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Hydrology and Earth System Sciences Discussions

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Interactive comment

Interactive comment on "Catchment-scale drought: capturing the whole drought cycle using multiple indicator" *by* A. J. Gibson et al.

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Comment 1: Somehow, I missed the information on how the authors have objectively defined the criteria for the drought onset and termination.

Authors' Response: The authors refer the reviewer to the definitions of drought onset and termination in line 121. In particular: "For this study, an SPI period of 6 months (SPI6) was chosen to capture persistent droughts, with meteorological drought onset being defined as a period of six successive months of SPI6 below -1 (Dettinger 2013; Verdon-Kidd et al., 2017). Drought severity was then categorized, based on SPI values, as; mild (-1 < SPI < -0.5), moderate (-1.5 < SPI < -1), severe (-2 < SPI < -1.5) and extreme (SPI < -2), as recommended by McKee et al., (1993, 1995). Following this,

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termination of a drought event was then defined as a period of six, successive months where SPI6 was above -1 (Dettinger, 2013; Verdon-Kidd et al., 2017)."

Comment 2: While there appears to be two study catchments analyzed in this study – but the hydrological droughts (SWSI6) and NDVI anomaly (in Figures 3, 4, 9 and 12) is just a single plot. For which catchments these data refer to? Or these plots use data combined for both basins – in this case how the underlying drought indices were aggregated into single values?

Authors' Response: The data refers to a single record created using average values across both catchments. This was done to match the single rainfall record developed from the two BoM stations (Line 112). A single record of streamflow and NDVI were developed first by taking the average across both catchments, with drought indices calculated from this. Line 156 has been modified to clarify this. The data then diverges to both catchments for the Millennium Drought study due to an increase in data availability.

Comment 3: I understand that the authors used the AWAP simulated streamflows in their analyses. Since the following hydrological analysis is based on this modeled dataset, I would recommend the authors to make a quality check (skill assessment) against the available observed streamflow – though it might be the short time series – in my opinion the analysis will provide good foundation. Related to the above – I would also recommend the authors to check the differences between the precipitation datasets (and the resulting meteorological drought index) i.e., one use as forcing in the AWAP product and the one the authors used in their analysis (i.e., BoM-Roscommon). This is really important to check in light of the author's discussion/conclusion on Page 10: "Not all meteorological droughts were found to progress to hydrological drought for our study catchment. The best example of this is the absence of a hydrological drought with the 1982–83 meteorological event. This was the most severe meteorological drought, with an average SPI6 of -2.32, and had a rapid rate of onset (outlier in Fig. 3), however, there was no associated hydrological drought."

Authors' Response: The authors thank the reviewer for their comment and have added a reference to Gibson (2016) to line 112 of the revised paper which details the instrumental validation for this catchment suggested by the reviewer. Demonstrated in this reference is a local validation of the AWAP streamflow against the limited available observed data. The authors have compared the drought indices derived from the AWAP rainfall product. The two SPI records were found to be near identical, with the AWAP SPI = 0.94 x Observed SPI (R2 = 0.91, $p < 0.01$). Between the two records there is only a slight difference in the timing of droughts. As the paper is already lengthy, this analysis was not explicitly included, however we agree this should be cited.

Comment 4: Could the authors explicitly specify the motivation as well the settings (parameters) they used in the Box-Cox transformation of discharge. What is the unit of Q (Y-axis) in Figure 9?

Authors' Response: This transformation results in the heavily skewed runoff data to approximate a normal distribution, with the relationship with rainfall then becoming linear and more widely applicable as outlined in Saft et al. (2015). This has been added to line 141 of the revised manuscript to clarify. The parameters used have been explained further in the methods section. As this is a transformation of values, Q becomes unitless. "This transformation results in the heavily skewed runoff data to approximate a normal distribution, with the relationship with rainfall then becoming linear and more widely applicable (Saft et al., 2015). and regressed against annual rainfall. This was carried out for each "drought period" and non-drought years using the best transformation selection method, with $\lambda = 0.264$. A t-test was used to determine if a significant change within this relationship had occurred within each drought period (Saft et al., 2015)."

Comment 5: It is not clear which line on the Figure 4 corresponds to drought #4 or #9 (as mentioned many times in the manuscript). I can only guess.

Authors' Response: We thank the reviewer for pointing out this oversight and in response have adjusted lines 217-223 accordingly. Rather than focusing on Figure 4, we have reworded the text to highlight that Drought 4 is a typical onset, while Drought 9 is more rapid and an outlier in the drought record.

Comment 6: Line 224: Please explain how did you identify the specific season from information provided in Figure 5.

Authors' Response: The seasonality of the droughts is clarified by adjusting line 217 and the caption to Figure 6. The reference to Figure 5 in line 224 has also been changed to Figure 6.

Comment 7: I do not concur with the author's interpretation (Lines 270, 280, and 347) "the propagation from meteorological drought to agricultural drought is rapid. . . " Just because the lag is zero it does not mean a rapid propagation. Note that you have taken SPI6, which accounts for the past 6 months of (accumulated) precipitation anomaly – which inherently account for the antecedent conditions (and create a memory effect). I would like to hear the authors opinion on this issue.

