service, to issue forecasts of forthcoming non-severe, severe and extreme heatwaves. The service is based on the excess heat factor (EHF) or heatwave intensity concept, which quantifies the extent of the temperature elevation during a heatwave in a manner relevant to the expected impact of the heatwave on human health. The forecasting system makes use of both daily maximum and minimum temperatures, the latter providing implicit information about average humidity levels, without humidity being included explicitly in the calculation.

This paper will document the heatwaves of the 2013/2014 Australian summer, in terms of the EHF metric, and will describe how well they were forecast by the new service.

INTRODUCTION

Heatwaves represent a significant natural hazard in Australia, arguably more hazardous to life than bushfires, tropical cyclones and floods. In the 2008/2009 summer, for example, many more lives were lost to heatwaves (374 excess deaths in Victoria alone, VDHS 2009; an additional 50 to 150 deaths in South Australia have been estimated, Reeves et al. 2010) than to that summer's bushfires (173 deaths, VBRC 2010) which were among the worst in the history of the Australian nation. Yet for many years, these other forms of natural disaster have received much greater public attention than heatwaves. This might be changing in Australia however, as health and emergency services increasingly use weather forecast information to become proactive in providing advice to the community on how to mitigate the effects of heatwaves. Significant community engagement took place during the 2013/2014 Australian summer, a summer which generated some significant heatwaves, comparable to those of 2009, 2004, 1939 and 1908.

In January 2014, the Australian Bureau of Meteorology introduced a pilot national heatwave forecasting service, to issue forecasts of forthcoming non-severe, severe and extreme heatwaves. The service is based on the excess heat factor (EHF) or heatwave intensity concept (Nairn and Fawcett 2013), which quantifies the extent of the temperature elevation during a heatwave in a manner relevant to the expected impact of the heatwave on human health. The forecasting system makes use of both daily maximum and minimum temperatures, the latter providing implicit information about average humidity levels, without humidity being included explicitly in the calculation.

This paper will document the heatwaves of the 2013/2014 Australian summer, in terms of the EHF metric, and will describe how well they were forecast by the new service. We also compare the 2014 Melbourne heatwave with earlier heatwaves in its history.

METHODOLOGY AND DATA

The EHF is a new measure of heatwave intensity, incorporating two ingredients. The first ingredient is a measure of how hot a three-day period (TDP) is with respect to an annual temperature threshold at the particular location. If the daily mean temperature (DMT) averaged over the TDP is higher than the climatological 95th percentile for DMT (denoted T_{95} in what follows), then the TDP and each day within in it are deemed to be in heatwave conditions. [This calculation uses the period 1971-2000.] On average, around 18 days per year will have a DMT exceeding T95, but it is necessary to have three high DMTs in succession in order to form a heatwave according to this characterisation. The second ingredient is a measure of how hot the TDP is with respect to the recent past (specifically the previous 30 days). This takes into account the idea that people acclimatise (at least to some extent) to their local climate, with respect to the temperature variation across latitude and throughout the year, but may not be prepared for a sudden rise in temperature above that of the recent past.

The heatwave intensity (i.e., the EHF) is a combination of these two ingredients, and larger values of each ingredient result in a larger EHF (see Nairn and Fawcett 2013 for a detailed explanation of the calculation and the climatology periods adopted). The heatwaves across the period 1958-2011 are assessed, and the severity threshold at each location set to be the 85th percentile of EHF values. This implies that 15 per cent of the TDPs in heatwave at a particular location will be severe. The extreme heatwave threshold is then set at a multiple (three) of the severity threshold. The units of EHF are $(°C)^2$, or perhaps more conveniently K^2, as the EHF is a modified product of the two ingredients described above.

EHF values may be calculated using site daily temperature data (as in Figure 2 below) or using gridded analyses of daily temperature such as the Bureau of Meteorology's operational analyses (Jones et al. 2009; the choice of 1958 as the start year for the climatology period arises from data availability considerations in these operational analyses). Forecasts of DMT, and subsequently of EHF, have been prepared using the modified Gridded Objective Consensus Forecast (GOCF) system described in Fawcett and Hume (2010). This GOCF system allows forecasts of DMT for seven consecutive days, and consequently forecasts of EHF for five consecutive overlapping TDPs to be made once each day. While these EHF forecast were only issued to the Australian public from 8 January 2014 onwards, the Bureau of Meteorology was generating these forecast internally before their public release, and accordingly we present forecast verification results for the period November 2013 to March 2014 inclusive.

The heatwave forecasts issued to the public took the form of maps (an example is shown in Figure 1) showing areas forecast to be in extreme, severe and non-severe heatwave, or not in heatwave at all, together with supporting commentary. Underlying these maps were gridded forecasts, but these were not made available to the public during the 2013/2014 summer.

