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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 reviewer comments and suggestions. We greatly appreciate all comments and careful evaluation done by the anonymous reviewers, which substantially improved the manuscript. In the revised MS italic parts are completely modified. Light comments and types have also been included as suggested.

Sincerely,

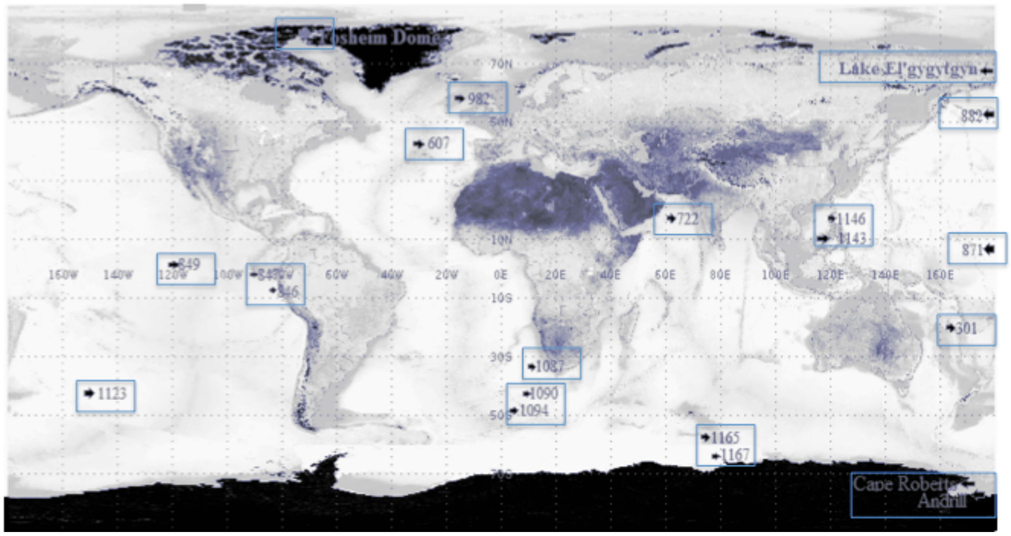
Flavio Justino

A major concern of the reviewers is related to the model biases in the extra-tropical latitudes, as well as associated with the Meridional Overturning Circulation (MOC) and Oceanic Heat Transport (OHT) magnitudes. This is an important point indeed, and to provide the reader with comparison of our modeled values, the revised MS includes in figure 4 observations based on Ganachaud and Wunsch (2000; 2003) for OHT and Talley (2003), Griffies, et al (2009), Sterl et al (2012), Stepanov and Haines (2014) for the MOC.
An extensive discussion of the model caveats is included in the MS pages 3-4, insofar as SST, sea-ice and E-P flux are concerned. The CTR climate simulation is compared to HadSSTI dataset for SST and sea-ice and to ERAI for E-P flux.

Reviewer 2 also suggested an intercomparison of our MIS31 simulation with similar experiments for the MIS1 and 5e interglacial. We recognize that seeing our MIS31 experiments in relation to these two other intervals would be very useful. However, this will require another set of experiments specifically 6 additional runs. We regret that at this stage is not feasible to proceed as suggested by the reviewer, as new modeling experiments could not be conducted in due time. Because an AOGCM is used, demanding computational time and complexity in interpreting global results make this task un-attainable in due time. In fact, it is for the first time that such experiments have been performed with a full rather than a slab ocean model. We will leave this interesting comparison to a potential follow up publication.

The introductory section has been substantially modified to better define the manuscript focus as suggested. Also it is emphasized that our study is an improvement of previous ones conducted with slab ocean models. Indeed, this is the first study conducted with an AOGCM to evaluate the MIS31 interglacial, performed to disentangle individual climate responses to astronomical and WAIS topography forcings.

Regarding the paleo-model inter-comparison shown in Figure 2c of the original MS version, we are confortable in saying that the revised MS includes an extensive inter-comparison between modeled results and 19 globally distributed proxies, as shown in the figure below.



This Figure is included in the Supplementary Material. Moreover, in revised MS the Table 2 shows temperature values based on paleo-proxies and differences from the MIS31 simulation (see below). This approach is based on results by Wet et al (2016, EPSL). The discussion is provided in pages 8-9.

