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 L355-360.

L315-321:

The time derivatives 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).

L355-360:

To obtain the time series of overturning rate and simulate the AMOC transition between different equilibrium states in the time series, we no longer set the time derivatives in Eqs. (5) and (8) to be zero, instead using a leapfrog time differencing scheme to forward the temperature and salinity so as the overturning rate. Although an unstable equilibrium can be obtained by solving the equations, a small perturbation on the solution will grow exponentially (Shen et al., 2011), so it is rather than a physical solution. In this study, the equilibrium states obtained by using the time differencing scheme are all stable solutions.

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.