

A risk assessment framework for interacting tipping elements

Jacques Bara^{1,2}, Nico Wunderling^{3,4,5}, and Wolfram Barfuss^{1,2,4,6}

¹Center for Development Research, University of Bonn, 53113 Bonn, Germany

²Transdisciplinary Research Area Sustainable Futures, University of Bonn, 53115 Bonn, Germany

³Center for Critical Computational Studies, Goethe-University Frankfurt, 60322 Frankfurt am Main, Germany

⁴Earth Resilience Science Unit, Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, 14412 Potsdam, Germany

⁵Senckenberg Research Institute and Natural History Museum, Member of the Leibniz Association, 60325 Frankfurt am Main, Germany

⁶Institute for Food & Resource Economics, University of Bonn, 53115 Bonn, Germany

Correspondence: Jacques Bara (jbara@uni-bonn.de) and Wolfram Barfuss (wbarfuss@uni-bonn.de)

First, we would like to thank both the reviewer and the editor for their time and effort in reviewing our manuscript once again. As previously, we provide below a point-by-point response in blue to Reviewer 1's comments in black. We will improve the focus of the Conclusions by having clearer demarcating it into three subsections of, as suggested, Sect. 4.1 Core findings, Sect. 4.2 Limitations and Sect. 4.3 Future research direction. Moreover, we will move the paragraph discussing node-level/network-level interventions later into the new future research direction subsection.

1 Reviewer 1

The authors have satisfactorily addressed most of my previous comments. However, I still find the Conclusion to be overly long and insufficiently focused. I recommend a clearer separation between core findings, limitations, and future research directions, which would help sharpen the main take-home messages and improve readability.

10 First, thank you again for your thorough feedback as well as your time and effort. We are now clearly following the reviewer advice and will split the Conclusions section into the three subsections that were suggested: Sect. 4.1 Core findings; Sect. 4.2 Limitations; and Sect. 4.3 Future research directions. In doing so, we move the paragraph discussing node-/network-level interventions later into Sect 4.3 on future research directions. We will also remove some repetitive/extraneous sentences and refine wording throughout the Conclusions to better sharpen the focus of the section as a whole.

15 More generally, while I find the methodological framework interesting, the conclusion places disproportionate emphasis on advocating it, at times extending beyond what can be supported by a probabilistic risk-assessment approach. In particular, the use of language implying physical prediction (e.g. 439-442) or methodological superiority over process/physics-based model studies (see comment below) should be tempered, with clearer emphasis on the stylised nature of the results when it comes to future predictions.

20 We thank the reviewer for their comment and have accordingly adapted our manuscript by including clarifications in the Conclusions. Here we now highlight that, given the differences of our stylised framework to process/physics-based models,

our framework is a useful one to complement the physics-based models, while of course the physically based ESMs should and will be used in future studies to complement and inform our work. Moreover with respect to lines 439-442, we will include “Our stylised model study suggests that” and replace the phrase “highlighting the fact that such limits must be treated...” with “suggesting that such limits be treated...” in order to temper the strength of our claims regarding the Paris Agreement limits.

1.1 Specific comments

Line 30: The statement “most interactions are destabilizing and may cause tipping cascades” is too strong. A formulation such as “most interactions are destabilizing, increasing the likelihood of tipping cascades” would be more accurate and better aligned with the probabilistic nature of the framework. Fixed, we will replace “may cause tipping cascades” with “, increasing the likelihood of tipping cascades”.

Line 33: As these references are cited repeatedly, the most recent and relevant work would be Sinet et al. (2025), Science Advances. Fixed, we will also include this citation throughout the manuscript.

Line 35: Jackson et al. (2015) does not directly state this claim. Rather, it shows a cooling over Greenland associated with AMOC weakening. The wording should be adjusted accordingly to better reflect the original result. Fixed, we will replace “may also stabilise” with “may cause intense cooling of” the Greenland ice sheet, to more accurately reflect their wording. Moreover we have removed the preceding clause “although this has been contested (Wunderling et al., 2021, 2023)” as this clause was erroneously left in the text.

Line 65: While I understand the intended point, the sentence involving N-tipping remains awkward. In particular, N-tipping is not an “example” of stochastic noise. Thank you for this point, we agree that our expression was somewhat clumsy. Our intention was to give N-tipping as an example of works that incorporate stochastic noise, rather than the noise itself. To overcome this we will alter this sentence and the preceding one to “First, uncertainty has only been studied either through stochastic noise... An important phenomenon resulting from the former is noise-induced tipping”, to highlight the fact that N-tipping is caused by the stochastic noise.

Line 121: “Below in Eq. (1)” here is redundant. Fixed, this will instead say “given in Eq. (1)” i.e. we will remove “below”.

Line 301: I still do not understand the role or meaning of the phrase “far from being a neat theoretical result/exercise”. This expression appears vague. Thank you for this point, we will remove the entire clause to avoid confusion.

Line 422: In relation to the general comment above, if “refute” is understood in the academic sense, it is essentially synonymous with disproving. While I see that the conclusions of the cited studies and those of the present work are not compatible, I do not see how a probabilistic risk assessment can disprove results from a process-based model study, or vice versa.

Thank you for this point, we had used “refute” not intending fully disproving but rather that our results, as you noted, are incompatible with the other studies. To this end, we will remove this whole sentence and instead highlight that our results are “in contrast” with those other studies. Moreover, as we have in the previous paragraph already discussed that interactions generally increase the tipping risk, removing this sentence will help eliminate excessive repetitions and thus better focus the section.

450: remove “Particularly” Fixed.

References

Sinet, S., von der Heydt, A. S., and Dijkstra, H. A.: Meltwater from West Antarctic ice sheet tipping affects AMOC resilience, *Science Advances*, 11, eadw3852, <https://doi.org/10.1126/sciadv.adw3852>, 2025.

60 Wunderling, N., Donges, J. F., Kurths, J., and Winkelmann, R.: Interacting tipping elements increase risk of climate domino effects under global warming, *Earth System Dynamics*, 12, 601–619, <https://doi.org/10.5194/esd-12-601-2021>, 2021.

Wunderling, N., Winkelmann, R., Rockström, J., Loriani, S., Armstrong McKay, D. I., Ritchie, P. D. L., Sakschewski, B., and Donges, J. F.: Global warming overshoots increase risks of climate tipping cascades in a network model, *Nature Climate Change*, 13, 75–82, <https://doi.org/10.1038/s41558-022-01545-9>, 2023.