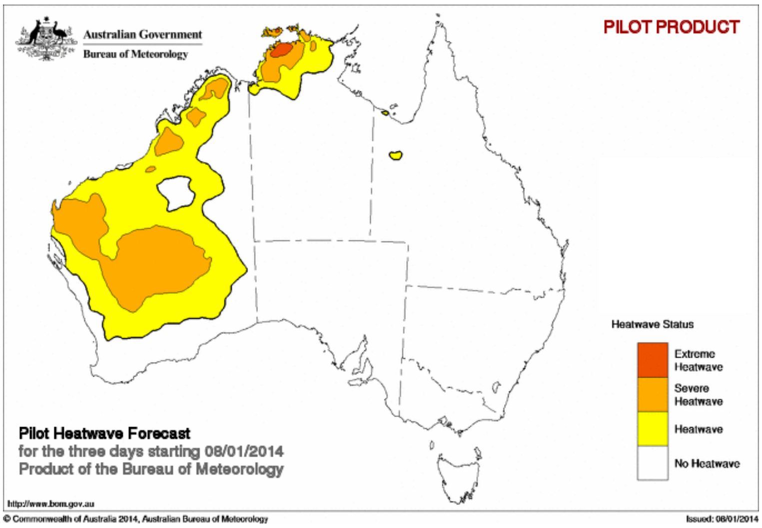

Figure 1: Heatwave forecast map for the TDP 08/10 January 2014, prepared in the morning on 8 January 2014. The coloured shades denote regions with heatwave, severe heatwave and extreme heatwave forecasted.

RESULTS

Figure 2 compares the heatwaves of 1908, 1939, 2009 and 2014, as they appear in the daily temperature data from the Bureau of Meteorology's Melbourne Regional Office site (Station number 086071), using the base periods described in the previous section. These daily temperature data are quality-controlled, but not homogenised. To put these four years in context, a pre-federation heatwave in mid-January 1875 saw three consecutive days with maximum temperatures above 41°C in Melbourne, with a peak EHF of 140 K^2 (more than five times the severity threshold). The cool temperatures in the weeks preceding this event were a notable contributing factor to the very high EHF. Thirty years later, an event in mid-January 1905 saw three consecutive days above 40°C and a peak EHF of 94 K^2 (more than three times the severity threshold).

The 1908 heatwave (Figure 2a) peaked (at 82 K^2) just into the extreme range at Melbourne, with the city experiencing five consecutive days with maximum temperatures of 40°C or above, and six consecutive days of 39.9°C or above, setting consecutive-day records which still stand. While the peak intensity of this event was less than that of the 1905 event, the longer duration of the 1908 event made it much more significant in terms of cumulative heat load. 246 fatalities across southern Australia have been reported for this heatwave (Reeves et al. 2010).

The 1939 heatwave (Figure 2b) was weakly represented in the Melbourne data, with its strongest presence in southwest New South Wales. Melbourne experienced some very hot days during the heatwave (43.1°C on the 8th, 44.7°C on the 10th, 45.6°C on the 13th and Melbourne's then hottest day on record broken only in 2009), but they were not consecutive and were interspersed with much cooler days. 438 fatalities have been reported (Reeves et al. 2010), 300 being in country NSW.

The 2009 Melbourne heatwave (Figure 2c) in late January was extreme, with 9 consecutive days of heatwave and six consecutive days of severe heatwave. The peak intensity (132 K^2) was nearly five times the severity threshold. There were three consecutive days with maximum temperatures above 43°C, a new three-day record. An analogous two-day record was also set during the event: both still stand. A week after the heatwave, on 7 February, a new daily record (46.4°C) was set, breaking the previous 45.6°C record of 13 January 1939, both days of catastrophic bushfires (Pyne 1991; VBRC 2010).

The 2014 Melbourne heatwave (Figure 2d) in mid-January was even more extreme than the 2009 heatwave, with a peak intensity (147 K^2) more than five times the severity threshold. There were seven consecutive days of heatwave and six consecutive days of severe heatwave. There were four consecutive days with maximum temperatures above 41°C (from the 14th to the 17th), a new four-day record. In summary, the 2014 heatwave in Melbourne was comparable with the worst previously experienced in the instrumental record (which extends back to 1856).

