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Modelling changes in extreme rainfall for Australia

Conrad Wasko [a], **Lalani Jayaweera** [b], **Rory Nathan** [b], **Rohan Eccles** [c] **Jozef Syktus** [d]

[a] *School of Civil Engineering, The University of Sydney, Sydney, Australia*
[b] *Department of Infrastructure Engineering, University of Melbourne, Melbourne, Australia*
[c] *Department of Energy and Climate, Queensland Government, Brisbane, Australia*
[d] *School of the Environment, The University of Queensland, Brisbane, Australia*
Email: conrad.wasko@sydney.edu.au

Abstract: Climate change is increasing the estimates of extreme rainfall that are used in many applications, such as climate change impact assessments and engineering design. While these applications require updated rainfall estimates, the large uncertainty in rainfall projections and their high regional variability often hampers the adoption of the non-stationary methods that seek to update extreme rainfall estimates for climate change. There are three main lines of evidence, or methods, for assessing changes in extreme rainfall with climate change: (1) historical trends, (2) correlations with temperature or other climatic variables, and (3) projections using climate modelling. In this paper, using rainfall gauge stations with data of 6-minute resolution from 1967–2021 across the continent of Australia, we use and evaluate these three methods to understand the impacts of climate change on extreme rainfall.

Historical trends in extreme rainfall annual maxima are first examined. It is found that, while there is strong evidence for increases in sub-hourly maxima, there is little evidence for changes in rainfall of longer durations. To model the changes for rarer events, a split sample method was applied fitting a generalized extreme value (GEV) distribution to first half and the latter half of the data, the difference between these periods then examined. Rarer events, up to the 1 in 100 Annual Exceedance Probability (AEP) were found to exhibit increases greater than those more frequent events, implying that the skewness of the GEV distribution is shifting under climate change. This observation was found to have implications for non-stationary frequency analysis (the second line of evidence), as it means that all three parameters of the GEV distribution should be non-stationary with climate change.

The association between extreme rainfall changes and a variety of covariates was then investigated using a non-stationary GEV distribution which varied all its three parameters with each covariate. These included annual global temperature, annual Australian average temperature, annual Australian annual diurnal temperature, Indian Ocean Dipole, The El Niño Southern Oscillation, The Southern Annular Mode, annual Australian precipitable water, and annual Australian average dewpoint. It was found that global temperature was the best covariate for modelling changes in extreme rainfall with climate change due to its strong association with the historical increasing trend in extreme rainfall. Surprisingly, covariates such as The El Niño Southern Oscillation performed poorly due to their strong association with interannual variability, rather than the signal due to climate change.

Finally, hourly extreme rainfall projections were both evaluated against historical observations and projected using a 15-member ensemble of the Conformal Cubic Atmospheric Model, with the evaluation performed on events ranging from the 1 in 5 AEP to the in 1 in 100 AEP for durations from 1hour to 168 hours. Longer duration extremes, such as daily extremes appeared to be well modelled for more frequent extremes but there was a slight underestimation for rarer extremes, whereas a consistent underestimation was found across rarities for 1 hour rainfall. Despite this, the underestimation was relatively small, and the extreme rainfall simulated was deemed suitable for investigating changes in extremes. Projections show increases across durations, something that was only observed for short durations in the historical record, and greater increases for rarer events. However, compared to the historical record the projections underestimate the rate of change for short duration rainfalls.

These results are now reflected in the climate change considerations in Australian Rainfall and Runoff, Australia's national flood guidance, with adjustment factors for historical design rainfall varying with duration and adjusted based on the global rate of warming. Future work should focus on the evaluation of convective permitting modelling to better understanding the projected changes in extreme rainfall.

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