climate extremes
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Future weather and climate extreme events

ARC Centre Of Excellence for Climate Extremes Briefing Note 4

Weather and climate extremes occur on a wide range of time and space scales. Weather extremes occur on shorter timescales and are regionally or locally specific while climate extremes tend to be on longer timescales and can impact a region through to the whole globe. This note provides a statement on what we know about how weather and climate extremes might change in the future.

To predict the future behaviour of weather and climate extremes requires either statistical or physical modelling and there is no single solution to providing reliable predictions. Extreme events are, by definition, rare and any time series of measurements will have only a few examples and may have no examples of extreme events that might threaten the resilience of a system. Consequently, statistical modelling, such as regression approaches that use observations to predict future behaviour, is unlikely to provide good predictions once the behaviour of the system being predicted changes. The whole basis of concerns over future climate is scaffolded on an understanding how the teleconnections, temperature, moisture and salinity gradients within the Earth System will change. Profound changes in regional climate, and the emergence of "novel climates" are expected. Attempts to predict future weather and climate extremes using statistical approaches are therefore very likely seriously flawed – this means a focus on physical modelling is essential.

In terms of physical modelling, global and regional weather and climate models are commonly used to examine how extremes will change. Weather models are extraordinarily skilful on timescales of 5-7 days in simulating the weather, and increasingly skilled in simulating weather extremes. They achieve this by assimilating extensive observations and using very high resolution (i.e., grids with fine detail); neither of these options exists for climate models simulating extremes for 2030, 2050 or 2100. Here, coarser resolution climate models are used. These cannot assimilate observations that have yet to be taken, nor can they properly resolve the spatial scales upon which many of the weather extremes occur.

Climate models are routinely used to examine extremes. A range of indices have been developed – the hottest/coldest day of the year, consecutive wet/dry days and so on. These are not truly extreme – the average hottest/coldest day of the year does not damage infrastructure. What is needed are estimates of extreme events that threaten the resilience of infrastructure, or the capacity of hospitals to manage

demand, or the viability of supply lines to businesses, or the financial viability of a mortgage book. These are not "annual" events – they may be a 1 in 100-year event, or a 1 in 200-year scale rainfall event, or the drought event that lasts several years, or the heatwave that lasts 10 days rather than a more common 5, or other record-breaking events that may occur on timescales as short as a single day (e.g. Black Saturday).

Analyses of climate model simulations for rare events are almost non-existent. This is not due to a lack of enthusiasm by the climate modellers; it is a recognition that the climate models were not built for such purposes. There have been some analyses of how well climate models simulate droughts lasting longer than a few months and those studies concluded the models systematically failed to capture droughts lasting a year or more. There have been analyses of changes in the 1 in 20-year rainfall event, but these were not founded on a careful analysis of how well the climate models simulated events of this scale in the present day. There is almost no analysis of how extreme winds might change, climate models do not simulate hail, tornados and so on.

There are many estimates in the literature of climate-model derived changes in extremes, but not the rare events discussed above. They often relate to the largest or hottest event of a year, or decade. In addition, most extremes are treated as single risks, and not compound events, or risks of cascading feedbacks. There is also high confidence that warming and associated impacts are amplified at the regional scale. For example, the signal of warming is much larger over land, which has serious implications for heatwaves. Also, localised extreme rainfall events are likely to increase in intensity at a larger rate than the 7% per degree determined from thermodynamic theory.

The current situation is therefore:

- For extremes that occur roughly annually, climate models provide information to assess how these are changing. For temperature-related extremes the changes in these events tend to occur on a large (regional) scale associated with large-scale synoptic patterns. Climate models likely have some skill here; some models do seem to connect large scale drivers (e.g. ENSO) with changes in the likelihood of temperature and perhaps rainfall extremes. The literature is rich with these sorts of analyses and they are likely broadly reliable, but that does not make them necessarily useful.

- Evidence exists, from targeted examination of individual events, that some extremes will become worse in a warmer world. For example, a specific storm can be examined under current and future climate conditions. These case studies tend to point to more intense future rainfall, more intense heatwaves and so on but most assume the large-scale background state does not impact the synoptic conditions that led to the event. Despite this, they do provide considerable evidence that many extremes will intensify in the future but they do not provide guidance of where events may cease to occur, or occur more frequently.

- For extremes of a scale that threaten the resilience of a system – that is events that might occur about once every 100 years – analyses of climate models provide little confidence that we can use these models to simulate these events. There are arguments that climate models can simulate the change in these events even though they cannot capture the probability of them in the current climate. Evidence to support this view is very weak.

- Truly transformative events are commonly compound events – where simultaneous events occur. There has been almost no analysis of how well climate models can capture the risk of these events and it is extremely unlikely they can.

- A category of extreme events known as abrupt climate change events exist. These include collapse of the thermohaline ocean circulation, collapse of the Amazon ecosystem, collapse of the west Antarctic ice sheet and so on. Global climate models do not simulate these systems in a way that they can be reliably used to assess the risk of such events and expert judgment informed by palaeoclimate data is most commonly used to examine these phenomena.

There are ways forward:

- Building climate models to reflect synoptic scales properly (~10km), and then running large ensembles is a 10-year research challenge but may provide more reliable simulations of extremes, and better ways to estimate the statistics of extremes.

- Embedding regional climate models in existing high-resolution models (e.g. HiResMIP) may provide a more reliable large-scale state to downscale than existing CMIP5 models, where large errors in the mean state likely limits their reliability. This is achievable in ~3-5 years.

- Targeted studies of events to understand the physical processes that are woven together to explain the extreme may provide insight on how processes influence these events in the future and how the events can be better represented in models.

- Targeted studies on compound events that result in failure of human and natural systems, guided by analysis of the vulnerabilities of these systems.

In case there is any misunderstanding, the lack of reliable evidence from climate models of how truly extreme events may change should not be interpreted as suggesting these events will not change. The general sense of more extreme events in the future is well founded on observations and theory and it is more likely we are underestimating how fast and by how much extremes will change on local to regional scales.

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