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Discussions

Interactive comment on "Glacial marine carbon cycle sensitivities to Atlantic ocean circulation reorganization by coupled climate model simulations" *by* M. O. Chikamoto et al.

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Reply to Referee1

Thank you very much for your helpful suggestions and comments. *Iteric font* shows referee1 comments and roman font shows our reply.

1. The impact of different ocean circulations has already been studied in details with another GCM (Tagliabue et al., 2009) and the new results presented here have to be discussed more in the light of the previous study.

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We discussed the comparison with the previous GCM study for the modeled δ13C in Subsection 3.2 and argued the common feature of the small sensitivity of the atmospheric CO_2 in Subsection 5.1.

2. Moreover, although the glacial ocean circulation cannot be directly constrained, the use of proxy data such as d13C and D14C is very useful. As the model simulates both (as presented for the preindustrial simulations) the glacial distribution of d13C and D14C obtained in the different model configurations should be compared to the data (and presented on figures). Oxygen is also an important constraint (whether the deep ocean becomes anoxic or not) which can be looked at.

We added the description of δ13C and Δ14C in Subsection 3.2.Δ14C in the preindustrial and glacial experiments were shown in Figures 1 and 5 and δ13C anomaly and proxy data were shown in Figure 6. In both LGa and LGb, a 80-100 mmol/m^3 reduction in oxygen appears at intermediate depth in the North Pacific, indicating the suboxic condition. Oxygen is also deficit by 45 mmol/m^3 in the North Pacific deep ocean. In contrast, the oxygen concentration increases increases by 26 mmol/m^3 in the South Atlantic.

3. Only two different circulations are presented: LGa which has a stronger NADW and lower AABW and LGb which has a lower NADW and stronger AABW. In the conclusion, the potential effect of other possible circulations should be discussed, for example a case with stronger NADW and stronger AABW or one with lower NADW and lower AABW.

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We have shown two circulation patterns in this study: a case of stronger NADW and stable AABW and the case of weaker NADW and stronger AABW. The former case corresponds to the PMIP2 result. The later case was the simulation that mimic the enhanced AABW according to proxy data that reconstruct the enhancement of AABW flow into the Atlantic Ocean and model-comparison results with a wide range of AABW feature in the glacial simulation. As you suggested, there could be another possibilities in the case of both weaker NADW and AABW and case of both stronger NADW and AABW. How much carbon is pooled in the abyssal ocean is related to the carbon content of the northern and southern sources: carbon-rich AABW water or carbon-poor NADW water. Therefore, the stronger AABW can carry more carbon into the deep ocean, whereas the stronger NADW contributes to carry less carbon. The best pattern looks LGb among four hypotheses. However, in our study, the weakening of deep-water formation in the North Atlantic is linked to expanded sea ice in the Northern Hemisphere that increases atmospheric pCO$_2$ through preventing ocean carbon uptake. Our sensitivity experiments demonstrate the presence of compensating effects of different physical processes in the ocean on glacial CO$_2$ and the difficulty of finding a simple explanation of the glacial CO$_2$ problem by invoking ocean dynamical changes.

p.1263 l.7 Because of the reduced vegetation, the remaining glacial-interglacial CO$_2$ difference is more than 75 ppm, it is important to remind it.

Modified.

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Paragraph on the reorganization of ocean circulation: Other studies have also discussed changes of circulation and mixing, for example Toggweiler, 1999; Paillard and Parrenin, 2004; Koher et al., 2005.

Added.

l. 3 The effect of sea ice on atmospheric CO_2 *has also been studied by Archer et al., 2003.*

Added.

l.14 "outin" should be replaced by: "out in"

Modified.

l.16 Another GCM has also been used to evaluate the impact of different oceanic circulations on the glacial atmospheric CO_2 *which can be introduced here: Tagliabue et al., 2009.*

We added the more details of Tagliabue et al. (2009) in Introduction.

l. 21 "past, present, and future": the future is not discussed in this study, so

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“future” should either be suppressed, or it should be explained.

Removed.

2. Method 2.2. p. 1266 l.9-11 Why is there a warming bias? l.13-16 Is there any physical reason to change the GM parameterization?

The current version in our AOGCM overestimates the incoming shortwave radiation in the Southern Ocean in associated with small cloud covers and then tends to have a warming bias (Watanabe et al., 2010). An isopycnal/Gent-McWilliams (GM) eddy parameterization that parameterizes mesoscale eddy mixing on isopycnal surfaces was changed to the typical value for coarse-resolution models of 7.0 × $10-6$ cm^2/sec (Hirst and McDougall, 1996) from 3.0 × $10-6$ cm^2/sec (Gent et al., 1995; Watanabe et al. 2010) in the PIa and LGa versions.

p1271 l.1271 How is the ACC? Does it change significantly?

In LGb, the ACC transport at the Drake Passage defined by the south-north difference in vertical integrated barotrophic stream function increases 15 %. On the other hand, in LGa, the ACC transport in turn decreases 12 %.

4.1. p. 1275/ l.3 Is the temperature lower in experiments b compared to a? Could it play a role in the solubility pump?

Yes. Since the temperature change is larger in LGb than in LGa, the solubility effect is larger in LGb than in LGa.

4.3 p. 1276/ l. 3 The effect of sea ice coverage should also be discussed in the light of Menviel et al., 2008.

We added Menviel et al. (2008) for the comparison with the biological response due to sea ice.

4.4 p. 1276/ l. 16 Please specify by how much CO_2 is changed.

Added.

5.2. What about iron fertilization?

According to your comments, we added the hypothesis of iron fertilization in Subsection 5.2. Some model studies show the atmospheric CO_2 reduction of 8-40 ppmv due to iron fertilization (Watson et al, 2000; Archer et al, 2000; Bopp et al, 2003). In the MIROC experiment LGb, the glacial dust deposition simulated by a global aerosol transport model lowers atmospheric CO_2 by 42 ppmv (Oka et al., 2011). This suggests that the atmospheric CO_2 can be further reduced due to the altered biological productivity through iron fertilization.

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5.3. p. 1280 l.6 The possible role of winds has been discussed in Toggweiler et al., 2006, which could be included here.

We changed the reference in Toggweiler et al. (2006).

6.Conclusions p.1280 l.26 Studies have also been carried on with GCM simulations (Tagliabue et al., 2009).

Added.

p.1281 l. 4 "Enhanced of" should probably be replaced by either "enhancement of AABW" or "enhanced AABW".

Modified.

Figure 7. The atmospheric pCO$_2$ response is for both PIa and Lga on the left panel and PIb ans Lgb and the right panel, it should be explained more carefully in the caption and Lga and Lgb on the figure should be changed, for exemple to a and b.

We modified the caption as follows: Atmospheric pCO$_2$ responses to the climate dynamic changes. The left panel of the figure shows configuration 'a' experiments, which

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switch on or off the climate factors of LGa. The right panel is the same in the left, but for configuration ‘b’ experiments, switching on/off the climate factors of LGb.

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