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To the Editor
Climate of the Past (CP):

Our paper, "**Oceanic response to changes in the WAIS and astronomical forcing during the MIS31 superinterglacial**" is reviewed.

Please find enclosed replies to the comments and suggestions. We greatly appreciate all comments and careful evaluation done by the Editor, which substantially improved the manuscript. In the revised MS, *italic* parts stand for modified paragraphs and news statements. Lighter comments that do not lead to misinterpretation of results have been removed. Typos have also been corrected but now always edited in *italic*. All figures have been modified to highlight differences that are statistically significant.
The 3rd version of our Manuscript has been carefully revised by all co-authors including Aaron Wilson and David Bromwich, both native English speaker.

In the following we have sequentially addressed all points raised, as shown below.

Sincerely,
Flavio Justino

Abstract:

The word “substantial” has been REMOVED

Introduction:

-Reference/citation style has been revised according to the CP LaTeX template.

PAGE 2

-The expression “such as” has been REMOVED and citation added

- Citation added (Coletti et al 2015, Lund et al 2017, Roychowdhury and DeConto, 2016)

-Sentence removed *“This approach is explored here by using a coupled model”*

-Sentence removed *“At large …”*

-Sentence moved to Page 2, line 16 as suggested.

PAGE 3

-Sentence moved to Section 3, Page 4 line 8 as suggested.

-Section 2 has been modified starting with a description of the model characteristics.

-Removed all informal text such as “*It has to be mentioned* …
“

EDITOR REMARKS PAGE 4: Given the reviewers concerns about potential bias, it is critical that you are honest about areas where the model performs less well too. Will this difference not have influence on your deep-water formation locations and magnitude?

Editor comments on page 6 most deal with biases in deep-water formation.

In order to address this issue we have compared our simulated AABW and NADW with oceanographic data as suggested. This is included in the revised MS as the initial part of the subsection “Changes in MOC and OHT” PAGES 8 and 9:

The ICTP-CGCM AMOC exhibits values that closely match observations (Kanzow et al., 2010; Ferrari and Ferreira, 2011; Talley et al., 2003) as well as higher *resolution models (Stepanov and Haines, 2014). Consequently, a fair representation of the AMOC should lead to proper OHT estimates under present day conditions, because the majority of the OHT is driven by the AMOC. Moreover, the resolution of ICTP-CGCM across the tropics is sufficient enough to capture the majority of the OHT for the globe.*

The Antarctic bottom-water (AABW) is closely related to sea-ice processes that involve brine release due to sea-ice formation and winds (Stössel et al., 1998). Despite limitations in reproducing the sea-ice seasonal features in the ICTP-CGCM, simulated deep water formation in the SH occurs in both the Atlantic and Pacific Oceans (Figs. 3-4).

The AABW represented by our CTR run in the Atlantic attains values of about 5 Sv (10^6 m^3 s^{-1}), which is comparable to 8 Sv based on absolute geostrophic velocity from hydrographic data (Talley et al., 2003) and from climatological Ekman transports. At 25°S, the ICTP-CGCM delivers AABW in the Pacific Ocean up to 10 Sv also in line with Talley et al. (2003), and 6-8 Sv at 10°N matched values found by Wijffels et al. (1996).

Figures 3a and 3d show that compared to data-based estimates (Ganachaud and Wunsch, 2000), the ICTP-CGCM properly reproduces the magnitude of the North Atlantic Deep Water (NADW, 15 ± 2 Sv) at 24°N. The main sites of the NADW formation, namely Greenland-Iceland, Norwegian (GIN) and Labrador Seas (Wood et al., 1999) are also properly located as shown by analyses of the density contribution (Fig. 3a). Thermal changes dominate the NADW formation in comparison to the haline contribution. Indeed, a much colder extra-tropical atmosphere over the warmer ocean increases the vertical air-sea temperature contrast and consequently the ocean-atmosphere heat exchange (Schmitt et al., 1989; Speer and Tziperman, 1992). This leads to stronger convective mixing (Fig. 3a).

-Citation removed: Kucharski et al, 2015.

PAGE 5.

-MIS 31 included as suggested: applies the MIS 31 WAIS topography...

-References included: *Dahl-Jensen et al., (2013), and Coletti et al., (2015)*

PAGE 6 Lines 1-5. The revised version includes Figures in global projection including the polar region.

