Clim. Past Discuss., 10, C1168–C1176, 2014
www.clim-past-discuss.net/10/C1168/2014/

Climate of the Past
Discussions
Open Access

CPD
10, C1168–C1176, 2014

Interactive Comment

Interactive comment on "Ocean Biogeochemistry in the warm climate of the Late Paleocene" *by* M. Heinze and T. Ilyina

M. Heinze and T. Ilyina

mathias.heinze@zmaw.de

Received and published: 28 July 2014

Response Reviewer #2

Reviewers comment: This study investigates the response of biogeochemical cycles to climate change at the late Paleocene. The biogeochemistry at the Late Paleocene is of great interest because of its hot-house climate conditions which could serve as an analog for future climate change. The authors use a state-of-the-art carbon cycle model imbedded in the MPIOM OGCM. In general the paper is well written, but can be improved by including a more sophisticated comparison with the IODP cores as done in the previous early Cenozoic modeling studies of Panchuk et al. (2009, Geology) and Winguth et al. (2012, Geology). The model has been spun-up from the fully coupled simulation of Heinemann et al. (2009), but it has not been documented how well the

OGCM simulation drifts from the fully coupled simulation. A time series of the simulation (average potential temperature and salinity in 4000 m and strength of Pacific MOC) should be provided. Moreover, the simulation includes sedimentary geochemistry, but the paper lacks a detailed interpretation of the sedimentary changes and a comparison with the present-day sediment composition and distribution inferred from IODP cores. Check justification of alkalinity –weathering Ca isotopes.

Authors' response: As suggested by the reviewer, we included IODP data for a better evaluation of the model results. Since we initialize our simulation with the data of the coupled simulation and force the model with the coupled model atmospheric fields, the mean model state shows only minimum differences/drift (see attached temperature plots and MOC [response to reviewer 1]). We discuss the marine calcium concentrations in the Late Paleocene simulation in the 'specific comments' section.

Specific comments:

Abstract

Reviewers comment: L.20: The pH change is linked to an increase in CO2 invasion into the ocean (see Caldeira and Wickett, 2003, Nature)

Authors' response: We clarified this by reformulating the sentence: Yet, consistent with the higher atmospheric CO2 the surface ocean pH and the saturation state with respect to CaCO3 are lower than today.

Reviewers comment: L.24: Replace "sluggish ocean" with "vertically stratified ocean"

Authors' response: Corrected as suggested.

P.1935 Reviewers comment: L.1 change "Recently, the" to "Studies of the "

Authors' response: Changed to "The Late Paleocene".

Reviewers comment: L.1. delete "special"

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

Authors' response: Corrected as suggested.

Reviewers comment: L.5 Reference: Zachos et al., 2005, Nature

Authors' response: Reference added as suggested.

Reviewers comment: L.17 change "waters" to "water masses"

Authors' response: Corrected as suggested.

Reviewers comment: L.18 16 °C above ice free temperature; reference Zachos et al., 2008

Authors' response: We included Zachos et al., 2008 instead of Zachos et al., 2001 as a reference.

P.1936 Reviewers comment: L.2 reword "very rare"

Authors' response: Changed in the text to: In previous studies the Late Paleocene ocean biogeochemistry has been addressed exclusively with Earth System Models of intermediate...

Reviewers comment: L.4 Reference: Winguth et al., 2012, Geology

Authors' response: Reference added as suggested.

Reviewers comment: L.24 Discuss the pCO2 value which is controversial, see e.g. Zachos et al., 2008; McInerney and Wing, 2011, Annu. Rev. Earth. Planet. Sci.

Authors' response: Heinemann et al., 2010 established a Late Paleocene climate state based on a 560 ppm CO2 atmospheric concentrations. The simulated surface and deep ocean temperatures match the proxy record quite well (Lunt et al., 2012). Since we are using Heinemann et al. 2010 data to force our model we also prescribe an atmospheric CO2 concentration of 560 ppm. Of course the spectrum of possible atmospheric CO2 concentrations for the Late Paleocene background climate is wide, and our study is at the lower end of it.

CPD

10, C1168–C1176, 2014

Added in Line 23: Estimates for Late Paleocene atmospheric CO2 concentrations range from 600 to 2800 ppm (Pagani et al., 2006).

Added in line 25: The applied atmospheric CO2 concentrations and Late Paleocene boundary conditions cause a new equilibrium climate state, which fits the proxy record based SST quite well (Lunt et al., 2012).

