Response to Reviewer 2 comments

General Comment:

The manuscript 'Meteorological Drought Projections for Australia from Downscaled high-resolution CMIP6 climate simulations' presents the future drought features (SPI and SPEI) based on the downscaled precipitation and potential evapotranspiration data. The work is well-presented. However, there are some issues that need to be clarified further before the publication.

Response:

We thank the reviewer for their time and constructive comments on our manuscript. Our comments below show where we plan to make changes to the manuscript to address these concerns.

Comment:

1. This study utilizes various drought characteristics, including duration, frequency, percent time (Figure 2), and shifts in the moving average, to predict future droughts. However, since the downscaling is applied only spatially, all temporal analyses could be conducted using GCM data. Yet, only Figure 10 presents a spatial map. What is the rationale for using downscaled data in this context?

Response:

We thank the reviewer for their comment. It is important to note that downscaling does improve the temporal and the spatial resolution of the projections (for instance CCAM has sub-daily data available). However, as this analysis was conducted using accumulated monthly precipitation and PET, outputs from GCMs could also be applied as suggested by the reviewer, though at a much coarser spatial resolution. We have found in previous work that the downscaling does improve the representation of precipitation and temperature, even when assessed at coarse spatial scales (Chapman et al., 2023). The benefits are greater for coastal regions or where the terrain is complex. These improvements provide benefits to projections of future drought events even when assessed across the Natural Resource Management (NRM) regions, which are relatively coarse. We will make improvements to the introduction to make these benefits clearer in the revised manuscript. It is also important to note that as part of this paper we provide regionalised drought characteristics for Australian Local Government Areas and River Basin (https://doi.org/10.6084/m9.figshare.26343823), for which the finer granularity of the downscaled projections is very beneficial.

We made a conscious choice in the manuscript to combine the spatial maps into subplots where possible to allow for the changes to different drought characteristics to be interpreted spatially together between SPI and SPEI as this allows for an easier comparison of the differences. For instance, Figure 10 highlighted by the reviewer contains subplots of 36 maps for extreme droughts. Additional maps of changes to moderate droughts can be seen in the supplementary materials (Figure S14). Additionally, we will be including additional spatial maps of the 10th and 90th percentile of changes to better show the uncertainty of these changes.

we will include more spatial visualisations of the 10th and 90th percentile of changes to the

Comment:

2. Why did the author choose to use downscaled data from the Conformal Cubic Atmospheric Model (CCAM)? What advantages does CCAM offer compared to other downscaled datasets? Additionally, how can you demonstrate that drought characteristics derived from the downscaled data are more reliable or accurate than those based on raw GCM data?

Response:

The reviewer is correct that there are other downscaled datasets available as part of the CORDEX CMIP6 experiment. However, at the time that this work was undertaken, only the CCAM dataset was available for analysis. It should also be noted that we adopted the reference crop evapotranspiration (PET) for calculating the SPEI, which was derived offline from CCAM. This requires some considerable effort as several variables are required at a daily timestep (daily data solar radiation, vapour pressure, maximum and minimum temperature, mean sea level pressure, and wind speed). As such, offline PET is not available for either the GCMs or other downscaled datasets, making a one-to-one comparison difficult. Lastly, CCAM is advantageous over other datasets, as it is the largest ensemble available (15 models) and run at the highest resolution (10 km).

The CCAM dataset has been previously evaluated against the host GCMs as part of an assessment of added value, which showed downscaling improved simulations of precipitation and temperature with added value of up to 150% across Queensland's regions (Chapman et al., 2023), especially for extremes and over regions with complex terrain. We will better highlight these advantages in the introduction and methodology of our revised manuscript. Our other paper (Chapman et al., 2024) also shows how high resolution projections add details to regional climate hazard analysis. We will better highlight these advantages in the introduction and methodology of our revised manuscript.

Comment:

3. Is there any result about the comparison between the downscaled data and original data (such as precipitation and potential evapotranspiration) to evaluate the downscaling methods' performance?

Response:

We thank the reviewer for their comment. As we note above, the downscaled precipitation data has previously been evaluated against observations and compared to the host models in an assessment of added value (Chapman et al., 2023). This analysis found that downscaling improved performance over host GCMs for seasonal temperature and precipitation (10% and 43% respectively), and for annual cycles of temperature and precipitation (6% and 13% respectively). Downscaling also improved the fraction of dry days, reducing the bias for too many low-rain days. As PET was derived offline from the model (as noted above), we could not compare the performance from CCAM and the host GCMs. We will better highlight these advantages in our revised manuscript.

Comment:

4. The study area was divided into four distinct regions—Eastern Australia, Northern Australia, the Rangelands, and Southern Australia—based on climatic and biophysical characteristics. However, the specific climatic and biophysical parameters used for this classification were not

explicitly defined. Including detailed information on climate patterns (e.g., precipitation regimes, seasonal variations), dominant vegetation types, and temperature ranges could enhance the clarity of the classification framework. Such specifications would facilitate a more comprehensive interpretation of the analytical results by providing critical contextual information about regional environmental variations.