-We have clarified in the text that our comparison is to the CTR run.

PAGE 6, Lines 6-11. Modified as suggested (Page 6).

PAGE 7. McCreary and Lu 1994.

PAGE 7-8. We have clarified the discussion on the joint effect of WAIS topography and astronomical forcing in leading the MIS31 climate, as follow:

The global climate response due to the combined effect of changing WAIS topography and astronomical forcing (MIS31 simulation) is primarily a result of changes in the latter forcing, as Fig. 2c shows a similar SST anomaly pattern as Fig. 2b. Nevertheless, the combined forcing appears not to be linear in the vicinity of Antarctica (Supplementary Fig. 2). Linearity is noted, however, by intensified warming in the Ross Sea as a result of warmer SSTs in TOPO and AST compared to the CTR climate. Non-linearity is shown through reduced cooling in the Weddell Sea in the MIS31 simulation compared to the AST simulation (Supplementary Fig. 2). This is related to the absence of the WAIS topography that reduces the strong cooling associated with changes in the astronomical forcing. Comparison between the MIS31 and the AST runs can be indirectly used to further identify the effect of the WAIS topography in the SH sea-ice changes (Figs. 2e and 2f).

PAGE 8, 1st paragraph: Figures 2a,b,c in the revised version include the polar regions

PAGE8, 2nd paragraph: The sentence is included as an open statement to highlight the influence of air-sea coupling in leading sea-ice anomalies between the MIS31 forcing and the CTR climate. It has been added to the revised version:

Modification of the WAIS topography is associated with changes in sea-ice area, particularly in the Atlantic Ocean. Changes in the astronomical forcing on the other hand are more responsible for climate anomalies on a global perspective. Differences between MIS31 and AST usefully demonstrate that the substantial reduction of sea-ice cover in the Ross Sea and in some extent changes in Weddell Sea are substantially affected by the WAIS collapse (Supplementary Fig. 1c). Specifically, the MIS31 simulation is warmer in the Weddell and Ross Seas by up to 1.5°C with respect to AST, which is accompanied by an approximately 10% reduction in sea-ice cover. In fact, the individual influence of the collapse of WAIS in MIS31 is more evident in the Bellingshausen Sea (Figs. 2e and 2f). In the NH, the removal of WAIS and orbital forcing act in opposite directions for sea-ice changes.

The sensitivity experiments demonstrate that compared to CTR, warmer SSTs and reduced sea-ice are only simulated in the Ross Sea region. This is in agreement with the Cape Roberts Project-1 results and data from the Antarctic Geological Drilling project (ANDRILL) (Naish et al., 2009) (Fig. 2). In fact, outside of the Ross Sea, Antarctic sea-ice during the MIS31 interval may have been more abundant compared to current conditions. In the NH, sea-ice cover is substantially reduced b

PAGE 8 – ORB and Weddell have been removed

PAGE 8 Line 21 and 9 Line 10,: Sentence removed.

PAGE 9 and 10. We have a provided better description and references that confirm reasonable representation of the MOC in our CTR climate. The revised version includes in our view a solid explanation for changes in the MOC during the MIS31 epoch. It should be noted that we have provided new Figures (3 and 4). See revised MS pages 9-10 *in italic*.

PAGE 10, line 25 - Editor comment On the Oceanic Heat Transport (OHT)

R. Our assumption that weaker OHT in the Northern Hemisphere is due to limitation in the Atlantic Ocean, is related to the fact that the OHT in the Pacific is in the range of proposed values, as shown in Figure 4a (yellow triangles). By evaluating the modeled values in the Atlantic is clear that they reach up to 0.6 PW, whereas ”observation” estimates assume values as high as 1 +- 0.3 PW (green squares, Figure 4a). Thus, the global projection, which is the sum of all ocean basins contribution will result in model underestimation due to lower Atlantic OHT.

PAGE 11. Citation added (ODP site 846 Herbert et al., (2010c) and 849 McClymont and Rosell-Melé, (2005)

PAGE 11 on the Sverdrup transport:

We have removed parts involving the Sverdrup transport in the current revised version.

A section **“Summary and Concluding Remarks”** has been modified to include our main findings and shed some light on the need for a better coverage of paleo-proxies in the SH polar Ocean, because at present, they may not hemispherically represent the most dominant characteristics of the polar sea surface in the MIS31 interval, insofar as sea-ice is concerned.