Review of "Understanding the Australian monsoon change during the Last Glacial Maximum with multi-model ensemble" by Mi Yan et al.

General Comments

This paper presents a multi-model study of changes in the Australian monsoon at the Last Glacial Maximum based on PMIP3 simulations. The topic is an important one, and the study presents interesting results showing a change in seasonality of rainfall, with increased seasonal cycle due to winter drying and early summer rainfall increases. The mechanisms producing this change are also explored, and the role of local circulation changes due to altered land configuration is identified as a major contribution to the changes.

The study fails to adequately introduce the climate models used, or to deal with the uncertainty due to model biases or model disagreement on the sign of rainfall changes. The study also employs an overly simplistic method to decompose quantitative changes in rainfall due to dynamic and thermodynamic factors, relying entirely on multi-model mean changes and using a Clausius-Clapeyron scaling that is too large for the thermodynamic component.

Despite these limitations, I believe the study could make a valuable contribution to our understanding of Australian monsoon rainfall changes under LGM conditions. Major revisions are recommended, as outlined below in my comments.

Specific Comments

1. Line 69: The Australian monsoon is not defined clearly here or elsewhere, and the definition is not consistent throughout the paper or with other studies. Which domain is used? Does it include the Maritime Continent? Are land and ocean model grid points used? Is the domain the same in all models? How is the area shown in red in Figure 1a defined, and why does it include parts of the South Pacific Convergence Zone?

Note that the largest rainfall changes (Fig 1a) are over ocean to the north of Australia. If the results in this study are the area average over the grid points enclosed by the red line, then they represent mainly changes over PNG and the Maritime Continent, which makes it difficult to compare with proxy records or model studies focused on Northern Australian land areas. I suggest to re-calculate rainfall changes over Northern Australian land areas only (e.g. to 20S or 25S) and discuss and consider whether the results are consistent with those for the larger Australia-Maritime Continent domain.

Also, monsoon strength or intensity is defined in several different ways. Here (line 70) it is stated that a strong monsoon means wet conditions, whereas elsewhere a strong or intense monsoon means a large seasonal difference in rainfall between wet and dry seasons.

Please clarify: What is the monsoon domain used? Does it include both land and ocean? How is monsoon strength and intensity defined?

2. Lines 72-75: Several of these records are not from the monsoon region, so are not relevant here.

3. Line 94: Multi-model ensembles can also provide a clearer perspective on model uncertainty (when all models agree, the result may be more robust – although not always, as models may share systematic biases).

4. Lines 102-104: "This result… has not been proved yet" – it is not clear whether this discussion refers to models or proxy records. It is important to distinguish between these two sources of information, and to acknowledge that neither provides a "true" record of the LGM as proxy records require interpretation and calibration and may be spatially incomplete, while models contain biases.

5. Line 104-107: Bayon et al. (2017) discussion of subtropics is not referring to the monsoon, which lies within the tropics. Remove or modify this sentence.

6. Line 122: How many models were used? Comment on the model skill in simulating the Australian monsoon rainfall: the models used in PMIP3 are typically lower resolution CMIP5 models, and many do not have high skill in simulating regional rainfall. At least, cite some model evaluation studies of the Australian monsoon in CMIP5 models, e.g. Jourdain et al. (2013), Brown et al. (2016) and summarise model skill in this region.

7. Line 166: According to Held and Soden (2006), who should be cited here, global precipitation would be expected to increase (or decrease) by around 2%/K. Previous studies have found a slightly higher scaling of around 3%/K for Asian monsoon rainfall (Endo and Kitoh, 2014).

8. Page 8, first paragraph: I am not comfortable with a quantitative decomposition based on the multi-model mean. The sign and magnitude of changes will be different in each model and the decomposition is only valid for individual models. Also, the scaling of precipitation with temperature is likely too strong (see point above). Further, can all these changes be considered linearly? A more robust decomposition of dynamic and thermodynamic changes in each model should be applied, e.g. Seager et al. (2010), Chadwick et al. (2013) or Endo and Kitoh (2014).

9. Line 241: Where do the monsoon percentage changes come from? The rainfall changes in November-December shown in Figure 6 are in mm/day not %. The model spread (agreement) should also be discussed here and elsewhere: how many models simulate increased rainfall in the LGM and how many simulate decreased rainfall? How does this influence our confidence in the MMM changes?

