AUSTRALIA'S FUTURE NATIONAL HEATWAVE FORECAST AND WARNING SERVICE: OPERATIONAL CONSIDERATIONS.

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ABSTRACT

Heat wave is Australia's deadliest natural hazard. It is responsible for more hazard-related deaths than all other natural hazards combined. The incidence of severe and extreme heatwaves in Australia has been considerable and is projected to increase. Recent efforts to mitigate the impact of this rising frequency and severity of heatwave events across the nation has witnessed State and Territory authorities warning for impacts across human health, infrastructure, utilities, community events and business activities whilst the Bureau of Meteorology introduced a national heatwave service. Consultation across emergency services, health and media sectors has established the requirement for a national heatwave warning framework. Within the health sector separate calls have been made for a nationalised approach to heatwave warnings.

We describe an operational partnership model for emergency and health agencies community information and warnings facilitated by the Bureau's future heatwave forecasts and warnings in a multi-hazard warning framework.

Epidemiological studies have demonstrated that the Bureau's severity scale has skill in predicting health impacts in Western Australia, South Australia and New South Wales. The UK Meteorological Office has included the Bureau's heatwave and coldwave methodology in their Global Hazard Map project where it is also demonstrating acceptable levels of accuracy in identifying high impact events around the world.

The Bureau has supplied a national warm season heatwave severity service since January 2014 in the form of seven continental scale severity maps, updated once a day. Predictive skill and heatwave event severity characterisation reports for summers 2013-14, 2014-15, 2015-16 and 2016-17 have been circulated to the Bureau's internal Heatwave Services Reference Group to enable consideration and validation of the current heatwave service. This verification work is scheduled to continue with upgraded diagnostics included here for the 2017-18 season.

Future emergency services and human health information and warning services are prototyped using recently developed gridded heatwave service data. Heatwave forecast and warning services are demonstrated to characterise how each partner's information and warning services would have been supported during the 2017-18 summer.

EXTENDED ABSTRACT

Heatwave is now clearly understood to be Australia's deadliest natural hazard. Where once it was difficult to directly and accurately attribute deaths to discrete periods of extreme heat, (heatwaves), robust methodologies can now be applied to define and measure the direct and indirect, and tangible and intangible impacts of heat on human health and wellbeing (including mortality and morbidity), livelihoods, industry (including energy) infrastructure and agriculture.

Since the late 1800's extreme heat events have killed at least 5332 people and throughout the twentieth century heatwaves have been responsible for more than the sum of all other hazard related fatalities. More recently, in the period 2000 to 2010, 475 deaths are directly attributed to 8 events, including 435 from the 2009 Southern Heatwave, and 2 other events where over 10 deaths occurred (Risk Frontiers).

The entire Australian community is at some risk of suffering some level of harm or loss related to heat. The Australian Business Roundtable Report (p18) identified that in the 30 years between 1987 and 2016, 509 deaths; 2,800 injuries; and a total of 4,603,00 people were affected. They noted that during heatwaves generally there are more hospital admissions for mental health issues, workplace accidents and injuries, power outages and transport interruptions; which disrupt supply chains, businesses and community services and increase both the direct and indirect economic costs.

Heatwaves trends and projections exhibit an increase in frequency and intensity under a warming climate (Alexander et al., 2009; Kiktev, Sexton, Alexander, & Folland, 2004; Meehl & Tebaldi, 2004; Perkins, Alexander, & Nairn, 2012; Russo et al., 2014; Tollefson, 2012). Heatwaves extract a heavy toll upon vulnerable communities and on rarer occasions high intensity impacts spread to healthy people through failure of infrastructure, utilities and inadequate adaptation strategies (Department of Human Services & Victorian Government Department of Human Services Melbourne, 2009; Le Tertre et al., 2006; Mechler, Hochrainer, Aaheim, Salen, & Wreford, 2010; Yates, 2013).

