Interactive comment on “The role of East-Tethys seaway closure in the middle Miocene climatic transition (ca. 14 Ma)” by N. Hamon et al.

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General comments

Hamon et al. perform four atmosphere-ocean general circulation model experiments aimed at addressing the long proposed hypothesis that the production of warm, saline intermediate water in the Miocene Tethys played a decisive role in global climate change. The subject of this study is welcome and fits well with the themes of Climates of the Past. The methodology is sound (pending some details – see below) and the manuscript is well structured. However, some refinements (some minor, some not) and extra discussion are required before the manuscript should be accepted. The authors have identified a gap in the literature regarding the “Tethys Indian Saline Water” (TISW) hypothesis, first proposed in the 80’s, and have performed sensitivity model experiments to specifically test this hypothesis. However, the introduction doesn’t review previous modelling work in any detail. While as far as I’m aware this is the first general circulation modelling study to specifically address TISW, several Miocene modelling experiments (many cited in the discussion) exist which should be introduced here. Additionally some extensive box modelling has been performed on the subject which needs to be integrated into the discussion [Karami et al., 2009; Karami et al., 2011]. The introduction should include what previous studies found regarding TISW, how they are lacking (or why those studies are inadequate for the problem at hand) and thus why this paper is being written. This point shouldn’t be difficult to make, but still needs to be made. ’Major’ revision is harsher than warranted but I believe this contribution could be made more substantial with consideration of the points outlined.

We will rewrite part of our introduction in order to include a presentation of previous modeling works and to better explain the reason why we performed our study and its aim.

Specific comments (in no particular order)

-In the introduction and discussion the authors mention three mechanisms that have been proposed to explain Antarctic ice-sheet expansion via TISW. I) a decrease in Indian Ocean poleward heat transport due to east Tethys gateway closure, II) acceleration of the ACC and increased thermal isolation of Antarctica (though fixed-SST experiments show this has a relatively minor impact), and III) increased AMOC which would have led to increased moisture transport and precipitation to Antarctica. It should be noted to the reader that mechanism one and three are at odds with each other; one suggests increased heat transport to Antarctica is responsible for pre-MMCT warmth while three suggests increased heat transport leads to ice-sheet growth (similar opposing arguments exist for Greenland). On a related note, the model results here show that a deep eastern passage way leads to TISW, while a shallow/closed passage precludes this but leads to stronger outflow into the Atlantic and a strengthening of the MOC; this is an interesting result and it would be interesting to see plots (or at least numbers) of the changes in ocean heat transport, if they are significant. I suspect reduced heat transport toward Antarctica in the Indian Ocean under a closed gateway scenario would be somewhat compensated for by increased transport in the Atlantic Ocean.

We will include a brief discussion on these three hypotheses in the discussion, in order to better explain that i) the first and third hypotheses are contradictory and ii) previous experiments with fixed SSTs provide evidence against the second hypothesis. Concerning *the oceanic heat transport, the changes between the Mio4000 and the MioC experiments are not significant: less than 0.02PW in the Atlantic and Indian basins. For this reason, we decided not to show oceanic heat transport and to focus on oceanic circulation. However, we will indicate that the changes in heat transport simulated between the Mio4000 and MioC experiments are non-significant and therefore that our experiments aren't consistent with hypotheses I and III.*

-No details are given of model equilibration. Has the AMOC finished trending? What of temperature and salt trends? Also, it's good that FOAM compares well with other general circulation models for modern climate, but what are its significant biases with regards to the aspects relevant to this study? (e.g. it's Miocene Drake Passage throughflow seems extremely weak compared to modern observations, what is modern transport like?). The reader needs to know broadly how well the model can capture modern and/or Miocene climate.

The four model experiments ran during 3000 model years until equilibrium. The NADW, as well as the temperature and salinity trends, were stable during the last 500 years of the simulations. We will add these precision in our manuscript and a figure showing the evolution of temperature and salinity in our four simulations (figure R1).
Concerning model validation, FOAM was recently compared to other models for the ACC (Lefebvre et al., 2012). This comparison shows that FOAM simulates a modern ACC which is in good agreement with observations and coupled models from the IPCC AR4. Therefore we consider this model as an appropriate tool to study the impact of seaway closure on Southern Ocean circulation. These information will be included in the description of the model.

