climate extremes
ARC centre of excellence

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The ARC Centre of Excellence for Climate Extremes

9 May 2023
Committee Secretary
Legislative Council Standing Committee on Environment and Planning
Parliament House, Spring Street
EAST MELBOURNE VIC 3002

Submission to the Legislative Council Environment and Planning Committee on the Inquiry into the 2022 Flood Event in Victoria

Dear Committee Chair,

Inquiry into the 2022 Flood Event in Victoria

The **ARC Centre of Excellence for Climate Extremes** welcomes the opportunity to make a submission to the Inquiry into the 2022 Flood Event in Victoria. We applaud the committee in highlighting the issue of Victoria's flood preparedness and support the committee in their investigations.

Australia has an on-going exposure to weather and climate extremes and consequent disasters like the recent Victorian floods. The impacts to Australian communities are extensive, including interrupted access to essential resources such as food, water and fuel, significant damage causing social, environmental and economic costs as well as prolonged recovery periods and psychosocial effects. With these risks increasing with climate change, our region will face many more intense extremes in the future. Assessing Victoria's preparedness for and response to the major flooding event of October 2022 is therefore timely.

We thank the committee for the opportunity to make a submission on this important issue and offer our expertise on weather and climate extremes. We are happy to provide further information on any matters arising from this submission.

Yours sincerely,

[redacted]

Professor Andrew Pitman, AO, FAA
Centre Director
ARC Centre of Excellence for Climate Extremes

The ARC Centre of Excellence for Climate Extremes

The ARC Centre of Excellence for Climate Extremes (the Centre) is Australia's leading climate science centre consisting of five partner universities - The University of New South Wales, Monash University, The Australian National University, The University of Melbourne and The University of Tasmania as well as multiple national and international partner organisations. Our research focuses on understanding the underlying processes of climate extremes to reduce Australia's economic, social and environmental vulnerability to these events.

Submission to The Environment and Planning Committee on the Inquiry into the 2022 Flood Event in Victoria

Weather and Climate extremes are already affecting many facets of Australian society. It is crucial that the risk of disasters such as the 2022 Flood Event in Victoria (the *Flood Event*) are well understood to adequately assess Australia's resilience. This submission outlines the following aspects for the committee to consider:

1. The causes of the Victorian Flood Event
2. Increases in the frequency and intensity of weather and climate extremes
3. Hazard exposure, uncertainty and compound events
4. Maintaining and enhancing weather and climate research capability

1.0 The causes of the *Flood Event*

We refer to the *Flood Event* as the significant flooding that occurred during 13-15 October across Victoria, Australia and continued thereafter.

1.1 Antecedent conditions and large-scale climate modes

Flooding during October 2022 in Victoria occurred through the complex interplay of meteorological systems, large-scale climate modes and antecedent environmental conditions. The *Flood Event* was preceded by two consecutive La Niña phases of the El Niño-Southern Oscillation (ENSO) and coincided with the start of a rare third consecutive La Niña phase. La Niña is associated with above-normal rainfall over the Murray-Darling during the winter and spring seasons. In addition, a generally positive phase of the Southern Annular Mode (SAM) and generally negative phase of the Indian Ocean Dipole additionally favoured wet conditions in south-eastern Australia during the preceding year[1].

Figure 1 shows rainfall percentages relative to the long-term mean during the year preceding the *Flood Event*. Importantly, most of the Murray-Darling basin experienced rainfall well-above the mean during the preceding year. Although Greater Melbourne remained dry during September 2022, the month was particularly wet for the Murray-Darling basin, with some regions along the Murray River receiving up to 300% of their mean September rainfall (Figure 2). As a result, the ground was saturated or close to saturated and river levels were high prior to the onset of the events of October 2022.