Site (coordinates)	Surf.Temp.(^{0}C) reconstruction	Surf. Temp. (^{0}C) Speedy-NEMO	Differences between Speedy-NEMO and reconstructions (^{0}C)
Lake E (67N 172E)	14.3	12.5	-2.2
ODP 982 (57N 15W)	13.8	10.8	-3.0
DSDP607 (41N 33W)	17.5	16.9	0.6
306-U1313 (41N 32W)	18.0	16.9	-1.1
1146 (19N 116E)	26.0	25.0	-1.0
722 (16N 59W)	27.0	28.0	1.0
1143 (9N 113E)	28.3	27.5	-0.8
871 (5N 172E)	29.3	28.9	-0.4
847 (0 95W)	25.6	25.0	-0.6
849 (0 110W)	25.8	25.0	-0.8
846 (3S 90W)	24.3	24.8	0.5
MD-06-301 (23S 166 E)	25.0	23.9	-1.1
1087 (31S 15E)	18.0	17.7	-0.3
1123 (41S, 171E)	16.0	16.8	0.8
1090 (42S 8E)	11.5	9.8	-1.7

Regarding uncertainties in CO_2 concentration during the MIS31, we argued that Hoenisch et al. (2009) proposes that the MIS31 has the highest partial pressure of CO_2 of the mid-Pleistocene, by about 325 ppm. However, according to their Figure 1, the CO_2 concentration could vary between 300 and 350 ppm during the MIS31, due to propagated error of the individual pH, SST, salinity, and alkalinity. This uncertainty in the atmospheric composition may lead to overestimation in the NH warming as simulated in our study. Changes in CO_2 by about +50 ppm are however associated with only +0.3K change in globally averaged surface temperature. This alteration in temperature is within the uncertainties of the climate sensitivity (Bindoff et al. 2013), and therefore may not strongly compromise our results.

It has to be stressed that all figures in the revised MS include statistical significance based on t-test statistics.

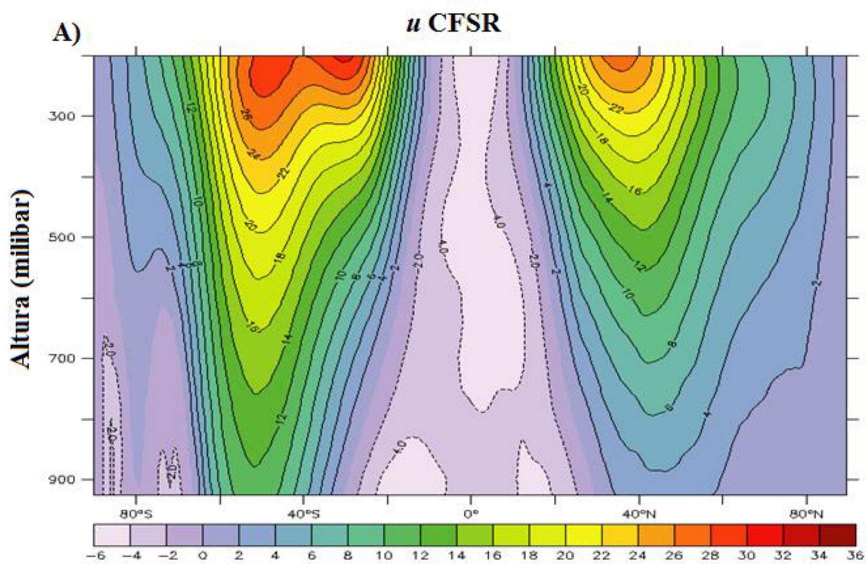
REVIEWER #1

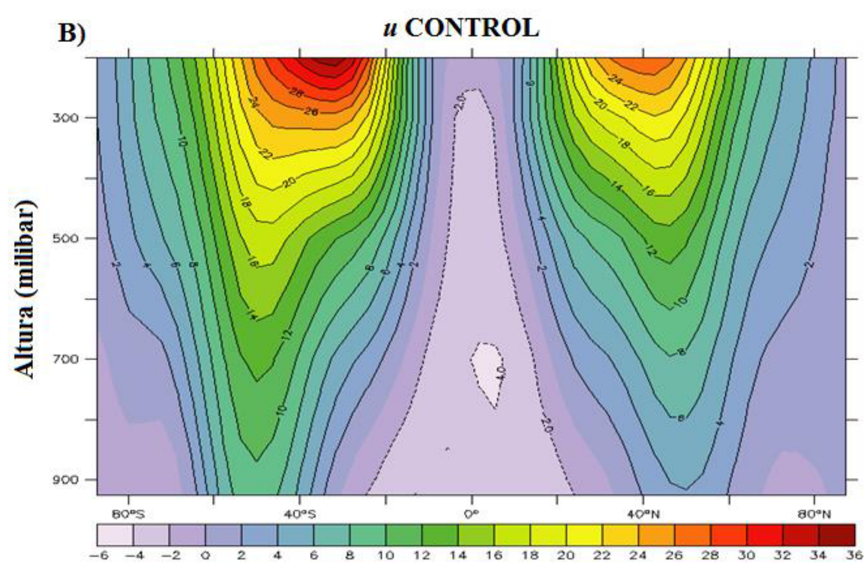
Comments annotated in the PDF file by the reviewer:

