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A HEATWAVE FORECAST SERVICE FOR AUSTRALIA

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ABSTRACT: The Australian Bureau of Meteorology monitors, researches, predicts and communicates Australia's weather and climate. Australia's mean temperature has risen by over 1°C since 1910, leading to an increase in the frequency of extreme heat events. Extreme heat can profoundly impact human health, infrastructure and the environment. Research conducted at the Bureau and elsewhere shows that climate change is impacting the intensity and frequency of extreme heat events. One way that the Bureau has responded to this challenge is by providing a forecast service specifically targeted at identifying heatwaves. The heatwave service identifies areas expected to be impacted by three or more consecutive days of unusually high maximum and minimum temperatures on a national map. The service has been developed with clear impact-based categories of heatwave severity. This heatwave service is now available operationally on the Bureau's website during the heatwave season (nominally November to March) and is proving a valuable tool for engaging the community, including emergency services, with forecasts and warnings of extreme heat.

Keywords: climate change heatwaves, heatwave forecasting systems, communication, weather forecasts, public safety

INTRODUCTION

In September 2018, the Australian Bureau of Meteorology (Bureau) presented two extreme weather scenarios at the Royal Society of Victoria's Future Thinking Forum. One scenario was of a future extreme heatwave impacting on southeastern Australia with record overnight and daytime temperatures. The forecast temperatures on the future dates proposed were based on temperatures occurring in past observed extreme heatwaves, and what temperatures may occur in Australia in the future under a warming climate (Lewis et al. 2017). This scenario was presented to aid discussion on the day around the future impacts on the community from extreme heat and what services and infrastructure may be needed to adapt to future increases in heatwave severity and frequency.

This paper details the processes behind the Bureau's development of an impact-based service for forecasting extreme heat. The heatwave service was developed using a number of steps. Research was undertaken pointing to the need for such a service, the service was developed and extensively tested, and importantly the delivery and communication of the service was also given priority, especially through partnerships with relevant state agencies. The delivery of the national heatwave service provides a model for the future development of services to support the Australian community.

There has been an increase in the number of days each year where the Australian area-averaged daily mean temperature is extreme relative to its monthly mean (Bureau & CSIRO 2018) and an increase in extreme warm months (Figure 1). Extreme heat can have major impacts on health and infrastructure. With extreme heat increasing in frequency and intensity, both globally (e.g. Perkins et al. 2012) and nationally on a range of timescales (e.g. Bureau & CSIRO 2018; Hope et al. 2016), responding to the challenge of managing for extreme heat, especially with respect to human health, is of national and global concern (WMO 2015). Some of the ways the Bureau is adapting to this challenge is through the provision of a heatwave service and increased communication and engagement.

One of southeast Australia's most severe heatwaves occurred in January and February 2009 leading up to the 2009 Black Saturday bushfires (Figure 2a). A subsequent comparable severe heatwave affected southeast Australia in January 2014. This latter heatwave was one of the most significant for Victoria and South Australia, in terms of both intensity and duration. Large areas across both states recorded maximum temperatures in excess of 40°C across the event (Figure 2b). Victoria had its hottest four-day period on record, for both maximum and daily mean temperature with Victorian average maximum temperatures exceeding 41°C on four successive days from 14 to 17 January.

Heatwaves are historically the leading cause of fatalities from natural disasters in Australia (Coates et al. 2014). After the extreme heatwave of January 2009, in which an estimated 374 people across Victoria died as a result of heat-related health issues, the state of Victoria enacted a heatwave response plan (DoH 2011). A similar response