Historically, human communities at greatest direct risk and most vulnerable to the health impacts during heatwaves have usually been considered to be the elderly, the very young and those working outdoors. However, in recent times death rates have decreased in the very young, most likely due to the wide availability of air conditioning and good monitoring of hydration and infant health. In the over 75 age bracket both mortality and morbidity rates are now marginally increasing. This may be related to increased opportunity for underlying health conditions that make them more susceptible. Australia's population is aging and this will increase the numbers in this at-risk cohort. Based on medium-level growth assumptions, the Australian Bureau of Statistics (ABS) projects the population to grow to 28.8 million by 2030 with the number of people aged 65 and over to rise by 91% and those aged 85 and over to more than double (ABS, 2008b). The elderly are also more likely to be increasingly living alone in urban dwellings where security concerns encourage keeping windows and doors closed, thus reducing ventilation, and economic concerns discourage the use of air-conditioning. Risk relating to exposure, on the other hand, is decreasing and with effective early warning can continue to decrease. Those working outdoors and exposed to the elements in relation to work such as farming,

mining, labouring and travelling and those engaging in extreme sporting activities can reduce their exposure and thus their risk with effective risk mitigation actions.

With or without climate warming, climatic extreme warning systems are required to reduce the risk of disasters, (Kovats & Kristie, 2006; Zia & Wagner, 2015). Choice of heatwave indices suitable for use in these systems must satisfy the following criteria:

1. Extreme values match user experience,
2. Useful as indicator of impact ,
3. Seamless services across climate records, 7-day, multi-week, seasonal and climate projection forecasts,
4. Ease of interpretation, and common to both policy and operational users
5. Mapped to provide timely and locally specific guidance, and
6. Operate within a multi-hazard warnings framework

Agencies tasked with generating the necessary environmental assessments, forecasts and warnings must also consider how policy-makers across the health sector, infrastructure and utilities can prepare and adjust to future climate scenarios. National meteorological agencies now consider seamless services as an achievable standard. Weather service infrastructure is easier to sustain and maintain, and enables clearer forecast and warnings messages consistent with a common protocol. A common message used in climate assessments and projections is more readily adopted when coupled with seamless daily, weekly and even seasonal forecast schemas. Policies that are replicated in operational practices will improve adoption and communication, and allow better partnerships within and between agencies.

Effective mitigation and response requires a negotiated national heatwave warnings framework in which the national weather service, emergency services and health agencies coordinate messages. The diversity of Australian extreme heat hazard lead-agencies across state and territory jurisdictions mandates the development of this framework to ensure a consistent service for the Australian community.

Recent investigations have focused on the need to understand and measure heatwave intensity in a manner that is meaningful for each location. Percentiles-based heatwave metrics are recommended to satisfy the locality criteria (Perkins & Alexander, 2013), whilst the development of an intensity calculation that is meaningful to any sector has produced the Heat Wave Magnitude Index (HWMI) and its daily derivative HWMId (Russo, Sillmann, & Fischer, 2015). Similar to HWMI, the Excess Heat Factor (EHF) (Nairn & Fawcett, 2014) measures heatwave intensity at each location with an additional component to account for adaptation. Whilst similar in principle to HWMI, EHF has distinctions worthy of note. Rather than the use of maximum temperature alone, daily temperature is considered important due to minimum temperature compounding extremes through modification of the diurnal heating cycle (Black, Blackburn, Harrison, Hoskins, & Methven, 2004; Chen & Zhai, 2017). EHF's assembly from long and short-term daily temperature anomalies creates a power-law time series that permits a novel normalization technique to build a dimensionless severity index (see Appendix A for derivation and supporting examples). Severity analyses have spatial and temporal consistency that has enabled the development of heatwave services.

The Bureau of Meteorology in Australia(the Bureau) and National meteorological agencies, the UK and United States have either put into operation or under evaluation the Excess Heat Factor (Nairn & Fawcett, 2014) for heatwave severity analysis and forecasts. The Bureau's heatwave service has published 7-day heatwave severity maps on the internet since 2014 (Bureau of Meteorology, 2014). The UK Met Office is evaluating 7-day probability maps of heatwave (and coldwave) within their Global Hazard Map (GHM) project (Helen A. Titley and Joanne C. Robbins, 2013) whilst the Bureau (Hudson & Marshall, 2014) and NOAA (personal communication, University of Maryland) have funded experimental multi-week probability maps. The Bureau is also contributing EHF heatwave severity maps to the Copernicus project (Gobron et al., 2016) for users to envisage meaningful heatwave climate change scenarios.

Percentile-based heatwave indices can be spatially constrained as their scaling against local climate variability can inhibit sensible inter-site comparisons and spatial analysis. They are reliable for time-series analysis at each location and spatially analysed for climate change purposes when rates of change are investigated (Perkins et al., 2012). Converting EHF intensity [$°C^2_L$] to dimensionless EHF severity enables heatwave magnitude spatial analysis.