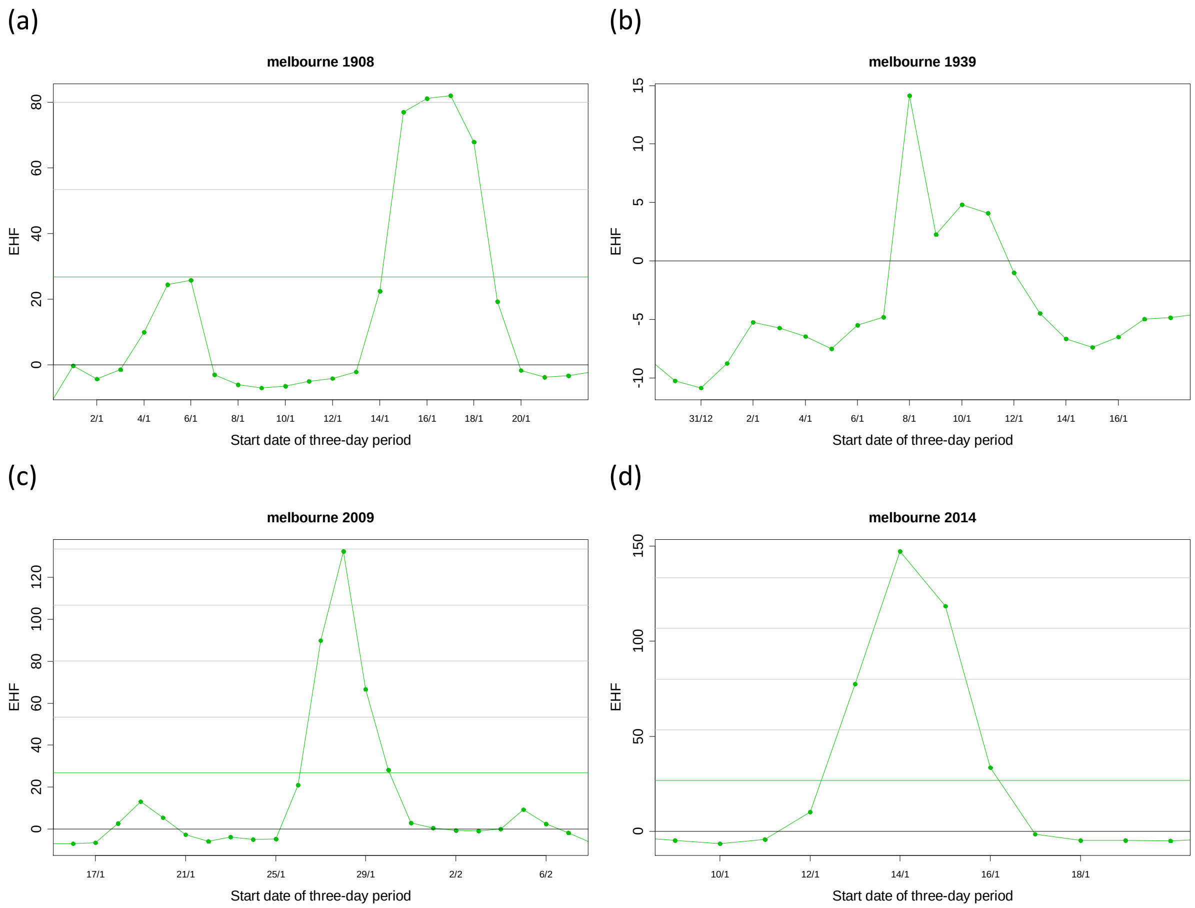

Figure 2: Four heatwaves in Melbourne, Victoria: (a) January 1908, (b) January 1939, (c) January/February 2009, and (d) January 2014. The horizontal green line represents the EHF severity threshold EHF85, with the horizontal grey lines multiples thereof. The calculation based on site data. At this site, T_{95} is 24.9°C.

Figure 3 shows the percentage area of Australia (as calculated using continental Australia and the main island of Tasmania) in heatwave for each TDP from November 2013 to March 2014, with Figure 4 and Figure 5 showing the analogous results for severe and extreme heatwaves, respectively. At the peak summer extent, more than half the country was simultaneously in heatwave, and more than 30 per cent simultaneously in severe heatwave. At one point (not shown) all of Victoria was in severe heatwave, and most of it actually in extreme heatwave.

