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Climate of the Past Discussions

Interactive comment on "Impact of brine-induced stratification on the glacial carbon cycle" *by* N. Bouttes et al.

Anonymous Referee #1

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The paper presents simulation results with the CLIMBER-2 model on the impact of a specific process (namely brine rejection or brine-induced stratification) on glacial atmospheric CO_2 and the vertical gradient in Atlantic δ^{13}C. It thus names explicitly one process which might be causing glacial Southern Ocean stratification, which was suggested by various (box)models to be possibly responsible for the glacial drawdown of CO_2.

The content is interesting, the study worth to be done and the paper should in my opinion be published in CP after some revision, in which details below need to be taken into consideration. In the present form the paper is too weak to be published in CP, but I am sure it can be improved significantly. My concern focus on two main subjects: (1) present presentation and discussion of results, and (2) further details on

the brine process.

The following list is ordered after appearance in the text, it is not ordered by importance! Let me first deal with the

1. **Further details on the brine process:**
    (a) Brine is produced during sea ice formation. However, the paper does not describe the amount of sea ice production in the various scenarios. It seemed therefore to be necessary to describe briefly the way sea ice formation is contained in CLIMBER-2. This is necessary to set the brine process into context with the sea ice formation. As I understood LGM sea ice is mainly increased in winter time, while it is at LGM summer more or less similar to present day (*Gersonde et al.*, 2005). Is this seasonality shown in the data also reproduced in sea ice in CLIMBER, and what does it mean for the brine rejection process?
    (b) The amount of brine rejection (volumetric fluxes) should be mentioned. Or does your approach mean, that only the ions are transported to the deep ocean without any water at all?
    (c) Can you finally give an estimate on which value of $frac$ (fraction of salt/brine transported to the deep ocean) you think is plausible? Are there any data on that or possibilities to measure it in the future?
    (d) Surely, the change in sea ice formation (LGM versus present) was largest around Antarctica, but sea ice in the Northern Oceans was surely also enhanced at LGM (e.g. *Pflaumann et al.*, 2003). What would be the effect of that on brine rejection in the Northern North Atlantic and thus on both ocean circulation and CO_2?
    (e) How long does it take for the model to gain steady state again, after brine rejection has changed the ocean circulation field due to density changes?

(f) What would the brine rejection process contribute to the explanation of glacial ^{14}C (e.g. *Broecker and Barker*, 2007)? As I understood it, stratification is increased, but carbon from the surface (with high ^{14}C) is also travelling fast to the deep ocean. This would counteract the need for the accumulation of ^{14}C-depleted C in the abyss. This can be done this by stating how much DIC (in terms of mol/yr) is travelling via the brine rejection process to the deep ocean and you can set that into relation with the amount of C distributed to the deep ocean via other routes (export production and ocean circulation).

2. **Present presentation and discussion of results:**

(a) The abstract contains a lot of references to other papers. This is very unusual for CP and they should be deleted.

(b) Intro, p 683, l 2: reduced Southern Ocean temperature: in the surface or deep ocean?

(c) Throughout the text: Equations are not numbered, making it hard to refer to them.

(d) Eq d13C: "Rref" should read "R_{ref}".

(e) Intro, p 683, l 8: PDB. If you describe PDB, the carbon isotope standard, in such a detail it would also be good to give its value here.

(f) Intro, p 363, l 12 and Fig 9: Data on LGM δ^{13}C: There are more data available than *Curry and Oppo* (2005), see for example the compilation given in *Köhler and Bintanja* (2008), Fig 5, which included the compilation of *Bickert and Mackensen* (2004).

(g) Intro, p 364, l 4–6: "Moreover, it has remained especially difficult to simulate simultaneously the very negative δ^{13}C in the deep ocean inferred from marine sediment cores.". Please consider the very recent paper of *Köhler et al.* (2010a) in this statement, which connects atmospheric CO_2 with

deep ocean δ^{13}C. Throughout the introduction it is not mentioned, that one main effect of lower glacial terrestrial C storage is to reduce oceanic δ^{13}C. Although, reduced terrestrial C should lower both surface and deep ocean δ^{13}C and therefore not impact on the vertical gradient, the absolute value in δ^{13}C from sediments can not be understood without some thoughts on terrestrial carbon.

(h) Methods, p 686, l 7: "Furthermore, like other GCMs, CLIMBER-2...": CLIMBER is not a GCM, so it should read "Furthermore, like GCMs, CLIMBER-2..."

(i) Methods, p 686, l 25: What about the radiative forcing of other GHG, such as CH_4 and N_2O? Are they considered here? If not why? Their radiative forcing at LGM adds up to -0.7 W m^{-2}, which is about 25% of the total radiative forcing from GHG (e.g. *Köhler et al.*, 2010b).

(j) Methods, p 689, l 3, 8: Equation on V_{bottom} and V_{surface}: If I make a check on the units of the equations, there seemed to be an error. Assuming V_{bottom} in m^3, $\frac{dX_{\mathsf{bottom}}}{dt}$ in mmol m^{-3}yr^{-1}, $frac$ is dimensionless, F_X in mmol m^{-3}yr^{-1} and area in m^2 I get one unit of "[m]" more on the left hand side of the equation.

(k) Throughout the results: Nearly most of the time results are described as follows: "scenario X performs better than scenario Y with respect to variable Z as seen in Fig A". The values of the results are nearly never given in the text. This make the text very difficult to read. Please specify explicitly which values the different results achieve, so explain your figures in more details and take values out of them to be fed into the main text.

(l) Results, p 693, l 7-22: There is no such thing as "$\delta^{12}C$". This is according to your definition (Eq 1) zero. It needs to be rewritten to "^{12}C".

