Response to Reviewer 1:

Reviewers comments are in black standard and the responses are in *blue italics.*

Anonymous Referee #1

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In this paper, the authors investigate the mechanisms driving the Permian megamonsoons and test the hypothesis that the location of the Paleo-Tethys Warm Pool, rather than the land/sea contrast, is the primary forcing agent of the monsoon. To do this, the authors conduct sensitivity experiments using the Community Climate System Model to evaluate the response to elevated CO2 and changes in geography.

This paper is perplexing. On the one hand, the topic and numerical experiments are interesting, as is the simulated influence of the warm pool on the monsoonal circulation. On the other hand, the definition of the megamonsoon is never made clear, and the results do not support the warm pool hypothesis (see below). One point that the authors should consider is that previous generations of models used to investigate megamonsoons used slab ocean models that did not simulate warm pools and yet simulated megamonsoons. To me, this is pretty solid evidence that the warm pool hypothesis cannot be right. This paper has the potential to be a nice contribution by demonstrating the interaction between the warm pool and the monsoonal circulation, but the current version confuses monsoonal and warm pool precipitation and requires extensive refinement and clarification.

We thank Reviewer 1 for their comments.

We have devoted a large section of the introduction to define what we mean by megamonsoon.

"The term "megamonsoon" is often referred to in the literature as the monsoonal circulation for the Pangean supercontinent and can be described as the cross-equatorial flow that brings warm, moist airflow from regions south of the equator into the Pangean supercontinent. The cross-equatorial flow provides the necessary moisture source to produce seasonal, heavy bands of precipitation to eastern Pangean. (Nordt et al 2015). To date, the surface land-sea temperature gradient has been hypothesized as the primary driver of the megamonsoon and its associated dynamical and precipitation signatures (Parrish 1993, Kutzbach and Gallimore 1989). However, in this paper, we present the idea that the Pangean megamonsoon is simply responding to the elevated sea surface temperatures in the Paleo-Tethys (i.e the warm pool), and this it is this mechanism, not a land-sea contrast, that drives the "monsoon" dynamics, cross-equatorial flow, and heavy seasonal precipitation. Traditionally, for both paleo and modern monsoonal systems, monsoon precipitation is often considered separately from tropical warm pool precipitation. Here we break again with tradition and suggest that the summertime megamonsoon precipitation, associated with the megamonsoon dynamics, is a product and response of the warm pool itself".

We respectively disagree with the comment stating our results do not support the warm pool hypothesis. We would like to note that this theory was originally published by Chao and Chen (2001) for a modern geography. They find that the sea surface temperature gradient in the ocean, i.e. warm pool location, is perhaps a driving mechanism for the Indian and Asian *monsoon systems. Also, Wang et al 2003 and 2005, found that "internal" forcing, such as El Nino, can significantly impact the intensity of the East Asian monsoon system due to, in part, the interaction of the classic monsoon system with warm SSTs. This result suggests that the warm pool has a significant role to play in monsoonal systems across all geologic scales).*

In terms of slab and fixed SST GCM experiments that do not <u>simulate</u> warm pools, yes, this is true, but still exist and are defined by prescribed SSTs and fix the warm pool exists in a specified place. In these simpler versions of a GCM, the ocean does not evolve in a dynamic way, and therefore could not be used for the NoIsle experiment as we have conducted for this study. So, by definition, monsoons in these earlier class of models, force the monsoon to stay put and therefore do not tell us anything about ocean currents, warm pools, ore precipitation movement due to warm pools. The precipitation will stay fixed because the SST is essentially fixed. In our fixed SSTs runs, where we remove the land, the precipitation stays fixed because the warm pool is fixed. If the land-sea gradient was the primary mechanism, then the precipitation maximum (and divergent atmospheric flow) would have moved landward, which they did not.