1. PAGE 1. In fact there exists changes of the MOC and OHT in both Atlantic and Pacific, but in the latter they are stronger. This will be modified in the abstract.
2. PAGE 1. We have explained the mechanisms responsible for changes in the PMOC (Figure 5 flowchart in original MS). We do not have reason to believe that these changes are related to the model biases due to its resolution. Speedy-NEMO is run in a reasonable resolution for a global model in particular in the tropics where most of the OHT is transported. The same applies for changes in sea-ice in the sensitivity experiments.
3. PAGE 2. The sentence will be modified to: “Additionally, 325 ppm characterizes the CO2 concentration by the year 1950 which does not include the increase in CO2 due to human emission in the end of the 20th century.
4. PAGE 3 -1. The analyses have been conducted for the last 100 years of a 2000 year -long simulation.

PAGE 3 -3, 4. The manuscript focuses on annual mean changes of the MIS31 climate. Discussion of the seasonal cycle, though very important, is out of the scope of the paper.

PAGE 3 -4, 5. To address the reviewer comment that our vertical wind structure and the jet is shifted southward as compared to those of reanalysis, we show below the zonal wind profile.





Here it is seen that despite limitation in our atmospheric component of the coupled model, Speedy is suitable for our study. Additional analyses are provided in http://users.ictp.it/~kucharsk/speedy8_clim.html.

PAGE 3 -6. We have discussed throughout the revised MS limitations of our analyses as well as caveats related to the modeling framework.

PAGE 4 -1. Statement will be modified according to reviewer suggestion.

PAGE4 -2. No, we have not included changes in the initial salinity field in response to the WAIS collapse. This has been treated similarly previously in Justino et al (2014 Cli. Dyn.). This is supported by Aiken and England (2008) who demonstrated limited response of the climate system to the freshening implied by Antarctic sea ice melt.

Moreover, Vaughan and Spouge (2001) argued that an outflow rate associated with WAIS melting is not realistically attainable, making it difficult to implement in a rose experiment. However, changes in temperature around Antarctica might be expected by adding freshwater. This has been included in the revised MS.

The MS focuses on analyzing the climate response to changes in the Antarctic topography due to WAIS collapse, insofar mechanical changes in orography lead to modified atmospheric lapse-rate.

PAGE 4 -3. All figures is modified accordingly

PAGE 4 -4. The sentence is removed.

PAGE 4 -5. Yes, Speedy-NEMO can properly capture the sites of deep water formation in the Northern Hemisphere as shown in Figure 3a. This is pointed out in the revised MS.

PAGE 4 -6. The statement will be removed as suggested to Section 2.1.

PAGE 5 -1. References will be added to observations and modeling based studies (Stepanov and Haines 2014 doi:10.5194/os-10-645-2014, Griffies, et al 2009 doi:10.1016/j.ocemod.2008.08.007, Sterl et al 2012 Cli. Dyn.)

PAGE 5 -2. Reference will be included, Mathiot et al. 2010 http://dx.doi.org/10.1016/j.ocemod.2010.07.001

PAGE 5 -3,4 Brackets will be included and Figure 2 is modified

PAGE 5 -5. In conditions of reduced sea-ice thickness there is an increase in the heat flux from the ocean to the atmosphere further increasing the convective mixing. The exchange of heat and mass between the atmosphere and ocean is strongly modulated by sea ice and vice-versa.

PAGE 5 -6. We are aware that seasonal analyses of the MIS31 sea-ice characteristics are important for understanding the global climate. However, in our analyses of MIS31, our main focus is climatic features that vary on long time-scales, such as AMOC, PMOC and OHT. We have shortly discussed in the revised MS changes in sea-ice.

PAGE 5 -7. Reference to Yin and Berger (2012) will be added

PAGE 5 -8. Paragraph is removed

PAGE 6 -1. Surface temperature refers to SST or land surface temperature. This is clarified.

PAGE 6 -2. This statement is important because it emphasizes the astronomically driven air-sea interaction which is a crucial mechanism related to changes in SST. We have included the Table 2 showing paleo-modeling intercomparison.

PAGE 6 -4. The statement is re-phrased.

PAGE 6 -5. The reviewer argues that the model bias can limit the reliability of our findings. It is well known that all coupled models exhibit limitations in particular over the polar regions, as assessed by the IPCC AR5.

