Nonlin. Processes Geophys. Discuss.,
https://doi.org/10.5194/npg-2020-4-AC2, 2020

Nonlinear Processes in Geophysics
Discussions
Open Access
EGU

Interactive comment on "Anthropocene Climate Bifurcation" *by* Kolja Leon Kypke et al.

Kolja Leon Kypke et al.

wlangfor@uoguelph.ca

Received and published: 7 May 2020

The authors thank Referee #2 for his helpful and constructive criticisms of the manuscript.

The referee states that this contribution needs to be better positioned with respect to the state-of-the-art. The paper appears to downplay important contributions of previous researchers. This was not intentional. The referee quotes several sentences from the Introduction to make this point. The authors will rewrite those introductory paragraphs, to better position this contribution in the discipline. The referee then points out that the interest of an EBM bifurcation analysis is not to provide an accurate prediction that would supersede the current state-of-the-art. It can provide a closer examination of the conditions that would generate a bifurcation.

The referee correctly points out that the existence of a bifurcation does not neces-

Printer-friendly version

Discussion paper

sarily imply an abrupt transition. However, the particular bifurcations found in this manuscript are organized around a codimension-two cusp bifurcation, which yields the phenomenon of hysteresis, and that does imply the possibility of an abrupt transition to a new equilibrium. After the mutual annihilation of the saddle and the node in a saddlenode bifurcation, trajectories pass slowly through the so-called "ghost equilibrium" in a neighbourhood where the saddlenode had been, see item 5. below. Outside of that neighbourhood, the time of the transition to the new equilibrium state is determined by the inverses of the rate constants c_S and c_A in equations (1) and (2), which are of order one (not large).

Also, the referee is correct in saying that the very simple EBM presented here includes an empirical component, and in fact does not rest exclusively on the basic laws of geophysics. The authors will clarify this in the manuscript.

Line-by-line comments:

1. Yes, the difference between \alpha_c and \alpha_w is quite large, but these values are taken from the literature. The smoothing effect of spatial distribution and seasonal cycles have been taken into account in equation (8).

2. Yes, \beta_1 and \beta_2 should be \zeta_1 and \zeta_2.

3. The authors feel that the section numbers are fine as they are.

4. The latitudes included in the Arctic model (and Antarctic) will be made explicit, in the final submission.

5. The authors agree that the transition indicated by an arrow in Figure 6 should not be interpreted as instantaneous. In fact, just to the right of the saddlenode bifurcation point, trajectories in the phase space move upward slowly through a neighbourhood that is sometimes called the "ghost" of the saddlenode (with transit time that has inverse square-root dependence on the unfolding parameter in that neighbourhood). Outside of that neighbourhood, trajectories have their normal velocity. The captions of Figure

Printer-friendly version

Discussion paper

6-11 will be rewritten accordingly.

6. The expected changes of heat flux, due to ocean and atmospheric transport, are matters of debate today. Some of this debate has been reflected in the manuscript. The melting of the Greenland ice cap surely will affect the North Atlantic - Arctic thermohaline circulation, in some way. The authors are not qualified to partake of this debate; however, this model is easily adapted to any heat flux scenario that is proposed.

7. Of course, the referee is right that this paper is not about mitigation strategies, only about the effects of various rates of CO_2 emissions. The IPCC is concerned about mitigation strategies and the effects of policy decisions. The Representative Concentration Pathways (RCP) are mechanisms that were invented to simulate the possible effects of different mitigation strategies. This paragraph will be rewritten.

8. Correct, this study does not consider the loss of land ice masses, other than, as stated, the loss of polar ice-caps will cause sea levels to rise, possibly increasing the rate of ocean heat transport.

9. Point taken.

10. We are happy with our Equilibrium Climate Sensitivity (ECS) value of 4.55 C calculated for the global EBM, which is at the high end of the IPCC range. It was [Priostosescu and Huybers (2017)] who explained that statistical models tend to lie at the low end of the IPCC range, while deterministic nonlinear models like ours are at the high end. We can not explain why some GCM's have a lower climate sensitivity without examining them individually.

11. Yes, we agree, the word "geophysics" is used inappropriately here (and also in point 10). What was meant was that deterministic, nonlinear physical reasoning is at the foundation of the model, not statistical modelling.

12. The referee is right; there have been plenty of EBM's that present bifurcations, going back to Budyko, Sellers, North and others. However we have, I believe, given

Printer-friendly version

Discussion paper

the first mathematical proof of the existence of a cusp bifurcation in an EBM, complete with the determination of the corresponding Center Manifold and the physical unfolding parameters. The complete mathematical analysis is given in a different paper of the authors [Kypke and Langford (2020)], for a slightly different EBM, that is our paleoclimate model. The present paper extends that analysis to the Anthropocene.

13. The model presented in this paper is just a first step in a program of research that eventually will combine the surface + atmosphere energy balance ideas of this model with the convective flow of the Navier-Stokes-Boussinesq spherical shell model in [Lewis and Langford (2008)]. Greg Lewis still has the code for that convection model, so it will be relatively easy to add the energy balance as in this model, to determine meridional surface temperatures implicitly. Greg has already proven the existence of a cusp bifurcation in that PDE model. Another goal is to adapt an open source model of intermediate complexity, such as perhaps PLASIM, to finding bistability and bifurcations, and then to compare results.

14. Code availability: We are currently investigating our options in providing the code for our results in an online repository.

Papers cited by the referee will be added as references in the manuscript.

Interactive comment on Nonlin. Processes Geophys. Discuss., https://doi.org/10.5194/npg-2020-4, 2020.