Clim. Past Discuss., 6, C1592–C1595, 2011
www.clim-past-discuss.net/6/C1592/2011/

Climate of the Past Discussions

Interactive comment on "Deep ocean ventilation, carbon isotopes, marine sedimentation and the deglacial CO₂ rise" *by* T. Tschumi et al.

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Received and published: 19 April 2011

We thank the reviewer very much for the careful reading of our manuscript and appreciate the constructive suggestions. Our response is given below.

Regarding the major comment we agree with the reviewer that the modelling strategy was probably not explicated clearly enough. We have addressed this problem on the one hand by means of an additional hint in the introduction to make clear that all experiments start from a stationary state compatible with preindustrial boundary conditions:

"All of these sensitivity experiments start from the same model steady-state that is compatible with preindustrial boundary conditions for ocean physics and the biogeochemical cycles as described in section 1.2."

Furthermore, we have conducted an additional sensitivity experiment to quantify the uncertainty due to the choice of the inital state of ocean ventilation. A new stationary state has been computed compatible with slowed ocean ventilation corresponding to 60%-SO wind stress relative to the standard. Carbon cylce boundary conditions were held unchanged (at preindustrial values). From this state, SO wind stress was increased by 80% to 140% relative to the standard. The results were then compared to the equivalent experiment in which SO wind stress was increased from standard values to 180%. Differences in the response of atmospheric CO_2 and its isotopic composition were very small. A further analysis of all sensitivities to the parameters in the carbon cycle initial conditions, however, would be beyond the scope of this study. We now discuss the issue of uncertainty due to the choice of initial conditions in the discussion section of the manuscript:

"When interpreting the model results in the context of carbon cycle changes during the last deglaciation it should be kept in mind that the starting point of all sensitivity experiments is a stationary state corresponding to the preindustrial climate and carbon cycle. This modelling approach has been chosen as the knowledge about glacial climate is subject to considerable uncertainty. The focus of this study is further laid upon a more qualitative interpretation of the interplay between different carbon cycle processes which depends less critically on the specific choice of initial conditions than the quantitative interpretation of a single paleoclimatic process or signal.

Nevertheless, we have have performed an additional sensitivity experiment in order to quantify the uncertainty associated with the initial state of ocean ventilation: Starting from a stationary state with preindustrial carbon cycle

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boundary conditions but with low ocean ventilation as resulting from 60%-SO winds, SO wind stress has been increased to 140%. Comparing the response in atmospheric CO_2, $\delta^{13}C_{CO_2}$ and $\Delta^{14}C_{CO_2}$ with the corresponding 180%-SO winds experiment starting from standard winds (red lines in Figure 6) has shown that the sensitivity to the initial ventilation state of the ocean is negligible as long as there is no structural shift in the large-scale circulation pattern such as a breakdown of AMOC."

Please find below the point-to-point response regarding the minor comments:

1. p. 1903: Done. Citation to the OCMIP2-Protocol (Orr et al. (1999)) has been added. The relevant information about the implementation of the DIC14-tracer can be found in this reference.

2. p. 1904, l.22–23: Done. In this phase of the spinning-up procedure the net burial flux of tracers is diagnosed at each time-step. In order to clarify this point we write:

   "The weathering rates are set equal to the net flux of the respective tracers across the ocean-sediment interface as diagnosed at each time-step such that annual mean ocean inventories are kept practically unchanged."

3. p. 1912, l.27: Done.

4. p. 1914, l.4–5: We have scaled both zonal and meridional windstress in the SO with a uniform factor. We now state:

   "In these idealized experiments we vary deep ocean ventilation in the model by uniformly scaling the prescribed amplitude of both zonal and meridional wind stress in the Southern Ocean (south of 51°S)."

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The strong discontinuities in Ekman transport at 51°S induced by scaling the winds are indeed seen in the modeled overturning streamfunctions. We find a strong correlation in the strength of the Deacon cell with the wind stress sacling factor. However, this effect is limited to the upper roughly 1000 meters in our model such that these changes have no significant impact on deep ventilation.

5. p. 1915–1916: Done. Order of figures has been corrected.

6. p. 1922-1923: We completely agree that both deep convection AND Ekman pumping in the SO contribute to enhanced deep ocean ventilation. We now say:

   > "The step-wise strengthening of SO wind stress as applied in our ocean ventilation experiments drives an immediate rise in deep upwelling in the Southern Ocean in response to enhanced Ekman pumping and more vigorous deep convection in the model."

7. References: Done. All indicated errors corrected.

8. Caption to figure 2: Done.

References

Orr, J., Najjar, R. G., Sabine, C. L., and Joos, F.: Abiotic-HOWTO. Internal OCMIP Report, Tech. rep., LSCE/CEA Saclay, Gif-sur-Yvette, France, 25pp., 1999.

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