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The effect of noise on the stability of convection in a conceptual model of the North Atlantic subpolar gyre

General Comments

This study uses a conceptual box model of the sub polar gyre to perform a bifurcation analysis and study noise-induced tipping. They find this model to be bi-stable, and test tipping from different initial conditions in phase space. As expected, the initial parametrisation and noise strength contribute to the likelihood of collapse in the time window observed. While an interesting model of the SPG, the model details and the implementation of noise needs to be much better explained and justified. I find that the results presented can be interpreted as simply confirming already known results of noise processes, and may not have such high impact. The grammar, equation, and some figure presentations need to be revised.

Specific Comments

- Section 2.1 I have difficulty understanding how the noise has been added to the model equations. First, it is not clear to me why there are not dynamical equations for boxes 2 and 4- this should be explained. Then, since there is no dynamic equation for box 2, the noise on S_2 is added to Equation 1d. I understand that since the noise is applied as an OU process, these noise processes have different time scales and will represent different physical processes. However, the way the noise is presented in the equations, this still appears to me as two noise processes added to box 1, not one on each box (1 and 2), therefore all noise processes would affect just box 1. The amplitude of the noise term with zeta_S will also be heavily influenced by the pre-factors, and it is not clear to me that this is fully taken into account. Similarly, why would precipitation only affect the surface gyre current and not the surface core box? What does ‘precipitation upstream’ mean (l.175)?

- Section 3.3 It is not clear to me that the collapses discussed are full tipping events? Are these full transitions to the alternative state? In the discussion lines ~250-270. It is noted ‘even in the least stable case… the gyre never becomes fully non-convective’. It is therefore not clear to me that a full tipping event has taken place? What does the alternative stable state correspond to, and therefore is this an expected result? Given the bifurcation diagram is found, could one not check if the system has actually transitioned to the alternative state and is in the alternative basin of attraction?

- The results discussed on page 11, I think are expected mathematically. As you move the initial conditions in phase space, you essentially start the simulations with different effective potential barrier heights for transitions. Therefore, with the same noise amplitude and a fixed time, a different percentage of transitions will take place according to large deviation theory (Freidlin & Wentzell, 1984, Bouchet & Reygner, 2016). Additionally, in some of these 'short excursions' if there is not a full transition to the alternative state, this would then be an example of a noise event followed by a noise-induced recovery (Chapman, Ashwin et al 2024). This could be checked, and the tipping (or not) mechanisms could be identified since the bifurcation diagram is known.

Minor Comments

- Grammar and phrasing needs revising throughout
- Model equations need to be defined more rigorously, not all variables are defined, should be defined immediately after the Equations.
- Where do the values of the model parameters come from? Literature, GCMs, physical estimates from observations?
- Figure 2 Labels need to be much larger, and a lot of white space can be removed from both subfigures. Could a 'zoom in' panel be provided near the hopf point to allow the detail there to be seen.
- Line 195 was other continuation software tested as well? Is the hopf super- or sub-critical? It is concerning to me that this cannot be identified/ is not a robust result.
- Figure 3 Is there not a 4th region between the hopf and saddle? However small, I think this should be acknowledged.
- Line 240 Why were no points with higher-than-reference salinity tested? Is there a physical justification?
- Line 400 The two sentences at the start of this section seem to contradict each other? Of course, with enough time and noise, any system would collapse/ recover. If the system is tipping because of noise fairly often (even for short times), I would say it is fairly unstable, and possibly near to a tipping threshold.
- Given the presence of a limit cycle, has the possibility of phase tipping been considered?