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Communicating the link between climate change and extreme rain events

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Extreme rainfall events are often linked to climate change based on simple thermodynamic arguments, but complex dynamic processes also play a role. Scientists have a responsibility to ensure they provide accurate information to the media and public.

Climate change is affecting extreme weather across the planet. Widespread warming and changing rainfall patterns are altering the likelihood and intensity of events locally[1]. When extreme events occur, scientists can offer useful commentary in real-time about the role of climate change even before a study, such as an attribution analysis, has been performed. Often, there is a diversity of views on the role of climate change when it comes to multi-day extreme rain events, and this may lead to public confusion about whether we should expect more or fewer of these events in a particular region. Much of the difference in commentary relates to the differing emphases placed on changes in dynamic and thermodynamic processes. Here, we examine what can be communicated about the potential link between climate change and extreme rain in the aftermath of such events using the extreme rain preceding floods in Australia in early 2022 as an example.

The Australian floods of early 2022

From 23rd February to 9th March, an exceptional heavy rainfall event took place over Eastern Australia, resulting in some of the worst flooding in living memory. This event saw rainfall totals exceeding 500 millimetres over a two-week period across large regions of the East Australian coast and occurred towards the end of an already wet La Niña summer.

Following this event, a number of press releases and scientists' quotations in the media implied a very clear connection between climate change and the extreme rainfall[2]. However, other media reports described the link as uncertain or included quotations of varying confidence[3]. Diverse statements on climate change and extreme rainfall can also be found in

media reports after other events, such as the Californian storms and floods of January 2023[4,5]. It is important that scientists' statements about the influence of climate change on extreme events are consistent, to avoid public confusion, and robust, because overconfidence in the presence of substantial uncertainty may lead to inadequate planning for risks associated with extreme rainfall.

Climate confusion over complex weather

When severe weather events occur, the question regarding the role of climate change is inevitably raised. There is generally good agreement that anthropogenic climate change is increasing the frequency and intensity of heat extremes. In contrast, the breadth of claims made on the role of human-caused climate change after extreme rainfall can be striking.

Extreme rain events occur due to two main factors, the first being a supply of moisture, and the second being a form of weather system that promotes ascent and triggers heavy precipitation. These are sometimes referred to as thermodynamic and dynamic processes, respectively. Both processes are necessary for extreme rainfall, but the influence of climate change on them is very different[6,7]. The effect of global warming on the thermodynamic process is broadly uniform across the globe, acting to intensify extreme rainfall due to an increase in atmospheric moisture. In contrast, the impact of climate change on dynamic processes is very regionally dependent[8]. It is therefore important we discuss both pieces of the puzzle, thermodynamic and dynamic, when linking human-caused climate change to an observed extreme rainfall event. If we only consider thermodynamic processes, we may understate the effect of climate change in regions where dynamic processes may further intensify extreme rainfall events. Alternatively, we may overstate the effect of climate change, in locations where warming reduces the occurrence and magnitude of weather systems that lead to extreme rain. In addition, the thermodynamic effect is likely of greater

importance for short-duration extreme rain[9], but for events lasting longer than a few hours the dynamic effect is more likely the limiting factor for rainfall totals.

In the case of the Australian floods in early 2022, the extreme rainfall was caused by a complex set of weather patterns that persisted for several days. Determining the effect of climate change on the systems associated with this event is extremely challenging and may be beyond current event attribution and, more generally, climate modelling capabilities. The persistence of the event, limitations in the observations, and the high degree of spatial heterogeneity in the rainfall also make the event challenging to characterise. The current likelihood of the rainfall and subsequent attribution may, therefore, be highly dependent on choices in the event definition[10].

In many instances, after extreme rain events like the Australian heavy rainfall, when communicating with the public scientists and organisations focus on the thermodynamic argument that in a warmer world the atmosphere can hold more moisture, resulting in intensification of these events[11]. After all, the thermodynamic change is simpler to explain given the high uncertainty in dynamic changes in many regions of the world[12]. However, this results in overconfident statements about the influence of climate change on extreme rainfall in the aftermath of such events and gives the incorrect impression that there is a greater understanding of climate change effects on localised extremes than currently exists.

Recommendations for science-informed statements

Scientists have a duty to enhance public understanding of extreme climate events. Extreme event attribution analyses help in estimating the human influence, but take time, especially for more complex events. This leaves a vacuum of information, which must be filled with credible and reliable commentary.

We recommend that scientists consider these lines of evidence before making public statements following an extreme rainfall event (Figure 1):

- Observational trends: How has rainfall changed historically on comparable spatial and temporal scales to the event in question?
- Climate change influence on thermodynamics: Globally, the moisture available for precipitation has increased under global warming, enabling increased precipitation efficiency. In isolation, the impact of climate change on thermodynamics has likely enhanced extreme rainfall.
- Climate change influence on weather patterns: How have the weather processes that led to the extreme rainfall event changed in frequency, intensity or persistence?
- Climate projections: How is rainfall on the relevant temporal scales projected to change under continued global warming and how uncertain is this projection?
- Past event attribution studies: What are the findings of relevant studies on previous events that are analogous to the extreme event in question?

