Response to Reviewer #1

Comments from Reviewer #1:

I must apologize to the authors and to the editors for the lateness of this review. It was clear from the authors' response to my first review that they interpreted my comments in the constructive spirit in which they were meant, and conscientiously responded. I was therefore confident that I would recommend publication of the revised version. However, I must ask for one further minor revision. My problem is that I don't understand the workings of the 3 box MOC model.

As the authors point out correctly, I did not fully understand the model of Shen et al. (2011), in that I did not see that a full AMOC model based on the work of Shen et al. would require switches. I now believe I see the necessity for switches, but I still don't understand the qualitative behavior of the 3 box AMOC model.

In particular, lines 315-320 need more explanation. Line 316:
"By solving the non-dimensional differential equations and the continuity equations, there are two stable solutions and one unstable solution, which means that the three-box model has three equilibrium states." I find this confusing. When you say "…the three box model has three equilibrium states," do you mean that (5) and (8), coupled with the continuity equation and the energy constraint, each has 3 solutions, two stable and one unstable? It seems more likely, from figure 3 that the thermal mode is stable within the parameter range under consideration, while the haline mode has a stable equilibrium state with near-zero overturning, and a stability transition on some set of critical points in parameter space. I might conclude from figure 3 that the haline and thermal modes have nearly equal overturning rates for e and omega greater than their critical values, and rho less than its critical value. Is this, in fact, the case?

Given the setup of the 3 box MOC model it is not clear what you mean by "The three box model has three equilibrium states," with 2 that are presumably stable and one that is not. I presume further that your model tracks the evolution of the overturning velocity by the energy constraint (14), and the system undergoes a transition when the overturning velocity changes sign.

Do I have this right? You really have to make this clear.

RE: Thanks for your thoughtful comment! In this revision, we have made a clear and concise statement about the solutions of the three-box model and the sentence you mentioned has been revised (L315-321). Based on your suggestions, we have added new lines to clarify the question of the unstable solution in L357-364.

L315-321:

The time tendency in Eqs. (5) and (8) are set to be zero, and then the governing equations for the thermal mode or the haline mode are solved, respectively. Equations (5)-(7) have one stable solution, and Equations (8)-(10) have one stable solution and one unstable solution. Hence, the three-box model has a total of three mathematical solutions. This result obtained by solving the equations could be found in Shen et al. (2011).

L357-364:

The first aim of this study is to simulate the AMOC transition between different equilibrium states in the time series. However, a time series of overturning rate cannot be obtained by solving the governing equations after setting the time tendency in Eqs. (5) and (8) to zero. Therefore, without setting the time tendency to zero, we use a leapfrog time differencing scheme to forward the temperature and salinity to obtain the time series. For an unstable solution obtained by setting the time tendency to zero, a small perturbation on the solution will grow exponentially (Shen et al., 2011), so it cannot be obtained by using the time differencing scheme. Thus, the equilibrium states resolved through integrating time tendency equations in this study do not include the unstable solution described by Shen et al. (2011).

References

Shen, Y., Guan, Y. P., Liang, C. J., and Chen, D. K.: A three-box model of thermohaline circulation under the energy constraint, Chinese Phys. Lett., 28, 059201, https://doi.org/10.1088/0256-307x/28/5/059201, 2011.

Response to Editorial Comments

Editorial Comments:

"using a leapfrog time differencing scheme to forward the temperature and salinity so as the overturning rate". - It appears a verb is missing from "so as the overturning rate"?

RE: Thanks for your careful checking. We have revised this sentence in L360-361.

L360-361:
we use a leapfrog time differencing scheme to forward the temperature and salinity to obtain the time series.

"a small perturbation on the solution will grow exponentially (Shen et al., 2011), so it is rather than a physical solution" - not clear what you mean by " so it is rather than a physical solution", please clarify.

RE: Following your suggestion, the sentences have been rewritten (L361-364). Thanks.

L361-364:
For an unstable solution obtained by setting the time tendency to zero, a small perturbation on the solution will grow exponentially (Shen et al., 2011), so it cannot be obtained by using the time differencing scheme. Thus, the equilibrium states resolved through integrating time tendency equations in this study do not include the unstable solution described by Shen et al. (2011).