

## **Anonymous Referee #2**

We thank the reviewer for their helpful comments and considerable time spent working on this manuscript. The contribution of the reviewer has added substantially to the quality of the manuscript, this is greatly appreciated particularly by the lead author. We sincerely appreciate the considerable time that the reviewer spent on the review. With regards to the reviewer comments, these are addressed in sequence by SJH with input from the co-authors. We will start with the general comments and then finish with the line-by-line comments.

### **Confusion over the number of experiments**

**It seems that the authors themselves are unsure how many experiments they have performed.[ ...]**

- i. Lines 4—5 on page 5 suggest that the authors have conducted two sets of “Pliocene experiments” with CO<sub>2</sub> at 280, 350, 400 and 450 ppmv (for a total of 8 Pliocene experiments) and where one set uses modern orbit whereas the other uses orbit for 3.205 Mya.**
- ii. In Lines 12–13 on the same page the authors talk about two new insolation sensitivity simulations E<sup>280</sup> and Eoi<sup>400</sup> therefore giving a total of 10 simulations so far. If we include the obligatory PI control, then we should be currently at 11 simulations.**
- iii. Further down that page, under section 3.1, new control experiments E<sup>400</sup> and E<sup>560</sup> are introduced. That brings us to 13 simulations which appear in Table 1. So far all good.**
- iv. On page 7 at the end of first paragraph under section 3.3, the authors talk about 8 experiments which are the two sets of orbit based simulations. That’s fine. But the following line at the start of next paragraph talks about “the ten Pliocene experiments”. How can that be? In the author’s nomenclature, the Eoi experiments are Pliocene, so we have 8 experiments and the experiment ! Eoi<sup>400</sup> giving 9 Pliocene experiments.**
- v. In the same line, to give an accounting for the ten experiments the authors say “(Core and Tier 1 detailed in Table 1 as well as Eoi<sup>400</sup>, E<sup>280</sup> and Eoi<sup>400</sup>)” but if we look at Table 1, there are 5 Core and Tier 1 experiments, so those five along with the three experiments <sub>orb</sub>Eoi<sup>400</sup>, <sub>1361</sub>E<sup>280</sup> and <sub>1361</sub>Eoi<sup>400</sup> add to 8 experiments! Not 10!!! Furthermore not all Core and Tier 1 experiments are Pliocene**

This has been corrected within the manuscript. Table 1 describes the 10 experiments, which consists of 7 PlioMIP2 protocol experiments (4 Pliocene based and 3 pre-industrial based) and 3 additional sensitivity experiments (2 Pliocene and a pre-industrial based experiment). This correct counting has been pulled through into the manuscript. Section 3 Experiment Design has been corrected and now concludes with the following paragraph

“In total 6 Pliocene experiments were run: the CORE (Eoi<sup>400</sup>), two Tier 1 (Eoi<sup>350</sup> and Eoi<sup>450</sup>), one Tier 2 (Eoi<sup>280</sup>) as well as an orbital (<sub>orb</sub>Eoi<sup>400</sup>) and TSI sensitivity experiment (<sub>1361</sub>Eoi<sup>400</sup>). These are accompanied by 4 pre-industrial experiments: the CORE (E<sup>280</sup>), a Tier 1 (E<sup>560</sup>) and Tier 2 (E<sup>400</sup>) as well as a TSI sensitivity experiment (<sub>1361</sub>E<sup>280</sup>). These 10 simulations are detailed within Table 1.”

### **Lack of significant connection to existing literature**

**A notable shortcoming of the paper is the general absence of connection between the author's own work and the literature on the Pliocene. One can get that sense even without reading the paper by simply looking at the length of their reference section. There are several missed opportunities in the paper for the authors to connect their findings to those from other studies — published results from other groups for PlioMIP2, published results from PlioMIP and other studies outside of these collaborations. As it currently stands, the authors almost exclusively compare, whenever they do, to their results from PlioMIP. While that is obviously required and good, they should put some effort into connecting to other literature as well.**

It is useful to consider this manuscript in context with the other papers within the Climates of the Past PlioMIP2 special issue. Currently there are three modelling groups who has so far presented initial model descriptions; the CCSM4 study of Chandan and Peltier (2017)<sup>1</sup>, the MRI-CGCM2.3 study of Kamae et al. (2016)<sup>2</sup> and the EC-EARTH study of Zheng et al. (2019)<sup>3</sup>. Chandan and Peltier (2017) compared globally integrated MASAT and SST against a selection of previous Pliocene simulations (mostly PlioMIP1). They also included some comparison of predicted AMOC although this was mostly with the previous CCM4 simulations within PlioMIP1. Kamae et al., 2016 compared their PlioMIP2 results with only their PlioMIP1 MRI-CGCM2.3 results (Kamae and Ueda, 2012). Zheng et al. (2019) focus on sea ice and do not compare with previous works in a way suitable for this manuscript.

