



## **The connection between protracted drought and extreme precipitation during recent decadal-scale drought episodes**

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Protracted dry periods lasting multiple years to decades have occurred in regions including southern Australia, the southwest United States and parts of the Mediterranean, since the latter part of the 20th century. Typically, these protracted droughts have been identified when a multi-year or decadal-scale average of precipitation or a hydrologic variable such as streamflow is well-below normal. However, we show that one of the most defining features of several of these recent protracted dry periods is not the presence of below or much-below average precipitation. Interestingly, most if not all of these protracted drought periods have the occasional year of near or above average precipitation. Rather, a distinct characteristic of recent protracted droughts is the absence of seasons or years of well-above average precipitation i.e. years or seasons of extreme precipitation. In this sense, we argue that extreme precipitation might be just as more important for determining the continuation of a drought as below average precipitation.

To demonstrate the importance of considering extreme precipitation for understanding drought, we present a case study in southeast Australia for the so-called “Millennium Drought”. The Millennium Drought was a persistent and prolonged dry period that began around 1997 and was predominantly characterised by the lack of autumn and winter precipitation. It is widely accepted that the Millennium Drought ended abruptly with the onset of strong La Niña conditions in 2010. However, we provide evidence that despite the high precipitation in the spring and summer of 2010, the anomalously dry conditions in autumn and winter never ceased and are not markedly different to those conditions observed during the Millennium Drought. This raises the question of whether the Millennium Drought ended, or whether it was just interrupted by the 2010 La Niña.

Rethinking how we characterise protracted drought is critical given that those areas described previously in Europe, Australia and North America have experienced several “bursts” of multi-year drought in the last few decades. Establishing what characteristics of precipitation variability are important for these “bursts” – and whether they are caused by decadal-scale variability or a non-stationarity in precipitation associated with anthropogenic climate change – are key questions.