In Section 4, the primary result is that after removing the Cathyasian Peninsula "the "monsoon" precipitation does not change in character, indicating that the underlying and primary forcing for the monsoon is unrelated to the land-sea temperature gradients." Figure 5 does not support this characterization. As shown in Fig. 5, JJA and DJF precipitation over the Cathyasian Peninsula certainly does change (e.g. the DJF minimum and JJA maximum at 30N on the Cathyasian Peninsula disappears), indicating that the land-sea contrast is critical to monsoonal precipitation on the peninsula.

We disagree with the assessment given here. Yes, the minimum for DJF is different and likely related to the land surface, however, the character of the maximums and the general location does not change. Monsoon evaluation primarily focuses on maximum precipitation (not minimum), and although there is a different shaped gradient over the Cathyasian Peninsula over JJA at 30N, the maximum precipitation is generally in the same spot and the same shape. Yes, the precipitation values for the case with the land over the peninsula indeed show precipitation reaching into the land, however, it is not the maxima. We are not arguing that there is no influence from the land, we are arguing that the primary drivers for the Pangean monsoon are maritime (as suggested Chao and Chen) and warm pool related.

However, we have amended the text to be clearer and state we are referring to precipitation maxima.

Similarly, Fig. 6 shows that JJA-DJF wind vectors are no longer converging over the Cathyasian Peninsula.

In Figure 6, the divergence winds (vectors) show convergence in approximately the same location for all three experiments. The bottom two panels can be compared directly because *these are both fixed SST experiments. The bottom panel does not have the peninsula, yet the wind vector directions and character of the velocity potential are unchanged.*

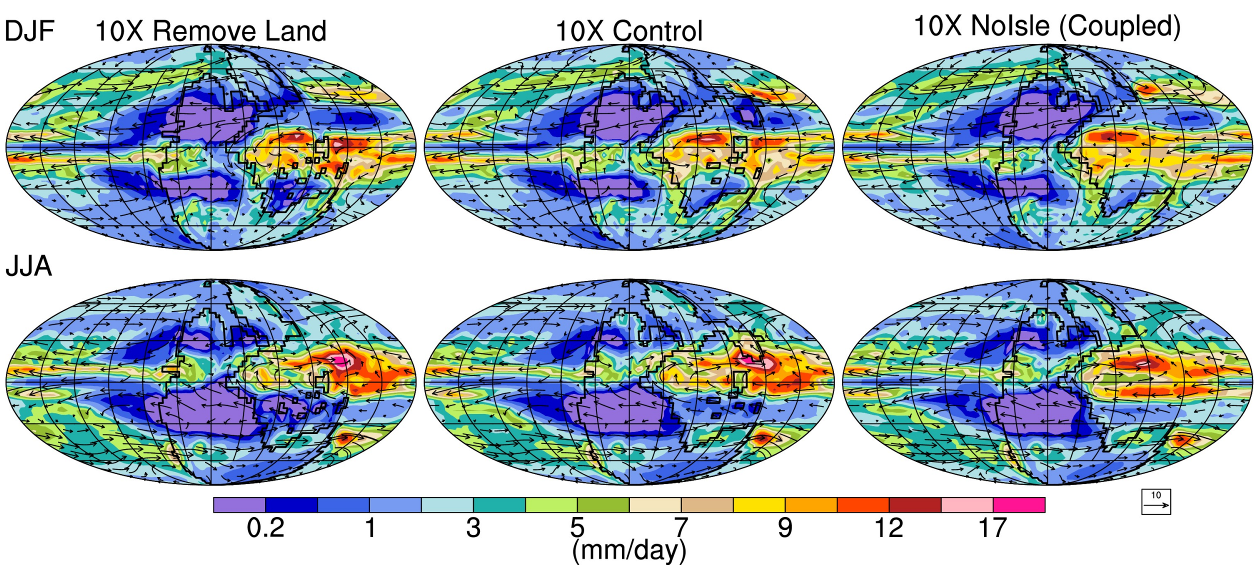
In Section 5, the main result is that “The monsoon precipitation does indeed follow the warm pool, in fact, the SST warm pool not only migrates landward, it clearly expands in all directions and in all seasons.” (As an aside, this sentence structure is not logical.)