Within the PlioMIP2 Climates of the Past individual group paper template<sup>4</sup> there is no requirement to compare results against previous Pliocene modelling. It is left to the modelling groups discretion to include comparison against existing Pliocene modelling studies. Nevertheless, I do agree that some comparison against previous work is beneficial to the reader. I have included a model-comparison of globally integrated MASAT (including CS and ESS), precipitation and AMOC.

#### **Analysis in this paper and author's plans for future papers**

**The authors mention that a future paper will describe the results from P4P Tier 2 experiments that will directly lead them into discussing the nature of forcing from different boundary conditions using the factorization methodology discussed in Haywood et al. 2016. In that case why do the authors pre-empt that effort here, by discussing in a limited way, contributions from CO<sub>2</sub> and palaeogeography the specific and restricted differences Eoi<sup>400</sup>-Eoi<sup>280</sup> and Eoi<sup>280</sup>-E<sup>280</sup> (see also my points 2 and 3 in the scientific comments section). By the time of the second paper, the authors will have all the experiments that will be useful for them to do a more thorough discussion of the forcings by taking into account dependencies on the background state and so they will be compelled to revise the findings from this paper anyway. So, why not put all that discussion together in one related paper? Why confuse a prospective future reader by providing them a paper with some results, and then presumably soon after another paper with related and potentially revised results? I think that given their plans for future papers, I recommend the authors to focus more on the climatology of Pliocene in this paper and to focus on forcings in a future paper.**

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<sup>1</sup> Chandan, D. and Peltier, W. R.: Regional and global climate for the mid-Pliocene using the University of Toronto version of CCSM4 and PlioMIP2 boundary conditions, *Clim. Past*, 13, 919-942, <https://doi.org/10.5194/cp-13-919-2017>, 2017.

<sup>2</sup> Kamae, Y., Yoshida, K., and Ueda, H.: Sensitivity of Pliocene climate simulations in MRI-CGCM2.3 to respective boundary conditions, *Clim. Past*, 12, 1619-1634, <https://doi.org/10.5194/cp-12-1619-2016>, 2016.

<sup>3</sup> Zheng, J., Zhang, Q., Li, Q., Zhang, Q., and Cai, M.: Contribution of sea ice albedo and insulation effects to Arctic amplification in the EC-Earth Pliocene simulation, *Clim. Past*, 15, 291-305, <https://doi.org/10.5194/cp-15-291-2019>, 2019.

<sup>4</sup> [https://geology.er.usgs.gov/egpsc/prism/data/PlioMIP2\\_Individual\\_Group\\_Papers\\_Guidance\\_CP\\_2018.pdf](https://geology.er.usgs.gov/egpsc/prism/data/PlioMIP2_Individual_Group_Papers_Guidance_CP_2018.pdf)

To avoid reader confusion, I have removed reference to any future publication plan within the manuscript. The manuscript can now be read as a closed piece of work. Subsequent papers, such as the Pliocene4Pliocene forcing factorisation work, will compliment this initial modelling paper.

### Quality of figures

- 1. Labels and legends on several figures are barely readable. The font sizes need to be increased.**

I have increased the size of the font used in all figure labels and legends, and where appropriate increased the size of the Figures.

- 2. The figures in Fig 2 should have a wider aspect ratio. As it currently stands the figures will not be single column, so might as well make it as wide as the text. Its hard to read anything.**

I have made this figure single column so that each subfigure can be wider. Within the Climates of the Past Latex typesetting specification, If the figures are horizontally aligned the width occupied by the entire figure [width=12cm] is less that 2 columns. If the figure is vertically aligned each figure can be wider [width=8cm].

- 3. Title for Figure 4 is incorrect**

I have corrected this

- 4. Features in Figure 8 are barely visible, and the fact that the authors are using polar projections with two different outer bounding latitude lines for different plots creates a lot of confusion and difficulty in interpreting the figure. The authors are encouraged to use just one value of outer bounding latitude line and increase the size of each of the sub figures.**

I have corrected this figure so that the latitudinal extent of the polar plots are equivalent. I have also increased the size of the font and increased the size of the Figure.