P.1937 Reviewers comment: L.1 Replace “sluggish” with “vertically stratified” ocean state

Authors’ response: Corrected as suggested.

P.1938 Reviewers comment: L.26 Magnesium and calcium values vary over geologic time and corrections are required for the Late Paleocene (see Panchuck et al., 2008, and references therein). Moreover the solubility product Ksp is dependent on the magnesium and calcium product.

Authors’ response: In Earth history the magnesium and calcium values probably differed over certain time periods to the ones of today. However, to our best knowledge there is no proxy which allows an obvious statement about the calcium concentrations during the Late Paleocene. The changes in calcium concentrations applied by Panchuk et al., 2008 are based on boron isotope measurements (Tyrell & Zeebe, 2004), which show a rather high uncertainty. Moreover, Zeebe & Zachos, 2007 do not apply the changed calcium concentrations for their PETM simulations either. The saturation state is not affected, because all studies which increase the calcite concentrations, decrease the carbonate ion concentration exactly for this reason.

P.1940 Reviewers comment: L.2 Paleocene to present sea level change, climate change, and tectonic changes (e.g. Miller 2005, Science) need to be considered. This paragraph needs to include a more detailed discussion.

Authors’ response: Based on the assumption that no more ice was stored on land during the Paleocene, (e.g., Zeebe et al., 2009) and that due to the warmer climate thermal expansion of water masses took place, the reduced ocean volume might not be a perfect assumption. However, the ocean volume is not affecting our results since we adapt the tracers to the different volume. The behaviour of the calculated tracers is not affected by the absolute size of the global ocean.

Added in the text: Although the missing ice sheets in the Late Paleocene setup would suggest an increase in oceanic volume, the provided bathymetry from Bice & Marotzke, 2001 results in a reduced ocean volume compared to modern conditions. Miller et al., 2005 propose a ∼60 m higher sea level during the Late Paleocene in comparison to today, due to higher ocean-crust production and tectonic reorganization (i.e., opening of the Norwegian-Greenland Sea). We do not consider these details in our bathymetry. However, since we adapt the inventories of the ocean biogeochmical tracers (see 'Initialization biogeochemistry'), we hold on to the reduced ocean volume bathymetry, since it allows a better comparison of the results to other models using this bathymetry (e.g., Panchuk et al., 2008, Heinemann et al., 2009). [Moved sentence from page 1941, line 11-13 to page 1940, line 1 for better understanding.]

Reviewers comment: L11: Change "has to be given" with "has been provided"

Authors' response: Changed to: The ocean stand-alone model approach requires an atmospheric forcing.

Reviewers comment: L19 30 years average of atmospheric forcing files appears to be very short because of the characteristic mixing time of the stratosphere. 50 years appears to be a more sophisticated value. The authors should state why this value is selected.

Authors' response: We could have also chosen an atmospheric forcing comprising 50 years, but as the forcing should demonstrate the mean atmospheric state, 30 years seem to be a commonly used time period. Climate modelling studies often even use shorter time periods to demonstrate the mean atmospheric state (e.g., Giorgetta et al., 2013). We feel that this representation does not influence our conclusions.

CPD
10, C1168–C1176, 2014

P.1942 Reviewers comment: L.15 Sentence unclear; reword.

Authors' response: We give a more detailed and better description of the applied factor for the sediment acceleration:

In the sediment module, the sediment layers are subdivided into a solid sediment fraction and a porewater fraction. The fraction of solid sediment varies with depth, but not with time. The downward shifting of particles depends on the "filling" state of the sediment. For the sediment acceleration we simply divide the volume fraction of solid sediment and porewater by a prescribed factor, while keeping the sediment thickness constant. As a result, the surface area of the sediment is reduced relating to its vertical profile. From a modeling perspective this reduction in volume (area) is acceptable, since the proportion of the grid single cells ($\sim$100 km x $\sim$15 cm) prevents horizontal gradients, anyway. By maintenance of mass conservation the tracers are distributed faster throughout the sediment, since the volume is reduced and the material is shifted faster to deeper layers. To prevent an overcompensation of the porewater, the diffusion has to be reduced by the same factor as the volume is reduced. As soon as the sediment is saturated and in equilibrium, the sediment module is extended to its original volume (area) again.

P.1947 Reviewers comment: L.6 Does it mean that there is uptake of CO2 in the Indian and Southern Ocean? Clarify sentence.