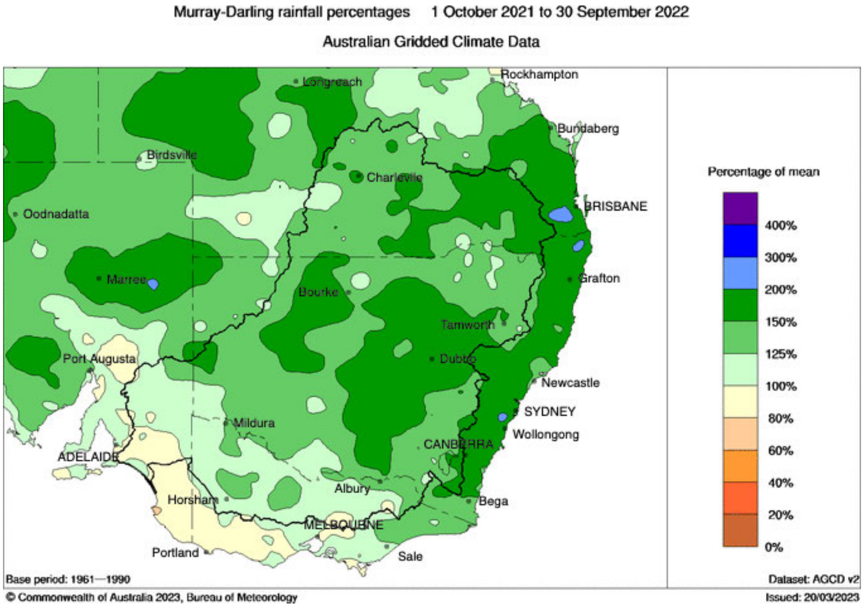

Figure 1: Observed 12-month rainfall preceding the Flooding event in October 2022. Values are percentages relative to the 12-month long-term mean (1961 – 1990) produced from the Australian Gridded Climate Data (AGCD) archive. Courtesy: Bureau of Meteorology (http://www.bom.gov.au/climate/maps/rainfall/)

1.2. Observed rainfall during October 2022

Rainfall was widespread throughout Victoria and the Murray River catchment during October 2022. This month brought the highest rainfall for any month on record in Victoria[2].

1.2.1 Area affected

Figure 2 shows the area affected by persistent rainfall during the month. The vast majority of Victoria and the Murray-Darling basin experienced above-normal rainfall during October 2022. The Murray River catchment and the western interior of New South Wales was the worst affected with some areas experiencing over 400% of the long-term mean for October. Generally, up to 200mm fell over most places over the state during October, with some recording up to 300-500mm, particularly in the Victorian Alps.

1.2.2 Daily rainfall totals

Figure 3 shows daily rainfall totals for a selection of stations in Victoria during October 2022. Although monthly rainfall totals were extreme, these accumulations resulted from only 3-4 events, with heavy rain falling between 5-8 October; 13-15 October and during the final week of the month. In isolation, daily rainfall totals were not at all unprecedented, with accumulations generally below 30mm. The exceptions occur during the event between 13-15 October where rainfall totals exceeded 50-60mm over the Murray River catchment and over the Victoria Alps (shown here by the Mount Buller station). It is additionally pertinent to note the significantly above normal rainfall that fell during November 2022 over the southern parts of the Murray-Darling basin. 300-400% of the normal November rainfall fell over the Murray River catchment (Figure 2) during 3 rainfall events (not shown) in early to mid-November. Although this is not the focus of this report, the additional rainfall is pertinent to the flooding events during October 2022 as it makes clean-up operations more challenging, producing further surface run-off on already saturated ground and prolonging impacts to flood affected areas.