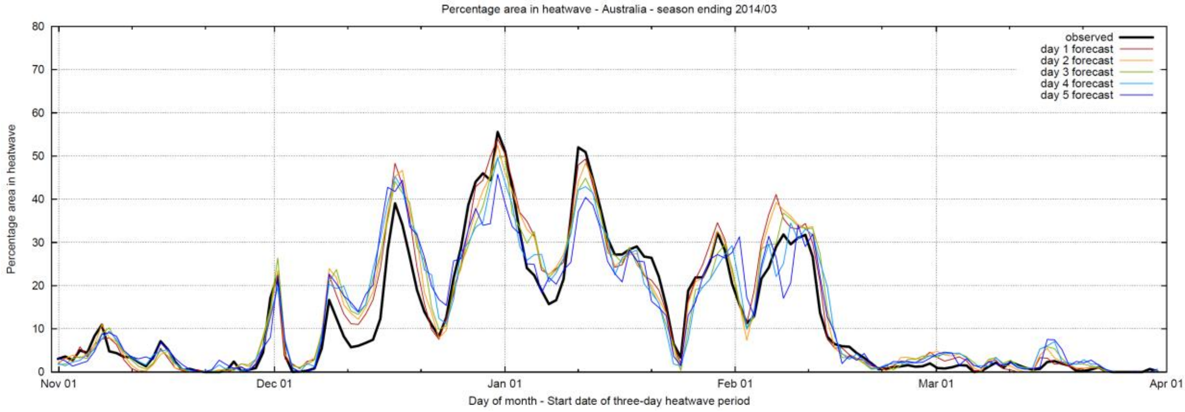

Figure 3: Percentage area of Australia in heatwave (black line) for the period November 2013 to March 2014, together with the percentage area forecast to be in heatwave at short (red, yellow) to long (blue, purple) lead times.

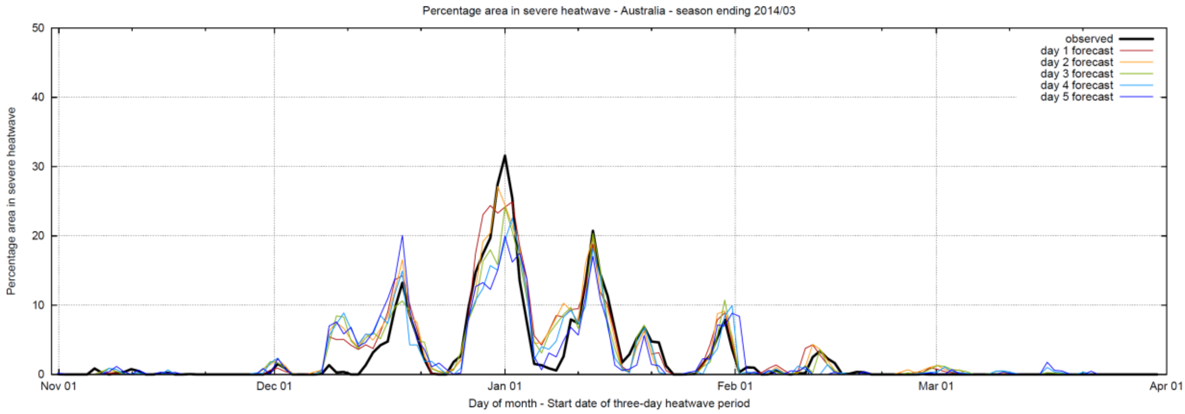

Figure 4: As per Figure 3 but for severe heatwaves.

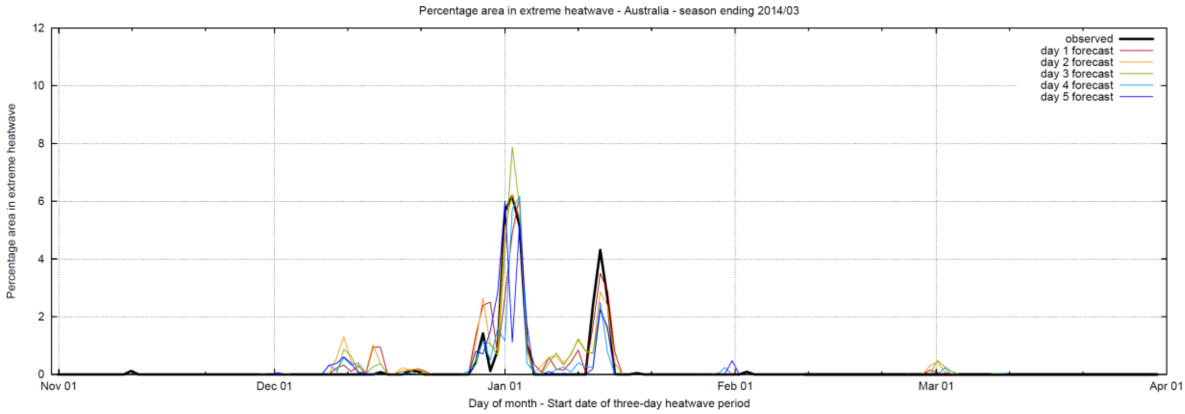

Figure 5: As per Figure 3 but for extreme heatwaves.

Six significant bursts of heatwave activity during the 2013/2014 summer may be identified in Figure 3. These will now be described using the gridded EHF data. In each case a representative location will be chosen to present a time series of EHF interpolated from the grids, together with a map integrating the positive EHF values within the nominated period to characterise the spatial pattern of the episode. The interpolated data are representative of a larger area (the analysis grid cells are ~ 20 to 25 km across) than would be the case for site data at the same location.