Authors' response: Changed to: This matches the present-day simulations with HAMOCC (Ilyina et al., 2013), but during the Late Paleocene it is mainly the CO2 uptake of the Indian and Southern Ocean which compensates for the CO2 outgassing in the Atlantic.

Reviewers comment: L.11 Sluggish circulation is imprecise; quantify changes in vertical stratification or changes in the MOC in Sv.

Authors' response: We added an additional plot (and reference to it in L. 11) showing

CPD
10, C1168–C1176, 2014

the pre-industrial MOC, to highlight the weaker general circulation in the Late Paleocene.

P.1948 Reviewers comment: L.11 Replace “biological production” with “export production of particulate organic carbon” Note that particulate organic carbon flux in the deep sea influences the vertical carbon gradient

Authors’ response: Corrected as suggested.

P.1951 Reviewers comment: L.3 Change “poor internal mixing” to “strong vertical stratification”

Authors’ response: Corrected as suggested.

Reviewers comment: L.18 Specify depth.

Authors’ response: Changed to: That the subsurface Atlantic (up to 1000 m depths) exhibits...

P.1954 Reviewers comment: L.5 See major comments. A quantitative comparison with observations would make the paper much stronger.

Authors’ response: As suggested we added the sediment core data of Panchuk et al., 2008 to Figure 12.

Reviewers comment: L.12 For a detailed list of available sediment cores in the North Atlantic Ocean see Thomas, 1998; Panchuk et al., 2007; and Winguth et al., 2012. The simulated CaCO3 distribution should be compared quantitatively with the observations.

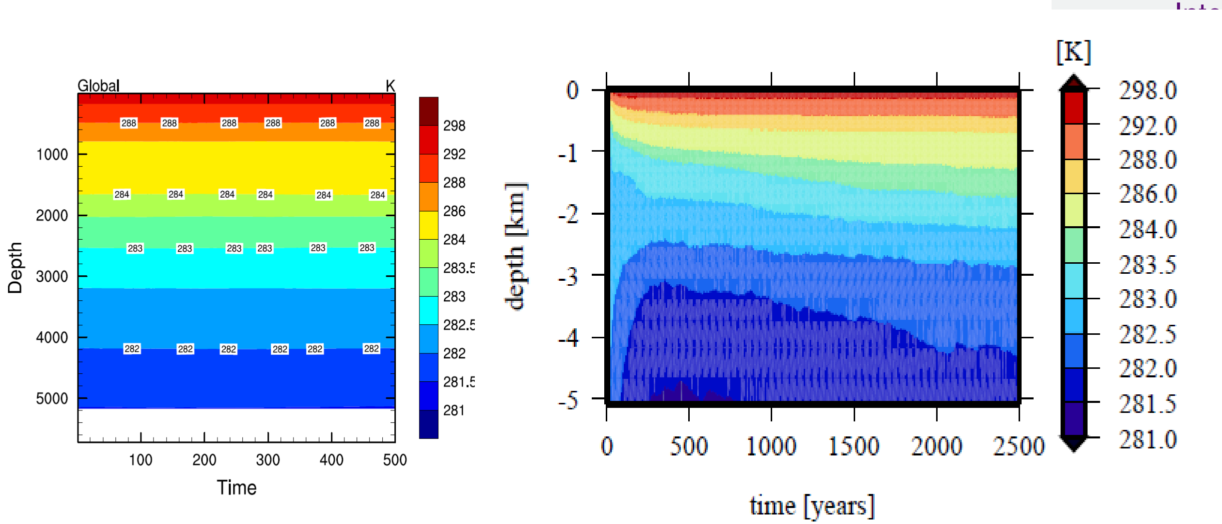
Authors’ response: Thank you for the information about the list of available sediment cores. The sediment core data of Panchuk et al., 2008 does include 2 data points in the Atlantic, which we now use to compare to our results. However, we are still looking for a sediment core which includes CaCO3 wt% data for the pre-PETM in the Central Atlantic.

CPD
10, C1168–C1176, 2014

Reviewers comment: L.5 replace “ocean stratification” with “thermal vertical stratification”

Authors’ response: Corrected as suggested.

Interactive comment on Clim. Past Discuss., 10, 1933, 2014.



Globally averaged ocean temperature in the stand-alone setup (left, covering 500 years) and for the spin-up of the coupled run (right, covering 2500 years) (Heinemann 2009, dissertation).

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper