

We thank V. Brovkin for his constructive comments which further improve our paper. Below, we reply to the comments made by V. Brovkin point by point. The responses are constructed as follows (1) original comments from the referee in **bold**, (2) our response in *italics*, and (3) description of changes applied in the revised manuscript in [blue](#).

**- Are DIC changes due to changes in SSTs (solubility) included into  $\Delta \text{DIC}^{\text{sat}}$ ,  $\Delta \text{DIC}^{\text{dis}}$ , or both? Please discuss this, as SST changes are essential for differences between cold and warm states.**

*Reponse:  $\text{DIC}^{\text{sat}}$  is computed with CO2SYS using the boundary conditions from each experiment (Sect. 2.3). Thereby, changes in  $\text{DIC}^{\text{sat}}$  include all the parameters listed in Sect. 2.3 and among them preformed ALK, SSTs and atmospheric  $\text{CO}_2$  concentration. However, in our model the changes in preformed alkalinity seems to mainly control the changes in  $\text{DIC}^{\text{sat}}$ .  $\text{DIC}^{\text{dis}}$  is the residual member of the equation and is obtained by subtracting all DIC components to the total DIC ( $\text{DIC}^{\text{tot}}$ ). Thus, changes in  $\text{DIC}^{\text{dis}}$  also include changes in SSTs.*

*Revision in Sect. 2.3 after Eq. 2: "In our model it seems to mainly refer to changes in preformed ALK. However, we compute this variable offline with the inorganic carbon chemistry program CO2SYS developed in Matlab (van Heuven et al., 2011) computation including other parameters such as the model output of preformed alkalinity ( $\text{TALK}^{\text{pre}}$ ), preformed phosphate ( $\text{PO}_4^{\text{pre}}$ ), surface silicate, salinity and temperature. In addition, the atmospheric  $\text{CO}_2$  concentration from each experiment is used."*

**- My understanding is that the biological pump changes are caused by changes in the physical circulation. If it is so, could it be briefly mentioned?**

*Response: Yes, V. Brovkin is right, the biological pump changes are mainly driven by changes in interior ocean ventilation timescale.*

*Revision in the abstract: "The biological pump is mainly driven by changes in interior ocean ventilation timescales, but the processes controlling the changes in ocean DIC disequilibrium remain difficult to assess and seem more regionally affected. While Atlantic bottom water disequilibrium is affected by the sea-ice induced SSW/NSW organization, the upper layer changes remain unexplained."*

**- Differences in atmospheric  $\text{CO}_2$  and total alkalinity between two simulations are minor (p. 4), but ocean DIC changes are minor too ( $< 1\%$  of ocean DIC content). DIC effect of changes in these boundary conditions ( $\text{pCO}_2$ , TALK) needs to be discussed.**

*Response: The boundary conditions on  $\text{pCO}_2$  and TALK only cause a change in DIC of about 32 PgC which remains small compared to the 314 PgC of changes between the two periods by taking all components of the carbon cycle into account. This infers that other processes are controlling the DIC inventory in the Ocean.*

Revision in Sect. 2.2: "The differences in  $p\text{CO}_2$  and TALK budget are small between the two experiment. Such changes would affect the DIC budget of about 32 PgC."

**- Please provide differences in weathering/sedimentation between two simulations, as they are essential for carbonate chemistry.**

*Reponse: V. Brovkin is correct in that weathering fluxes and sedimentation rates play an important role into the carbonate chemistry for long time scale simulations. In our simulations the difference in sedimentation rate between 125ka and 115ka is about  $6 \cdot 10^{-4}$  PgC, which is negligible compared to the change in DIC in the water column and therefore has only a minor effect on the carbon chemistry. The model we used for this study does not include weathering fluxes in its module.*

Revision in Sect. 2.2: "In addition, the difference in sedimentation rates between the two experiments ( $\approx 6 \cdot 10^{-4}$  PgC) appears to be negligible compared to the difference in DIC budget."

Revision in Sect. 4: "In addition, our model does not include weathering fluxes, which might influence the carbon budget on such longtime scale."

**- One of the interesting findings is that the ocean circulation, in particular formation of deep waters in the Southern ocean, is very sensitive to the orbital forcing changes via SH sea ice changes. Please provide 2-D plots for extent of summer/winter sea ice in the Southern Ocean. Plots of meridional overturning in Atlantic might be insightful too.**

*Response: We concur. We have added two figures (Fig. 1 and Fig. 2). Figure 1 depicts in shade the differences in SSTs (125ka – 115ka), the sea ice extent as contour lines (115ka in green and 125ka in purple) and the changes in the mixed layer depth as black (+100m depth) and blue (-100m depth) lines. We have added a completely new subsection (Sect. 3.1) that describes specifically the changes depicted in Fig. 1. Figure 2 shows the changes in the overturning circulation in the Southern Ocean during the two experiments and is explained in Sect. 3.2.*

**- Figure 4. What is the threshold in PO separating the SSW from NSW (dashed lines)? Is it the same value for both plots? If total phosphate inventory is different in two simulations, should PO be corrected for it?**

*Response: Yes, we used the same value in both experiment to separate SSW by NSW ( $\text{PO} = 0.57 \text{ mol O m}^{-3}$ ). V. Brovkin is correct in that a change in phosphate inventory would affect this threshold. However, the phosphate inventory between 115ka and 125ka experiments differs from 4.6%, which remains relatively small.*

*Figure R1 shows the distribution of PO at the surface of the ocean. In both experiments, SSW and NSW can be clearly identified in the Southern Ocean. Assuming threshold of about  $0.57 \text{ mol O m}^{-3}$  corresponds relatively well to the limit depicted by the surface PO for both experiments.*

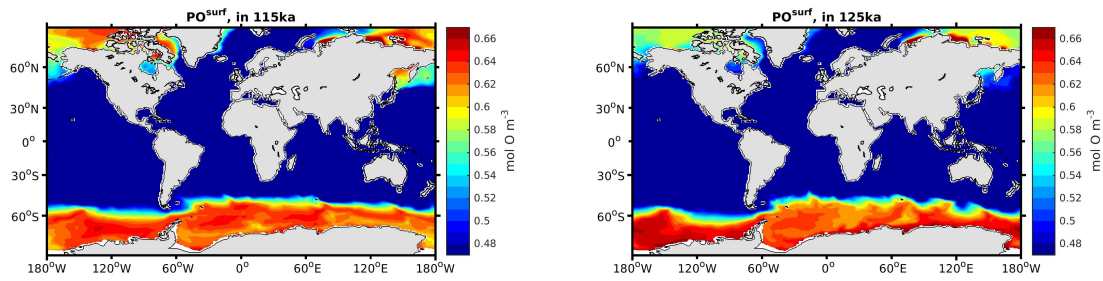


Fig R1: Surface PO in 115ka (left) and 125ka (right) experiments.

- **Figure 9.** A relevance of this figure to the study is unclear.

*Response: We agree. After careful consideration of all referee comments, we removed the previous Fig. 9 to keep this study clear and focus the reader on the model results. We still include a short comparison to proxy reconstruction, but only refer to the literature.*

Reference:

van Heuven, S., Pierrot, D., Rae, J. W. B., Lewis, E., and Wallace, D. W. R.: Matlab program developed for CO<sub>2</sub> system calculations. ornl/cdiac-105b., Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee, [http://cdiac.ornl.gov/ftp/co2sys/CO2SYS\\_calc\\_MATLAB\\_v1.1/](http://cdiac.ornl.gov/ftp/co2sys/CO2SYS_calc_MATLAB_v1.1/), 2011.