LATE NOVEMBER/EARLY DECEMBER

Although one fifth of the country was simultaneously in heatwave conditions, this was a mild event in terms of intensity. It covered much of inland Australia (Figure 6) and extended far into the southeast, but reached severe levels only in central and northwest Western Australia. It did not impact upon major population centres.

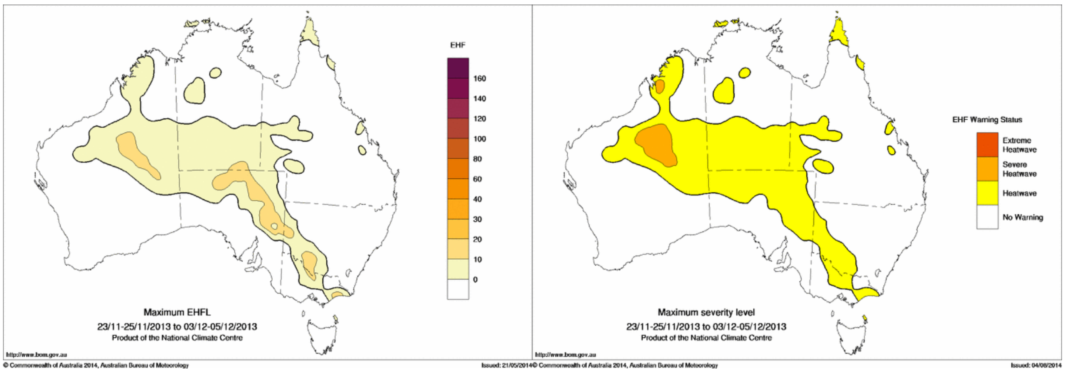

Figure 6: Maximum EHF attained during the first heatwave episode of the 2013/2014 Australian summer, expressed in terms of EHF values (left) and severity level (right).

MID-DECEMBER

This episode covered much of southern Australia (Figure 7), although without the southeast coastal regions being much affected. Mildura (Victoria) went into severe heatwave (Figure 8, peaking on 18/20 December), as did Adelaide and Oodnadatta (South Australia, not shown). Kalgoorlie-Boulder (southwest Western Australia) also experienced severe heatwave conditions (not shown, peaking on 15/17 December), but a few days earlier.

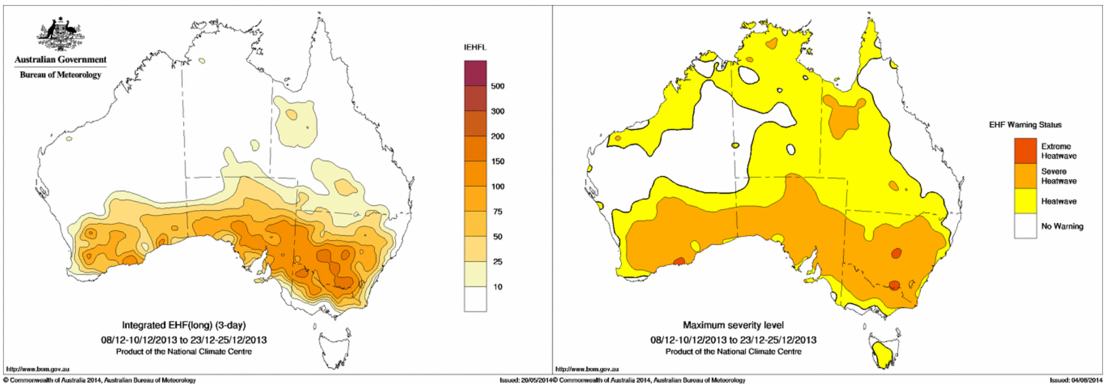

Figure 7: Integrated EHF across Australia for the period 08/10 to 23/25 December 2013 (left) and maximum EHF within that period expressed in terms of severity level (right).

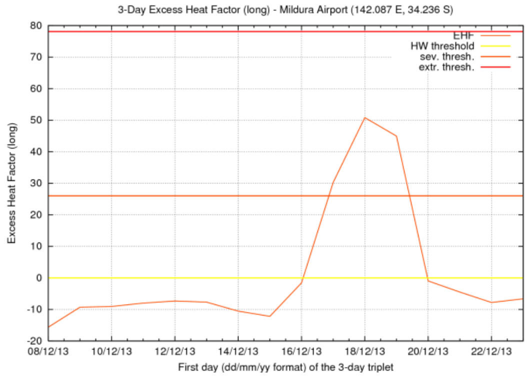

Figure 8: Time series of EHF (left) for Mildura (Victoria) for the period 08/10 to 23/25 December 2013. The peak intensity was 1.95 times the severity threshold (horizontal orange line). The yellow line denotes the non-severe heatwave threshold, and the red line the extreme heatwave threshold.