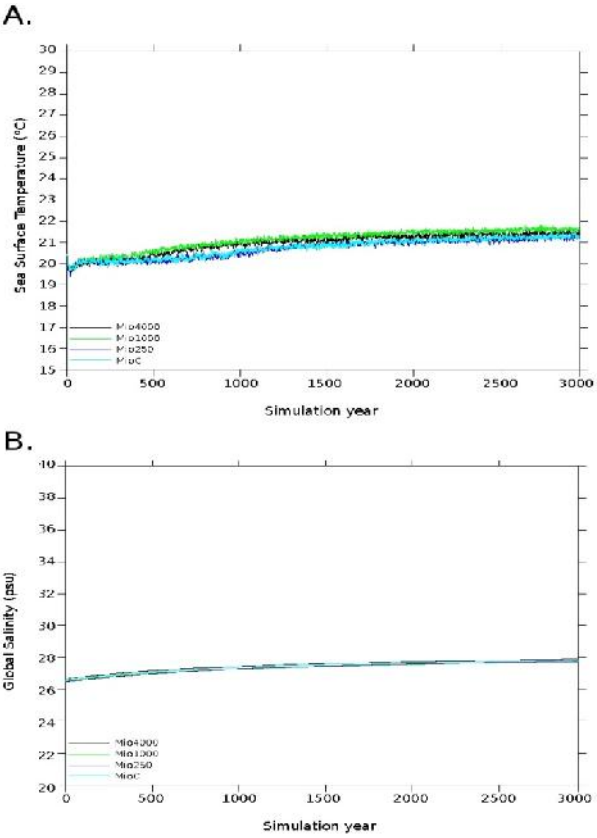

Fig. R1. Evolution of sea surface temperature (A) and global salinity (B) in the four Miocene experiments.

-Throughout the paper comparison is made to other Miocene studies that used slab ocean models. I think at this point it would be beneficial to only compare to coupled models (apples to apples), especially since some of the cited slab ocean studies didn't use heat fluxes derived from a coupled model in the first place. Similarly, on page 2120 line 9 the authors cite modelling studies that concluded CO2 must have been higher during the Miocene based on the fact that these models couldn't replicate proxy-derived temperatures. Here again some of these models only use a slab ocean with heat fluxes not derived from a coupled model.

Experiments performed with slab ocean models will be presented in the introduction, but not compared to our simulations. In the discussion, we will compare our results only with coupled experiments. Concerning the discussion on atmospheric CO2, as suggested by reviewer 2, we will remove it from our next version of the manuscript. The possible role of CO2 will be part of the conclusion.

-The authors have achieved an interesting result with their model (TISW formation) that other models have failed to achieve, as cited in their discussion. I know at least in my Miocene simulations TISW didn't form due in large part to the high river runoff to my Tethys. Thus this is an important and likely answer-changing boundary condition. The authors say river runoff was low, but what was the river transport in FOAM like and how was it prescribed?

In FOAM, the land and hydrology models are derived from CCM2. The difference is that the soil hydrology module has been replaced by a simple bucket model (0,15m-deep). When overflow from the bucket occurs, it is routed to the ocean using a parallel river transport. The direction of the transport is prescribed as a boundary condition using a graphic interface. In our experiments, we have specified that the runoff of large areas adjacent to the Tethys has to flow towards it. In other words, we have maximized the potential runoff incoming to the Tethys. Coastal river flow is the strongest in the northern part of the Paratethys, explaining the low salinity values in this region in figure 2. However, the combination of high evaporation rates and weak southward water current from the northern to the southern part of the Paratethys makes the latter rather insensitive to the river runoff. Overall, the Paratethys and Mediterranean salinity remains dominated by the negative P-E balance.

-The Tethys gateway vs CO2 debate mentioned here is interesting and parallels that of the gateway vs CO2 hypotheses for the Eocene-Oligocene Transition. The authors should mention the fact that ice-sheet modelling has shown that increases in poleward ocean heat transport does little to affect Antarctic ice-sheet growth [DeConto and Pollard, 2003] and fixed SST runs have already shown too that large increases in SST around Antarctica have little effect on the continental interior [e.g. Huber and Nof, 2006]. While this argument might be slightly different for the Miocene, given an ice-sheet was always present, it's an important point to note when discussing the MMCT. In this light, it's not surprising that even dramatic changes to gateways don't have a large impact on Antarctic climate in the model. The manuscript would benefit from a more explicit discussion of this; while it is oceanographically interesting determine whether and under what conditions TISW formed, a more important question is 'does/should it even matter for global Miocene climate?'. This paper clearly contributes to the answer but the setup for the question needs fleshing out. Such a discussion will give this the strength needed to help put the idea that TISW had a critical role in global climate to rest.