Epidemiological studies (Hatvani-Kovacs, Belusko, Pockett, & Boland, 2015; Herbst et al., 2014; Jegasothy, McGuire, Nairn, Fawcett, & Scalley, 2017; Langlois, Herbst, Mason, Nairn, & Byard, 2013; Scalley et al., 2015; Xiao et al., 2017) have demonstrated EHF severity dose/response skill for morbidity and mortality in Australia for both city and regional communities. These multidisciplinary studies have formed the basis for partnership discussions between health agencies, emergency services and the Bureau for development of a national heatwave forecast and warning framework. EHF severity has been shown to be useful as an exposure index that scales well against human health impact for and between exposed locations. EHF severity is an effective dimensionless impact index for Australia. As a percentile-based index, constructed on statistics of extremes principles it is being tested in real-time on global platforms (GHM, NOAA) and developed on climate projections (Copernicus). Forecasts for the Australian 2017-2018 summer are demonstrated, with examples of decision support products that would enable dialogue between warning agencies. Forecast skill must also be considered when using this guidance for message generation. An assessment of the 2017-2018 summer forecast skill is presented as part of this discussion.

1. Summer 2017-2018 Heatwave Forecasts

Since the start of the Bureau's heatwave service in January 2014, it has prepared annual reports (e.g., Fawcett, 2015; Fawcett, 2016) on the performance of the service, focussing on the months of the heatwave season (typically November to March, but with October and/or April able to be included according to the observed heatwave activity). As the heatwave service is based on forecasts of the EHF, current verification efforts are focussed on assessing the performance of the EHF forecasts. This involves comparing the forecasts against analysed EHF via (i) integrated positive EHF across the heatwave season, (ii) number of heatwaves (three-day periods with positive EHF), (iii) number of severe heatwaves, (iv) number of extreme heatwaves and (v) time series of percentage area in heatwave, severe heatwave and extreme heatwave. Time series of percentage area overlap between observed and forecast heatwave, severe heatwave and extreme heatwave can also be calculated. Figure 1 shows one of these forecast verification products for the 2017/2018 heatwave season. It shows a comparison of the time series of percentage area of Australia observed to be in heatwave with the percentage areas forecast at each of the five operational forecast lags. The percentage areas are calculated for all three-day periods in the five months in the heatwave season (day 1 in the plot is the three-day period from 29 October to 1 November 2017). While this plot does not show whether or not the forecast heatwaves were in the same places as the observed heatwaves, it does show that to a large extent the forecast system was generating heatwaves of an appropriate magnitude at the right times, and that no large-scale heatwaves went unforecast.

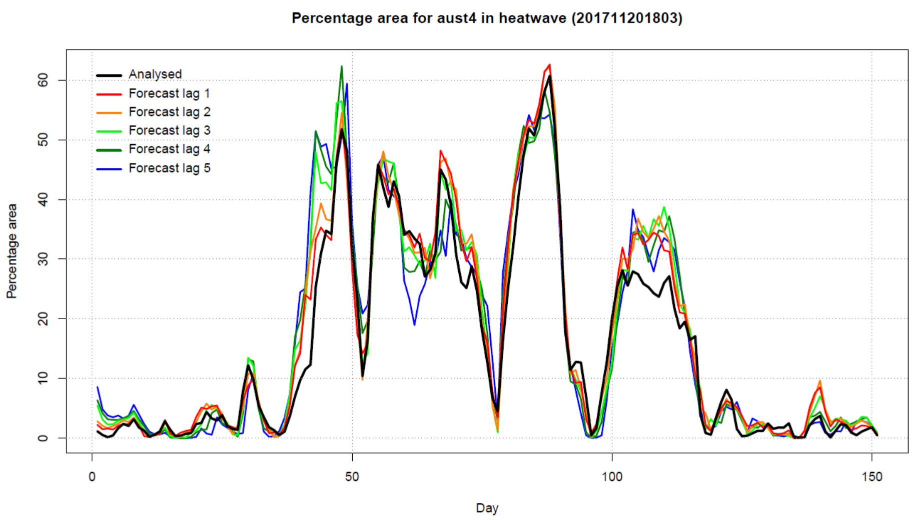

Figure 1: Percentage area of Australia in heatwave conditions (black line) and as forecast (coloured lines), November 2017 to March 2018. Day 1 is the three-day period 29 October to 1 November 2017. Coloured lines above (below) the black line indicate over-forecasting (under-forecasting).

The three-day EHF forecasts are themselves derived from forecasts of daily maximum and minimum temperature, which are combined to generate forecasts of daily temperature. The performance of those temperature forecasts can be assessed directly and has been reported on.

