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Perspectives on the Feb-Mar 2022 east coast extreme rainfall event

Sugata Narsey, James Risbey, Dörte Jakob, and Michael Grose

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Executive Summary

The Australian Climate Service convened a half-day online workshop to discuss the meteorology of the February 2022 extreme rainfall event that occurred over the east coast of Australia. Available evidence suggests that the event was exceptionally rare (estimated recurrence interval between 300 and 800 years). Many aspects of the event's synoptic meteorology are commonplace although the resulting impacts of the event were not. The quasi-stationary nature of the system was important for the resulting impacts and is the subject of on-going research. There is no clear trend in observations for multi-day extreme rainfall over the east coast of Australia. Similarly, global-warming related changes in multi-day rainfall extremes for the east coast of Australia are currently not well understood. More research is needed to understand the role of climate change in these types of events. Follow-up workshops or discussions should consider the hydrological impacts of the extreme rainfall, as well as any other factors leading to extreme impacts (for example, antecedent conditions, exposure and vulnerability).

1. Introduction

1.1. Date & Time

A MS Teams meeting on Friday 2 September 2022, from 9am to 1pm

1.2. Organising Committee

James Risbey (CSIRO), Sugata Narsey (Bureau of Meteorology), Doerte Jakob (Bureau of Meteorology), and Michael Grose (CSIRO)

1.3. Background

The Australian Climate Service (ACS) conducted a half day post-event discussion workshop to share knowledge and perspectives on the February-March 2022 east coast extreme rainfall event. The event was held online on the morning of Friday 2 September 2022. The focus of the workshop was mostly on the meteorology of the event, including the forecasts and warnings, likelihoods, and projected future changes. The hydrology, flooding, and impacts associated with the heavy rainfall events were not covered here. The intention is for other groups in ACS to cover these issues as a prelude to a more integrated workshop around this event.

Key outcomes from this workshop include:

- better understanding of the meteorology of the event
- better understanding of what knowledge was useful before, during and after the event

- a clearer picture of weather knowledge gaps that ACS may be able to address at multiple time and spatial scales

The presenters were Jane Golding (BoM), Blair Trewin (BoM), Linus Magnusson (ECMWF), Michael Barnes (Monash), Damien Irving (CSIRO), Kate Saunders (QUT) and Steve Sherwood (UNSW).

2. Session 1: Meteorology of the event

2.1. Summary of presentations

2.1.1. Blair Trewin: BoM Special Climate statement

The extreme rainfall events in both Queensland and NSW were a series of events, not just one extreme event. The events featured a trough or cutoff low along the east coast, together with a block in the Tasman Sea. While daily rainfall totals were high, they were not the highest on record, whereas the one- and two-week accumulated rainfall totals were the highest on record for the extended east coast region.

2.1.2. Linus Magnusson: ECMWF Forecast of the event

The ECMWF (50 member) ensemble forecasts included indications of an extreme rainfall event in the Brisbane region up to a week in advance. While the ensemble mean rainfall was still low at one week lead, some members showed higher rainfall than in any of the past history of EC forecasts for that location. At 3 days lead even the ensemble mean showed heavier rainfall totals than past single members. The EC high resolution (HRES) deterministic forecast showed similarly high totals at 3 days lead. At one day lead, both the EC ensemble forecast and the HRES forecast showed the event moving off the coast with much reduced totals in the Brisbane region. This appeared to be a feature of only one forecast cycle, and the event returned to its original forecast intensity in Brisbane for subsequent forecasts. Dedicated work would be needed to understand why one forecast cycle differed.

2.1.3. Jane Golding: The NSW Commission of Inquiry

Multiple inquiries have been held in relation to the extreme rainfall event and its associated flood impacts. The Bureau of Meteorology provided expert advice to these inquiries (NSW, Queensland, and ACT). The NSW Commission of Inquiry has released a report of their findings, noting a need to better understand flood risk. Jane highlighted the role of the Bureau of Meteorology in flood prediction and warnings: the Bureau is responsible for riverine flood forecasting at key locations. Flash flooding on the other hand is the responsibility of the local and state governments.

2.1.4. Michael Barnes: Dynamics of the rainfall event

The extreme rainfall events were characterised by slow moving potential vorticity (PV) anomalies. A comparison of past slow moving PV anomaly cases with past fast moving PV anomaly cases showed that the slow-moving cases produce higher rainfall totals. The Queensland and NSW events were comprised of repeating sequences of slow-moving PV. It is not clear what the broad scale conditions were that led to this repeating sequence and is the subject of ongoing research.

