Author response

We thank two reviewers for their helpful comments. Thanks for the review comments, we have taken into account the suggestions and revised the manuscript accordingly. Below is our response (in blue) to the comments (in dark).

The revised part is mentioned with page and line number and highlighted in the revised manuscript with red markup.

***Interactive comment on* "Simulating the mid-Holocene, Last Interglacial and mid-Pliocene climate with EC-Earth3-LR" *by* Qiong Zhang et al.**

Anonymous Referee #1

Received and published: 7 October 2020

In the paper, Zhang et al document the PMIP4 experiments run with EC-Earth3-LR, and further illustrate the simulated global and regional climate responses. The paper is well written. I have one suggestion for improving the paper. More information about the model, EC-Earth3, and its ability in simulating PI climate should be added in the revised version.

Line 84. Since the authors choose GMD to publish their PMIP experiments, I suggest that the authors add more information to introduce their model, rather than a simple sentence. "A detailed description of the ECEarth3 and its contribution to CMIP6 is documented in Döscher et al. (2020)."

Thanks for the comment, in the revised version we have added more information on different model component in section 2.1, Page 3, L70-101.

Line 85-93, the resolution of other EC-Earth3 CMIP6 versions should be introduced here.

We have now introduced the model resolution used in the other EC-Earth3 CMIP6 in section 2.1, Page 3, L87-94.

It reads as:

EC-Earth3 earth system model version also includes the atmospheric chemistry component TM5, the dynamic vegetation model LPJ-Guess and the ocean biogeochemistry component PISCES. The EC-Earth3 model contributes to CMIP6 in several configurations by using different resolutions or including different components. A detailed description of the EC-Earth3 and its contribution to CMIP6 is documented in Döscher et al. (2020). For example, regarding the resolution, the standard version EC-Earth3 with atmospheric resolution T255L91 (horizontal ~ 80 km) and ocean resolution ORCA1L75 (horizontal 1°) is used in most MIPs (e.g., CMIP, DCPP, LS3MIP, PAMIP, RFMIP, ScenarioMIP, VolMIP, CORDEX, DynVarMIP, SIMIP). The high-resolution model version with atmospheric resolution T511L91 (horizontal ~ 25km) and ocean resolution ORCA025L75 (horizontal 0.25°) is used for DCPP and HighResMIP decadal predictions.

The PMIP4 experiments require long spin-up and equilibrium simulations which are computationally demanding. We thus use model configurations without atmospheric chemistry and ocean biogeochemistry at low resolution, with atmospheric resolution T159L62 (horizontal ~ 125km) and ocean resolution ORCA1L75. For the *piControl*, the *midHolocene*, the *lig127k*, *lgm* and the *midPliocene*, we have used the EC-Earth3-LR, which is a configuration of EC-Earth3 with only atmosphere, ocean and sea ice components at Low-Resolution (LR). The coupled vegetation LPJ-GUESS is used for the *past1000* simulation with model configuration named EC-Earth3-veg-LR.

Despite using the lowest resolution among the EC-Earth3 CMIP6 MIPs configuration, EC-Earth3-LR has a relatively high resolution compared to the other PMIP4 models (Brierley et al., 2020).

In the section 3.4, I suggest that some figures from Fig S1 (for PI simulations) should be included in the main texts, since these figures are important and helpful to show the modelling ability of EC-Earth3-LR.

We now moved energy balance figure S1 to main text as Figure 3 and keep the other three in the supplement. For the evaluation of simulated PI climate, besides the comparison of the simulated PI temperature with reanalysis, we now added a new figure on comparison of the simulated PI precipitation with ERA20C as Figure 6. The comparisons show that the EC-Earth3 model does have the cold and dry biases in northern Hemisphere and warm and wet biases in southern Hemisphere in PI control.

New Fig.3 can be found Page 10, related text is in Page 12 L237-256.

New Fig.6 can be found in Page 16, related text is in Page 17 L325-330.

Line 242, does the 0.5 W m-2 energy leak appear in PI control experiments run with other EC-Earth3 versions? How long is the spin-up of EC-Earth3-LR PI control run? This important information should be introduced here.

I suggest the authors reorganizing the section 3.4, and providing more information about their PI control experiment, together with some comparisons to other EC-Earth3 versions.

The energy imbalance differs for different resolution tunning. For example, in the EC-Earth3 standard resolution T255L91, the energy imbalance is in the order of 0.25 W m-2 (Döscher et al., 2020), and in the high resolution T511L91 tunning version the imbalance is 0.9 W m-2 (personal communication). We have revised the text to provide the information of energy imbalance for T255L91 and T511L91 on Page 12 L241-243.

The spin-up of EC-Earth3-LR PI control is run for approximately 1000 years during the course of development and tunning process. We have run another 200 years. The 200 years spin-up run shown in Fig.S1(now Fig.3) is continued from the previous long spin-up by using the implemented physics. This is mentioned in the beginning of Sect. 3.4 on Page 11 L225-235.