By considering these lines of evidence, scientists can provide informative commentary on extreme rainfall events and the link with climate change.

For locations where there are known increases in extreme rainfall and prior event attribution studies that identify intensification due to anthropogenic influences, such as in the UK in autumn and early winter[13,14], this approach would likely allow for a strong statement. For the case of the Australian multi-day extreme rainfall in early 2022, these lines of evidence are inconsistent (Figure 1). This suggests there is insufficient evidence at present to say that human-caused climate change played a major role in this particular extreme rainfall event. This does not mean that climate change did not play a role - just that with our existing observational record, and with the current ability of climate models, we are limited in the

strength of the conclusions we can draw. The wording of statements may have a large effect on people's response[15] and should be carefully considered by scientists when preparing media statements in the aftermath of extreme events.

It is worth noting that the framing of this conclusion is derived from the frequentist principles often applied in event attribution[16]. An alternative framing could be to suggest that "human-caused global warming has altered atmospheric processes relevant to extreme rainfall, so it has played some role in this event, but the nature and magnitude of its influence is currently unclear." Such an approach shifts the null hypothesis from one of there being no human influence to one of there being a human influence. This is not inherently preferable because the null hypothesis in this approach, based on the global-average, would be increased extreme rainfall, but both increases and decreases are plausible locally due to circulation changes[17]. In locations experiencing reduced extreme rainfall there would be greater chance of misunderstood conclusions about the role of climate change using this framing.

While we recommend careful consideration of multiple lines of evidence, it is important to note that their relative importance is dependent on the duration of the event. For multi-day extreme rain events, the influence of climate change on dynamics will be of greater importance than the influence on thermodynamics, and *vice versa* for sub-daily extreme rainfall. For short-duration extreme rain events resulting in flash flooding there is more evidence to say that human-caused climate change is causing intensification.

The lines of evidence we have outlined cover the meteorological factors which should be considered when discussing extreme rainfall. However, how extreme rainfall translates into flooding involves further non-meteorological factors, such as land use and water management practices. Therefore, additional care should be taken when discussing the impact of climate change on flooding, where the knowledge of hydrologists needs to be incorporated.

The nuance of the science relating climate change and extreme rainfall is often lost in its communication to a general audience[2,18]. The uncertain dynamical changes are sometimes not discussed whereas the better understood thermodynamic change is commonly the focus of public discourse. This can cause widespread misunderstanding and result in unrealistic expectations of what the future may hold. Informative statements from scientists would implicitly incorporate both dynamic and thermodynamic processes. We hope that our suggestions, alongside other recommendations on how to frame communication of climate change and extreme events[19], aid in improving the effectiveness of climate scientists' statements in the media and, ultimately, increasing public understanding of climate change effects on extreme weather.

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Competing Interests Statement

The authors declare no competing interests.

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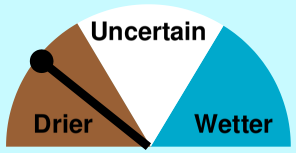
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Figure Captions

Figure 1. Considerations for statements to the media and public regarding the influence of climate change on an extreme rainfall event. Statements made in the immediate aftermath of extreme rainfall events should be clearly framed and consider multiple lines of evidence, including the location and duration of the event. The dials illustrate the assessment for the example case of the extreme rainfall in eastern Australia. An example final statement based on these lines of evidence is shown.

Lines of evidence for rapid statements on climate change role in extreme rain events

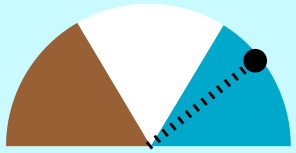
Observed trends



Understanding of climate change influence on weather patterns



Understanding of climate change influence on thermodynamics



Climate projections

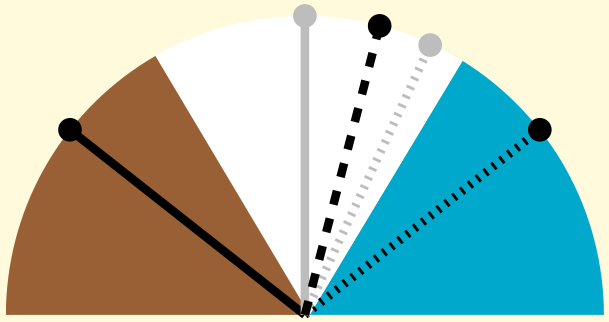


Past event attribution studies



Final statement example

The climate change effect on multi-day extreme rainfall in the flooded region is uncertain



Lines of evidence point in different directions