LATE DECEMBER/EARLY JANUARY

This episode was active across Queensland and the Northern Territory (Figure 9), although extending into South Australia and inland Western Australia. The peak intensity (19.8 K^2, on 03/05 January) at Brisbane (Figure 10) was more than 3.8 times the severity threshold, making this an extreme event there. Archerfield in suburban Brisbane reached 43.5°C on the 4th, its hottest day on record. This was also an extreme event further inland at locations such as Dalby (not shown).

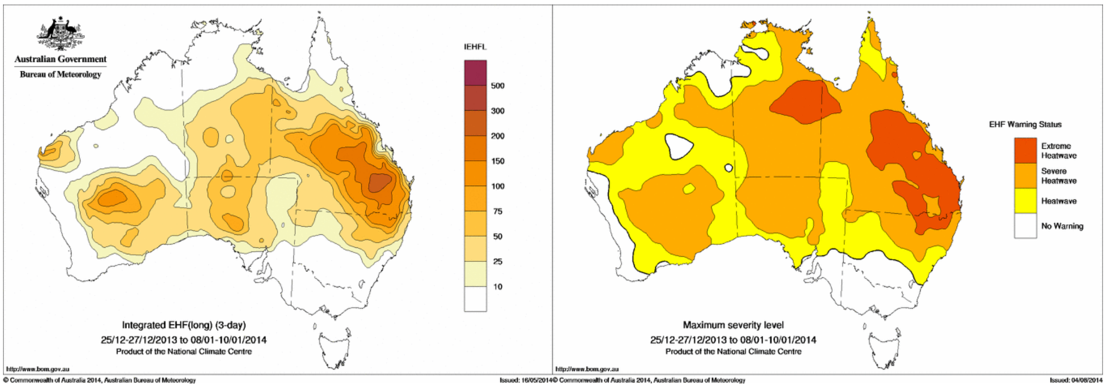

Figure 9: As per Figure 7 but for the period 25/27 December 2013 to 08/10 January 2014.

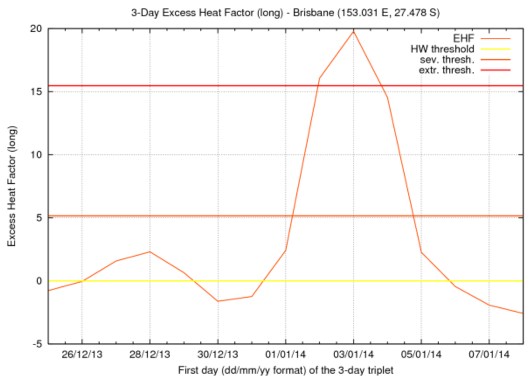

Figure 10: As per Figure 8 but for Brisbane (Queensland) for the period 25/27 December 2013 to 08/10 January 2014. The peak intensity was 3.8 times the severity threshold.

MID-JANUARY

This episode was in many respects a typical southeast Australian heatwave, although a particularly intense one. Peak intensities were across Victoria and adjacent parts of South Australia (Figure 11). Early assessments suggested that this heatwave resulted in at least 100 excess deaths in Victoria (ABC 2014). For Melbourne, the peak intensity was 5.5 times the severity threshold (Figure 12), for Adelaide 3.5 times (implying that it was slightly less intense than the 2009 event there).

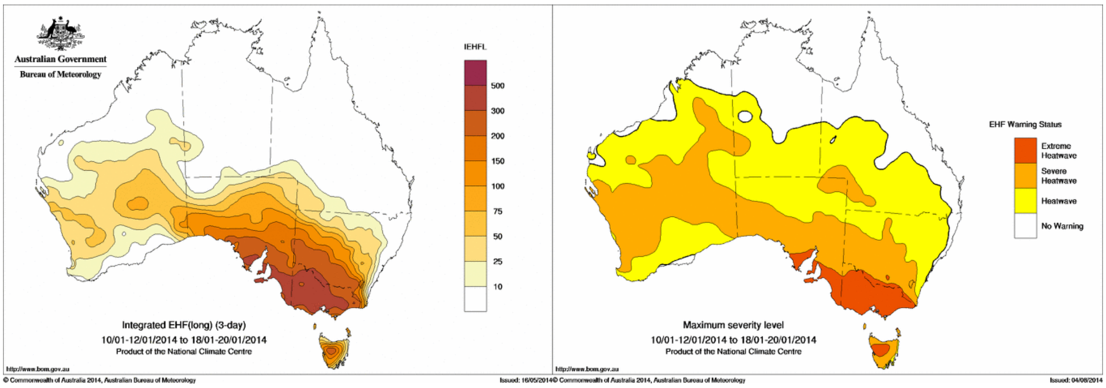

Figure 11: As per Figure 7 but for the period 10/12 to 18/20 January 2014.

