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Climate of the Past
Discussions
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Interactive comment on "The impacts of Meltwater Pulse-1A in the South Atlantic Ocean deep circulation since the Last Glacial Maximum" *by* J. M. Marson et al.

Anonymous Referee #1

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General comments

Marson and co-authors investigate a transient simulation starting at the LGM to present day. In this simulation several artificial meltwater discharges arising from sources in both the southern, and northern hemispheres are implemented and their effect on the Atlantic deep ocean circulation is analyzed. In general this a very promising and exciting research area which is of interdisciplinary interest. I am also sure the authors work has substantial results that merit publication. In its present form, however, I can not recomment the paper for publication in CP without a major revision. In the following line numbers refer to to printable version.

Section data and methods

This section needs to be rewritten. The experimental setup is not sufficiently described. The reader doesn't know the location where freshwater was injected. This, however, is an important information as several previous studies have emphasized the sensitivity of deep water circulation to the geographical position of the meltwater source relative to deep water formation sites (e.g. Mikolajewicz, 1998). The reader only learns that several meltwater schemes were tested and validate using proxy data. But no description of the schemes is given and it is not clear what kind of proxy data has been used for validation. It is also important to know how the model was initialized at the LGM and how long it was spun up before starting the simulation. As this information crucial for the understanding of the results it is from my point of view not sufficient to only refer here to the studies of Liu et al (2009) and He (2011, an unpublished PhD thesis). This brings me to the next point: There are several meltwater pulses before MWP1A are discussed in the text (e.g. line 20, page 6382)with frequently repeated reference to the studies Liu et al (2009) and He et al. (2013). It should become clear how much of the results have already been discussed in theses studies (and those parts should be moved to the introduction, see specific comments) and what is the contribution of the present work.

Section Results and discussion

Marson et al. present an interesting evolution of the Atlantic deep water circulation since the LGM. The authors main conclusion is, that at the LGM a "very salty AABW" resulted in a first step in a "salinity barrier" (for example line 13, page 6384) at 13 kaBP in the north Atlantic hindering surface waters sink to depth thus suppressing NADW. But it becomes not clear how this "salinity barrier" is established. From Fig. 5 one would guess the model was already initialized with such a barrier and with an deep Atlantic Ocean that was much saltier than today. Therefore, the reader must know in which way and under which assumptions the model was initialized and how it was spun up. Furthermore, the south deep Atlantic freshens between 19 and 14.1 kaBP

(Fig. 5a-c) without any meltwater source in south (Fig.1). Is there model drift or is it internal variability?

In a second step the authors hypothesize that the MWPA1 meltwater contribution from the southern hemisphere then made the deep North Atlantic more and more fresher over several thousand years thereby removing this “barrier” after 13 kaBP. However, after 13 kaBP the only significant FW contribution comes north (Fig. 1). Therefore, this hypothesis is not very convincingly supported by the provided model results (see also the specific comments below).

Quite often the authors infer changes in NADW formation and AMOC alone from the Atlantic heat transport time series in the South Atlantic 30 S – 0 (in Fig.2). The argumentation would be much more convincing if the authors would show corresponding time series for the heat transport in the (northern)North Atlantic (see also specific comments). In addition to that, if possible, the authors may consider also presenting an overturning function for specific time slices as quite often in the text changes in the AMOC are assumed to have occurred which are mostly inferred from salinity sections and heat/salt transports in the SH alone (e.g. page 6381, line 4-8).

As there is only one experiment is analyzed, without any sensitivity experiments or control integration (without the artificial MWP1A), the uncertainties/robustness of the model results should be discussed.

Specific comments.

Page 6375

Authors affiliations should be set in the right order.

Page 6376

line 13 remove “... associated with with the North Atlantic Deep Water,..“

line 23 include reference for “..20m of sea level rise in less than 500yrs“

Page 6377

line 11 – be more specific: which proxy evidence do you refer here?

