Clim. Past Discuss., 7, C774–C779, 2011
www.clim-past-discuss.net/7/C774/2011/

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.

Z. Zhang et al.

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Received and published: 9 June 2011

We are grateful for the suggestions and comments made by the reviewers, all of which will be taken into account in the revised version of the manuscript.

As we have responded to the comments by Gilles Ramstein earlier (www.clim-past-discuss.net/7/C239/2011/), we will focus on the responses to comments by Anna von der Heydt (www.clim-past-discuss.net/7/C464/2011/) in this final response.

Detail answers to reviews:

Review: While these are important conclusions and well performed experiments, I have the feeling that the conclusions drawn in the manuscript concerning the relevance to Cenozoic climate cooling remain very vague and sometimes involve circular

arguments. The main problem I have with the experiments is the fact that the CO2 concentration is kept at a very high level in all simulations, while some of them clearly represent Miocene times with significantly lower CO2 concentrations. Therefore, I don't agree with the first referee in accepting this limited approach. I strongly recommend the authors to include at least some of their planned future experiments with lower CO2 in this present manuscript. Otherwise the conclusions drawn from this paper remain speculative as to their relevance to real climatic events in the Cenozoic.

Sijp, England and Toggweiler 2009 indeed use present day topography in their study, which leads to a relatively strong ACC once Drake Passage is opened. But they also show that the sensitivity to CO2 changes is very different in their model with open or closed Drake Passage. This is an important remark, and could be also the case for the Tethys seaway. Therefore, it is essential to include a simulation with lower (Miocene realistic) CO2 in the series of experiments where the low-latitude gateways are closed.

Page 973, line 22-26: This is indeed a typical pattern when the MOC changes and has also been observed in (simplified) model studies without gateways, even for the Eocene-Oligocene boundary (Tigchelaar et al. 2011).

Answer: In the study, we carried out four sensitivity experiments, all based on the Early Eocene control experiment. In order to highlight the impacts of tropical seaways, we only considered changes in the bathymetry, without additional changes to the climate forcing. This was done to better isolate the role of the seaways.

However, as noted by the reviewers and in the manuscript changes in the carbon cycle and atmospheric CO2 is a key component of the changes to climate at the Eocene/Oligocene boundary. Therefore, we will include our future plans for additional sensitivity experiments with lower CO2 levels in the revised version of the paper. In fact, we are using NorESM (Norwegian Earth System Model)to repeat these experiments.

In our mind, there should be no circular arguments in the described relationship between changes to seaways and the response of ocean circulation and climate (Figure

1). In the manuscript we used the following steps to demonstrate the important role of tropical seaways: 1) We carried out and evaluated the Early Eocene simulation in view of previous studies and a synthesis of the proxy archive. 2) Based on the realistic Early Eocene simulation, we carried out several sensitivity experiments finding that the constriction of tropical seaways was important for the initiation of NADW formation. This transition in the dominant mode of ocean overturning circulation caused a significant cooling in the Southern Hemisphere, in particular over East Antarctica.

Review: Although the Tethys seaway may have changed a little across the Eocene-Oligocene transition, I think it is too far fetched to claim that the simulations would indicate that such a small change could have triggered the SODW-NADW transition (Page 978, line 27-29). This can be claimed only if a simulation with some- what shallower Tethys and fully open Panama Strait would also show NADW dominated ocean circulation.

Answer: We agree that it is more precise to state that a shallower Tethys Sea and fully open Central American Seaway leads to a NADW dominated ocean circulation. We will make this clear in the revised version of the manuscript.

However, we do not agree that the changes to the Tethys seaway were small across the E/O boundary. According to the geological map form Barrier and Verielynck (2008), the East Tethys seaway was about 7 degree (about 700 km) wide in the Late Eocene, and it became 2 degree (about 200 km) wide in the Early Oligocene. Deep marine sediments appeared in the Late Eocene, but totally disappeared in the Early Oligocene. This indicates that changes to the Tethys Seaways were indeed significant across the E/O boundary.

Review: In addition, as the experiments are meant to span quite a long time, it may be necessary to include the widening of the Atlantic through this time. This could also have an impact on the preferred pattern of the meridional overturning circulation (von der Heydt and Dijkstra, 2008). The authors should at least comment on this issue.