2. Heatwave Warning Decision Support (2017-2018)

The following discussion considers how the Bureau heatwave service data can be used to support warning messages. Message content is not discussed in this extended abstract.

Figure 2 (inset) shows observed three-day EHF severity for 12 February 2018 for Australia and Queensland utilising severity thresholds used by the Bureau of meteorology's heatwave service.

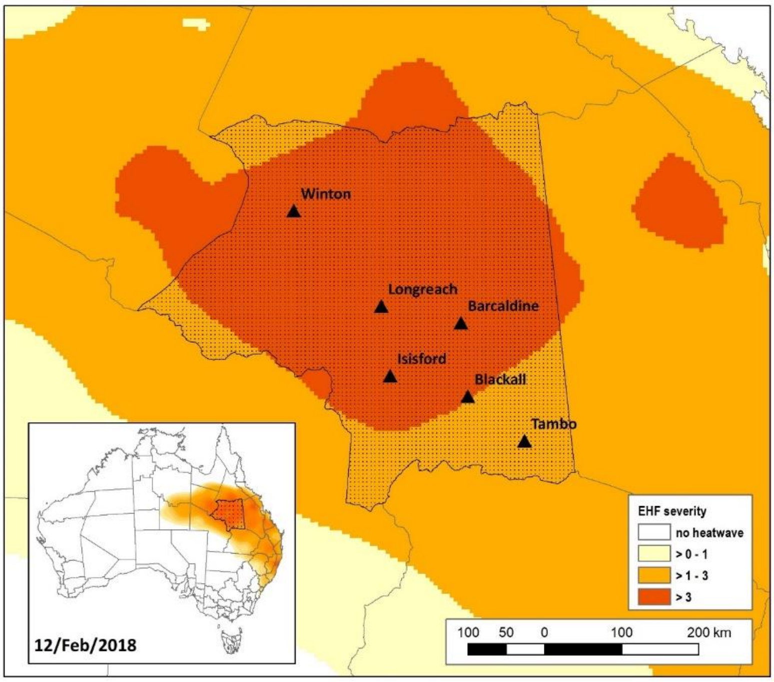

Figure 2. Observed (Day 0) EHF Severity map for Queensland, Central West District, 12 February 2018.

Figure 2 shows the weather districts used by the Bureau for issue of forecasts and warnings across Australia. The Central West weather district is shown in detail with principle cities and towns displayed. The sequence of observed heatwave severity maps for 8 to 15 February in Figure 3 shows growing heatwave severity as it moved up from New South Wales, with peak severity over central Queensland on 12 February.

