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Climate of the Past Discussions

Interactive comment on "Tropical seaways played a more important role than high latitude seaways in Cenozoic cooling" *by* Z. Zhang et al.

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Thank you for the helpful suggestions and comments. I believe that we can make all of the improvements that you suggested in the next round of revisions.

We answer your questions or comments in details in the following texts.

Detailed answer to review:

1. Introduction

Review: I agree with the authors that there is inconsistency in symmetric pattern of cooling (Moran, 2006; Tripati, 2008) and attribution of these cooling's to DP opening. Nevertheless, as the symmetry is still an open question, it does not rule out the role of

DP opening.

Answer: We will notice this in the revised version.

2.2 Boundary condition

Review: The authors should explain why they account for both seaways closing in only one experiment (TSCN): whereas they could have provided 2 sensitivity experiments to test the impact of each closing separately.

Answer: Changes of the Tethys seaway and the Central American Seaway happened almost at same time. The narrowing of the Tethys Seaway (Barrier and Vrielynck, 2008) and the Central American seaway (e.g., Droxler et al., 1998) started in the Late Eocene. In the Middle Miocene, the tropical seaways were reorganized. The gradual shoaling of the Central American seaway began at ∼16 Ma (e.g., Droxler et al., 1998), and the Tethys seaway was permanently closed at about 15 Ma (Rögl, 1999). Thus, we included changes to both seaways in one experiment. However, it remains important to test the impact of these two seaways separately. This will be done in our future work.

Review: The authors should explain the choice of keeping the CO_2 constant to 8 PAL. They could use 3 / 4 PAL for 34Ma and 2 PAL at 15Ma which would be much realistic. The point is that all the sensitivity experiments are now run with a very high CO_2 and therefore in a strong greenhouse world which, indeed, was not the case all along Cenozoic. Therefore, this choice that I accept has to be strongly explained.

Answer: In order to highlight the relative climate effects caused by the changes of the major seaways, other boundary conditions were kept fixed. However, it is a good idea to also test different atmospheric CO_2 levels for different geological scenarios. These additional sensitivity experiments will be done in the near future. We will explain this in the revisions.

2.3 Initial Condition (spin up)

Review: Where do these empirical equations come from? The authors should explain this in the text.

Answer:

The equation is a statistical equation based on the present day vertical temperature profile for the ocean. t2 is bottom water temperature, t1 plus t2 is surface temperature, and d is depth.

Review: It would be interesting to have the initial 2D temperature field to compare with the final average early Eocene 2D temperature field, as well as vertical profiles of temperature (initial and at equilibrium) to make a comparison. What means quasi-stationary? Is there still a bottom temperature drift?

Answer: Generally, the ocean model requires thousands years to reach equilibrium. The EECO experiment was run for 2000 model years. Figure AS1 shows the time serials of global mean temperature at 10m, 2500m and 4900m depth in ocean. The figure shows that the ocean reached equilibrium, not only at the ocean surface, but also in the deep ocean. At equilibrium, global mean deep ocean temperatures are about 1-2 degree warmer than at the start of the run (Figure AS1).

However, the sensitivity experiments were only run for 750 years. The sensitivity experiments reached equilibrium at the surface, but reached quasi-stationary states in the deep ocean.

3. The Early Eocene simulation

Review: What is exactly the disagreement with TEX_86 reconstruction over Arctic? This bottom temperature is derived from the initial condition. Therefore, the comparison to data is biased. The authors should comment on this point.

Answer: In the Arctic, estimates based on the TEX86 method indicate that the surface temperature can reach 12-23 oC at the PETM (Sluijs et al., 2006), and about 9-12 oC at 48 Ma (Brinkhuis et al., 2006). However, our simulation and the simulation carried out by Shellito et al (2009) only show an Arctic ocean with surface temperatures of

about 5-6oC. It is likely that the models underestimate heat transport to the Arctic, or the atmosphere CO2 level used in the experiments is still low.

It remains interesting to notice that TEX86 temperature were systematically warmer than other temperatures (Figure 1 in the paper). Both the uncertainties from the reconstruction and the modeling side lead the warm Arctic to be an open question for future.