14ff – This needs further explanation: Do you mean the LIS contributed 37% or do you mean 37% of the original LIS are not enough for a 20m sea level increase?

line 22 – There are numerous meltwater modelling studies that showed the NADW decrease in response to freshwater input (e.g. Manabe, S. and R. J. Stouffer, 1997, 2000, Rind et al., 2001 etc.). Why not referencing them? There are also studies that emphasize the sensitivity of NADW formation to the routing of these meltwarter dicharges.

line 23 – Was the input of deep water to the world ocean constant during the geological past or at least to during the last glacial? Please include a reference for this or provide a physical mechanism which would keep the deep water input constant.

line 26 remove "water“ following AABW(ater). Usually, AABW is less salty. Remove "extremely salty“ which is confusing here. I browsed through the referenced Marchito et al. and Curry and Oppo papers and found no evince for an “extremely salty” AABW.

Page 6378 line 10 – Please explain more detailed why you want to investigate MWP1A (which occurred at ∼14 kaBP) when you hypothesize that the onset of modern deep water circulation was at 11 kaBP. What are the reasons to assume 75% meltwater contribution of the AIS and please tell the reader at which location the meltwater was injected.

line 21 – "It should be noted ...“. This sentence is misplaced here. If you aim to validate your model you should choose those parameters you are discussing in the results (for example AMOC strength or heat transport where several values from the models can be derived from literature).

Page 6379

line 3 Please describe the "meltwater schemes" and the sensitivity experiments in a more comprehensive way. The PhD thesis of He (2011) is not available. Which proxy data were chosen for selecting the specific meltwater schemes. Without this information it is difficult to asses the plausibility of the experimental setup.

Page 6380

line 9 As CP addresses to a broad and interdisciplinary readership it may be better to show not only anomalies in heat/salt transport. How did you calculate the mean of 0.23 PW? Does the mean refer to the undisturbed case or is it calculated from the entire simulation? It is also not clear from the figures why a strong northward heat transport at 0 – 30S results necessarily in "warm northern Hemisphere" since this is subject to several other processes. May a time series for heat transport in the northern Hemisphere would be better. Or is there an explanation in the Liu et al. (2009) study?

Page 6380 – 6381 lines 20ff – be more specific here. What are the physical mechanisms in you model that force the strong relationship between heat and salt transport? Which water masses play a significant role for this relation? It is also not surprising that with your freshwater perturbation the correlation is getting weaker as a reorganization if deep water structure can be expected.

Page 6381

line 6 Is there any indication that the AMOC is stronger at 21k in your model? It should be possible calculate the AMOC from your model output in a similar way as equation 1.

Page 6382 line – 3ff How was the model initialized and spun up for the LGM? Usualy modells are tuned present day climatologies. Did you then remove a water volume corresponding to a ∼120 m sea level equivalent? And how long was then the model spinup afterwards?

Line – 8 Its difficult to follow the line of arguments here. How can sea ice formation

be intensified by lower CO2 concentration? And resulting from increased sea ice formation the glacial ocean was much more stratified? Please be more specific here and provide a physically plausible chain of arguments. The authors here provide a survey of evidenced processes from other studies like changes in sea ice formation, deep convection in the north, stratification etc which agree with a reduced northern heat transport as observed in Fig. 2. But which of these important aforementioned processes can you really see in your model?

Are these processes eventually described in Liu et al (2009, line 17) or He et al 2011?. Then this paragraph should be moved to the intro to avoid the impression of reworking published material.

Line – 17 Do you see the opposing NH – SH in air temperature changes also in you model experiment as Liu et al. did? Or do you reinterpret the Liu et al results?

Line 20ff Again the author take an explanation from the Liu et al (2009) paper to explain a peak in heat transport anomaly shown in Fig 2. Do you see this "overshooting" in AMOC also in your experiment or do you analyze the same result as Liu et al. (2009)? Can you estimate how robust are the changes in North Atlantic circulation with respect to the geographical location of the H1 FW injection ? If not, this uncertainty should be discussed somewhere in the text.