(m) Results, p 693, l 23-27: You varied "one variable at a time". There is certainly a nonlinearity component to this, meaning that the sum of the results from this “one variable at a time” scenarios is different from a scenario, in which all variable are active simultaneously. To my understanding this would mean the comparison of your Fig 2 and 3. Maybe this can be done by plotting the overall results (Fig 2) into Fig 3 for comparison and then the nonlinearly can be calculated.

(n) Overall discussion: The results of the study (how much glacial CO_2 and δ^{13}C can be explained) should be discussed in the context of other recent studies on glacial CO_2 and δ^{13}C, e.g. *Brovkin et al.* (2007); *Tagliabue et al.* (2009); *Köhler et al.* (2010a).

(o) References, p 698: The reference Jahn et al 2005 is given as Clim Past Discussion paper, but this is already published in CP as *Jahn et al.* (2005), so please update reference.

(p) Fig 2: Is the salinity in Fig 2 c that of the whole ocean, or deep ocean or deep Atlantic? Please specify.

(q) Fig 3: It is not mentioned that Fig 3b is the δ^{13}C gradient in the *Atlantic* ocean. Please specify, if it is the whole ocean (not only Atlantic), then you need to explain more in the main text.

(r) Fig 4: Units of the color-bar are missing.

(s) Fig 5: I do not understand the difference of Fig 5 to Fig 3. As you did some additional experiments to create Fig 5, they are not clearly motivated. Why is the contribution of S larger in Fig 5 than in Fig 3? Please expand?

(t) Fig 6: Units of colour-bar is missing.

(u) Fig 8: It is not mentioned that Fig 8b is the δ^{13}C gradient in the *Atlantic* ocean. Please specify.

(v) Fig 9: I would like to see results from Kz1 and Kz2 here. From Fig 8b I would suggest that the best solution to bring the vertical gradient in Atlantic δ^{13}C in alignment with proxy data is to use Kz1 and $frac$ between 0.4 and 1.0. Therefore the most likely results should be plotted here as well.

References

Bickert, T., and A. Mackensen (2004), Last Glacial to Holocene Changes in South Atlantic Deep Water Circulation, in *The South Atlantic in the Late Quaternary: Reconstruction of Material Budgets and Current Systems*, edited by G. Wefer, S. Mulitza, and V. Ratmeyer, pp. 671–695, Springer-Verlag, Berlin Heidelberg New York Tokyo.

Broecker, W., and S. Barker (2007), A 190‰ drop in atmosphere's Δ^{14}C during the Mystery Interval (17.5 to 14.5 kyr), *Earth and Planetary Science Letters*, *256*, 90–99, doi:10.1016/j.epsl.2007.01.015.

Brovkin, V., A. Ganopolski, D. Archer, and S. Rahmstorf (2007), Lowering of glacial atmospheric CO_2 in response to changes in oceanic circulation and marine biogeochemistry, *Paleoceanography*, *22*, PA4202, doi: 10.1029/2006PA001,380.

Curry, W. B., and D. W. Oppo (2005), Glacial water mass geometry and the distribution of δ^{13}C of $\sum CO_2$ in the western Atlantic Ocean, *Paleoceanography*, *20*, PA1017, doi: 10.1029/2004PA001,021.

Gersonde, R., X. Crosta, A. Abelmann, and L. Armand (2005), Sea-surface temperature and sea ice distribution of the Southern Ocean at the EPILOG Last Glacial Maximum — a circum-Antarctic view based on siliceous microfossil records, *Quaternary Science Reviews*, *24*, 869–896, doi:10.1016/j.quascirev.2004.07.015.

Jahn, A., M. Claussen, A. Ganopolski, and V. Brovkin (2005), Quantifying the effect of vegetation dynamics on the climate of the Last Glacial Maximum, *Climate of the Past*, *1*, 1–7.

Köhler, P., and R. Bintanja (2008), The carbon cycle during the Mid Pleistocene Transition: the Southern Ocean Decoupling Hypothesis, *Climate of the Past*, *4*, 311–332.

Köhler, P., H. Fischer, and J. Schmitt (2010a), Atmospheric $\delta^{13}CO_2$ and its relation to $p$$CO_2$ and deep ocean δ^{13}C during the late Pleistocene, *Paleoceanography*, *25*, PA1213, doi:10.1029/2008PA001703.

Köhler, P., R. Bintanja, H. Fischer, F. Joos, R. Knutti, G. Lohmann, and V. Masson-Delmotte (2010b), What caused Earth's temperature variations during the last 800,000 years? Data-based evidences on radiative forcing and constraints on climate sensitivity, *Quaternary Science Reviews*, *29*, 129–145, doi:10.1016/j.quascirev.2009.09.026.

Pflaumann, U., M. Sarnthein, M. Chapman, L. d'Abreu, B. Funnell, M. Huels, T. Kiefer, M. Maslin, H. Schulz, J. Swallow, S. van Kreveld, M. Vautravers, E. Vogelsang, and M. Weinelt (2003), Glacial North Atlantic: Sea-surface conditions reconstructed by

GLAMAP2000, *Paleoceanography*, *18*, 1065, doi: 10.1029/2002PA000,774.
Tagliabue, A., L. Bopp, D. M. Roche, N. Bouttes, J.-C. Dutay, R. Alkama, M. Kageyama, E. Michel, and D. Paillard (2009), Quantifying the roles of ocean circulation and biogeochemistry in governing ocean carbon-13 and atmospheric carbon dioxide at the last glacial maximum, *Climate of the Past*, *5*(4), 695–706.

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