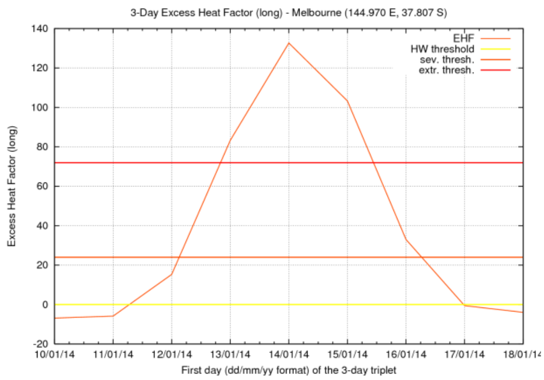

Figure 12: As per Figure 8 but for Melbourne (Victoria) for the period 10/12 to 18/20 January 2014. The peak intensity was 5.5 times the severity threshold.

LATE JANUARY

This episode, while affecting much the same area as the previously described episode, had a reduced impact along the Victorian coast (Figure 13). Accordingly, Mildura is chosen as the representative location (Figure 14) for this episode. With peak intensity 2.2 times the severity threshold, this event was well into the severe category at Mildura. The event was also severe at Adelaide (not shown, 1.3 times the severity threshold).

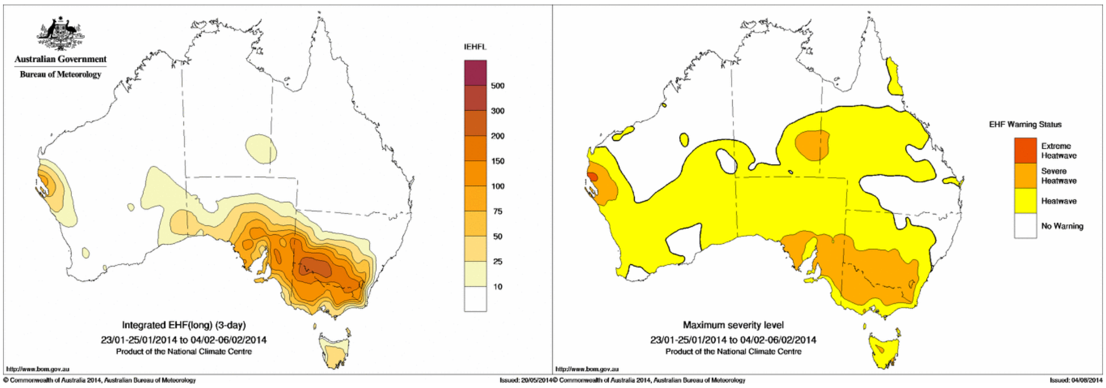

Figure 13: As per Figure 7 but for the period 23/25 January to 04/06 February 2014.

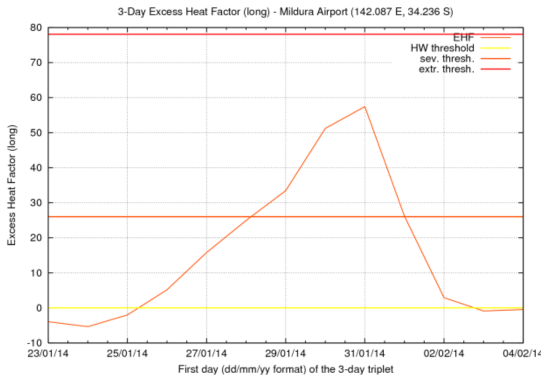

Figure 14: As per Figure 8 but for Mildura (Victoria) for the period 23/25 January to 04/06 February 2014. The peak intensity was 2.2 times the severity threshold.

EARLY FEBRUARY

This last episode of the summer mainly affected inland parts of southeast Queensland and the southeast States (Figure 15). Peak EHF severity levels were attained along the Queensland-New South Wales border and around Carnarvon in Western Australia, at twice the local severity threshold. Moree (New South Wales) is chosen in Figure 16 as a representative location. During the period represented in Figure 15, nearly all the southern half of the country experienced non-severe heatwave conditions at some point.