### Scientific Comments

**There is confusion about what is a Pliocene and a pre-industrial experiment. For example, why are  $E^{400}$  and  $E^{560}$  called pre-industrial? The pre-industrial was a 280 ppmv world. These two experiments are sensitivities to  $CO_2$  and not at all pre-industrial.**

This is a good point, and I agree it was sloppy writing. I have corrected the descriptions of the  $E^{400}$  and  $E^{560}$  within the manuscript by referring to these experiments as pre-industrial based sensitivity experiments.

**A similar, issue arises with the authors calling all their Eoi experiments as Pliocene. Although the issue is less severe here because of the uncertainties in Pliocene  $CO_2$ , but since the word "Pliocene" is used throughout the paper in regards to their experiments with very rare reference to the specific experiment code, the authors should clarify to the reader what does the word "Pliocene" means in general in the context of the paper. When the authors say something to the effect of "the Pliocene is so and so" do they mean that the result they are discussing is robust in all of their Eoi experiments regardless of the  $CO_2$  or do they mean a specific experiment? Their sloppy terminology here gets a little messy at some places, for example on line 3, page 9, while discussing the impacts of various boundary condition changes, the authors say they they diagnose the increase in  $CO_2$  as  $Eoi^{400} - Eoi^{280}$ . So does this mean that Pliocene is 400 ppmv? Because otherwise they could have also used  $Eoi^{450} - E^{280}$  or  $Eoi^{350} - E^{280}$**

Historically, within the first PlioMIP program, the Pliocene had a single CO<sub>2</sub> level set at 405 ppm. Within PlioMIP2, the Pliocene CORE experiment 400 ppm CO<sub>2</sub> level represents our “best guess” and so I focus on Eoi<sup>400</sup> in an attempt to keep the manuscript clear and concise. I have clarified this within Section 4 (Results)

“In order to keep discussion clear and concise, we principally compare the two PlioMIP2 CORE experiments which we refer to as the *control* experiments, Eoi<sup>400</sup> and E<sup>280</sup>. Whilst there is uncertainty in mid Piacenzian (MIS KM5c) CO<sub>2</sub> levels, 400 ppm represents the middle of the anticipated CO<sub>2</sub> range derived from marine and terrestrial based reconstructions. We therefore consider Eoi<sup>400</sup> as our “best estimate” simulation.”

**Why is change due to paleogeography always inferred as Eoi<sup>280</sup> – E<sup>280</sup> and not alternatively/ simultaneously as Eoi<sup>400</sup> – E<sup>400</sup>. The authors should make clear why they are favouring this difference, after all we know from other studies that there should be background dependence on CO<sub>2</sub>**

I have clarified this within the beginning of the Results Section. I have also discussed this dependency on CO<sub>2</sub> within Section 4.1.1.

“From Table 3 it is possible to decompose the factors that contribute to Pliocene warming relative to the pre-industrial (E<sup>280</sup>). Considering the CORE Pliocene experiment, Eoi<sup>400</sup>, we find that the change in palaeogeography (Eoi<sup>280</sup>-E<sup>280</sup>) accounts for a temperature change of 1.4 ± 0.7°C, whilst the increase in CO<sub>2</sub> (Eoi<sup>400</sup>-Eoi<sup>280</sup>) accounts for a further 1.5 ± 0.7°C of warming. Considering uncertainty in Pliocene CO<sub>2</sub> level, we find temperature changes of 0.9 and 2.0 ± 0.7°C for Eoi<sup>350</sup>-Eoi<sup>280</sup> and Eoi<sup>450</sup>-Eoi<sup>280</sup> respectively. The PlioMIP2 experimental design provides a second pathway to examine Pliocene palaeogeographical and CO<sub>2</sub> forcing (e.g. Eoi<sup>400</sup>-E<sup>400</sup> and E<sup>400</sup>-E<sup>280</sup>). here the Pliocene geography (Eoi<sup>400</sup>-E<sup>400</sup>) accounts for 1.8 ± 0.7°C of warming and the increase in CO<sub>2</sub> (E<sup>400</sup>-E<sup>280</sup>) accounts for 1.1 ± 0.7°C of temperature increase. These differences highlight that there are non-linearities within the climate systems response to changes in boundary condition.”

**On page 4, the draft says “The land-sea mask is effectively 3.75 x 2.5 resolution in the top 200 m but beneath increases to 1.25 lateral resolution.” I don’t follow this. Didn’t the previous line say that the horizontal resolution is 1.25?**

The two statements are compatible. The ocean model has grid cells that are 1.25 x 1.25 degree in size. The land sea mask in the top eight ocean layers is 3.75 x 2.5 degree and beneath it is 1.25 x 1.25 degrees. I understand the confusion. I have clarified this (and removed superfluous information) by changing the sentence to “To simplify coupling with the atmosphere model, the ocean model’s coastline has a resolution of 3.75 x 2.5° at the uppermost level.”