We have changed the sentence structure for clarity.

The latter result is that the SST warm pool migrates and expand is clearly shown and is interesting. The former resultâˇA ˇ Tthat monsoon precipitation follows the warm poolâˇAˇ Tis not. (I would have appreciated DJF and JJA precipitation maps for the NoIsle case and recommend adding them as subpanels to Fig. 5.) The analysis of temperature and precipitation (Figs. 8 and 9) is over marine regions and has no bearing on monsoonal precipitation. (In the modern climate, the warm pool is a region of high precipitation; this is not considered monsoonal precipitation.)

Thank you for this suggestion, we have added the NoIsle cases to Figure 5. As for Figures 8 and 9, we find these of critical importance to showing the migration of the warm pool, and thus precipitation. As discussed earlier, we have added text to more clearly describe what we mean by the megamonsoon such that this includes tropical warm pool precipitation and have added citations from other groups (published in the literature) to bolster our ideas that these two phenomena are one and the same for this geography.

The new figure is included here:



The paper requires considerable editing. There are numerous grammatical errors, incomplete and awkwardly phrased sentences. In some places, these mistakes make the text incomprehensible (e.g. p. 4, line 12).

We have changed this sentence for clarity.

The figures are fine. The figure captions should be expanded to include more detail. Units and labels should be added to all label bars. Undecipherable experiment names (e.g. b30.111) should be removed from the figures.

Done.

Additional minor points:
Introduction. The introduction lacks description and substantive discussion of the megamonsoons and also a review of previous works on the megamonsoons, of which there have been a considerable number most unreferenced here. The third paragraph of the introduction, except for the final sentence, is irrelevant and should be removed.

Done.

p. 3, lines 8-9. The explanation for why the 1x Permian case is colder than the 10x case includes lower solar forcing. According to Table 2 both the 1x and 10x cases have the same solar forcing so that this is not a reason.

This sentence was not clear, thank you. The solar constant was the same for all experiments. We have modified this sentence for clarity. The reason, as stated, is the lower CO2. The lower solar forcing was in reference to modern.

p. 3, line 18. Some further discussion of the cause of the shift in precipitation would be welcome here. Presumably this is linked to the shift in maximum SSTs (p. 4, line 4).

We have amended the text.

Please then comment on the shift in the seasonality of the SSTs.

SST seasonality is not the focus of this paper, rather the precipitation response to the SSTs. However, we have added further commentary linking figures 2 and 3. In depth analysis on SST seasonality changes is best suited for a different paper and further research.

"Although the two cases are similar in terms of structure, it is clear the position of the SST warm pool has shifted. Linking Figures 2 (top panels) and 3 highlight the coupling between the SST and precipitation seasonality".

p. 4, lines 10-11. This statement may be true, but vertical velocities are not a good indicator of convective activity (implied by "sinking due to colder seasonal SSTs"). The vertical velocity changes described here are most likely associated with dynamical changes in winds.

We show vertical velocities because this is an intuitive metric to show sinking/upwelling locations. However, you point is well taken which is why was have also analyzed the salinity (and is mentioned in the text). We are not necessarily interested in convection or bottom water formation for the ocean, we are simply using salinity as a way of diagnosing fresh water on the sea surface from precipitation.

Fig. 1. caption. "Plots. . ..are spaced every 30 degrees." Latitudinal/longitudinal lines are spaced every 30 degrees; the plots are spaced every couple of inches.

Done.

p. 8, line 9. Please explain in more detail how precipitation and salinity are affecting upper ocean vertical velocity.

We have amended the text as follows:

"We generally see a saltier Paleo-Tethys and western Panthalassic and a gentler halocline leeward of the largest island (~100E). Locations with heavier rainfall over the ocean will freshen the sea surface salinity, which promotes upward motion and suppresses sinking water because fresh water is less dense than salty water. Therefore, upper ocean vertical velocity changes in the monsoon and equatorial regions are, in part, a direct reflection of these salinity and precipitation changes".