10. Line 247: See point 1 above, please use a consistent definition of monsoon intensity. I suggest use "intensified seasonality" here for clarity. It is also necessary to describe in this paper how the average summer or wet season rainfall changes at the LGM, as this is the normal measure of the strength of the Australian summer monsoon. You should show (e.g. in a bar chart or table) annual mean and wet season (November to April) rainfall change for EACH model and for the MMM. This provides the context for the more detailed discussion of changes in seasonality and is more directly comparable with proxy reconstructions of annual or wet season rainfall and with studies of future monsoon (wet season) rainfall changes.

11. Line 258-265: The discussion of Tharammal (2017) is confusing. Do your results agree with theirs? If so, then simply state this.

12. Line 278: Why would the precipitation change lag the insolation change by two months? Provide a reference.

13. Line 288: "Strong convergence rain belt": Do you mean the ITCZ?

14. Line 291: A little more northerly? It is not clear what is being compared to what here.

15. Line 309 and line 314: See discussion under point 10. State that the *monsoon seasonality* is amplified or intensified (rather than the monsoon itself).

16: Page 12, paragraphs 2 and 3: I repeat that I am not comfortable with a quantitative MMM decomposition. At least, you need to make it clear that your results are MMM values and state the model spread or uncertainty as well.

17. Figure 1: How is the monsoon domain defined? Why does it include the SPCZ region? Show some measure of model spread in Figure 1b, such as standard deviation of model range.

18. Figure 10: It may be more useful to show a smaller domain, excluding the North Pacific, with a smaller contour range. This would make the changes in Pacific and Indian Ocean tropical SSTs easier to see.

19. Figure 11: What is the "increased AR region" (11b)? What is the "central Australian monsoon region" referred to in the caption? Define the domain used.

20: Figure 12: I am not sure if this diagram is very useful. Also, arrows (if any) and linking lines are not clear in my print version.

21: Table 1: Were all model run years used from each model? This should be mentioned in Section 2. It would be more consistent to use the same number of years from each model.

Technical Corrections

Line 85: Change wording: "The change in the Australian monsoon was inconclusive…"

Line 94: Multi-model ensembles can reduce or cancel out the biases, not "delineate" (describe, define) them.

Line 107: Remove "insight" before "studies".

Line 110: Here and elsewhere in the paper, use "thermodynamic" not "thermal dynamic".

Line 127: A simpler version of the PMIP3 website address is: https://pmip3.lsce.ipsl.fr/.

Line 151: Here and elsewhere, do not use the American term "Fall" to refer to Southern Hemisphere Autumn (use "Autumn").

Line 159: Insert "global" before "temperature and humidity".

Line 205: Remove "We noticed that".

Line 256: It is not clear what the personal communication refers to here, I suggest remove it.

Line 307: Insert “global mean” before “temperature and water vapor”.

Line 336: “Synthesized” does not make sense: should this be “simulated” (i.e. from models) or “multi-model mean” (i.e. averaged over many models)?

Line 469: Treble reference is incorrectly appended to Tharammal reference.

References:

Brown, J.R, A. F. Moise, R. Colman, and H. Zhang (2016), Will a warmer world mean a wetter or drier Australian monsoon? *J. Clim.*, **29**, 4577-4596, doi:10.1175/JCLI-D-15-0695.1.

Chadwick, R., I. Boutle, and G. Martin, 2013: Spatial patterns of precipitation change in CMIP5: Why the rich do not get richer in the tropics. *J. Climate*, **26**, 3803–3822, doi:10.1175/JCLI-D-12-00543.1.

Endo, H., and A. Kitoh, 2014: Thermodynamic and dynamic effects on regional monsoon rainfall changes in a warmer climate. *Geophys. Res. Lett.,* **41**, 1704–1710, doi:10.1002/2013GL059158.

Held, I. M., and B. J. Soden, 2006: Robust responses of the hydrological cycle to global warming. *J. Climate,* **19**, 5686–5699, doi:10.1175/JCLI3990.1.

Jourdain, N. C., A. Sen Gupta, A. S. Taschetto, C. C. Ummenhofer, A. F. Moise, and K. Ashok, 2013: The Indo-Australian monsoon and its relationship to ENSO and IOD in reanalysis data and the CMIP3/CMIP5 simulations. *Climate Dyn.*, **41**, 3073–3102, doi:10.1007/s00382-013-1676-1.

Seager, R., N. Naik, and G. Vecchi, 2010: Thermodynamic and dynamic mechanisms for large-scale changes in the hydrological cycle in response to global warming. *J. Climate,* **23**, 4651–4668, doi:10.1175/2010JCLI3655.1.