**Page 9 first para on precipitation says:**

**“Regions that have little (< 0.1 mm day<sup>-1</sup>) change in precipitation are regions that receive little precipitation within E<sup>280</sup>— North Africa and the East Antarctic Ice Sheet. Therefore, the models response to elevating CO<sub>2</sub> in the Pliocene context seems to largely follow the wet get wetter paradigm.” There are two things wrong with this. Firstly, the conclusion in the second sentence does not follow from the first. In the first sentence you are saying there is no change over dry regions, which is not the same as saying wet gets wetter (or that dry regions get drier; which you haven’t said directly, but is part of the same paradigm). Secondly, I don’t agree that the model necessarily follows that paradigm — the anomaly over Australia for example is wet, whereas it is a desert today. There is also significant drying over the entire Amazon as implied by the anomaly, but today it is very wet. So a dry Australia has become wetter and a wet Amazon has become drier.**

This was unfortunately another poorly structured paragraph, and I agree completely with what you note. With regards to the wet-get-wetter phrase I was referring to the effect of increasing Pliocene CO<sub>2</sub>. The wet Australia and dry Amazon occur due to palaeogeographic change (Eoi<sup>280</sup> – E<sup>280</sup>).

Nevertheless, whilst I do say that it “..largely follows the wet get wetter paradigm..” (emphasis mine), it is still a loose phrase. I there removed it. The paragraph now reads

“The globally integrated Mean Annual Precipitation metric (MAP; Table 4) is influenced by both Pliocene geography and CO<sub>2</sub> changes. Pliocene geography acts to increase globally integrated MAP although this appears sensitive to the background CO<sub>2</sub> level (e.g. Pliocene geography increases MAP by 0.07 and 0.05 mm day<sup>-1</sup> at 280 and 400 ppm respectively). The geographical distribution of MAP change can be seen within Figure 5. Northern Hemisphere land masses generally see increased precipitation within the Pliocene although this effect is minimal in the continental interiors. In the Southern Hemisphere much of South America and South Africa receives less precipitation whilst Australia and Northern Greenland see an increase in precipitation during the Pliocene. Increasing Pliocene CO<sub>2</sub> generally intensifies the precipitation anomaly which is most apparent in the tropics. Regions that have little (<0.1 mm day<sup>-1</sup>) change in precipitation under increasing Pliocene CO<sub>2</sub> are regions that receive little precipitation within E<sup>280</sup> e.g. North Africa and the East Antarctic Ice Sheet.”

**The authors should give more details about this “diffusive pipe” (page 4) that is used along the Strait of Gibraltar. An important oceanic phenomena there is the flow of extremely dense and saline waters from the Mediterranean to the Atlantic after crossing the strait and which has important implications for the Atlantic overturning circulation. How do the authors expect the lack of such transport to affect the climate in their simulations?**

I have expanded upon the description of the diffusive pipe so that it now reads (The 1200m is significantly deeper than the main sill, this depth was chosen by the model developers (MOHC) as it was assumed that Mediterranean waters would sink to this depth.)

“Water mass exchange through the Strait of Gibraltar, a channel that falls subgrid-scale, is achieved with a diffusive pipe. This pipe provides transport of water properties through the 13 topmost layers of the ocean (~ 1200m) between the Eastern Atlantic with the Western Mediterranean.”

**I don't follow the comment “Observation derived upper-boundaries to Arctic and Antarctic sea ice concentration of 0.995 and 0.980 are used” regarding the conversation on the sea ice model on page 4.**

The description within the manuscript has been expanded and clarified so that it now reads “To account for sea ice leads, upper-boundaries of 0.995 and 0.980 are imposed to Arctic and Antarctic sea ice concentrations, based upon the parameterisation of Hibler 1979.”

**The Persian Gulf is not really present in the PRISM4 reconstruction, but apparently it is in the author's ocean grid shown in Figure 1. Similarly, the Barents Sea is absent in PRISM4 reconstruction (there is a small negative orography depression, but that is just a resolution/ reconstruction limitation).**

Firstly, regarding the Barents Sea. The PRISM4 reconstruction (Figure 3 of Dowsett et al., 2016<sup>5</sup>) does have the Barents Sea present as does our Pliocene model configuration (Figure 1). Svalbard is extended within PRISM4, yet within the MOHC developed pre-industrial boundary conditions, Svalbard is missing due to model development choices. It was decided when generating PRISM4 model boundary conditions to omit the extended Svalbard to keep consistent with the MOHC-developed pre-industrial boundary conditions.