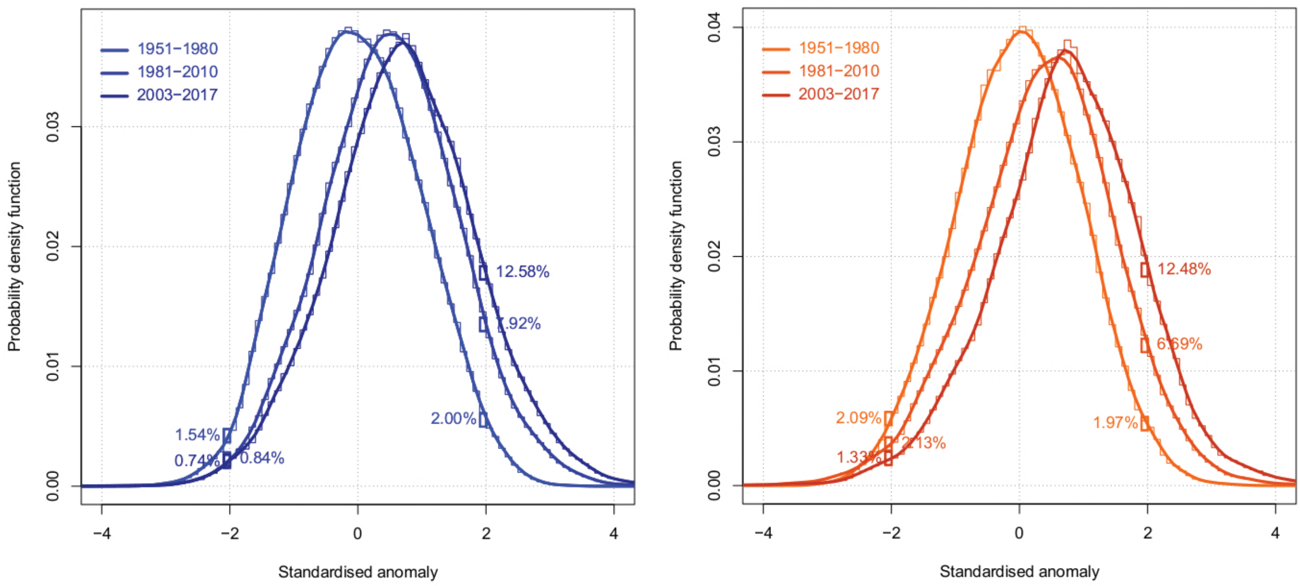

Figure 1: Distribution of monthly minimum (a) and maximum (b) temperature anomalies (standardised with respect to the 1951–1980 base period) aggregated across all grid points across Australia (based on a 5 km grid) and all months of the year, for three periods: 1951–1980 (light blue, orange), 1981–2010 (medium blue, medium orange) and 2003–2017 (dark blue, red). Very warm months correspond to two standard deviations from the mean. Very warm monthly minimum and maximum temperatures that occurred around 2% of the time over the period 1951–1980 now occur over 12% of the time. Updated from BoM and CSIRO (2016).

was also seen in South Australia with the introduction of an Extreme Heat Plan (SES, viewed 2019). During the January 2014 extreme heatwave across both South Australia and Victoria, the heatwave response plans were credited with reducing the morbidity and mortality of the event. Across Victoria the number of deaths attributed to the heatwave was reduced, with an estimated 167 excess deaths reported (DoH 2014). A decrease in morbidity was also observed across both States (DoH 2014; Nitschke et al. 2016).

The reduction in lives lost with the implementation of a dedicated heatwave warning plan demonstrates the benefits and importance of a national service aimed at forecasting for heatwave conditions that may impact on human health and the community. The Australian Bureau of Meteorology, as the national weather service provider, has developed a heatwave service aimed at forecasting for extreme heat with an impact-based component. This service complements and extends the traditional weather forecast.

DEVELOPING A HEATWAVE SERVICE FOR AUSTRALIA

Australia's heatwave definition has been developed to specifically identify when it is unusually hot at any location across Australia. Determining whether heat is unusual with respect to past temperatures is important, as systems are acclimatised to what is normal for that location. The Excess Heat Factor (Nairn & Fawcett 2014) uses the average of the maximum and minimum (daily) temperature over a three-day period to create long-term and short-term temperature anomalies, which are factored together as a measure of heatwave intensity. In developing a measure of extreme heat, the long-term temperature anomaly is set against the 95th percentile of daily temperatures over a 30-year reference period (1971–2000). The percentile (statistical) approach has allowed every location to have a specific or percentile-based threshold that is sensible for each location's climate. The short-term anomaly is set against that location's daily temperature for the previous thirty days. The long-term anomaly records the significance of the heat event against the climate record, while the short-term anomaly measures the size of the acclimatisation or adaptation challenge. These anomalies reflect the considerable (if not unlimited) ability of people to adapt to the seasonal cycle of temperature at their particular location, and to adapt to a new seasonal cycle upon migration to a new location.

It is not unusual to use a percentile of only maximum temperature over three or more days as a heatwave definition. Inclusion of the minimum temperature, however, acts as a proxy for the presence of humidity (higher minimum temperatures are induced by a humid atmosphere) and for modifying the diurnal heating cycle (high temperatures are reached sooner and sustained longer for higher minimum temperatures). High night time temperatures also exacerbate the impact of hot days on human health, so the mean temperature, which averages maximum and minimum temperatures, is an important measure of heatwave intensity.