2.2. Summary of discussion

Following the first four presentations there was time for a brief discussion. Several topics were briefly discussed, including an on-going discussion through the chat function of the meeting. One discussion point centred on the definition of the event in both space and time. It was noted that the extreme nature of the event was different depending on location, with some places receiving remarkably extreme daily rainfall totals, whereas other locations were considered extreme at longer timescales. Similarly, the synoptic sequence was not simple to define, with multiple upper-level synoptic features occurring in sequence. The slow-moving nature of the synoptic features was highlighted as important for the resulting extreme rainfall totals.

There was some discussion on how well the event was observed, and whether these observations would be assimilated into the BARRA reanalysis. It was noted that BARRA does not assimilate rainfall, although other aspects of the event would be assimilated, for example soil moisture. Although some observations were considered incorrect (due to overflow of gauges) alternative lines of evidence are available (e.g., radar observations).

The EC high resolution forecast at different lead times was a point of interest, with the extreme event seen to be forecast several days in advance. However, in the immediate lead-up to the event the model forecast of the event predicted it would have lower severity, although the prediction of extreme rainfall over-land returned in the next forecast cycle. It is not currently understood why that particular forecast cycle predicted that the heavy rainfall would move offshore, and how this compared to forecasts from the ACCESS model was not discussed in detail. The issue of bias-adjustment for the forecasts was raised, with some discussion of how value can be added to these types of events. It was noted that the adjustments needed may be event-specific and would be challenging to systematically implement.

Aside from the atmospheric conditions, relatively warm sea surface temperatures were proposed as potentially influencing the severity of the event. A question was raised on whether the relatively weak signature in the near-surface atmospheric state may be associated with prediction skill for these types of events.

It was noted that for these extreme events it is not only the science and prediction that can be improved: there is also a need to better understand how to communicate the risks being predicted. One way to increase awareness of an event is to assign it a name. Current ACS activities were described whereby the most likely, as well as worst-case outcomes are provided to customers. How can we improve public communication for unprecedented events?

3. Session 2: Likelihood and climate change perspectives

3.1. Summary of presentations

3.1.1. Damien Irving: Likelihood analysis based on observations and large ensembles

The `event' was defined as the 15-day rainfall total along the east coast. The analysis assessed the largest value of contiguous 15-day rainfall in each calendar year, RX15D. The 2022 value of RX15D was the highest on record by a wide margin. The GEV fit to observations of RX15D yields a return period for the event of about 300/800 years depending on whether the event is included/not included in the sample assessed. The statistics of RX15D events along the east coast were assessed in a wide range of model large ensemble datasets (UNSEEN). Tests of the model distributions for RX15D indicated that about half the models provided a reasonable representation of the statistics and half did not. Process studies in the models are needed to ensure that the synoptic dynamic processes generating extreme rainfall in the models are similar to the real world. The models indicate return periods for the event closer to the long end of the GEV range, but with a broad range across models. The statistics of RX15D in the models are similar when broken down by decade for the past four decades, which means there is no apparent non-stationarity for RX15D in the models. The assessment of non-stationarity is relevant to attribution studies in that a finding of non-stationarity helps in making attributions of change.

3.1.2. Kate Saunders: Statistics of extreme rainfall events

In analysing 'events' from an impact's perspective, it is important to distinguish between high intensity events at small local scales and more widespread events of lesser intensity. Max-table processes can be used to model spatial extremes allowing for dependence. Recent work had considered the spatial distribution of rainfall extremes and the influence of ENSO (Saunders et al 2017). It would be useful to repeat these analyses for more recent events. The analysis of extreme rainfall events requires choices in defining the event such as the spatial and temporal averages for rainfall. These choices in turn have consequences for the generalised extreme value distributions fitted to the event and to the conclusions one can draw from them. New work is providing better estimates to quantify the uncertainties introduced through choice of spatial and temporal averages and will be used to provide better assessments of return periods.