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<sup>5</sup> Dowsett, H., Dolan, A., Rowley, D., Moucha, R., Forte, A. M., Mitrovica, J. X., Pound, M., Salzmann, U., Robinson, M., Chandler, M., Foley, K., and Haywood, A.: The PRISM4 (mid-Piacenzian) paleoenvironmental reconstruction, *Clim. Past*, 12, 1519-1538, <https://doi.org/10.5194/cp-12-1519-2016>, 2016.

The PRISM4 boundary conditions specify a small inland sea in the vicinity of modern Persian Gulf. When we look at the MOHC-developed pre-industrial model boundary conditions, due to spatial resolution issues the Persian Gulf is represented by a large inland sea. A choice was made to keep the Persian Gulf constant, although it could be argued that the inland sea should have been made smaller in the Pliocene model. A sensitivity experiment has shown that this has some regional impacts but globally is minimal and doesn't alter the results of this manuscript. We will present a wide range of these additional sensitivity experiments within a future paper.

## Technical Comments

1. **Page 1, Line 6: What does a “control Pliocene” mean?**
2. **Page 1, Line 7: “integrated surface air temperature”**
3. **Page 1, Line 11: “by both geographical - and land surface changes, and the increase in CO<sub>2</sub> increase”**

(reviewer comment 1-3): The abstract has been rewritten so that it now reads

“We present the UK’s input into the Pliocene Model Intercomparison Project Phase 2 (PlioMIP2) using the HadCM3 climate model. The 400 ppm CO<sub>2</sub> Pliocene experiment has a mean annual surface air temperature that is 2.9°C warmer than the pre-industrial and a polar amplification of between 1.7 and 2.2 times the global mean warming. The PRISM4 enhanced Pliocene palaeogeography accounts for a warming of 1.4°C whilst the CO<sub>2</sub> increase from 280 to 400 ppm leads to a further 1.5°C of warming. The climate system’s sensitivity to a doubling of CO<sub>2</sub> is 3.5°C for the pre-industrial and 2.9°C for the Pliocene. Precipitation change between the pre-industrial and Pliocene is complex, with geographic and land surface changes primarily modifying the geographical extent of mean annual precipitation. Sea ice extent is reduced during the Pliocene, particularly in the southern hemisphere, although it persists though Summer in both hemispheres. The Pliocene palaeogeography drives a more intense Pacific and Atlantic meridional overturning circulation (AMOC). This intensification of AMOC is coincident with more widespread sites of deep convection in the Southern Ocean and North Atlantic. We conclude by examining additional sensitivity experiments and confirm that the choice of total solar insolation (1361 vs. 1365 Wm<sup>-2</sup>) and orbital configuration (modern vs. 3.205 Ma) do not to significantly influence the anomaly-type analysis in use by the Pliocene community.”

4. **Page 1, Line 21: “through its ~~uses-a~~ potential as an analogue for the contemporary”** This sentence has been replaced with “The Pliocene Model Intercomparison Project Phase 2 (hereafter PlioMIP2; Haywood et al. (2016)) has dual focus: 1) to improve understanding of Pliocene climate and 2) to evaluate climate model uncertainty for a warmer than modern climate.
5. **Page 1, Line 24 “are ~~required-to-be~~ completed by all model groups participating in PlioMIP2, while whilst the optional”** This sentence has been replaced with “The CORE components are required for all modelling groups whilst the Tier 1 and Tier 2 components are optional with Tier 1 experiments higher priority than Tier 2.”
6. **Page 2, Line 2—4: Rewrite the sentences on these lines as: “Table 1 summarizes the experiments conducted within this study. These experiments include several PlioMIP2 experiments as well as non-PlioMIP2 experiments that explore additional sensitivities. From the set of proposed PlioMIP2 experiments we conduct all core and Tier 1 experiments as well as ....”** This sentence has been replaced with “Table 1 details the PlioMIP2 experiments

conducted within this study, along with an additional set of non-PlioMIP2 experiments that explore model sensitivities. We conduct all CORE and Tier 1 experiments as well as the Pliocene4Future Tier 2 experiments as described within Haywood et al. (2016).”