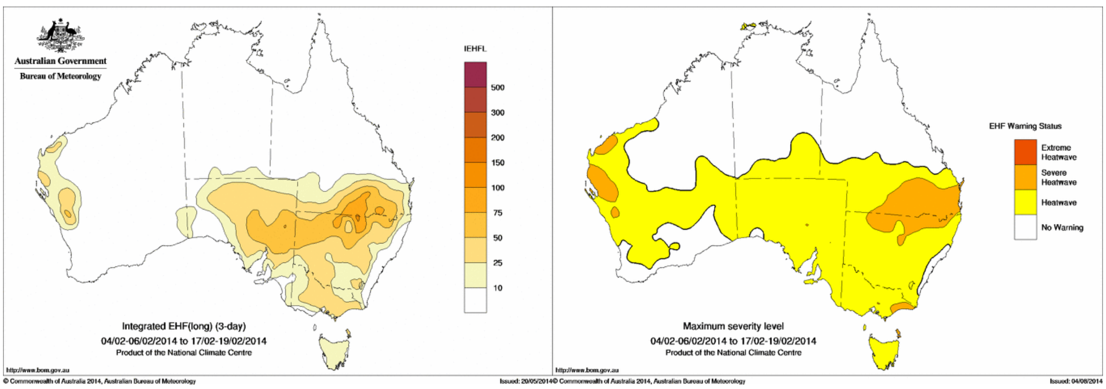

Figure 15: As per Figure 7 but for the period 04/06 to 17/19 February 2014.

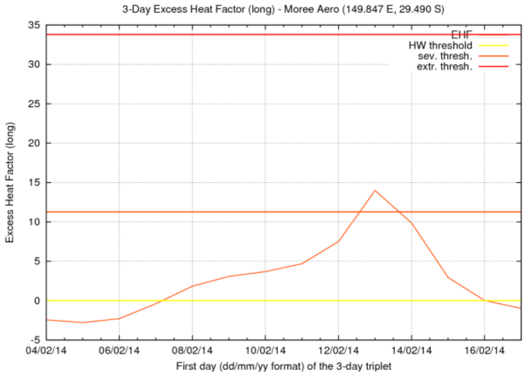

Figure 16: As per Figure 8 but for Moree (New South Wales) for the period 04/06 to 17/19 February 2014.

DISCUSSION

The 2013/2014 Australian summer saw some very significant heatwaves, comparable to the worst previously seen in the historical record. For Melbourne, this meant a lapse of just five years since the previous event of a comparable magnitude. It should be noted that the site data used to generate the results shown in Figure 2 are quality-controlled but not homogenised and that lack of homogenisation may have some bearing on the interpretation of the results. Across the period represented by the results (1875 to 2014) the observing site (086071) has moved once (January 1908), with a possible change in the screen used to house the thermometers. Ashcroft (2013) found statistical evidence for a minor inhomogeneity in minimum temperature around the time of the site move, but none for maximum temperature, so its impact on the EHF would likely not be large. In recent decades the site has seen significant building construction nearby, and so a significant urban heat island (UHI) effect may be present in the minimum temperatures. On the other hand, the UHI is thought to be more noticeable on cool, clear nights which would not normally be associated with spikes in the EHF at this site. In the preparation of homogenised temperature time series, the removal of non-climatic signals such as those caused by site moves, changes in observing practices (including instrumentation and instrument housing) and changes in site surroundings is required. This normally motivates an avoidance of city sites affected by the UHI effect, although for some purposes the UHI effect is only significant (and therefore to be removed) if it *changes* across the duration of the time series. In the heatwave context, while most of the above noted non-climatic signals should be removed in a temperature homogenisation process, we would recommend the retention of the UHI effect in the temperature data contributing to the EHF calculation because of its direct relevance to the human experience of heatwave.

Figure 3 indicates that there is considerable skill in forecasting the national percentage area in heatwave, even at long lead-times (e.g., four days), although the percentage area may sometimes be over-forecast or under-forecast. None of the major severe heatwave events (Figure 4) or extreme heatwave events (Figure 5) were missed, although there were some false alarms (i.e., events forecast which did not subsequently occur). It should be noted that the ability to forecast EHF essentially arises from the ability to forecast daily maximum and minimum temperatures. At short range, daily maximum and minimum temperatures are well forecast, although forecast skill does typically degrade with increasing lead time, and the consequences of this can be seen to some extent in Figure 3 and Figure 4. The ability to forecast the extreme events (Figure 5) is not as good as that achieved for severe events (Figure 4). This is not an unreasonable result when considering the infrequency of extreme heatwaves in comparison to severe heatwaves.

The pilot heatwave forecast service product consists of an image graphic supported by limited text. As such this service is not integrated with the Bureau's official digital forecasts and warnings system. The Bureau's Next Generation Forecast Warning System (NexGenFWS) is responsible for the generation and distribution of Australia's official forecasts and warnings, which is held in the Bureau's Australian Digital Forecast Database. The Bureau is investigating community interest in the generation of a national heatwave warning system within the NexGenFWS, which would enable multiple formats and delivery channels for the delivery of heatwave forecasts and warnings.

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