Review of Lewis et al. "Storylines of Future Drought in the Face of Uncertain Rainfall Projections: A New Zealand Case Study"

Summary:

The authors used results from dynamically downscaled RCM simulations over New Zealand to explore two contrasting "storylines" (wetting or drying) and implications for soil moisture droughts. The paper is interesting, well written and suited for ESD. The paper provides important and valuable information to inform changing drought hazard risk in New Zealand. I recommend revisions and have provided some comments that the authors could consider to strengthen their paper. These relate to clarifying the novelty of the study, placing it in context of the wider literature and an expanded discussion of the uncertainties involved.

Main comments:

The authors should provide more motivation and introduction on the storyline approach, including a wider literature search of the approach in New Zealand and its applications elsewhere. Has the storyline approach been applied previously in New Zealand for variables like rainfall and temperature and what did they show? The storyline approach or variants of the approach have been applied to look at meteorological, hydrological and soil moisture droughts elsewhere. A wider literature search should enable better scene setting.

- The selection of individual climate model realisation as "storylines" in this study differ from most other uses of the storyline approach in the literature, which tends to group multi-model ensembles based on a selection of physical climate drivers rather than just picking an individual model realisation (e.g. Zappa and Shepherd 2017; Ghosh et al. 2023; Harvey et al. 2023). The authors could consult and refer to the definition of storylines and references therein in the IPCC AR6 Chapter 10 Box 10.2 (Storylines for constructing and communicating regional climate information). One study the author could refer to that do follow similar methodology is that of van der Wiel et al. (2024) but they group multiple dry-trending/wet-trending models.

- There is also another group of studies focused on "event-based storylines" which samples for specific events/sequences that could lead to high impacts (Sillmann et al. 2023). This concept is similar to what the authors did when sampling for the top five driest years. Just a few example seof event based storylines that have been used to explore droughts in Europe (e.g. van der Wiel 2021; Chan et al., 2023).

Details of the water balance model

- Was the water balance model ran on a grid, at the same resolution as the RCMs? Some evaluation or reference to past literature on the water balance model's ability to simulate historical observed soil moisture droughts would also be useful.
- Was the RCM precipitation, temperature and PET bias corrected before being used to drive the water balance model?
- There should also be some discussion of the simulated soil moisture driven by the different model simulations over the historical period – do they exhibit similar long-term average soil moisture behaviour to observations, where does observed soil moisture (or

modelled soil moisture driven by observations) lie within the range of the GCM's historical period?

Results

- It isn't clear whether the two downscaled GCMs chosen as storylines are at diverging ends of the CMIP range or not. The authors do mention that these GCMs were chosen based on historical performance and spread of ECS but if the aim is to characterize uncertainty in drought changes, it would be useful to know where they lie in terms of the wider CMIP range of change in temperature and precipitation?
- Similar to figure 4, consider adding a figure in the main text showing mean change in SMD/drought metric across all GCMs for the different regions, this would help place the two storylines in context.
- The results show that even in the "wetting" storyline, soil moisture droughts in the summer months would still worsen with future warming for some regions due to temperature induced increases in PET, although severity is offset by increase in rainfall. Could the authors reflect on the robustness of this result, would it remain the same given a different GCM/RCM combination which also show a wetting signal? Is it the case that NZ drought will worsen regardless of storyline? The authors could consider adding a figure on transient changes in annual PED accumulation just to visualise changes in soil drought over time from the two storylines.
- The results section focuses on changes in drought within the two climate models but could be strengthened by relating metrics to actual historical observations. The authors made statements such as "*driest years in the future would be unprecedented relative to any recorded before*", implying that direct comparisons with historical observations were made. Rather, the results show droughts in the historical period of the climate model simulations. Can the authors provide some quantification of how much worse the droughts in the future projections are compared to magnitudes of historical observed (or simulated) droughts?

Discussion

- The authors correctly identify that internal climate variability needs to be more thoroughly examined, and this is not possible with only six models and two storylines. There should be more discussion of the different sources of uncertainties, especially that in the near-term, it is likely that internal variability is the dominant uncertainty and single realisations of climate model simulations under-estimates possible changes in drought risk. Additionally, internal climate variability means it is possible in the current climate for unprecedented droughts to occur given natural variability and SMILEs provide an opportunity to explore those droughts (e.g. for Europe: Suarez-Gutierrez et al. 2023 and Australia: Falster et al. 2024).
- Some discussion of the results' sensitivity to the water balance model chosen would be helpful – impact model related uncertainty can be large and is also a main factor in the cascade of uncertainty. Have there been previous attempts to apply national scale hydrological or land surface models?

Minor comments:

The authors used the terms "storyline" and "scenario" somewhat interchangeably throughout the manuscript – a more consistent wording would be clearer.

L22: What is "model internal variability"? I think there are two concepts that are mixed up – 1) internal climate variability, which is indeed irreducible but can be better characterised/explored using large ensembles, and 2) the ability of GCM/RCMs to estimate the full range of internal variability, which could relate to model biases. It would be clearer for readers if the authors can identify which of these they are referring to.

L29: For international readers not familiar with projections over New Zealand, it might be worth briefly commenting about general New Zealand projections on rainfall in CMIP5/6. Is the uncertainty in rainfall changes just uncertainty in the magnitude of change or do models also disagree on the sign of change as well. This would help further motivate why a multi-model mean would not be appropriate.

L38: Some general discussion at the start of this paragraph on the different sources of uncertainties that contribute to uncertain rainfall projections would be helpful to set the scene (i.e. uncertainty in atmospheric circulation response to climate change, model biases, internal climate variability, amongst others).

L84: What were the variables required from the RCM to compute PET?

Figure 4 – which of the dots belong to the two GCMs that was chosen as storylines?

Figure 5 – please clarify in text or caption whether the period for the SSP370 lines here was also averages from 2070-2099?

L154 – consider rephrasing – the sentence seems to suggest that you're comparing PED accumulation in the climate model with the five driest years in the historical observations but from my understanding of the results, you're comparing with the five driest years in the historical period of the climate model simulations.

L200 – similar to comment above, should clarify that comparison is made to the historical period in the climate model simulations, not observations.

L201 – consider deleting "even if it is not the most likely outcome" as it is slightly contradictory after the authors point out that no likelihood should be assigned to the storylines in the sentence before.

L203 – unclear what "combination of the two" would mean as the two storylines were selected to be diverging. Do you mean internal variability here?

Abstract – make clear in the abstract that this paper only considers soil moisture/agricultural droughts and not other forms of drought.

References:

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