7. **Page 2, Line 11: atmospheric shouldn't be capitalized.** Corrected
8. **Page 2, Line 27: I don't understand the part "or regional geographical sensitivities were explored".** I have changed this to "or regional palaeogeographical uncertainties were explored."
9. **Page 2, Line 29: atmosphere and ocean in small letters.** All instances of "Atmosphere" and "Ocean" have been decapitalised where appropriate
10. **Page 2, Line 33: "have been made since 2000" The sentence with this phrase is poorly worded. Please rewrite it as "Subsequent corrections and improvements to the model, as well as a thorough evaluation against observational data has been described in Valdes et al. (2017)." I agree this should have been better written. I have changed it to your recommendation.**
11. **Page 3, Line 6 "pressure-levels at height aloft"** I have changed this to "...has 19 vertical hybrid sigma-pressure levels extending to 10 hPa"
12. **Page 3, Line 8: Oasis in capital** This sentence was rewritten at the suggestion of Reviewer #1.
13. **Page 3, lines 13—14: The last sentence sounds weird and appears incomplete. This sentence was changed to "The radiative effects of background aerosol are represented by a simple parameterisation based on modern climatological conditions (Cusack et al., 1998)."**
14. **Page 4, Lines 8—9: rephrase the sentence to: "Within the modern boundary conditions, cells overlying important subgrid-scale channels, such as those along the Denmark Strait, the Iceland- Faroe and the Faroe-Shetland Channels, and straits surrounding the Indonesian archipelago, are artificially deepened to improve flow representation." I have rephrased this sentence.**
15. **Page 4, Line 3: "in an attempt order to improve representation"** Changed.
16. **Page 4, Line 14: "Hudson Bay outflow Strait" ... "subsequently therefore unrepresented"** Changed.
17. **Page 5, Line 4: "setup of the Pliocene and the pre-industrial experiment experiments"** Changed.
18. **Page 5, Line 8: "and the letters o and o indicate inclusion of PRISM4 orography (including PRISM4 vegetation, soil and lakes) and ice-sheets., the former includes PRISM4 vegetation, soil and lakes." Changed.**
19. **Page 5, Line 10 "giving yielding experiments" .... "components from the PlioMIP2 experiment design." Sentence restructured at the request of Reviewer #1**
20. **Page 5, Line 11 "We use a preceding subscript in the name of an experiment to indicate"** Sentence restructured to "We investigate the validity of this orbit choice by rerunning  $E_{orb}^{400}$  with a 3.205 Myr orbital configuration within experiment  $_{orb}E_{oi}^{400}$ ."
21. **Page 5, Line 15 What is the expression at the end? Presumably you want to mention something like "which we diagnose as the anomaly  $E_{oi}^{280} - E^{280}$ " I have moved this sentence to the first paragraph of the Results section (Section 4) and have added these words.**
22. **Page 5, Line 16: "Pre-industrial Control experiments description" Again, the various E experiments are not all pre-industrial. I have changed the subsection heading to "Pre-industrial and associated sensitivity experiments ( $E^{280,400,560}$  and  $_{1361}E^{280}$ )"**
23. **Page 5, Line 18: "from the 'Levitus' observed" I have changed the sentence to "...had been initialised from the observed ocean state of Levitus and Boyer (1994)"**
24. **Page 5, Line 22: "In accordance to with the PlioMIP2" This has been changed**
25. **Page 5 Line 27: "PlioMIP2 enhanced and modern boundary conditions For PlioMIP2 the boundary conditions for the modern day and the 'enhanced' variant of the Pliocene reconstruction" ... "held within" I have changed this sentence to "For PlioMIP2 the**

boundary conditions for the modern day and the 'enhanced' variant of the Pliocene reconstruction are provided on regular 1° grids ..."