3.1.3. Steve Sherwood: Climate change and extreme rainfall

The climate change contribution to precipitation increases can be split into a thermodynamic term (captured in specific humidity, q), a dynamics term (captured in vertical velocity, w), and a microphysical efficiency term related to cloud microphysical processes generating rain (Pfahl et al 2017). The thermodynamic contribution has increased rainfall totals relatively uniformly around the globe following the Clausius Clapeyron relationship, and this contribution increases in climate change projections. The dynamic term's contribution to rainfall changes in past decades and future projections is much more heterogeneous, and in concentrated locations such as the tropics it is the dominant factor. For climate projections, there are larger uncertainties associated with the dynamic and microphysical efficiency terms than the thermodynamic term. The dynamic contribution modulates the regional responses, importantly weakening the response over Australia. The change in extreme daily rainfall (quantified using RX1D) is linked to the change in mean rainfall. It was noted that the latest climate models (CMIP6) did not offer obvious new information compared to the previous ensemble (CMIP5).

3.2. Summary of discussion

Following the last three presentations there was another brief discussion. This included an on-going discussion through the chat function of the meeting. The **value of large ensemble approaches** was affirmed in the discussion, especially for estimating the likelihood and changing likelihood of rare extreme events. This included a discussion of extreme events that could have occurred in the present climate yet didn't due to chance. There was further discussion on the **choice of metrics such as RX15D**, as well as the **ability of models to represent them with fidelity**. Similarly, the discussion turned to the use of **modified initial condition experiments** to attribute the event to climate change and other drivers. Is it appropriate to use these experiments for events where the model forecast was poor? Is there clear scientific guidance, based on verification, for what metrics can be confidently used from each of the models used within research and operations?

Another topic discussed was on the **likelihood of the event and how it may be changed due to global warming**. Evidence was provided that the event was an extremely rare occurrence, although precisely how rare it was is uncertain. For the metric considered (RX15D) it was noted there was no evidence of non-stationarity in recent decades. Another related discussion point was the **communication of probabilities** for these events. While return periods or recurrence intervals may seem intuitive to understand they may also lead to confusion when multiple extreme events occur in succession. It was suggested that communicating exceedance probabilities may be more useful, even if it is more difficult to explain.

Finally, the discussion turned to **the role of climate change in this event**. There are multiple pathways through which global warming may have affected the extreme rainfall that occurred. It was noted that much of the literature on extreme rainfall focuses on daily rainfall extremes metrics such as RX1D, which are not actually very extreme (since by definition they occur on average once a year). Future discussions on the impacts of this and other events should consider what metrics (and on what timescales) make sense for extreme impacts at each catchments scale. Can those relationships be generalised by catchment properties e.g., catchment area?

The evidence for a climate change influence on observed extreme daily rainfall events over Australia is challenged by some compelling evidence. For example, it was noted that projected changes to extreme daily rainfall tend to correlate to mean changes in rainfall. Since the trend in mean rainfall over the region is negative it runs counter to the argument for an increase in extreme daily rainfall due to global warming. A key caveat here is that the very extreme nature of the event, especially on multi-day time scales, may imply mechanisms that are different to those that influence mean rainfall. Further research is needed on the topic of multi-day extreme rainfall events, their drivers, and how they may change with global warming. More specifically, a discussion point was raised on the influences of thermodynamic, dynamic, and microphysical processes for the event. While reliable statements can be made on the role of climate change for thermodynamic changes in these types of extreme events, it is actually the dynamical changes that are likely to dominate the severity of the rainfall. In this case, what drove the quasi-stationary nature of the system, and how are those factors influenced by climate change?

4. Next Steps

4.1. Knowledge gaps

Each of the speakers highlighted key questions for further research. Here we attempt to summarise some of the key knowledge gaps for the event, relating specifically to meteorological aspects:

- How do we define an event such as this one?
- What were the key synoptic drivers of the event? E.g., what factors contributed to the long-lived quasi stationary low-pressure system?

- Why did the forecast falter and then return to its earlier prediction in the days before the event?
- How can we best communicate known or predicted risk for these types of events?
- Do our models (forecast, seasonal prediction, climate change projections) adequately capture the dynamics of these extreme events?
- Can we better quantify the past and future probability of these events using the datasets and methods available to us?
- What role does climate change play for these extreme events? Can we conditionally quantify or attribute the influence of climate change on different key processes or aspects of the event?

4.2. Opportunities for ACS

The post event workshops are explicitly intended to throw up case studies of recent climate hazard events that can present learning opportunities for ACS, its partner agencies, and clients. Providing a “best practice” climate service requires us to routinely assess how we are doing and what we can do better. **Since this workshop focused on the meteorology of the event only, we recommend further workshops on the hydrology and flood dimensions of the event. These workshops in turn should be followed by a more integrated workshop where we consider the production and use of warnings, outlooks, projections, impacts, and information sheets with the client agencies and those working on the interface with the clients.** These workshops would assess what information was provided, how it was used, and how it could be improved to do even better for future events like this one.