Answer: The widening of the Atlantic might be also important for understanding the formation of NADW. We will include a comment to this end in the revised version of the manuscript.

Review: Page 967, line 6-10: It is indeed controversial when Drake Passage opened, but not only with respect to earlier opening, but there is also a later opening (20 Ma) being suggested by Eagles and Livermore 2002, Lagabrielle 2009.

Answer: we are puzzled by this comment. The reviewer used the synthesise work done by Lagabrielle et al., (2009) to support the later opening of Drake Passage. However, Lagabrielle et al. suggested that “the opening of the Drake Passage was not STEADY STATE since ca. 30Ma”. But, they did not deny the early opening of the Drake Passage. Their “compilation of stratigraphic records from the active boundary between the South American and Scotia plates show that deep sea environments were present in the Tierra del Fuego and the North Scotia Ridge regions during Eocene-Oligocene, thus confirming the early opening of the northern Drake Passage region to proto-ACC circulation.” They also give support for an open Drake Passage before the E/O boundary.

Review: Page 974, line 7: I am puzzled by the fact that the Tethys outflow provides fresh water to the North Atlantic. The Tethys should have been a highly evaporative area, so why would there freshwater enter the Atlantic from there? In the simulations by von der Heydt and Dijkstra (2006) the opposite is the case. In the present manuscript this statement should be made more quantitative by evaluating the relative effect of Pacific or Tethys inflow.

Answer: As stated in the manuscript; the closing of the Tethys Seaway shuts down the relatively fresh surface current that flows into the North Atlantic, increasing SSS in the subtropical North Atlantic.” I.e. although the water entering the Atlantic from the Tethys is relatively fresh, it is not fresh water. In the simulations the salinity in the Tethys Seaway is lower than in the tropical and subtropical North Atlantic. This is due

to the salinity of the inflowing Indian Ocean water feeding the Tethys Sea. A similarly low salinity in the Tethys was also found in the model study of Winguth et al.(2010) with CCSM3. This will be further clarified in the revised manuscript.

Review: Page 978, lin 1-17: A strong reduction of CO2 across the E/O boundary may not be necessary, if the climate system such as ice-sheets reacts non-linearly to certain thresholds.

Answer: Certainly, non-linear feedbacks due to ice expansion would play an important role, but it is not within the scope of this paper to include interactive ice sheets.

Review: Page 980, line 1-4: Earlier in the paper the authors state that a ocean circulation pattern transition induces warming in the North and cooling in the South with only weak global mean temperature changes. This is in contrast to what they say here! Please comment.

Answer: This paragraph will be rewritten. The main message is that active NADW corresponds in time with closed stages of the Tethys Seaway (and vice versa).

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

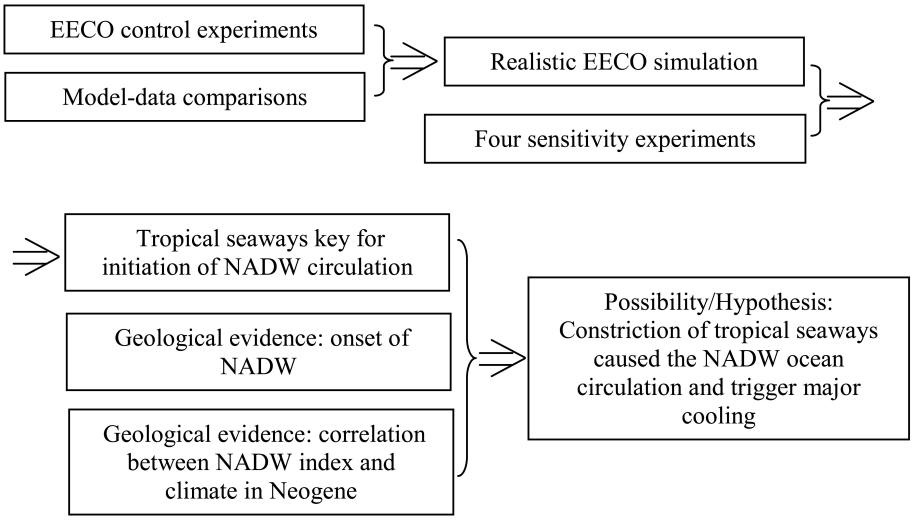

Fig. 1. Figure 1. Logical arguments for the paper