26. **Page 6, Line 7: "despite subaerial extension within PRISM4". I don't follow what this has to do with omitting the islands. Aren't you saying the extensions of bathymetry are subaerial?** At the request of Reviewer #1 I changed the phrase subaerial extension" to "subaerial exposure" so that sentence now reads "In remaining consistent with the pre-industrial boundary conditions developed by MOHC we remove Svalbard and Novaya Zemlya despite subaerial exposure within PRISM4". Within the pre-industrial experiment, the islands were removed by the MOHC to improve ocean circulation in that region. Within the PRISM 4 boundary condition these islands are larger than present day. This therefore poses a conceptual problem. I therefore omitted them in the Pliocene experiments also.
27. **Page 6, Line 8: What is this diffusive pipe you are talking of?** The diffusive pipe is common to the pre-industrial and Pliocene models so I have moved its description to the Section 2.2 where it is first mentioned. I have added the following sentence "This pipe provides transport through 13 topmost layers of the ocean (~1200m) between the Eastern Atlantic with the Western Mediterranean."
28. **Page 7, Line 8: "First the Atmosphere atmosphere model"** All instances of "..Atmosphere model.." have been changed to "..atmosphere model.."
29. **Page 8, Line 2: "yet modest, disequilibrium represented departures from equilibrium and are characterized by TOA imbalances"** I have changed the phrase "... ,disequilibrium represented ..." with "..departures from equilibrium and are characterized ..."
30. **Page 8, Line 4: "occurring at depths of > 2000 of in the "** At the request of Reviewer #1 I have changed this to read "..depths deeper than 2000 m in the Pacific basin."
31. **Page 8, Line 5: Sentence beginning on this line is strangely worded.** I have corrected this so that it now reads "The Indian and Antarctic oceans are the most equilibrated, particularly at intermediate depths and deeper."
32. **Page 8, Line 6: "equilibrium states"** Corrected
33. **Page 8, Line 6: "Figure 2 presents the time-evolution of ocean temperature" for which simulation? You have several simulations, which one of it is on Figure 2. Even the caption on the figure doesn't say that.** I have clarified this and it now reads "...Figure 2 presents the time-evolution of ocean potential temperature of the Pliocene control experiment, Eoi<sup>400</sup>."
34. **Page 8, Line 11: "We derive base our analysis on climatological averages"** This has been changed
35. **Page 8, Line 11: The range of climatology years is not applicable to the pre-industrial controls.** You are correct. I have removed the text "(model years 2450 through to 2499) as it was also superfluous.
36. **Page 8, Line 15: "Modelled mean annual surface air temperatures (hereafter MAT MASAT)" .... "Tables 3". NOTE: Table 3 uses MASAT, and you should use MASAT everywhere just like Table 3 as that is the more accurate term.** I have corrected the manuscript (including tables and figures) so that MASAT is used throughout.
37. **Page 8, Line 17: "coincide with Greenland and Antarctic regions of Pliocene ice sheet retreat (and topographical reduction) over Greenland and Antarctic.** I have rephrased the sentence so that it now reads "Differences in MASAT of up to 31.3°C coincide with Greenland and Antarctic regions where Pliocene ice sheets and the respective elevation are smaller than pre-industrial."
38. **Page 8, Line 19: "This pattern of warming is in a similar in distribution to HadCM3 results within PlioMIP under using the older PRISM3".** I have changed this sentence to "This pattern of warming is similar to results derived with HadCM3 within PlioMIP1 under PRISM3 boundary conditions (Exp. 2 of Bragg et al. (2012))."
39. **Page 8, Line 25: "Figure 4 shows the Annual and Sseasonal ..... and Eoi<sup>400</sup> compared to the PI control" NOTE: Figure 4 does not show what you are saying it shows. It shows only**



**annual anomalies.** Figures 3 and 4 had become swapped when I had reworked the Figures prior to initial upload. I have decapitalized “Annual” and “Seasonal”.