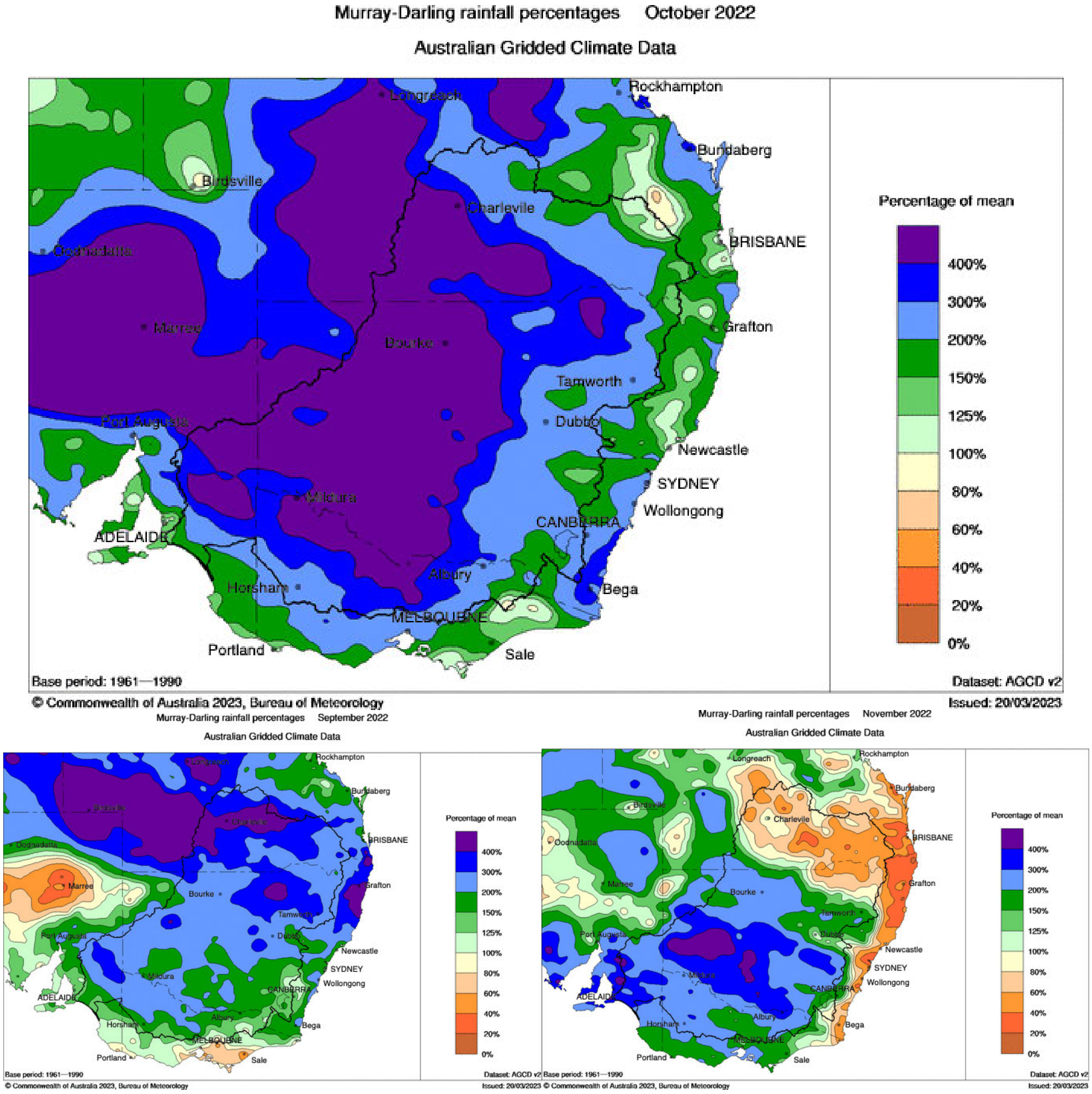

Figure 2: Observed rainfall during October 2022 (top), September 2022 (bottom left) and November 2022 (bottom right). Values are percentages relative to the 12-month long-term mean (1961 – 1990) produced from the Australian Gridded Climate Data (AGCD) archive. Courtesy: Bureau of Meteorology (http://www.bom.gov.au/climate/maps/rainfall/)

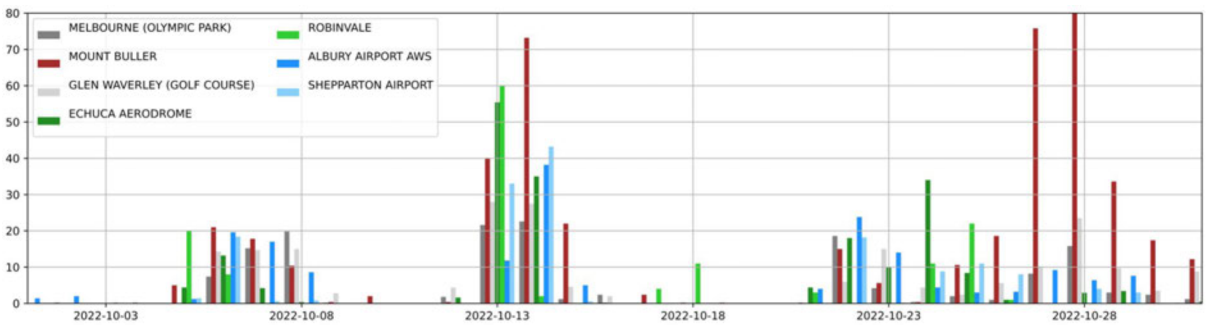

Figure 3: Observed rainfall (in mm) for a selection of stations in Victoria during October 2022. Courtesy: Bureau of Meteorology (http://www.bom.gov.au/climate/data/index.shtml)

1.3 Meteorology of the flooding during October 2022

Section 1.1 and Figure 3 show that the rainfall that fell on already saturated ground during October 2022 consisted of 3-4 periods of organised rainfall. This section describes the meteorology of the rainfall of each of these events. We additionally briefly describe the processes associated with rainfall during spring 2022 (including September and November) more generally.

1.3.1 Meteorology of the *Flood Event* (13-15 October 2022)

The heavy rainfall that occurred between 13-15 October 2022 was caused by a deep cyclone which provided the moisture rich air, and the uplift required for rainfall. The slow-moving nature of this system resulted in persistent and heavy rainfall over the Murray-Darling catchment. A second weaker front provided additional rainfall during 14 October 2022. Rossby waves were fundamental to the weather systems that resulted during the *Flood Event*. These systems are discussed in this section.