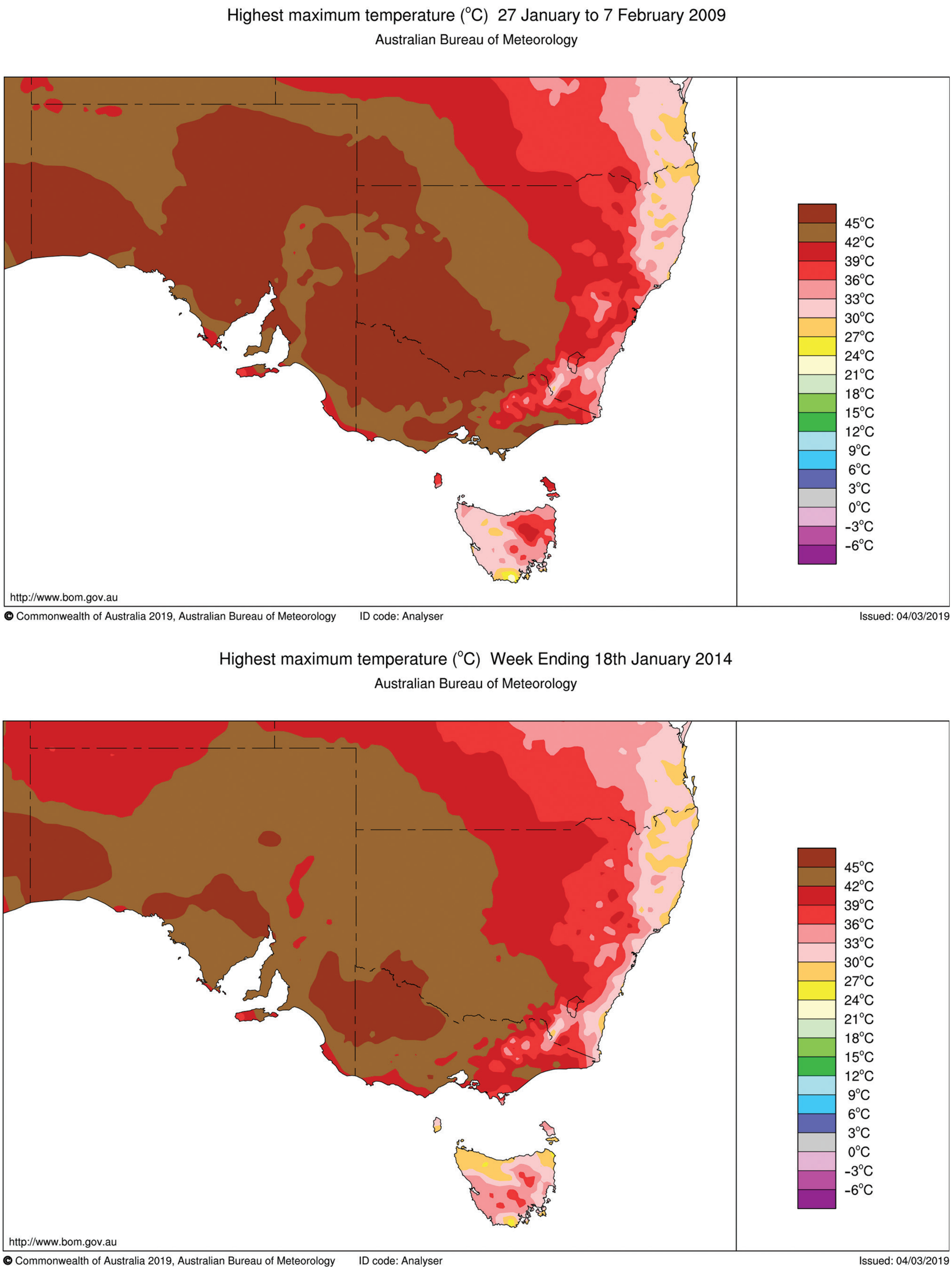

Figure 2: The highest temperature reached during the period 27 January to 7 February 2009 (a) and 12 to 18 January 2014 (b).