We thank Dr. Herold for this comment which is very interesting and will greatly improve our manuscript. We will discuss the role of TISW in global climate in more detail in the introduction, in order to better explain what motivated our study. In addition, we will replace the discussion on the role of CO2 by a review of previous work on seaway vs CO2 for the Eocene-Oligocene, and for the Pliocene. We will then compare our results concerning the

East-Tethys seaway to previous modelling studies on the Drake Passage and Panama seaway.

-When specific depths are mentioned in statements like page 2128 line 8, it should be noted to the reader that these are obviously model dependent.

We will add this precision in our manuscript.

-Page 2130 line 9 the authors suggest climate sensitivity was higher in the Miocene compared to present based on Miocene simulated sensitivity vs the IPCC sensitivity range. But to make this statement accurately the present day sensitivity would need to be compared to Miocene sensitivity using only the models adapted for the Miocene (i.e. that of Hamon et al. [2012] and Krapp and Jungclaus [2011]). What is FOAM's and ECHAM's modern climate sensitivity?

For the middle Miocene, the climate sensitivity modeled by Krapp and Jungclaus (2011) is 3.8°C, whereas modern climate sensitivity of their model (ECHAM) is 2.6°C (according to the IPCC reports). For the coupled model FOAM, we performed two modern simulations, with atmospheric CO2 concentration of respectively 280 and 560 ppmv. The climate sensitivity we calculated is 1.8°C, that is 3°C less than the sensitivity in the middle Miocene experiments. Therefore we conclude that the climate sensitivity was higher in the Miocene compared to present-day, and we suggest that it can be due to the oceanographic changes between these two time-periods.

-Page 2130 line 16: This paragraph mentions the burial of carbon in the Paratethys. But nowhere in the manuscript is the Monterey hypothesis touched upon [Vincent and Berger, 1985] which would have also been a positive feedback on climate deterioration and one of the central competing hypotheses explaining Miocene cooling.

In this paragraph, we use our results to discuss the possible burial of carbon in the Paratethys. As our simulations do not allow a discussion of the Monterey hypothesis (a model including carbon cycling should be used to test this hypothesis), we did not discussed it. But we agree that it is one important aspect of the debate on the causes of the middle Miocene cooling. In the future version of our manuscript, we will mention the Monterey hypothesis in this part of the discussion.

References

DeConto, R. M., and D. Pollard (2003), Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO2, Nature, 421(6920), 245-249.

Hamon, N., P. Sepulchre, Y. Donnadieu, A.-J. Henrot, L. François, J.-J. Jaeger, and G. Ramstein (2012), Growth of subtropical forests in Miocene Europe: The roles of carbon dioxide and Antarctic ice volume, Geology.

Herold, N., M. Huber, D. R. Greenwood, R. D. Müller, and M. Seton (2011), Early to Middle Miocene monsoon climate in Australia, Geology, 39(1), 3-6.

Huber, M., and D. Nof (2006), The ocean circulation in the southern hemisphere and its climatic impacts in the Eocene, Palaeogeography, Palaeoclimatology, Palaeoecology, 231(1-2), 9-28.

Karami, M. P., P. T. Meijer, H. A. Dijkstra, and M. J. R. Wortel (2009), An oceanic box model of the Miocene Mediterranean Sea with emphasis on the effects of closure of the eastern gateway, Paleoceanography, 24(4), PA4203.

Karami, M. P., A. de Leeuw, W. Krijgsman, P. T. Meijer, and M. J. R. Wortel (2011), The role of gateways in the evolution of temperature and salinity of semi-enclosed basins: An oceanic box model for the Miocene Mediterranean Sea and Paratethys, Global and Planetary Change, 79(1–2), 73-88.

Krapp, M., and J. H. Jungclaus (2011), The Middle Miocene climate as modelled in an atmosphere-ocean-biosphere model, Clim. Past, 7(4), 1169-1188.
Ramsay, A. T. S., C. W. Smart, and J. C. Zachos (1998), A model of early to middle Miocene deep ocean circulation for the Atlantic and Indian oceans, in Geological evolution of ocean basins; results from the Ocean Drilling Program, edited by A. Cramp, C. J. MacLeod, S. V. Lee and E. J. W. Jones, pp. 55-70, Geological Society of London, London.
Vincent, E., and W. H. Berger (1985), Carbon dioxide and polar cooling in the Miocene; the Monterey Hypothesis, Geophysical Monograph, 32, 455-468

Lefebvre, V., Y. Donnadieu, P. Sepulchre, D. Swingedouw, Z.-S. Zhang (2011), Deciphering the role of southern gateways and carbon dioxide on the onset of the Antarctic Circumpolar Current, Paleoceanography, 27, PA4201