40. Page 8, Line 26: “the Hudson Bay and the Baltic Sea regions” This has been corrected
41. Page 8, Line 27: “during he the summer” This has been corrected
42. Page 9, Line 1: “From the results in Table 3 it is possible to decompose diagnose” This has been corrected
43. Page 9, Line 4: “The Climate climate system’s Sensitivity sensitivity to a doubling” This has been corrected
44. Page 9, Line 7: “When we neglect geographical changes”. I don’t follow.... This sentence has been changed so that the paragraph ends with “When we approximate Earth System Sensitivity (ESS) using  $E_{oi}^{400}$  and  $E^{280}$  (with  $ESS = 1.88 \times \Delta T_{E_{oi}^{400} - E^{280}}$ ) we obtain  $\sim 5.5 \pm 1.3^\circ\text{C}$ . Subsequently the ESS/CS ratio is  $\sim 1.90$ , which lies at the higher-end of the 1.1-2.0 ensemble range of PlioMIP1 (Haywood et al., 2013a) in which HadCM3 had a ratio of 2.0. It must be noted, however, that this calculation assumes that the PlioMIP2 enhanced boundary condition represents the equilibrated Earth System under a contemporary doubling of  $\text{CO}_2$ , hence neglecting non-glacial elements of the PRISM4 retrodicted palaeogeography.”
45. Page 9, Line 9: “Subsequently Consequently”
46. Page 9, Line 13: “Mean Annual Precipitation metric (MAP; Table 4)” This has been corrected
47. Page 9, Line 14: “and is relatively insensitive to Pliocene the chosen  $\text{CO}_2$  changes in the Pliocene experiments” I have rephrased the sentence so that it now reads “The globally integrated Mean Annual Precipitation (MAP; Table 4) is influenced by both Pliocene geography and  $\text{CO}_2$  changes.”
48. Page 9, Line 21: “plots of precipitation change between the 400 and 280 ppm versions of Pliocene and the PI control are shown in can be seen within Figure 6” I have changed this to “Seasonal plots of precipitation change between the Pliocene ( $E_{oi}^{400}$ ) and the pre-industrial ( $E^{280}$ ) control experiments are shown in Figure 6.”
49. Page 9, Line 25: Capital S in South Corrected
50. Page 9, Line 26: “more eastward further east” Corrected
51. Page 9, Line 28: Last sentence is weird and incomplete I have removed the discussion on the monsoon systems.
52. Page 9, Line 30: two “the” I have removed the discussion on the monsoon systems.
53. Page 10, Line 10: “The time averaged, zonal mean, meridional” Corrected
54. Page 10, Line 11: “the indirect Ferrel” (the word is unnecessary here) I have removed the superfluous “indirect”
55. Page 10, Line 13: “Assuming Taking the maximum in of the meridional streamfunction represents as a measure of the Hadley cell strength” This sentence has been modified following your suggestion.
56. Page 10, Line 15: “than the Southern cell which is in contrast to contradiction with observational and reanalysis data (...) that show consistently show the southern cell being stronger” This sentence has been modified accordingly.
57. Page 10, Line 17: “stronger than the northern cell” also replace the “for” occurring in the parentheses with “in” This sentence has been modified accordingly.
58. Page 10, Line 22: “and Polar Jet streams (PJ)” Corrected
59. Page 11, Line 5: While Table 6 does show the MASSTs of the experiments, Figure 9 does not show that. It shows the anomalies of very specific sets of experiments. Please rephrase and rearrange this sentence. This sentence has been changed to “Modelled mean annual SST’s (MASST) are detailed within Table 6 and Pliocene anomalies are shown within Figure 9.” Figure 9 caption has also been corrected.
60. Page 11, Line 7: I think you mean  $E_{oi}^{400} - E_{oi}^{280}$  so as to be consistent with what you say on Line 3 in Page 9. This has been corrected

61. **Page 11, Line 9: “Within the North Atlantic sub polar gyre where  $E_{oi}^{400} - E^{280}$  reaches +9.3C”** That sentence does not stand on its you. You probably forgot to complete your thought here. This has been corrected to “The greatest warming occurs within the North Atlantic subpolar gyre where  $E_{oi}^{400} - E^{280}$  reaches 9.3°C.”
62. **Page 12, Line 4: “Here we rely upon the mixed layer depth (MLD) as calculated as a diagnostic variable within HadCM3 climate model”** What kind of sentence is that? Not only is there nothing in that sentence, it doesn’t sound proper either. I agree. The intention of this sentence was superfluous so I have removed it.
63. **Page 12: Reference the mixed layer figure in the section on mixed layer.** The first sentence now reads “The mixed layer depth (MLD) for  $E^{280}$ ,  $E_{oi}^{280}$  and  $E_{oi}^{400}$  is shown within Figure 11.:
64. **Page 12, Line 13: “streamfunctions” “are shown” plural..** This has been corrected.
65. **Page 12, Line 14: Rewrite sentence on this line** This has been rewritten as “The Atlantic Meridional Overturning Circulation (AMOC) streamfunctions for  $E^{280}$ ,  $E_{oi}^{280}$  and  $E_{oi}^{400}$  are shown within Figure 12 and detailed within Table 7. The pre-industrial experiment  $E^{280}$  has a maximum AMOC strength at 26.5°N of  $13.4 \pm 1.2$  Sv. This compares reasonably well with the estimate of  $17.2 \pm 4.6$  Sv derived by McCarthy et al. (2015) using measurements from the RAPID array between April 2004 and October 2012. The all-latitude maximum in AMOC strength ( $AMOC_{max}$ ) within  $E^{280}$  occurs at ~650 m depth at 33.75°N with a strength of  $15.7 \pm 1.2$  Sv.”
66. **Page 12, Line 15: “Our AMOC... (put value here) differs to from that in Bragg et al. (2012; strength of 17.6 Sv), a difference that we ascribe to the latter’s use of”** I have removed the reference to Bragg et al. (2012). The sentence is now shown in answer to your comment no/65
67. **Page 12, Line 17: “Fluctuations of the order in the AMOC” huh???** Sincerest apologies. I have completed this sentence so that it now reads “Multidecadal to centennial fluctuations including a dominant ~225 year oscillation are present within the Pliocene experiments but not the pre-industrial experiment.”