Anonymous Referee #2

Received and published: 12 October 2020

This paper presents the results of the EC-Earth3-LR for simulating the three past warm periods (mid-Holocene, Last Interglacial, and mid-Pliocene) which are documented in the Paleoclimate Model Intercomparison Project (PMIP) phase 4. In this paper, Zhang et al provide a comprehensive and diagnostical analysis on the modeling results. This work is very meaningful and valuable for the PMIP4 group. I would recommend its publication after addressing the comments as follows :

1. The introduction is a bit broadly. I suggest the authors can provide more information on the three past warm periods rather than giving a general introduction for all PMIP4 target periods.

As suggested, we removed the mention of other PMIP4 target periods in the introduction, and wrote more on the motivation for simulating the past warm periods.

2. In section 2.2.2, the authors organize a whole paragraph to describe the new albedo parameterization of snow on ice-sheet, but for the readers, we still have no idea about the core information of this new

scheme. I suggest the authors can put forward directly the core information about this scheme rather than citing a reference.

The core information for introducing a new albedo parameterization is to better represent the albedo-feedback by allowing the snow can fall and melt over the icesheet, instead of static in previous scheme. We now mention this core information in the beginning of section 2.2.2 in Page 4 L122-125.

3. I suggest to change the title of section 4.1, since the authors present both SAT and PRECIP anomalies. Or the authors can integrate section 4.1 and 4.2 as one section describing the response of global mean temperature and precipitation.

Thanks, as suggested we now combine 4.1 and 4.2 into one section 4.1 to describe the large-scale features of climate change. We added a figure for global change in precipitation as Figure 6. A data-model comparison on SST is presented in the following section 4.2. Now the global changes in three commonly used variables (surface air temperature, precipitation and SST) are presented in Fig 4-6.

4. In line 333, “and induce weaker Hadley circulation (Fig. 5c)”, is it weaker or stronger ?

Thanks for your carefully reading and observed this mistake. Indeed, it should be “stronger” Hadley circulation but not the “weaker” as stated in the manuscript. As shown in Figure 4b and 4c, the *midHolocene* and *lig127k* simulations show slight cooling in the SH compared to the tropics. This can induce a slightly stronger meridional temperature gradient and favor a stronger Hadley circulation in Figure 5a and c. This is corrected in Page 20 L395.

5. In Figure 5, could the authors provide the contour interval value. For the walker circulation, the authors interpret westward shifts of the ascending part in lig127k and midpliocene. For the readers, it is not straightforwardly understood in Fig 5. Could the author provide a supplement fig for the climatology result of these two simulations for the walker circulation ?

Label all the contour interval in Fig 5 (now Fig 8) looks messy. To show the shifts more clearly, we present the climatology of vertical integrated zonal mass stream function (ZMS) of three simulations in Fig 10. Compared to the *piControl*, the most striking features in all three warm period simulations are westward movement of the Walker circulation. Especially, there is more westward shift in the *lig127k* and *midPliocene* with respective to *midHolocene* simulation. There features are consistent with the results in Figure 5.

New Fig 9 can be found in Page 20, related text is in Page 20 L395-399.

6. How do the authors define the sea ice edge in Fig 7 ? The Arctic minimum SIE in midpliocene in Fig 7 disappears, does it mean no sea ice in midpliocene in Aug ? However, in Fig 6, the Arctic SIE anomalies between midpliocene and piControl show that the SIE anomalies in August is weaker than that in March, which seems not consistent with the sea ice edge presented in Fig 7.

The sea ice extent defines a region as either "ice-covered" or "not ice-covered." In the model grid, for each grid cell, either the cell has ice (usually a value of "1") or the cell has no ice (usually a value of "0"). A threshold determines this labeling. Here we apply a commonly used threshold 15% (such as used by National Snow and Ice Data Center NSIDC), meaning that if the model grid cell has greater than 15% ice concentration, the cell is labeled as "ice-covered." A threshold can also be as high as 30 percent. The sea ice edge is the 15% sea ice concentration isocline. We added our definition of sea ice in the text on Page 21 L450-454.

Indeed, the sea ice in the mid-Pliocene disappears in August and that is why there is no sea ice edge in Figure 7c (we showed for September instead of August) for the mid-Pliocene. We mentioned this in Page 22 L479-48 as “midPliocene SIE anomalies are lowest in the summer because low sea ice concentrations during this season limit SIE decrease in the mid-Pliocene, while SIE can still decrease more in the PI simulation." It is true that the SIE anomaly is smaller in melting season than in frozen season. This is because during mid-Pliocene all sea-ice becomes seasonal sea-ice, and during PI there are perennial sea-ice However, in August the PI SIE is also smaller, and since the SIE in the mid-Pliocene is already small in July and then zero in August (little decrease), the anomaly is smaller.

7. Last but very important question, how do the model results comparing with the records ? Since the authors highlight “the ability of the model to capture the climate response under different climate forcings, providing potential implications for confidence in future projections with EC-Earth model”in their abstract. It is better to examine the model performance with the related reconstructions.

Thanks for the comments. We use the available SST reconstructions for lig127k and mid-Pliocene, add a data-model comparison on SST as Fig 4.6 in section 4.2, Page 17-18, L334-377.