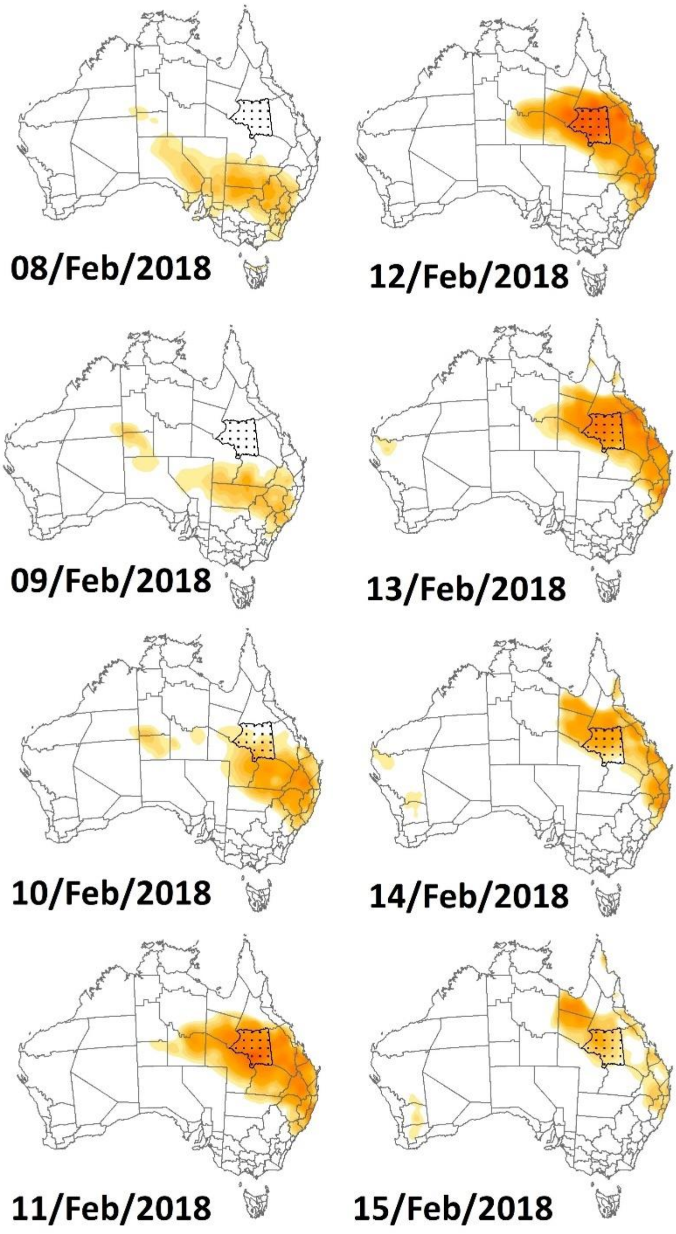

Figure 3. Observed (Day 0) EHF Severity maps, 8 to 15 February 2018. Central West weather district (Queensland) stippled.

Throughout summer seven heatwave severity maps were issued, corresponding to any row in Table 1.

Observed heatwaves for Longreach and Isisford shown in column 'Day0' correspond to the values mapped in Figures 2 and 3. Forecasts shown in Table 1 are shown with the date of issue (Date), which corresponds to Today(0). Columns labelled Day-2, Day-

1, Today (0), Day+1, Day+2, Day+3 and Day+4 correspond to the seven heatwave service maps (not shown) issued on that day (Date) by the Bureau.

Date	Town	**Day(0)**	Day-2	Day-1	**Day0**	Day+1	Day+2	Day+3	Day+4
2018-02-03	Longreach	**0**	0.09	-0.45	**-0.75**	-0.82	-0.66	-0.57	-0.43
	Isisford	**0**	0.01	-0.55	**-0.70**	-0.70	-0.53	-0.46	-0.32
2018-02-04	Longreach	**0**	-0.46	-0.74	**-0.80**	-0.61	-0.58	-0.46	-0.17
	Isisford	**0**	-0.62	-0.76	**-0.67**	-0.49	-0.44	-0.31	-0.04
2018-02-05	Longreach	**0**	-0.75	-0.80	**-0.54**	-0.50	-0.44	-0.28	0.04
	Isisford	**0**	-0.74	-0.64	**-0.46**	-0.42	-0.34	-0.17	0.12
2018-02-06	Longreach	**0**	-0.79	-0.54	**-0.49**	-0.45	-0.30	-0.02	0.98
	Isisford	**0**	-0.64	-0.46	**-0.44**	-0.39	-0.24	0.03	0.88
2018-02-07	Longreach	**0**	-0.51	-0.47	**-0.46**	-0.36	-0.11	0.39	2.07
	Isisford	**0**	-0.44	-0.41	**-0.39**	-0.30	-0.06	0.54	2.19
2018-02-08	Longreach	**0**	-0.47	-0.44	**-0.33**	-0.07	0.66	2.63	3.81
	Isisford	**0**	-0.42	-0.39	**-0.27**	-0.01	0.74	2.39	3.24
2018-02-09	Longreach	**0**	-0.44	-0.30	**-0.02**	0.86	2.66	2.66	1.98
	Isisford	**0**	-0.38	-0.24	**0.05**	1.22	2.89	2.76	1.89
2018-02-10	Longreach	**0.25**	-0.37	-0.09	**0.82**	2.64	2.81	2.34	1.60
	Isisford	**0.80**	-0.31	-0.02	**1.18**	2.89	2.81	2.02	1.12
2018-02-11	Longreach	**2.29**	-0.20	0.34	**2.43**	2.86	2.39	1.54	1.22
	Isisford	**3.53**	-0.12	0.62	**2.66**	2.86	2.06	1.32	0.81
2018-02-12	Longreach	**3.19**	0.20	2.16	**3.67**	3.36	2.44	1.29	0.51
	Isisford	**3.62**	0.51	2.53	**3.53**	3.01	2.11	1.05	0.42
2018-02-13	Longreach	**2.52**	2.06	3.70	**3.16**	2.50	1.06	0.52	0.33
	Isisford	**1.97**	3.08	4.14	**2.86**	1.90	0.81	0.43	0.41
2018-02-14	Longreach	**1.15**	3.88	3.21	**2.22**	1.08	0.87	0.55	0.16
	Isisford	**0.59**	4.72	3.16	**1.56**	0.63	0.46	0.30	0.13
2018-02-15	Longreach	**0.90**	2.16	1.16	**0.52**	0.38	0.28	0.15	0.02
	Isisford	**0.62**	2.13	0.64	**0.26**	0.16	0.18	0.13	0.02
2018-02-16	Longreach	**0.49**	1.05	0.51	**0.62**	0.32	0.11	-0.04	-0.20
	Isisford	**0.55**	0.67	0.34	**0.37**	0.20	0.07	-0.09	-0.28