The BA period is mostly recognized in Northern Hemisphere proxy data sets. Fig. 2, however, shows only the heat transport anomaly between 30 S and 0. When you assume that a change in the oceanic heat transport contributed much to BA warm period, then it would be more appropriate when you show the oceanic heat transport anomaly for the NH (perhaps 0 – 40 N, 30 N – 60 N). Or you should explain why the 30 S – 0 heat transport as shown in Fig. 2 is more indicative for the NH climate.

line 25 – 28 From Fig. 1 it is obvious that there is also a significant meltwater contribution from the NH contemporaneously. How can you be sure that the salinity anomaly arises only from the southern FW source? How many years were averaged for the plots in Fig.5 ? According to Fig. 1 the meltwater discharge associated with the YD starts at already at 13 kaBP. Do you average across this event ? Then you should consider how much of the change between Figs 5c and 5d is according to YD meltwater in the NH?

line 28ff

From the salinity profiles alone it is difficult to deduce the presence/absence of NADW formation. It seems there is no strong NADW formation as long you have a strong freshwater source in the NH which is the case from 17 kaBP to around 11 kaBP. After that, a modern-like salinity pattern can be recognized in Fig. 5. f-g. May be this could be one of the main conclusions of paper (rather than that the southern meltwater sources are important)?

Page 6382 line 29 – Page 6383 line 1

The YD (or H0) meltwater injection starts already at 13 kaBP (according to Fig. 1). Shouldn't this meltwater discharge suppress the NADW formation rather than building up a precursor of modern NADW?

Page 6383

line 8 – 10 I agree that the termination of the YD meltwater input leads to the establishment of NADW formation after 11.7, which in turn forces an increased northward heat transport in the NH. But doesn't this contradict your main conclusion that MWPA1 in the SH was crucial to the set up of modern NADW (stated in the abstract, last sentence) ?

line 10 – 12 be more specific. Which salinity barrier do you mean? Earlier (line 1 page 8363), you stated that the upper layer temperature was too high for the water to sink at 13 kaBP (Fig. 1d, so it was rather a temperature barrier?). After 13 kaBP there almost only a strong northern FW source in your experimental setup. It's not plausible how the erosion of the salinity barrier might come from the south. From 13 kaBP to 11 kaBP the entire Atlantic freshens more and more with only very minor FW contribution from the south but much more FW from the north (Fig.1). Also the south

Atlantic further freshens profoundly after stopping the FW contribution from MWPA1. How is this possible?

line 22ff Yes, these conclusions appear reasonably. But as far as I understand the establishment of NADW formation is mostly sensitive with the presence/absence of a NH FW source. Maybe you overestimate role of the southern meltwater sources.

Page 6384

line 13ff From the plots in Fig. 5 I would guess you already initialized the model with a "salinity barrier". Otherwise you should explain when exactly this barrier was established, which processes were responsible for it and how it advanced to the north. Considering the total FW inputs seen in Fig. 1 I would think much of the strong Atlantic freshening seen in Fig. 5 is from the northern sources.

line 24 (page 6384) – 2(page 6385) This sentence appears a bit misplaced in the context and in the conclusions at all.

Technical comments

Fig. 2 caption: "...positive values... indicate a northward transport...". According to the Y-label you show here anomalies. Do you mean a northward transport (less southward transport respectively) relative to the mean transport?

Fig. 5: The color bar is not readable: How many years have been averaged for the individual slices?

References Manabe, S. and R. J. Stouffer, 1997: Coupled ocean-atmosphere model response to freshwater input: comparison to Younger Dryas event. Paleoceanography, 12, 321–336

Manabe, S. and R. J. Stouffer, 2000: Study of abrupt climate change by a coupled ocean-atmosphere model. Quaternary Science Reviews, 19, 285–299.

Mikolajewicz, U. 1998: Effect of meltwater input from the Antarctic ice sheet on the thermohaline circulation, Annals of Glaciology, VOL 27, 311-315.

Rind, D., P. Demenocal, G.L. Russell, S. Sheth, D. Collins, G.A. Schmidt, and J. Teller, 2001: Effects of glacial meltwater in the GISS Coupled Atmosphere-Ocean Model: Part I: North Atlantic Deep Water response. J. Geophys. Res., 106, 27335-27354, doi:10.1029/2000JD000070.

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