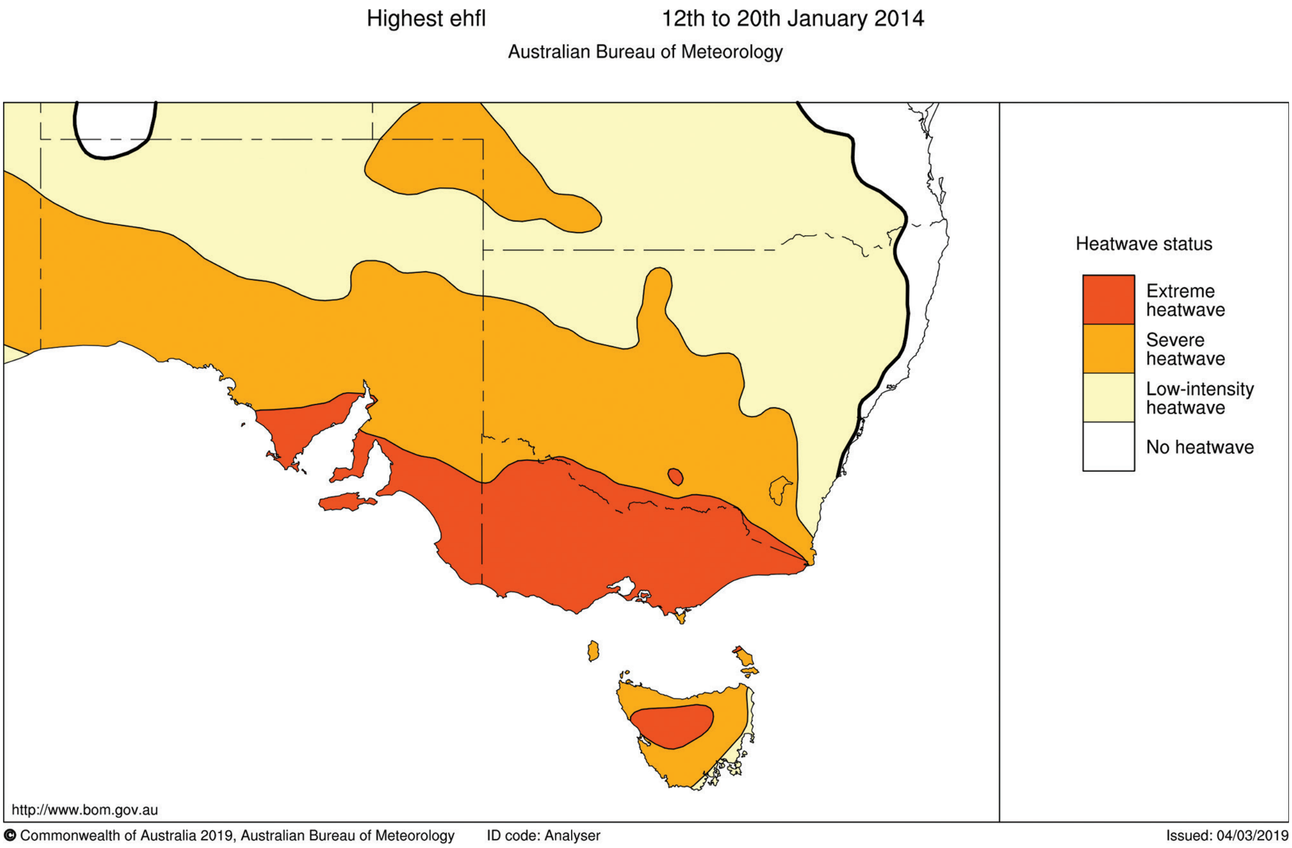

Figure 3: Extreme heat in January 2014. Heatwave status (highest three-day EHF) for the period 12 to 20 January 2014.

In the extreme heatwave of 2014 (Figure 3), which saw large health-related impacts across Victoria, high temperatures were observed across Melbourne during both day and night. From 14 to 17 of January the maximum temperatures recorded at the Melbourne Regional Office were all above 41°C, with daily minimum temperatures over the 15–17 period all above 25°C (Bureau of Meteorology 2014). The duration of this extreme heat (greater than three days) was also a factor in the impact on human health.

The ability to map Excess Heat Factor required an additional statistical treatment due to the wide disparity in temperature anomalies between the tropics and mid-latitudes. The 85th percentile of each location's heatwave intensity climate record resulted in a specific intensity threshold that is used at every location as the denominator to convert heatwave intensity into a severity index. The Australian heatwave service maps heatwave severity in the form of colours typically associated with hazards (pale yellow, orange and red) that identify limits of adaptation to increasing heatwave intensity. In Australia's heatwave service there are three categories: a severity between 0 and 1 is mapped as a low-intensity heatwave (pale yellow), between 1 and 3 as a severe heatwave (orange) and greater than 3 as an extreme heatwave (red). The restriction to three categories has been shown to aid communication and understanding of the forecast, especially over social media platforms such as Twitter (Figure 4).