Evaluation of sea ice in models is hampered by insufficient observations of some key variables (e.g. ice thickness). Nevertheless, particular climate anomalies resulting from inclusion of distinct boundary conditions may be primarily assumed to be climate-driven. Though, we will emphasize in the revised version limitations in our simulation of sea–ice in the Weddell Sea.

PAGE 6 -6. We compared the sea-ice extent in all experiments MIS31,TOPO and AST. This is important to provide to the reader an evaluation of the individual impacts of implementing the boundary conditions. Moreover, this can shed light on non-linear effects of the joint forcing (TOPO + AST) applied in the MIS31 run.

PAGE 7 -1, 2, 3. We provided new figures, but kept the subsection "*Changes in MOC and OHT.*" Reference will be included (Stouffer et al 2007).

PAGE 7 -4. Stronger mean winds refer to comparison to annual mean conditions, this occurs for instance in winter months. This may also apply for the sensitivity experiments in comparison to CTR simulation. This will be better explained.

PAGE 7 -5,6. New figure and the statistical significance of differences is provided for Table 1.

PAGE 7 -7. The reviewer is right, there is no clear evidence indicating a shallower cell in the TOPO. The statement is removed.

PAGE 7 -8,9,10. The paragraph is modified.

PAGE 7 -11. We implemented in the revised MS as suggested: "changes in topography of the WAIS, shown in Figures 2 and 3, have no significant impact and therefore AST and MIS 31 show very similar results. Thus we choose to show only results for MIS 31."

PAGE 7 -12. The reviewer is right, we have not discussed changes in the main site of NADW formation between CTR and MIS31. To clarify this we will include in the revised MS: "The joint effect of the astronomical and WAIS topography forcings in the MIS31 climate is to increase density flux in the Labrador Sea and the North Atlantic in the MIS31, as compared to the CTR counterpart (Figure 3c). Another source of NADW formation during the MIS31 interglacial is located in the Norwegian Sea, as shown in Figure 3f."

PAGE 7 -13. All figures have been redone including t-test statistics. This has shown that our statement on the intrusion of AABW in the North Atlantic included in the original MS is valid.

PAGE 14 -1. Statement will be removed.

PAGE 14 -2. In fact, superficial transport does not decrease. In CTR simulation the zonal mean flow in the North Atlantic is southward between 20N-Equator (Fig. 3d) whereas in MIS31 it shifts northward with maximum between 20N-40N. This is clarified in the revised MS.

PAGE 14 -3. The reviewer suggestion is included.

PAGE 14 -5. This paragraph shows the initial mechanisms related to the formation of the PMOC. The flowchart (supp. Material Fig 4) explains in more detail the climate interaction related to the PMOC formation.

PAGE 14 -6. Paragraph is modified to include the reviewer suggestion.

Reviewer #2

The main comment raised by the reviewer concerns the possibility of comparing our MIS31 simulation with similar experiments of MIS1 and 5e. We recognize that seeing our MIS31 experiments in relation to these two other interglacials would add to the manuscript value. However, this will require another set of experiments specifically 6 additional runs. We regret that at this stage is not feasible to proceed as suggested by the reviewer, as new modeling experiments could not be conducted in due time. Because an AOGCM is used, demanding computational time and complexity in interpreting global results make this task un-attainable. In fact, it is for the first time that such experiments have been performed with a full rather than a slab oceasn model. We will leave this interesting comparison to a potential follow up publication. However, all other comments by this reviewer are addressed.

We modified the introductory section to better define the manuscript focus. Also we will emphasize clearer that our study is an improvement of previous ones conducted with slab ocean models. Indeed, this is the first study conducted with an AOGCM to evaluate the MIS31 interglacial, performed to disentangle individual climate responses to astronomical and WAIS topography forcings.

We added the suggested references, and their main findings in the Introduction.

We included a paragraph on the CO2 uncertainties during MIS31, and their potential impact on our results which assume present day CO2.

* Regarding to CO_2, CH_4 and N_2O concentration.

It has been proposed by Hoenisch et al. (2009) that the MIS31 has the highest partial pressure of CO_2 of the mid-Pleistocene, by about 325 ppm. However, according to their Figure 1, the CO2 concentration could vary between 300 and 350 ppm during the MIS31, due to propagated error of the individual pH, SST, salinity, and alkalinity. The uncertainty in the atmospheric composition may lead to overestimation in the NH warming as simulated in our study. Changes in CO_2 by about +50 ppm may be associated with +0.3K change in globally averaged surface temperature. In fact, this alteration in temperature is within the uncertainties of the climate sensitivity (Bindoff et al. 2013). The CH_4 (800 ppb, Loulergue et al. 2008) and N_2O (288 ppb, Schilt et al. 2010) concentrations are similar to Coletii et al. (2015).