Rossby waves are large planetary-scale waves in the jetstream that occur high up in the atmosphere. They are fundamental to meteorology, driving or influencing much of the surface weather that we experience daily. Like ocean waves at the beach, they may grow larger in amplitude, and eventually overturn and break, producing meanders in the upper level jetstreams of the Southern Hemisphere. When these waves break, they may lead to changes in surface weather such as the development of high pressure weather systems or deep cyclones like the one that occurred during the *Flood Event*.

The cyclone which impacted south-eastern Australia formed on 8 October 2022, a week prior to its eventual landfall in Victoria. Its development was linked to Rossby wave breaking which occurred south of Australia. The deep cyclone extended from the surface into the upper troposphere. The specific type of Rossby wave breaking, called poleward anticyclonic Rossby wave breaking, produced a meteorological pattern known as "atmospheric blocking". This is characterised by persistent slow-moving or "stalled" weather systems that can last for prolonged periods.

The slow-moving nature and persistence of the weather pattern made it susceptible to influence from Rossby waves moving from west to east over the Southern Ocean. Another high amplitude Rossby wave pattern caught up with the deep cyclone on 10 October 2022, merged with it and broke as a result. The Rossby wave break was of a similar type to the first, producing a second atmospheric blocking type structure. The interaction between the deep cyclone and the second Rossby wave breaking resulted in both the deep cyclone's persistence and further development. The cyclone's development as a result of the second Rossby wave breaking event was both rapid and intense with its central pressure dropping from 1002 Hectopascals (hPa) on 10 October 2022 to 989 hPa on 11 October 2022 (according to both ERA5 reanalysis data and the Bureau of Meteorology surface analysis). This is a drop in 1300 Pascals. Cyclones that undergo rapid intensification are often associated with intense surface winds, heavy precipitation and other weather hazards. This cyclone's rapid intensification and development undoubtedly contributed to the impact felt in Victoria a few days later. Importantly, the generation of the second "atmospheric blocking" pattern allowed for the persistence of the relatively slow eastward motion of the deep cyclonic weather system.

The deep cyclone provided the two fundamental ingredients required for rainfall: moisture and upward vertical motion. The strong surface frontal zone associated with the deep cyclone made landfall over Adelaide during 12 October 2022. Importantly, it linked up with a heat trough extending from north-western Australia. This promoted the transport of moisture-rich air from tropical Australia. This is shown in Figure 4 by a zone of strong moisture transport extending from north-western Australia (often referred to as an "Atmospheric River"). Upward vertical motion was provided by surface convergence at the leading edge of the surface front and was additionally supported and intensified by the upper-level cyclonic structures of the deep cyclonic weather system. Upward vertical motion is shown by the grey stippling in Figure 4. The surface front moved over Victoria during 13 October, bringing widespread heavy rainfall to much of the state and more importantly the Murray River catchment (as described in Section 1.2). A weaker front, the result of a secondary development generated behind the main frontal zone, provided some additional showers and rainfall during 14 October 2022, mostly confined to the southern and eastern parts of the state.

It should be emphasised, that the rainfall produced by this weather system did not occur in isolation. Rain fell on already saturated ground from an above average 12-24 months of rainfall in the region (Figure 1) and in particular well above average rainfall the month prior (September 2022, Figure 2). The effect of this was a greater amount of surface water run-off into already full river catchments. Rainfall that occurred months prior to this event is therefore critical to the flooding that occurred during October 2022.

