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Reply on RC1

Jorgen Segerlund Frederiksen and Stacey Lee Osbrough

Author comment on "Regime transitions of Australian climate and climate extremes" by
Jorgen Segerlund Frederiksen and Stacey Lee Osbrough, Weather Clim. Dynam. Discuss.,
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*Interactive comment on "Regime transitions of Australian climate and climate extremes"
by Jorgen S. Frederiksen and Stacey L. Osbrough*

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1 Methods section

We will follow the reviewer's suggestion and include a Methods section in the revision of the paper. This will include a pedagogical summary of the method of determining rainfall and temperature deciles as described by the Bureau of Meteorology (2022b), some of the issues in point 2 below, and discussion of regression methods and averaging methods. Much of the discussion on anthropogenic climate change tipping points has focussed on major tipping points of global extent that may be exceeded in the future. For example, Lenton et al. (2019) discuss tipping points such as the possible acceleration of the melting of the Greenland ice sheet that could occur with a 1.5° C warming. As noted, our particular interest in this article is whether the changes that have already occurred in Australian climate and climate extremes over the last seventy years are indicative of regime transitions in a noisy environment. We also discuss the relationship between these changes and the large-scale circulation and in the revision will further expand on additional implications and connections.

2 Extended seasonal and annual deciles

Perhaps to provide background to our response it is useful to first summarize the development and uses of rainfall and temperature deciles over the last 55 years. As noted by Keyantash (2021) "An established quantile methodology is the usage of ten quantiles,

or *deciles*. A decile-based system for monitoring meteorological drought in Australia was proposed by Gibbs and Maher (1967) and adopted by the Australian Bureau of Meteorology (BoM) to monitor drought conditions in that nation." Gibbs and Mayer (1967) presented Australian maps of the distribution of decile ranges of annual rainfall for the years 1885 to 1965 in a study of drought. The Bureau of Meteorology (2022c) has continued the publication of Australian maps of annual rainfall deciles from 1900 to the present and has presented them for extended seasons (e.g., Bureau of Meteorology and CSIRO 2020) as well as for seasons and years in numerous reports. Keyantash (2021) further notes "The rainfall decile methodology begins by assembling three-month (or longer) precipitation totals ... as drought is not validly recognized for briefer periods in Australia...". The caption in Fig. 11.1 of Keyantash (2021) states "Decile map of 12-month precipitation totals in Australia, through April 2020. Meteorological drought in Australia may be assessed across a variety of timescales, but the duration must be a minimum of three months." Keyantash (2021) further notes "It is interesting that BoM also examines monthly rainfall totals from the decile perspective, even when drought characterization is not the objective".

Keyantash and Dracup (2002) have made similar determinations to those above and note that, in the USA context, for Meteorological Drought the rainfall decile index as used at BoM is the superior index overall and particularly in terms of robustness, transparency and extendability (their Table 3). In the Handbook of Drought Indicators and Indices by the World Meteorological Organization and Global Water Partnership (2016) some of the properties of deciles are noted. In particular: deciles are "easy to calculate" and "examples from Australia are useful". "Daily, weekly, monthly, seasonal and annual values can all be considered in the methodology, as it is flexible when current data are compared to the historical record for any given period.". "Applications: With the ability to look at different timescales and time steps, deciles can be used in meteorological, agricultural and hydrological drought situations." Table 2 of the Handbook also lists some of the Meteorological Institutions, in addition to those in Australia and USA, that use deciles.

Deciles of rainfall and temperatures have also been used in the horticultural and agricultural industries on a variety of time scales including the extended seasonal time scale. For example: Cool season – April to October – rainfall deciles were used in the South Australian Government study of climate change, wheat production and erosion risk by Sweeney and Liddicoat (2012). In a study of "The Riverland Climate for Almond Production" Thomas and Hayman (2019) examine September – April deciles of temperature. Hayman and Hudson (2021) explore the value of recent new BoM forecast products of weekly, monthly, and seasonal rainfall and temperature deciles for grain production.

The Bureau of Meteorology (2022a) publishes monthly, seasonal, extended seasonal and annual deciles of rainfall and temperatures and has published numerous reports in which they are employed for various purposes.

In view of the above background, we do not understand why the reviewer thinks that extremes-based results using deciles for long seasons should be artifacts. There is no essential difference in studying time span averaged data in decile 5 – the median for general distributions and the mean for symmetric distributions – and any other decile. As noted by Keyantash (2021) the decile approach is nonparametric so there are no fitted distributions or assumptions. The approach involves a simple time span averaging, ranking, ordering, and binning of the observed results and the values, in a given decile, at a particular time, and time scale, represent just the reality of the observations. If the regime transitions are more obvious for decile 10 than decile 5 then that is the reality of the meteorology, the climatology, the physics and the chemistry just as they are for streamflow compared with rainfall. This is the case whether the resulting distribution is Gaussian, Poisson or fat-tailed and whether the future is just a shift in the mean or a

significant change in the tail. The frequency of bushfires and the failure of crops are the reality of phenomena that depend more on the extremes than the mean or median.

The broad conclusions of our study are borne out by monthly, seasonal, extended seasonal and annual data. Monthly data are, of course, noisier which is why for many purposes seasonal, extended seasonal or annual deciles are preferred as generally presented by the Australian Bureau of Meteorology.

3 Other comments

L16-17: Yes, agreed – thank you.

L86: Yes, agreed – thank you.

Section 2.2: Yes, we will expand on this section in the revision and point out that the NCEP data is not used for the extremes but only the mean circulation and reference comparisons.

L95-97: Thank you – will be referenced in the revision.

L124-125: The purpose of the quadratic fit is just to indicate why the streamflow is more sensitive to changes in rainfall than mean rainfall itself. In that sense the streamflow acts like the decile 10 rainfall. We will rephrase this to make it clearer in the revision.

L140: SWWA rainfall has often historically been considered for the SWS season of April to November and for the winter season of June to August and more recently also for the CS season of April to October. We feel that we should point out that our conclusions are broadly the same for all these periods.

L208-209: Yes, the time series are essentially synchronous – thank you.

L234: Yes, agreed – thank you.

Section 5; We feel that it is important to point out that the rainfall changes in Northern Australia have been largely opposite to those in Southern Australia. We will consider this point further in the revision.

L251: Yes, agreed – thank you.

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