Authors' Response: This is an interesting point and understanding catchment memory's role in drought is a topic widely discussed in the literature. While memory would have a role in drought propagation here, the lack of a lag in correlation between NDVI and SPI is unique in this study when compared to others that show lags of up to 5 months (using SPI6) improving correlations (e.g. Verdon-Kidd et al.,. 2017). As a result of this, we have come to the conclusion that the transition from meteorological to agricultural drought is relatively quicker in this catchment compared to other areas. References and edits to line 284 have been made to clarify; "This shows the propagation from meteorological drought to agricultural drought is rapid compared to other studies (e.g. Verdon-Kidd et al., 2017). This is an important aspect of using the SPI6 to quantify drought here. A response at short timescales between rainfall and vegetation may not be seen, however using the longer-term SPI highlights the response of vegetation after sustained rainfall deficits (Dettinger et al., 2013, Verdon-Kidd et al., 2017)."

The role of catchment memory, size, vegetation and rainfall patterns does warrant further investigations, and we hope to in the future, however this is just not possible within the current scope of this paper.

Comment 8: Since soil moisture also exhibits strong seasonality, I would have expected that authors to remove those seasonal effect (as they consider in case of NDVI) and consider the anomaly term in their analysis. Please comment on this.

Authors' Response: The authors recognise that there can be strong seasonal variations in soil moisture, however, at our particular study site, rainfall is quite uniform throughout the year (compared to other areas of Australia with a distinct seasonality in rainfall). Additionally, volumetric soil moisture data is important for understanding the water available to plants during drought and standardising the data would remove this aspect. Standardising the three depths of soil moisture also removes the differences in soil moisture between them. The fact there is small variation in deep soil moisture over the time series is believed to be important for catchment recovery to drought. While both the raw timeseries and anomalies could be explored, this would extend the paper with adding little to the discussion that is not already captured in the raw time series (as show in Figure 1).

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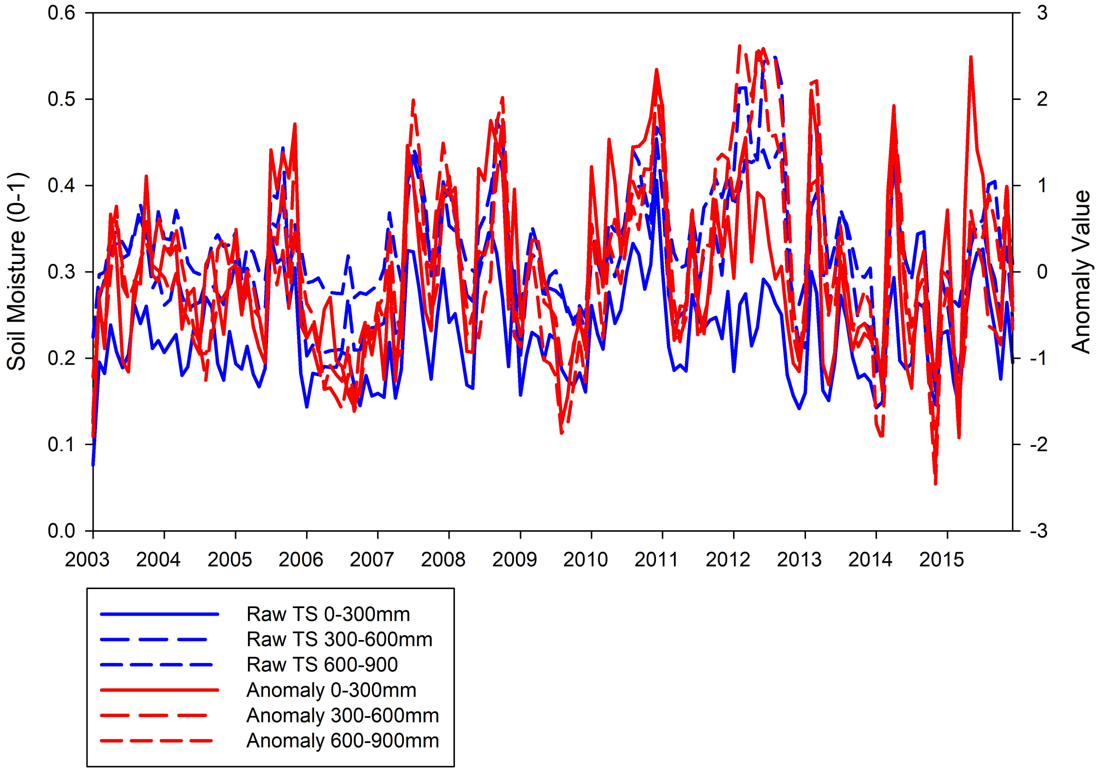

Fig. 1. Comparison of anomaly and raw soil moisture data for the Krui catchment. The Merriwa was not included due to the similarities between the datasets.