An intercomparison of the available forecasts leading up to the event would be useful. The presentation on the ECMWF forecasts showed that the forecasts were incredibly good on the whole (for the Brisbane event assessed) in picking up the extreme nature of the rainfall with at least several days advance lead time. There was the curious feature that the EC forecast backed off the event in one forecast cycle near the event, and the reasons for that are unclear. We note that the regional expertise of the Australian (BoM) forecast team on why they think the EC (and perhaps other) forecast systems weakened the event on one cycle would be valuable in advancing our understanding of predicting these extreme rainfall events. Members of the BoM forecast team were invited to participate in this workshop but were unable to present this time.

This workshop identified the need for dedicated process studies of the meteorology of events like those producing the extreme rainfall experienced in February 2022. The factors relating to the persistence and recurrence of the blocking highs and troughs along the coast need to be identified and assessed in weather and climate models. The workshop also identified the need for rapid attribution studies that could help unpack the role and contributions of climate change to extreme rainfall events. Similarly, developments in characterising the statistics of extreme events will be useful in putting events like this one in context. ACS work in conjunction with the Universities and NESP can help advance our understanding in all of these areas and we have active collaborations which need to be maintained and developed.

References

Saunders, K., Stephenson, A.G., Taylor, P.G. and Karoly, D., 2017. The spatial distribution of rainfall extremes and the influence of El Niño Southern Oscillation. *Weather and climate extremes*, *18*, pp.17-28.

Pfahl, S., O'Gorman, P.A. and Fischer, E.M., 2017. Understanding the regional pattern of projected future changes in extreme precipitation. *Nature Climate Change*, *7*(6), pp.423-427.

Appendix

A. Schedule

Time (AEST)	Speaker	Title
0900	Sugata Narsey (BoM)	Introduction
0905	Blair Trewin (BoM)	BoM Special Climate Statement
0925	Linus Magnusson (ECMWF)	EC forecast of the event
0945	Jane Golding (BoM)	The NSW Commission of Inquiry
1005	Michael Barnes (Monash)	Atmospheric dynamics related to the event
1025	Morning tea break	
1040	James Risbey (CSIRO) & Sugata Narsey (BoM)	Discussion 1
1120	Damien Irving (CSIRO)	Likelihood analysis based on observations and large ensembles
1140	Kate Saunders (QUT)	Statistics of extreme rainfall events
1200	Steve Sherwood (UNSW)	Climate change and extreme rainfall
1220	Doerte Jakob (BoM) and Michael Grose (CSIRO)	Discussion 2
1250	Richard Matear (CSIRO) and David Jones (BoM)	Closing remarks
1300	Close	

B. Attendees

Name
Sugata Narsey
Michael Grose
Ulrike Bende-Michl
Paul Fox-Hughes
Linjing Zhou
Jordan Notara
Andrew Dowdy

Acacia Pepler
Alicia Takbash
Marcus Thatcher
Julien Lerat
Naomi Benger
James Risbey
Didier Monselesan
Genevieve Tolhurst
Doerte Jakob
Damien Irving
Blair Trewin
Richard Matear
Surendra Rauniyar
Dougie Squire
Tess Parker
Judith Landsberg
Christine Chung
Alison Oke
Michael Barnes
Pandora Hope
Jane Golding
Francois Geffroy
Linus Magnusson
Lynette Bettio
Conrad Wasko
Matthew Wheeler
Zoe Gillett
Andrew King
Carly Tozer
Stephen Stefanac
Francois Delage
Mitchell Black
Mark Hemer
Evan Morgan
Corey Robinson
Ramona Dalla Pozza
Chris Lucas
Justin Peter
Kate Saunders

Nandini Ramesh
Steven Sherwood
Ghyslaine Boschat
Irina Rudeva
Shishutosh Barua
Masoud Edraki
David John Martin
Agus Santoso
Wendy Sharples
Shoni Maguire
Andrea Taschetto
Kimberley Reid
Jannatun Nahar
David Gooding
Chun Hsu Su
David A. Jones
Andrew Watkins
Mahadi Hasan
David Walland
Hamish Ramsay
William Wang
Kathy McInnes
Morgan Pumpa
Karl Braganza
Sharmila Sur