Most heatwaves are low-intensity (Figure 4, pale yellow). As this is a common experience during the warmer months it is reasonable to consider that the population has adequate adaptation measures which may confer some protection from heat impact at this level. Severe heatwaves (orange) are rarer and more intense, and will challenge people that may be vulnerable through factors such as age impairments, fuel poverty or disease. This has been shown to occur at this threshold in two Australian cities (Nairn & Fawcett 2013) where mortality in people over 65 years of age began to appear at this threshold. Even rarer, much more intense, extreme heatwaves (red) require protective action by the entire population. Normal heatwave adaptive measures are inadequate for healthy people at this exposure. This is evident when people without co-morbidity (including elite athletes) suffer impact, and as infrastructure begins to fail, exposing the population to reduced adaptive resources (Nairn & Fawcett 2013). Studies of extreme heatwave impacts around the globe have been able to be mapped with Excess Heat Factor severity.

The heatwave service is now operational on the Bureau's website over the warm season (www.bom.gov.au/australia/heatwave/). Over the period of the January heatwave in 2014, ending on 18 January, nearly all of Victoria and southeast South Australia experienced an extreme heatwave (Figure 3). Contrasting this map with

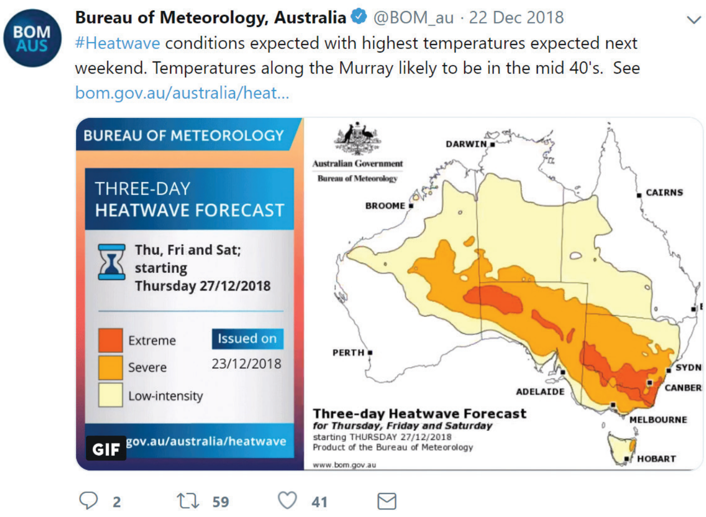

Figure 4: Twitter post showing the issuance of a heatwave forecast for the three-day period 27 to 29 December 2018.

the map of the highest temperatures reached during the event (Figure 2b) shows that the heatwave impact map gives more information about the climatological context and about the impacts associated with the temperatures experienced. This allows for better decision making and communication of the likely impacts of forecast extreme conditions.

Heat and heatwave impact services

Continuous improvement of numerical weather prediction modelling has increased lead-time and confidence in forecasts of extreme temperatures. The heatwave service has combined high quality climate data and forecast temperatures in a manner that forecasts community impacts, improving the national dialogue with both the public and emergency services. Forecasts of Excess Heat Factor act as predictions of exposure (heatwave intensity) that predict human health impact, verified in multiple human health studies (Langlois et al. 2013; Herbst et al. 2014; Hatvani-Kovacs et al. 2015; Scalley et al. 2015; Nitschke et al. 2016; Jegasothy et al. 2017; Williams et al. 2018).

Growing awareness of increased adverse health outcomes arising from intense heatwaves among health authorities and emergency services has created increased demand for Bureau services. Following a project in 2018, the resolution of the heatwave maps was increased from 25 km to 5 km and the data underpinning the heatwave maps were made available, to support state-based heat health plans. Victoria's Department of Health and Human Services has operated a Heat Health Alert system from November to March for several years. The system is based on percentile-based temperature thresholds above which heat-related illness and mortality increases. It utilises the Bureau's seven-day maximum and minimum temperature forecasts to determine when thresholds are expected to be breached.