For deep time simulation, it is still difficult to simulate the deep ocean temperature, since climate models spend a lot of time to reach equilibrium in deep ocean. Thus, we set a warm initial condition for EECO experiment. Considering that the EECO reached equilibrium in the deep ocean, we think that the bias in model-data comparison of deep ocean temperature should be small. We will comment this in the revisions.

4. The sensitivity experiments

Review: This is the very interesting part of the paper because the authors simulated the shift from a dynamics governed by SODW to a world (our world) dominated by NADW. Moreover, they clearly attributed this shift to Tropical seaways closing or narrowing. It would have been clearer if they provide 2 sensitivity studies (one for each seaway) but the results are very convincing, but indeed this is not a major criticism, reviewers always claim for more experiments.

Answer: We appreciate this suggestion. We will investigate the relative sensitivity to the Tethys Seaway and the Central American Seaway in a future study.

Review: The discussion is interesting, but the analysis of the results could be enhanced by a discussion on mass balance over Antarctica (East and West) including analysis of the key terms: Is it a drastic cooling which decreases ablation or a drastic change in hydrologic cycle which increases accumulation? I would like to know more about results over Antarctica.

Answer: Once ocean circulation switches to the mode dominated by NADW formation, temperatures decrease over East Antarctica, which is beneficial for ice accumulation (Figure AS2). In contrast, temperatures increase over West Antarctica, and do not support accumulation of a West Antarctic ice sheet. Note also that the accumulation of ice over East Antarctica is further promoted by an increase in precipitation.

As our experiments were carried out with constant high (2240 ppmv) atmospheric CO2 levels, the surface temperature at the two poles remains above 0 degree. Thus, our experiment can not resolve the question of glaciation in detail. To further elucidate the ice-sheet development over Antarctica at the E/O boundary, would require a simulation with a realistic change in atmosphere CO2 as well as changes in ocean circulation. In this study we focus only on the latter.

Interactive comment on Clim. Past Discuss., 7, 965, 2011.

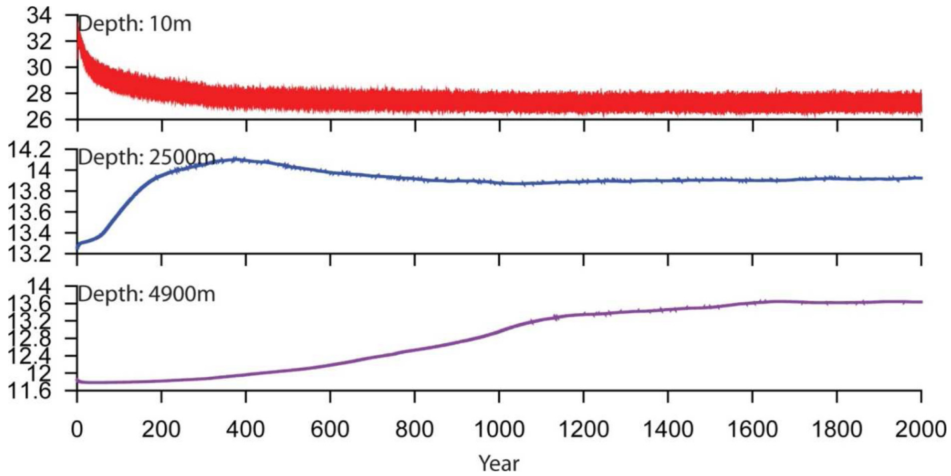

Fig. 1. Figure AS1 time series of global mean temperature at ocean surface and in the deep ocean, in the EECO experiment.

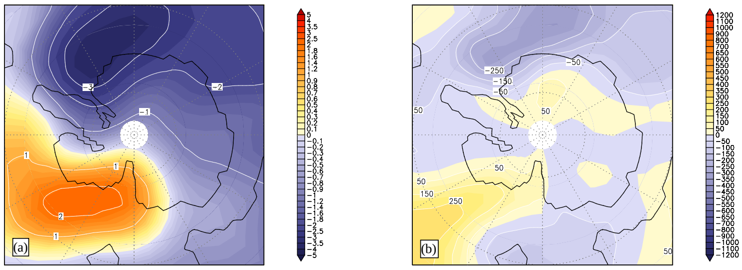

Fig. 2. Figure AS2 anomalies of annual temperature (a, oC) and precipitation (b, mm/y) between TSCN and DPGD experiment.