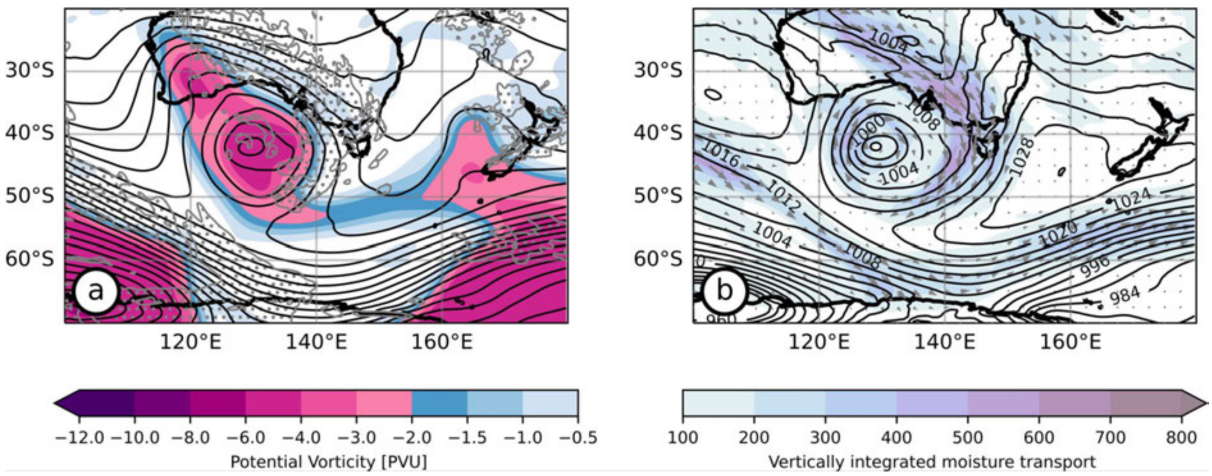

Figure 4: Synoptic overview of the weather systems that affected Victoria on 12 October 2022, valid at 06h00 UTC. a) Upper level synoptic features depicted by potential vorticity (PV) on the 315K isentropic surface (shaded) and 500hPa geopotential height (contours). b) Low-level synoptic features depicted by mean sea level pressure (contours) and vertically integrated moisture transport (vectors, direction and shading, intensity).

As shown above, the weather of the *Flood Event* was greatly influenced by slow-moving weather systems produced through Rossby wave breaking processes. Rossby wave breaking and its associated "stalled" weather systems are fundamental to the meteorology of Australian rainfall, and of extreme rainfall in particular, in various regions and seasons. The record-breaking rainfall and flooding during early 2022 along the east coast of Australia were produced by similar fundamental processes (Rossby wave breaking and slow-moving (upper-level) cyclones). Owing to their importance, this is an active area of research at the ARC Centre of Climate Extremes (e.g. Barnes et. al, 2023).

1.3.2 Other significant rainfall events during Spring 2022

As shown in Figure 2, several rainfall events occurred throughout Spring 2022, which resulted in a well above normal rainfall season. The above normal rainfall during September 2022 and early October 2022 was associated with a series of surface cyclones and their associated cold fronts passing through the state and the Murray-Darling catchment. These differ from the more intense rainfall experienced during the *Flood Event* in two primary ways. First, these cyclones were not slow-moving (with frontal propagation speeds of between 25-40 Knots according to the Bureau of Meteorology surface analyses) with less rain falling over the state and Murray-Darling River catchments as a result. Despite some of these weather systems also being associated with Rossby wave breaking, the type of wave breaking that occurred (largely equatorward cyclonic breaking) does not ordinarily promote stalled, slow-moving (or atmospheric blocking-type) synoptic patterns.

Secondly, these systems did not tap into tropical moisture in and around the Murray-Darling basin as was the case with the weather system associated with the *Flood Event*. Although there would have been moisture available for rainfall, the lack of tropical moisture from northern Australia would have hindered heavy rainfall as was experienced through much of the state and surrounds during mid-October 2022. Despite these caveats, the sequential nature of the weather systems (although relatively ordinary rainfall totals occurred) saturated soils and filled river catchments prior to the onset of the *Flood Event*.

An extended period of rainfall was experienced in Victoria during late October 2022. The underlying processes which occurred during this period were similar to that of the *Flood Event*, except translated eastwards. The processes associated with the final week of October 2022 closely resemble that of flooding that took place along the east coast during early 2022 (see State of Climate Extremes 2022 for more details). The period was affected by an east coast low which, under the influence of upper-level processes and associated approaching cold front, persisted, intensified and affected the region for several days. Similar to those processes associated with the *Flood Event*, this period was associated with “stalled” weather systems and an atmospheric blocking pattern. Much of the heavier falls took place along the eastern seaboard of Victoria and NSW during 23-24 October when the east coast low progressed towards southern Victoria, becoming a fairly complex large-scale low-pressure system. The eastern parts of Greater Melbourne were hit by thunderstorms and flash flooding on 25 October 2022. Lilydale and surrounding areas were particularly affected. The Murray-Darling catchment also received intermittent showers throughout the period, exacerbating impacts in flood affected areas.

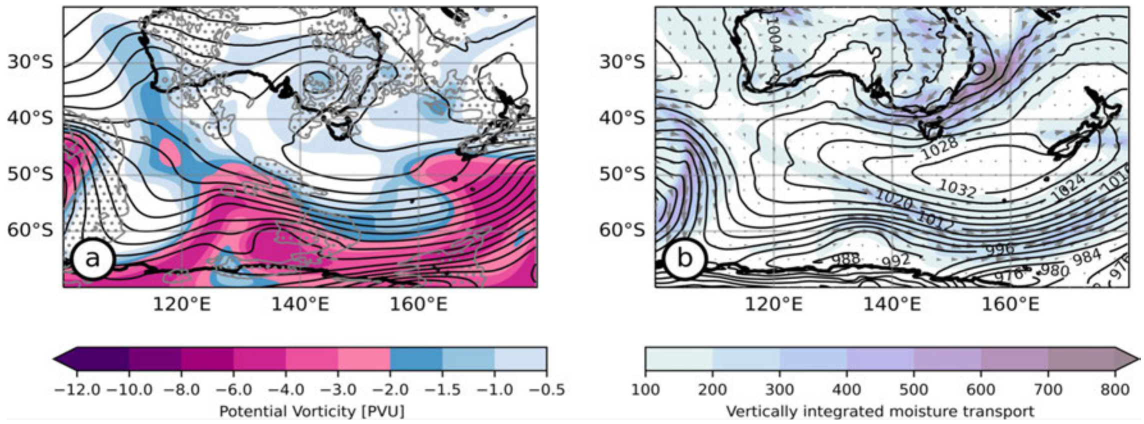

Figure 5: Same as Figure 4, but valid for 24 October 2022 at 06h00 UTC.

2.0 Increases in the frequency and intensity of weather and climate extremes

Various climate extremes have already increased in frequency and intensity as a consequence of human-induced global warming. It is therefore vital that Victoria prepares for more climate disasters of the type illustrated by the Victorian *Flood Event,* but also trends in drought, heatwaves and fire.

Australia experienced a year of record-breaking extremes in 2022[3] (Figure 6) with extreme rain and flooding overshadowing all other events. Persistent, heavy rainfall broke multiple daily, monthly and yearly rainfall records in many parts of the country. Rainfall variability is expected to increase with climate change, with more frequent swings from extreme droughts to flooding rains[4]. High intensity rainfall events are likely to increase, impacting the risk of flash flooding[5] while long-term rainfall declines in some regions which will further intensify droughts[6], challenging water resources and bushfire management in some parts of the country. Other extremes such as land and marine heatwaves and fire weather are expected to worsen with climate change while some extremes, including hailstorms and lightening are understood too poorly to know what to expect in the future.

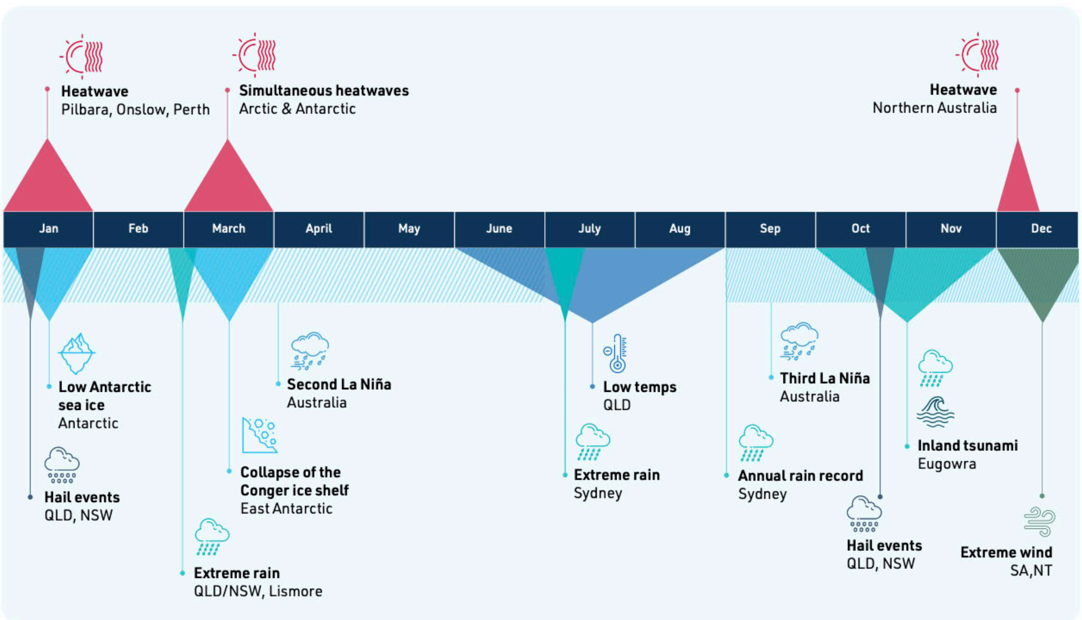

Figure 6: Timeline of Australia's major extreme events in 2022.

The link between carbon emissions and climate change is unequivocal. The latest report from the UN's Intergovernmental Panel on Climate Change (IPCC)[7] states climate change is causing greater impacts than anticipated, and these impacts are emerging at lower amounts of warming than expected. The report underlined the urgent need for emissions reductions to limit warming to below 2°C to avoid dangerous climate change, as stated in the Paris Agreement.

Every fraction of a degree of warming increases the risk of extreme weather events.

Australian surface temperatures will continue to rise until at least 2050 under all emission scenarios and further increases in climate extremes are inevitable[8]. The impacts from climate extremes are likely to increase with the warming that is already locked in. The more we emit now, the worse climate change will be in the future.

Currently, linking the Victorian *Flood Event* to global warming is beyond the capacity of existing science. It is clear that short duration rainfall is intensifying, but the Victorian *Flood Event* was not a "short duration" rainfall event. The relevant science is known as "event attribution" – that is whether one can scientifically "attribute" an event like the Victorian *Flood Event* to a specific cause (e.g. global warming). For a range of reasons, which we can explain if requested, our assessment is that the science of event attribution is simply too immature to make scientifically rigorous statements concerning the Victorian *Flood Event.* This *does not mean* that global warming did not influence or affect this event; rather it means that the scientific evidence to robustly link global warming to this event does not currently exist.

Reducing emissions is a key component of disaster resilience.

3.0 Hazard exposure, uncertainty and compound events

As outlined in Australia's National Disaster Risk Reduction (homeaffairs.gov.au), and the United Nations Office for Disaster Risk Reduction, Sendai Framework for Disaster Risk Reduction 2015-2030 | UNDRR, one of the main priorities to prevent new, and reduce existing disaster risks is to understand the weather and climate processes that contribute to risk. Building the understanding of the processes causing weather and climate extremes, such as the *Flood Event* and how these may change in the future is the focus of research at our Centre. Utilising the latest developments in climate science research improves Australia's national capacity for assessing disaster risk.

Understanding the processes causing climate extremes, and how they may change is crucial for Australia's resilience.

Disaster risk is a function of hazard exposure, vulnerability and the capacity to adapt. Navigating exposure risk to weather and climate hazards is complex because they are caused by various combinations of physical processes. These processes are complex and can compound nonlinearly, making each climate hazard unique. This is then coupled with social, political and economic factors that impact risk. Considering this complexity, it is important that the analysis and interpretation of climate data is undertaken with expert help. Climate scientists such as those at our Centre can provide technical expertise and guidance in this process.

When assessing hazard exposure, looking at historical observations of severe weather provides a useful starting framework to assess future risk. Using a storyline approach[9] to build a narrative to consider plausible future climate scenarios is also a useful approach. This combines quantitative data from climate science with knowledge from other disciplines such as social sciences, engineering and economics to create reasonable estimations for a region. Storylines are necessarily customised depending on the hazard, location and timeline in question.

We would like to comment on two important aspects for assessing climate risk: uncertainty and compound events.

3.1 Uncertainty

Climate uncertainty

Uncertainty is an inherent component of assessing climate risk. Uncertainty arises from current limitations in climate projections, natural variability of the climate system and knowledge gaps in our understanding. Uncertainty is amplified by social, political and economic complexities which impact how risk is experienced. Ultimately, there is considerable uncertainty when quantifying the risk of future climate extremes. For example: it is difficult to robustly predict if more intense rainfall will impact a specific suburb despite knowing, on average, rainfall intensity will increase.

It is important that specific estimates of physical climate risks consider uncertainty, as trying to provide false confidence around climate projections risks economically costly investments and maladaptation.

Specific event uncertainty

The best way to navigate this uncertainty often involves undertaking local scale bespoke assessments with expert guidance, the storyline approach. It is vital that information is presented to decision makers in a useful way, for example, describing hazard exposure through ranges such as: severity, likelihood, duration, frequency and confidence. There should also be transparency around climate data used including methodology, assumptions, sources of data, areas of confidence and areas of uncertainty. This process must be performed within a robust governance framework to record and provide assurance around climate data. Using data from climate projections without a detailed and expert understanding of how it was created risks investment in maladaptation.

Forecast and real-time uncertainty

There is also uncertainty inherent within the weather forecasts, hazard forecasts and impact forecasts that are used during a natural disaster. This uncertainty needs to be propagated along the warning chain in order to be prepared for the full range of possible outcomes.

Communicating uncertainty intelligently can help both emergency management and the public to maximise the time available to respond during a hazard event.

3.2 Compound events

As discussed in section 1.0, multiple weather and climate hazards can co-occur to produce a disaster such as the *Flood Event.* These are known as compound events. Compound events arise from multiple hazards or drivers, a succession of hazards, hazards in multiple connected locations, or preconditioning[10]. Compound events are difficult to capture in risk assessment, as they are caused by multiple factors. For example: an increase in rainfall or in wind gusts of 10% in isolation are unlikely to be significant. However, if they both occur simultaneously the impact can be considerable. An East Coast Low affecting the Sydney Basin can cause beneficial increases to water storages. Three East Coast Lows affecting the Sydney Basin within a few weeks could be catastrophic.

As discussed in the case of the *Flood Event*, a combination of meteorological phenomena (Rossby wave breaking, a slow-moving deep cyclone and a front) caused persistent, heavy rain to fall on catchments that were already saturated and primed for flooding due prior rainfall. The antecedent conditions and the La Niña raised the risk. For the risk to be realised the extreme rainfall event was necessary, something that was not predictable until a week in advance.

Climate risk assessments should consider compound events.

Australia has experienced a variety of compound events that have led to loss of life and negatively impacted the Australian economy over the past decades. Currently, our understanding of many compound events is insufficient to reliably assess the risk they pose. The Centre continues to incorporate compound event research into its program of research. Our research has found that future climate change will lead to an increase in prolonged hot and dry compound events over all of Australia[11]. Current climate models project an increase in wet and windy compound events in the northern parts of Australia dominated by tropical cyclones and thunderstorms, and a decrease in events in the south where fronts and frontal systems are the dominant drivers of extreme wind and rain.

4.0 Maintaining and enhancing weather and climate research capability

It is crucial that we understand the weather and climate processes behind extreme events such as heavy rainfall, and how these processes are changing to improve Australia's preparedness for disasters like the *Flood Event*. Research at the Centre continues to investigate the causes of extremes in weather and climate, and how these may change in the future. Increasing our understanding of how the climate is changing in the context of major disasters is necessary for resilience.

Improving Australia's resilience relies on incorporating our knowledge of current disaster events into a robust resilience framework. Mitigating the risk of disasters depends on several aspects of the disaster itself: what we are preparing for, when will it happen, where will it happen, how often will it happen and how extreme it will be. Although it is impossible to answer definitively, there are strategies that would increase our national capacity to plan for and cope with future disasters. A key component of this is enhancing weather and climate research capability.

Australia's research capacity is critical for predicting what may happen in the future, including our capacity as a nation to forecast disasters in the short and long term. Forecasting is highly complex and long-range predictability is generally beyond our current predictive skill. However, the ARC Centre of Excellence for Climate Extremes is amongst many organisations (including the Bureau of Meteorology, Natural Hazards Research Australia, the Australian Climate Service, CSIRO and research organisations worldwide) supporting and developing these skills through fundamental research. Investment in these organisations lacks an overarching strategy, any defined common goals, or strategies to cross-fertilise innovation. These organisations are effectively encouraged to compete which is unlikely to maximise Australia's capacity to build resilience.

Below is a selection of cutting-edge research on rainfall extremes from the ARC Centre of Excellence for Climate Extremes led by researchers at Monash University and the University of Melbourne. This demonstrates our contributions towards Australia's capacity to understand and predict events such as the *Flood Event*:

- In all regions of Australia, the two necessary atmospheric conditions required for extreme rainfall are (1) very high moisture content and (2) strong upward vertical motion. Understanding how extreme rainfall will change with climate change therefore requires us to understand how both dynamics (how air flow in the atmosphere changes, including weather systems, and their intensity) and thermodynamics (heat and moisture content of the atmosphere) change as the planet warms[12].
- Inundation along the east coast of Australia is due to slow-moving vortices in the upper atmosphere. Copious rainfall such as that in 2022 occurs because these vortices linger over eastern Australia and force air upward on their eastern flank. In 2022 these vortices inextricably linked to a surface anticyclone over the Tasman Sea, which directed moist easterlies onshore. Rossby wave breaking is the physical process responsible for slow-moving upper-level vortices and the associated surface weather patterns[13].
- Rainfall variability during different phases of the Madden-Julian Oscillation (MJO) varies between El Niño and La Niña conditions. In comparison to El Niño conditions, the rainfall maximum propagates as a focused region from west to east across northern Australia during La Niña. One result of particular relevance is that the rain is highly focused on the eastern seaboard in the later stages of the MJO. This research paper is currently being written.

We note that the Australian Research Council has recently funded the ARC Centre of Excellence for the Weather of the 21st Century, led by Monash University and Professor Christian Jakob. This research centre offers Victoria world-leading capability to answer critical problems and we recommend the Inquiry makes contact with Professor Jakob to understand how that centre can support Victoria's emerging challenges around extreme events.

Thank you for the opportunity to make this submission. The Centre is happy to provide further information on climate extremes and disaster resilience to the committee.

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