Victoria's fire and emergency services have always monitored rising heat with concern due to rising fire danger. A specialist advisory service is provided to the Victorian State Control Centre by an embedded Bureau meteorologist, moving to a seven-day a week operation during the warm season. Advice on forecast certainty and climate outlooks assist emergency management teams to position resources with greater confidence. The ability to diagnose, forecast and observe unfolding events, including heatwaves, assists with decision making. Increased awareness of heatwave impact has resulted in briefing products now incorporating a focus on interpretation of upcoming heatwaves.

IMPACT FORECASTS AND COMMUNICATION

Development of the Bureau's heatwave service has improved community awareness of impending heatwaves. Extensive education material to support the service has also been developed. Briefing meteorologists work with journalists through a variety of media channels to provide reinforcing commentary as heatwaves approach. Great interest is shown in the potential for broken temperature records, effects of heat on fire danger and when relief from the heat can be expected. Pre-recorded audio and video interviews with climatologists and meteorologists can now be embedded within radio and TV news features. Press conferences for mass media can meet higher demand, particularly when joint presentations with health and emergency services partners are required (Figure 5).

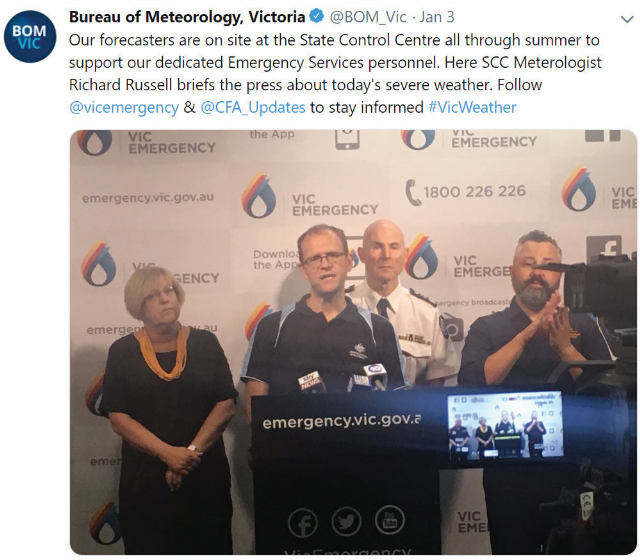

Figure 5: Twitter post of Bureau meteorologist briefing the press about upcoming severe weather in coordination with emergency service agencies and linking to relevant emergency agencies websites.

High-quality professional videos are also produced within the Bureau to provide succinct information on nationally significant weather events, including continental scale heatwaves. These videos are published online and shared through social media channels.

The Bureau's heatwave service use of three heatwave intensity categories lends itself to communication through Twitter (Figure 4). In the lead-up to extreme heat events, Twitter is now used to notify followers of significant forecasts, to re-tweet messages from health authorities and emergency services and broadcast any warnings that have been issued. Tweets from state and territory Bureau handles quickly update the community about conditions as they unfold. On a recent hot day in Victoria, routine updates on the progress of a cool change moving across the state informed the community on timing of relief from the heat. The use of Twitter hashtags encourages followers to engage with specific hazards such as heatwaves.

DISCUSSION

It is virtually certain that further warming will continue to increase the frequency and intensity of extreme heat events over Australia (CSIRO & BoM 2015; King et al. 2017) with attribution studies showing that large-scale warming is having an impact on recent extreme heat events over Australia and globally (e.g. Herring et al. 2016; Hope et al. 2016; Lewis & King 2015).

To adapt to the challenge of increasing heatwave intensity and frequency, a heatwave intensity and severity measure that can be used on climate and forecast time scales including multi-day, multi-week, seasonal and climate projection[1] time scales has been developed. As a statistical scheme it is also being tested on national and global forecasting platforms (Nairn et al. 2018). This scheme has been shown to be well associated with health impacts from heatwave events and allows improved communication of the likely impacts and climatological context of extreme heat among Bureau stakeholders, media and the general public.

A national heatwave service as delivered by the Bureau supports a coordinated awareness and response across the nation. A proposed new working group chaired by Emergency Management Australia aims to develop a national heatwave forecast and warning framework. This framework will provide a more consistent approach and terminology to heatwave warnings across all Australian jurisdictions to enhance community understanding of heat risk within and across state boundaries.

1 https://climate.copernicus.eu/feeling-heat-down-under

The development of the heatwave forecast service from researching the need of such a service through to development and implementation provides a model for an adaptation to a warming climate and for research at the Bureau informing operations to benefit the Australian community.

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Conflict of interest
The authors declare no conflicts of interest.

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