2018-02-17	Longreach	**0.74**	0.22	0.27	**0.34**	0.13	-0.11	-0.33	-0.43
	Isisford	**0.82**	0.25	0.19	**0.19**	0.03	-0.17	-0.41	-0.50
2018-02-18	Longreach	**0.20**	0.56	0.86	**0.19**	-0.14	-0.46	-0.63	-0.58
	Isisford	**0.21**	0.45	0.69	**0.11**	-0.15	-0.46	-0.61	-0.57

Table 1. EHF Severity values for Queensland, Central West District towns of Longreach and Isisford, 7 to 13 February 2018.

On 12 February 2018 the Bureau's heatwave service forecast an extreme heatwave (>3) for Longreach and Isisford (**Day0**: 3.70, 4.14) which verified as an extreme heatwave (**Day(0)**: 3.19, 3.62). The long-range forecast (Day+4) issued on 8 February forecast an extreme event (3.81, 3.24), although subsequent forecasts included lower values (lowest 2.66). The example provided in Table 1 shows the evolution of forecast guidance for the strongest heatwave observed over Australia for the 2017/2018 warm season. In this instance a severe/extreme heatwave worthy of community warning messages was sustained throughout the development and easing of the heatwave event that moved into the Central west forecast district. Further analysis is warranted for weaker heatwave events that are closer to the recommended heatwave warning threshold (severity 1). Community consultation/research is required to understand how warnings would be received if communicated as a State, Weather District or Township impact event, whilst considering the spatial characteristics of forecast skill. This consultation must also consider appropriate warning lead-time and the development of standardised operating procedures for multi-hazard message construction amongst partner warning agencies.

3. Multi-Agency Heatwave Warnings

Whilst the appetite from the Bureau and emergency and health services across the jurisdictions for a national approach to heatwave warnings and messaging is clear, the challenges of establishing a coordinated nationwide methodology in a federated system are equally apparent. Neither emergency or health services are exclusively the control or lead agency for heatwave across Australia's jurisdictions. Consequently, each jurisdiction is locked into existing nomenclature and process. There is undoubtedly efficiency in governance and systems currently in place for mitigation and response to heatwaves by jurisdictional lead agencies. However, heat health impacts are just one consideration. Heat related impacts on infrastructure, continuity of utilities, efficiency of transport systems and industry impacts also require management. Contemporary governance in public policy, including disaster management, must evolve from a hierarchical command-and-control focus developed from central/national government-led programs focused on response and recovery. International and intergovernmental collaboration and coordination on disaster risk reduction, mitigation and preparedness has evolved through the United Nations International Strategy for Disaster Reduction's Sendai Framework. The Sendai Framework aspires to achieve "substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries". The framework places primary responsibility for reducing disaster risks on nation states and recommends they share this responsibility with local governments, the private sector, academia, civil society and other stakeholders (UNISDR, 2015). The Australian Government in turn has established the National Resilience Taskforce to reduce the impacts of natural disasters on the Australian community, including establishing a national disaster risk information capability to equip decision-makers and Australians with the knowledge they need to prepare for natural disasters (Ministry of Home Affairs, 2018).

Greater collaboration and coordination is required to change our approach to health impacts of heatwave. Incorporation of a national heatwave warning framework to inform clear and consistent community messages, requires new governance considerations. A more adaptive governance must address more than Federal, State and Local Government responsibilities. The operational partnership must include the Bureau, emergency and health agencies, non-government, business and community sectors. Meaningful community messaging must be mapped backward from the community we aim to inform and not focus on existing biases and assumptions. At the international and national levels our commitment to reducing disaster risk and providing information to help people and communities prepare is clear. We need to listen to those communities and understand the language and messages that makes sense to them and build a path back to the existing and effective national heatwave warnings, adapting and flattening out our governance along the way.

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