Response:

We thank the reviewer for pointing out the lack of information regarding how the NRM regions were defined. It is important to note that we did not classify these regions ourselves. Rather, we adopt pre-defined regions which were developed by CSIRO and BOM to specifically assess climate change in Australia (CSIRO and Bureau of Meteorology, 2015). These regions are recommended for use in climate change studies of Australia and have been widely applied for this purpose (Chapman et al., 2024; Grose et al., 2020; Wasko et al., 2023), including for droughts (Kirono et al., 2020). We will update our manuscript to include the original reference in the methodology which details how they were defined (CSIRO and Bureau of Meteorology, 2015). As these regions are relatively large, there are a number of vegetation types and climate zones included within each one. We have collated some of the relevant information from the original report into a table as suggested by the reviewer (see below), which we will include in the updated supplementary materials.

Additionally, we will revise Figure 1 in the revised manuscript to include the major climate regions as a background so that these can be easily compared against the delineated NRM regions.

NRM super-cluster	Area (1000 km^2)	Climate Zone	Ecoregions
Eastern Australia	767	Subtropical (north) Temperate (south) Grassland (west)	Temperate broadleaf and mixed forests Temperate grasslands, savannas and shrublands Tropical and subtropical grasslands, savannahs and shrublands
Northern Australia	2084	Equatorial (north east) Tropical (north) Subtropical (far east) Grassland (south)	Tropical and subtropical grasslands, savannahs and shrublands Tropical and subtropical moist broadleaf forests
Rangelands	4888	Grassland (scattered) Desert (majority)	Deserts and xeric shrublands (majority) Mediterranean forests, woodlands and scrubs (south west & far south) Temperate grasslands, savannas and shrublands (east) Tropical and subtropical grasslands, savannahs and shrublands (north east)
Southern Australia	1464	Subtropical (west coast) Temperate Grassland	Mediterranean forests, woodlands and scrubs Temperate broadleaf and mixed forests Temperate grasslands, savannas and shrublands Montane grasslands and shrublands

Comment:

5. The discussion's comparative analysis of the SPI and SPEI offers valuable methodological insights. However, stronger integration with region-specific climatic and biophysical drivers would benefit the interpretation. Additionally, the spatial specificity of distinctions between SPI and SPEI across sub-regions remains insufficiently delineated, limiting the granularity of conclusions.

Response:

This paper focussed on a broadscale analysis across Australia using NRM regions to delineate impacts. However, some of the insights may be scale dependent and analysis of smaller extents such as local government areas and basins may reveal a more locally relevant outcome. As discussed above, we have used the NRM regions to be consistent with recommended approaches for climate change assessment in Australia. We agree with the reviewer that the scale of the NRM regions is often insufficient to draw localised conclusions, which is why we have also provided regionalised drought characteristics for Australian Local Government Areas (566 sub-regions included) and River Basin (219 sub-regions included) as part of a supplementary dataset to this paper (https://doi.org/10.6084/m9.figshare.26343823). This delineated dataset may be used by readers to investigate localised impacts of the projected changes, which cannot all be included in this paper due to the number sub-regions involved. We also use the methodology presented within this paper as the basis from which to develop regionalised specific drought indices for a range of different region types (Local Government, Bio-Regions, NRM Regions, Regional Planning Areas, River Basins, and Disaster Districts) in Queensland, which are presented as a dashboard product through: (https://www.longpaddock.qld.gov.au/qld-future-climate/dashboard-cmip6/#responseTab5). As the reviewer suggests we will expand on our discussion of how meteorological droughts interact with biophysical factors, including land cover in section 4.3.

Comment:

Can more spatiotemporal visualizations (e.g., seasonal or interannual variability in drought indices in different regions) be incorporated to elucidate sub-regional heterogeneity clearly?

Response:

We will include more spatial visualisations of the 10th and 90th percentile of changes to the different drought characteristics along with the multi-model average. This will give a better understanding of the uncertainty of the projected changes and will better highlight regional differences.

The focus of our paper was on SPI-12 and SPEI-12 which includes the previous 12 months (annual) of accumulated of rainfall (and PET for SPEI), which is not suited to assessing seasonal variability. For this, a 3-month accumulation period would be better suited, which is broadly linked to agricultural droughts but outside the scope of our current work. We adopted a 12-month accumulation period for our assessments of SPI and SPEI as this was considered as a suitable timeframe for water deficits to impact various hydrological and agricultural systems (Zargar et al., 2011).

Comment:

The discussion should also explicitly articulate linkages between index disparities and potential localized environmental drivers, such as land cover status.

Response:

We thank the reviewer for their comment. We will include some discussion of how land cover change is incorporated into the projections (Eyring et al., 2016) and the associated impacts on meteorological droughts. We will also expand on our discussion of the interaction between meteorological droughts and environmental factors, including land cover as suggested by the reviewer in section 4.3.

References:

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